Atlantic Salmon

Salmo salar

Image © Monterey Bay Aquarium

Scotland

Marine Net Pens

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About Seafood Watch®

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

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

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

Guiding Principles

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

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

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

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

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

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

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

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

Final Seafood Recommendation

Atlantic salmon

Salmo salar

Scotland (Northwest, Southwest, Western Isles, Orkney Isles, Shetland Isles)

Marine net pens

There are five final recommendations for each of the Scottish production regions: Northwest, Southwest, Western Isles, Shetland Isles and Orkney Isles.

Scotland

Criterion	Production regions and scores				
	Northwest	Southwest	Western Isles	Orkney Isles	Shetland Isles
C1 Data	6.82	6.82	6.82	6.82	6.82
C2 Effluent	5.00	5.00	5.00	5.00	5.00
C3 Habitat	6.93	6.93	6.93	6.93	6.93
C4 Chemicals	2.00	2.00	2.00	7.00	2.00
C5 Feed	4.35	4.35	4.35	4.35	4.35
C6 Escapes	0.00	0.00	0.00	4.00	3.00
C7 Disease	0.00	0.00	0.00	6.00	0.00
C8X Source of stock	-5.00	-5.00	-5.00	0.00	0.00
C9X Wildlife mortalities	-2.00	-2.00	-4.00	-2.00	-2.00
C10X Introductions	-6.00	-6.00	-6.00	-1.80	-1.80
Total	12.10	12.10	10.10	36.30	24.30
Final score (0-10)	**1.73**	**1.73**	**1.44**	**5.19**	**3.47**

OVERALL RATING

	Northwest	Southwest	Western Isles	Orkney Isles	Shetland Isles
Final Score	1.73	1.73	1.44	5.19	3.47
Initial rating	R	R	R	Y	Y
Red criteria	3	3	3	0	3
Interim rating	R	R	R	Y	R
Critical Criteria?	1	1	1	0	0
Final Rating	R	**R**	**R**	Y	**R**

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

Scoring Summary – Scotland

- The final numerical scores for Atlantic salmon (*Salmo salar)* farmed in net pens in the Orkney Isles region is 5.19 out of 10, and with no red-rated criteria the final rating for the Orkney Isles region is yellow and a recommendation of Good Alternative.
- The final numerical scores for Atlantic salmon (*Salmo salar)* farmed in net pens in the Shetland Isles region is 3.47 out of 10, and with three red-rated criteria (Chemical Use, Disease and Escapes), the final rating for the Shetland region is red and a recommendation of Avoid.
- The final numerical scores for Atlantic salmon (*Salmo salar)* farmed in net pens in the Northwest, Southwest, and Western Isles regions of Scotland are 1.73, 1.73 and 1.44 out of 10 respectively, and with three red-rated criteria (Chemical Use, Escapes and Disease), of which the Escapes criterion is critical, the final rating for the Northwest, Southwest, and Western Isles is red and a recommendation of Avoid.

Executive Summary

Scotland's annual farmed salmon production has been somewhat variable over the last five years. The harvest of 203,881 metric tons (mt) in 2019 was a substantial increase from 156,025 mt in 2018, but more closely reflects a longer-term increase from 189,707 mt in 2017. The projected 2020 harvest was 207,630 mt. There were 76 freshwater sites producing eggs, fry, and smolts in 2019 (with a total of 53.0 million smolts stocked at sea), and 224 net pen marine sites for growout at sea, of which 146 were active (stocked) in 2019. Production is located in five regions, the Northwest (Highland) and Southwest mainland coasts, the Western Isles (also known as Eilean Siar or Outer Hebrides) and the northern island groups of Orkney and Shetland. The industry body is Salmon Scotland (formerly the Scottish Salmon Producer's Organisation) and all Salmon Scotland 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 mortalities, chemical use, feed production, escapes, introduction of secondary species (other than the farmed species), disease, the source stock, and general data availability[1]. As noted below, the overall data availability in Scotland is good and many types of data are defined by region such that each of the five production regions are assessed separately here (see Figure 3 for a map).

Uncertainty in the degree of impact resulting from interactions between farmed and wild salmon and sea trout continues to be a key characteristic of the industry's development in Scotland. Atlantic salmon and sea trout have been in long term decline across the Atlantic Ocean (in areas with and remote from salmon farming), and while the recent decline has been steep, it began prior to the peak of commercial catches in 1973 and therefore prior to any salmon aquaculture in Scotland (or elsewhere). The large majority of Scotland's wild salmon return to rivers on the east coast, with a small proportion within the aquaculture zone on the western and northern coasts; nevertheless, Atlantic salmon populations are vulnerable or threatened and the in many cases, farming areas coincide with important wild salmon and sea trout migratory corridors. While it is clear that salmon farms have not caused the widespread declines in wild salmonid populations (i.e., in areas with and without salmon farming), any substantial contributions to their local declines or inhibitions of their recovery must be considered.

There is a large amount of data readily available on salmon farming in Scotland, particularly through "*Scotland's Aquaculture*" database, the annual Scottish Fish Farm Production Survey, the Scottish Environmental Protection Agency (SEPA), and the Scottish Government website. Most data are published in a reasonable timeframe, but there are often substantial delays of more than a year in some datasets (noting the difficulties caused by a cyber-attack of SEPA in

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

late 2020). The review of the Environmental Impacts of Salmon Farming in Scotland conducted by the Scottish Association of Marine Science as part of the Scottish Government's 2018 Inquiry into Salmon Farming in Scotland has useful information of relevance to many of the criteria assessed here. The regulatory system is complex and challenging to understand fully, particularly as it continues to evolve. Salmon Scotland was open to discussing their production characteristics and their website publishes some useful data on salmon mortality rates, lethal control of seals and on cleaner fish, but these data can be unwieldy to analyze and/or in some cases are heavily aggregated. Impacts to wild salmon and sea trout in Scotland resulting from escapes and particularly from sea lice continue to be poorly understood, and there is minimal monitoring of wild fish (compared to Norway for example). In addition, the impacts of the collection of wild wrasse for use as cleaner fish is uncertain. While in some cases, the data availability lacks the quality and sophistication of that in Norway (particularly the impacts of escapes and disease), Scotland data excels on wildlife mortalities. 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 6.82 out of 10 for all regions of Scotland.

Scottish salmon farms have gradually increased their nutrient waste discharges as the industry has grown, with approximately 13,000 mt of nitrogen, 1,800 mt of phosphorous and 42,000 mt of organic carbon discharged in 2019. Salmon farms are thus substantial contributors of soluble and particulate wastes into the lochs, voes, and coastal waters of Scotland, but the review by the Scottish Association for Marine Science considers it unlikely that they would lead to a detectable change in amounts of phytoplankton, or that nutrient ratio changes would be large enough to appreciably perturb the balance of organisms. Benthic impacts are apparent, and while over 60% of sites are in satisfactory condition (according to the regulations), nearly 40% are borderline or unsatisfactory. With aggregated footprints only exceeding 4% of total seabed area in a few lochs and voes, there is a minor potential for cumulative impacts at the waterbody level. While there is no direct monitoring of soluble effluents and the results of the transition to a new Depositional Zone Regulation in 2019-20 remain to be seen at the time of writing, the substantial literature combined with the site-level benthic monitoring data provide a robust understanding of the nutrient-related impacts of the Scottish salmon industry; as such, the Evidence-Based Assessment method is used. The final score for Criterion 2 - Effluent is 5 out of 10 for all production regions.

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

The regulatory system for siting and impact assessment in Scotland is robust, but it is unclear how the range of potential impacts associated with the infrastructure of the net pen systems are managed, including from a cumulative perspective. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness is robust. The final score for Criterion 3 – Habitat is of 6.93 out of 10 for all production regions.

Scotland's antimicrobial use declined to 2015 when total use that year was less than 0.15 mt and relative use was 0.84 g/ton, but it has since increased with nearly 2.1 mt total and 10.94 g/mt used in 2019. Similarly, the number of sites treated increased from five in 2015 to 55 in 2019. While this is a concerning trend, the current use is considerably less than one treatment per site per year on average across Scotland. From a regional perspective, the Orkney Isles and the southwest region have the lowest antimicrobial use in Scotland.

Pesticide use is variable by treatments, with the in-feed treatment emamectin benzoate used most frequently and the bath treatment azamethiphos used in the greatest quantities by weight. Hydrogen peroxide is also used in large quantities with 5.3 million liters used in 2018. The total number of pesticide treatments per year has generally declined over the last ten years, but the industry still uses over three treatments per site on average each year, or over five treatments per 18-month growout cycle. On a regional basis, the Orkney Isles have a much lower reliance on pesticides, with only seven treatments in 2020 plus additional hydrogen peroxide treatments (six in 2018) equating to slightly less than one treatment per site per year.

The detection of these chemicals in the environment does not directly imply harm, and the number of sites exceeding the Environmental Quality Standards (EQS) for in-feed pesticide treatments (emamectin benzoate and teflubenzuron) is now low (and zero in Orkney in the last ten years). However, while azamethiphos and hydrogen peroxide treatments may have some acute impacts in the water column in the immediate site area, the comprehensive review by SEPA of emamectin benzoate impacts on the seabed added substantial weight of scientific evidence that the existing EQS in Scotland were not adequately protecting marine life. Resistance to emamectin benzoate is widespread, further indicating its overuse. New regulations have been adopted by SEPA but with ongoing multiple treatments per site in open production systems each year and coordinated treatments across multiple sites, the cumulative impacts are uncertain, and the efficacy of the new regulation is as-yet unknown. As such, the final score for the Northwest, Southwest, Western Isles and Shetland Isles for Criterion 4 – Chemical Use is 2 out of 10. With a much lower lice pressure experienced by farm sites in the

Orkney Isles, the need for chemotherapeutants is approximately once per site per year and considered a demonstrably low need for chemical use. Consequently, the final score for the Orkney Isles for Criterion 4 – Chemical Use is 7 out of 10.

Data on the types of feeds used across Scotland in addition to the inclusion levels and sources of marine ingredients were provided by Salmon Scotland. The inclusion levels of fishmeal and fish oil from forage fish sources were 19.2% and 8.4% respectively (with an additional 5.7% and 3% of fishmeal and oil from trimmings and byproduct sources). With an eFCR of 1.36, from first principles, 2.33 mt of wild fish must be caught to produce the fish oil needed to grow 1.0 mt of farmed salmon. Information on the source fisheries resulted in a high sustainability score of 8 out of 10 and resulted in a Wild Fish Use score of 3.2 out of 10. There is a substantial net loss of 66.7% of feed protein (score of 3 out of 10) and a low feed ingredient footprint of 7.71 kg CO_2-eq. per kg of harvested protein (score of 8 out of 10). Overall, the three factors combine to result in a final Criterion 5 – Feed score of 4.35 out of 10.

Despite the presence of a Scottish Technical Standard for Finfish Aquaculture, large escape events where several thousand fish are reported lost from marine net pens, are less frequent than in decades past. However, they do occur annually in Scotland. Such events occur for a variety of reasons, almost all associated directly or indirectly with human error (including insufficient design, construction, or maintenance of containment equipment to cope with extreme weather events). Very large-scale escape events, such as the loss of 154,549 fish in 2014 and, most recently 73,684, 48,834 and 52,000 fish in 2020, continue to occur sporadically. Additional undetected or unreported trickle losses may also cumulatively be substantial. The survival of escapees to maturity and therefore their potential to spawn with wild salmon is likely to be highly variable depending on the size, location, and time of year of escape. Extensive monitoring of escapee presence in rivers – such as that conducted in Norway and Atlantic North America – does not occur Scotland.

Quantifying the impacts to wild salmon populations is complex. As for escapee monitoring, the focused research on farm-to-wild genetic introgression that occurs in other salmon-farming regions has thus far been limited in Scotland. The research that does exist shows evidence of farm-origin genetic material within wild Scottish salmon populations; notably, though, some observed genetic introgression may have come from deliberate stocking attempts. Ultimately, there is great cause for concern for the health of native salmon populations – whose vulnerability is clear and seemingly increasing – based on comprehensive research and monitoring efforts in Norway and agreement amongst international experts that a risk of population-level impacts could occur in Scotland without highly effective fish containment going forward. There are some notable regional variations; for example, the Orkney Isles have low reported escapes over the last ten years (and zero since 2012) and both the Orkney and Shetland Isles do not have local wild salmon populations. Nevertheless, escapes here could migrate to rivers in other areas, but the risk of reaching spawning grounds is likely somewhat lower, particularly in Shetland. The final score for Criterion 6 – Escapes for the Orkney Isles is 4 out of 10, but with more frequent escapes, the final score for the Shetland Isles is 3 out of 10and Shetland Isles is 4 out of 10. For the Southwest, Northwest and Western Isles, there continue to be substantial escapes in areas that have vulnerable wild salmon populations, and without data to demonstrate a low rate of introgression or impact, the final score for Criterion 6 – Escapes is 0 out of 10 and a critical conservation concern.

Bacterial and viral pathogens infect farmed salmon in Scotland and negatively impact production, and their on-farm presence represents a reservoir of potential spillback to wild organisms. Their beyond-farm impact appears low yet remains uncertain (possibly due to the challenges of detecting diseased wild fish). 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 individuals, are recognized as a concern by the Scottish Government and by their Salmon Interactions Working Group (SIWG). While sea lice are not considered to be responsible for the long-term declines in wild salmon and sea trout (and there are many ongoing non-aquaculture pressures on the populations), there is a concern that the added pressure of sea lice transmission from salmon farms is a significant impactor on the health and recovery of wild salmonid populations.

In contrast to Norway, which has long term comprehensive monitoring and modelling of lice on farms and on wild salmon and sea trout, there is very little monitoring of sea lice on wild fish in Scotland. While the available research in Scotland indicates the mortality of sea trout due to sea lice has declined since the late 1990s and is now perhaps in the range of 10-20% per annum, the Scottish Government still defers to examples from Norway, where sea lice are considered to have the greatest negative impact on wild salmon and sea trout and are regarded as an expanding population threat. Without clear evidence on the impacts in Scotland and accepting that evidence in Norway cannot be fully representative of the situation in Scotland, the Risk-Based Assessment method has been used. The score is based on the open nature of the production system, the common exceedance of (recommended) lice limits that were established for the protection of wild fish, the high susceptibility of wild salmon and sea trout to lice, and the apparent high potential for population impacts to discreet wild sea trout populations in Scotland (due to their longer coastal residences in areas with increased sea lice infection pressures). With consideration of the vulnerable conservation status of both Atlantic salmon and sea trout in Scotland, the final score for the Northwest, Southwest, Western Isles, and Shetland Isles for Criterion 7 – Disease is 0 out of 10. In contrast, data indicate very low prevalence of sea lice on the farms in the Orkney Isles region are recognized here as posing a distinctly different level of risk of impact. Using the Risk-Based Assessment method, the score for Criterion 7 – Disease for the Orkney Isles is 6 out of 10.

As is common throughout the global salmon aquaculture industry, Scottish salmon farming production is based on hatchery-raised broodstocks of Atlantic salmon selectively bred over many generations. As such, it is considered to be independent of wild salmon fisheries for broodstock, eggs, or juveniles. With increasing use of non-chemical alternatives to sea lice treatment, large numbers of cleaner fish are used on in the Northwest, Southwest and Western Isles regions (not in the Orkney and Shetland Isles), and while hatchery production is increasing and provides all the lumpfish used in Scotland, approximately one million wild caught wrasse are used each year. Wrasse are a keystone species in inshore waters that are unusually vulnerable to over-exploitation, and despite the establishment of "*Voluntary control measures for the live capture of Scottish wild wrasse for salmon farms"* and an in-progress government consultation on making them mandatory, there are no substantive stock assessments; as such, the fishery is considered here to be, at best, of unknown sustainability, and perhaps demonstrably unsustainable. According to Salmon Scotland, 40% of the total Scottish farmed salmon production involves the use of wild caught wrasse, which equates to 54.4% of the production in the three western regions that use them. Therefore, the final score for Criterion 8X is a deduction of -5 out of -10 for the Northwest, Southwest, and Western Isles regions. With no use of wild caught wrasse in the Orkney and Shetland Isles, the final score for these regions in Criterion 8X – Source of Stock is a deduction of 0 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

The number of seals controlled by lethal means in Scotland (by salmon farming companies and fisheries managers) is low in comparison to the Potential Biological Removal (PBR) for Grey and Common (Harbour) seals (where PBR is defined by the Marine Mammal Research Institute as the number of individual seals that can be removed without causing a decline in the population). Seal mortality management and licensing in Scotland is based on seven management areas, each with an area-specific PBR value. The maximum number of single-species salmon farm mortalities of 21 Common seals in the Western Isles in 2019 represented 6.6% of that species' regional PBR (plus 1.6% of the PBR of Grey seals). In other areas, the percentage of PBR for Common seals varied from 0% in Shetland and Orkney, to 1.4% in the southwest, and for Grey seals, the percentage of PBR varied from 0.2% in Orkney to 2.2% in Shetland with intermediate values in other areas. Recently introduced regulations to align with the US Marine Mammal Act should limit future mortalities of seals to cases of accidental entanglement (i.e., the same as for birds). Entanglement mortalities are not required to be reported in Scotland and while the numbers are not known, they are considered to be uncommon. With good data availability on lethal control from the Scottish Government and robust information on the status of seal populations in each region, it can be seen that deliberate mortality is not routine, and in addition to entanglements, the total mortality does not significantly affect the population size. As such the final score for Criterion 10X – Wildlife Mortalities is a small deduction of -2 out of -10 for the Orkney and Shetland Isles, the Northwest and Southwest. For the Western Isles where the mortalities are higher and reach 6.6% of PBR of common seals, the populations are still not considered to be significantly impacted, but the Final Score for Criterion 10X – Wildlife Mortalities is -4 out of -10.

Movements of live fish are a characteristic of the Scottish salmon farming industry with a high dependence on international shipments of salmon eggs, movements of smolts from freshwater hatcheries to marine growout farms, and movements of cleaner fish from wild fisheries to those farms that use them. Assessing the risk of introducing a secondary species during those movements is complex given the different source and destination characteristics and the risk of infection and dissemination during transfers.

For Atlantic salmon, with an estimated 87% reliance on international movements of eggs from a relatively biosecure hatchery source, Factors 10Xa and 10Xb combine to result in a minor deduction of -1.8 out of -10. For movements of wild-caught cleaner fish, the lower reliance of the industry on their movements (estimated to be 40% of total Scottish production and 54% of production within the regions that use them) but seemingly absent biosecurity measures, means Factors 10Xa and 10Xb combine to result in a moderate deduction of -6.0 out of -10 for the three western regions that use them (Northwest, Southwest and Western Isles). For the Orkney and Shetland Isles, whose sites are not considered to use wild caught wrasse, the final score reflects the use of egg movements, and is -1.8 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

As noted above, each of the five production regions are assessed separately here.

- In the Northwest, Southwest and Western Isles regions of Scotland, pesticides are frequently used to treat sea lice, and wild caught cleaner fish are also used (and transported long distances) to treat them. Sea lice continue to be a high concern for vulnerable populations of wild salmon and sea trout, as are escapes that continue to occur in these regions. The final numerical scores for Atlantic salmon farmed in net pens in the Northwest, Southwest and Western Isles regions of Scotland are 1.73, 1.73 and 1.44 out of 10 respectively, and with three red-rated criteria (Chemical Use, Escapes and Disease, of which the Escapes criterion is critical), the final rating for the Northwest, Southwest, and Western Isles is red and a recommendation of Avoid.
- In the Shetland Isles, pesticide use is also frequent, and sea lice are a high concern for vulnerable wild sea trout populations. Wild caught cleaner fish are not used here. Escapes continue to occur here, and while there are no local salmon populations, the risk of escaped fish entering rivers with vulnerable wild populations remains but is lower. The final numerical scores for Atlantic salmon farmed in net pens in the Shetland Isles region is 3.47 out of 10, and with three red-rated criteria (Chemical Use, Disease and Escapes), the final rating for the Shetland region is red and a recommendation of Avoid.
- In the Orkney Isles, the geography and hydrodynamics of the region mean sea lice numbers are low, pesticide use to treat them is infrequent, and wild caught cleaner fish are not used. Reported escapes have been very low and with no local salmon populations, the risk of escaped fish entering rivers with vulnerable wild populations is lower. The final numerical scores for Atlantic salmon farmed in net pens in the Orkney Isles region is 5.19 out of 10, and with no red-rated criteria the final rating for the Orkney Isles region is yellow and a recommendation of Good Alternative.

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Introduction

Scope of the analysis and ensuing recommendation

Species: Atlantic salmon (*Salmo salar*)

Geographic coverage: Scotland-Northwest; Scotland-Southwest; Scotland-Shetland Isles; Scotland-Western Isles; Scotland-Orkney Isles.

Production method: Marine net pens

Species Overview
Atlantic salmon are native to the North Atlantic Ocean with high numbers of discrete genetic sub-populations through Western Europe in the NE Atlantic and the North America landmass in the NW Atlantic. 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.

Scotland is home to over 400 rivers hosting wild Atlantic salmon[2] (plus other native salmonids such as brown trout and Arctic char) whose conservation, particularly salmon, is highly prioritized (Nieto et al., 2015). Figure 1 shows a map of salmon and sea trout rivers in Scotland, and it is of interest to compare it to the map of salmon farm sites in Figure 3.

[2] https://www.salmon-fishing-scotland.com/fishing-in-scotland-for-salmon/

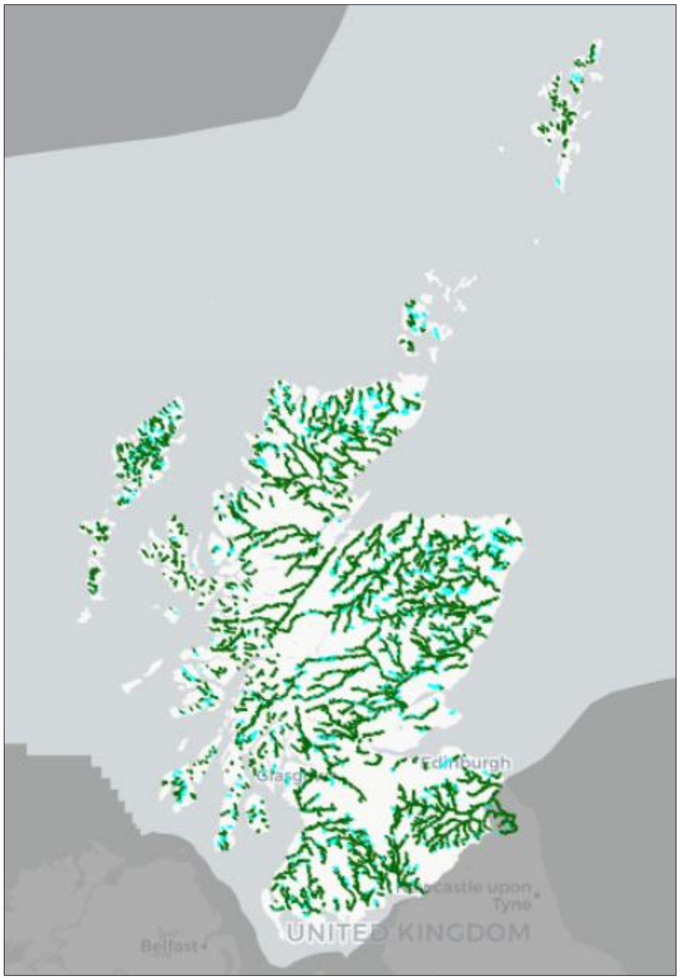

Figure 1: Map of salmon and sea trout rivers in Scotland. The green lines indicate "salmon (or sea trout) present" and the blue lines indicate "salmon (or sea trout) likely present". Map copied from Marine Scotland National Marine Plan Interactive[3].

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, but approximately 40% of smolts are produced in net pens in freshwater lochs (Munro and Wallace, 2020). 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, 2020), 203,881 metric tons (mt) of salmon (whole fish equivalent weight[4]) were produced in all production systems in 2019, representing a considerable increase from the 156,025 mt in 2018.

[3] https://marinescotland.atkinsgeospatial.com/nmpi/default.aspx?layers=843

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

Projections based on current smolt inputs show a further small increase to 207,630 mt in 2020. This is part of a long-term trend of increasing production (Figure 2). Of the 2019 total, almost all (99.9% or 203,853 mt) were produced in net pens, with 28 mt produced in tank-based systems. There were 76 freshwater sites producing eggs, fry, and smolts in 2019 (49 land-based sites using tanks and raceways, and 27 sites using net pens with a total of 53.0 million smolts stocked at sea). For growout at sea, there were 224 net pen marine sites of which 146 were active (stocked) in 2019.

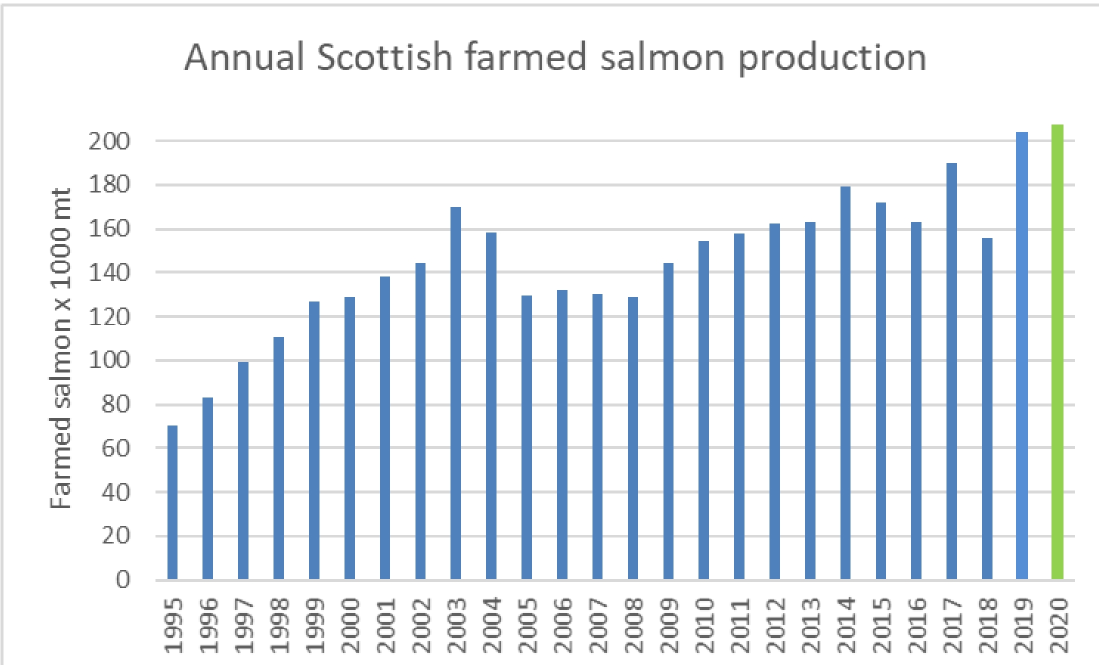

Figure 2: Annual Scottish farmed salmon production from 1995 to 2020. Value for 2020 is projected based on smolt inputs in 2019 Data from Munro and Wallace (20209).

Regional production

Salmon farming occurs in five regions in Scotland: the Northwest (also known as the Highland region, the Southwest coast of the mainland, the Western Isles (also known as the Outer Hebrides and Eilean Siar), and the northern island groups of Orkney and Shetland; see Figures 3 and 4 below. There are no salmon farms on the East and South coast in Figure 3. The annual Scottish Fish Farm Production Survey (Munro and Wallace, 2020) and Scotland's Aquaculture database report in different regional units, and for this Seafood Watch analysis, the separate Argyl & Bute and North Ayr regions in Scotland's Aquaculture database have been combined into the Southwest region as used by the annual production survey.

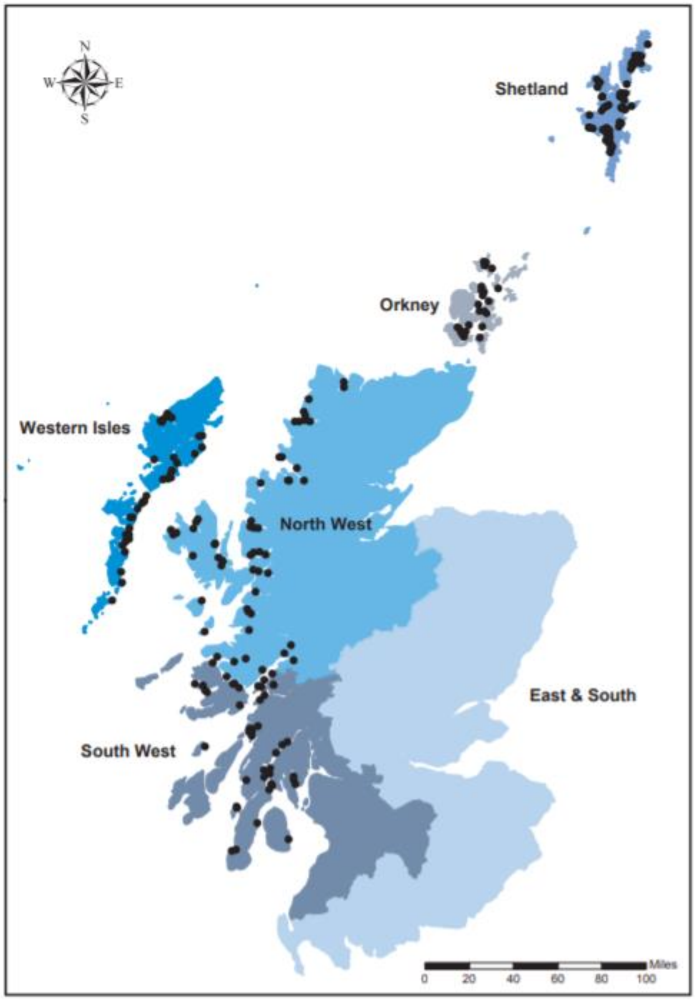

Figure 3: Active Scottish marine salmon production sites in 2019 (map from Munro and Wallace, 2020)

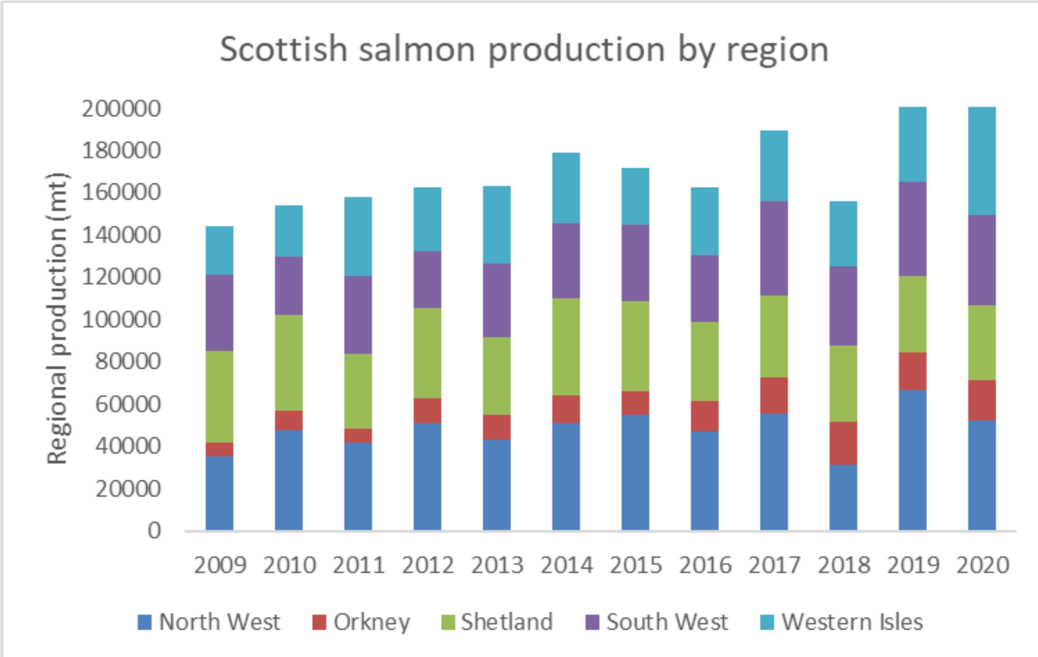

Figure 4: Regional production of farmed salmon in Scotland from 2009 to 2020 (note 2020 values are projections based on smolt inputs in the current production cycles). Data (and 2020 projections) from Munro and Wallace (2020).

Each region has many differing characteristics (e.g., geographic, hydrodynamic, climate, ecology, and industry production practices) and these are noted where relevant in each criterion of this assessment. With good data availability, each of the five salmon farming regions are assessed separately where possible (and where relevant).

Import Export Sources and Statistics

According to the Salmon Scotland export figures[5], the United States is the second largest market for Scottish salmon (after France and ahead of China). Volumes fluctuate depending on global salmon market dynamics, but 25,000 mt of farmed salmon were exported from Scotland to the US in 2019.

Common and Market Names

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

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

[5] https://www.scottishsalmon.co.uk/news/business/record-year-for-scottish-salmon-exports

Japanese	Taiseiyō sake

Product Forms

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

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

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

Criterion 1 Summary

All Regions of Scotland

C1 Data Category	Data Quality
Production	10.0
Management	7.5
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	7.5
Escapes	5.0
Disease	5.0
Source of stock	5.0
Wildlife mortalities	7.5
Introduction of secondary species	7.5
C1 Data Final Score (0-10)	**6.82**
	Green

Brief Summary

There is a large amount of data readily available on salmon farming in Scotland, particularly through "*Scotland's Aquaculture*" database, the annual Scottish Fish Farm Production Survey, the Scottish Environmental Protection Agency (SEPA), and the Scottish Government website. Most data are published in a reasonable timeframe, but there are often substantial delays of more than a year in some datasets (noting the difficulties caused by a cyber-attack of SEPA in late 2020). The review of the Environmental Impacts of Salmon Farming in Scotland conducted by the Scottish Association of Marine Science as part of the Scottish Government's 2018 Inquiry into Salmon Farming in Scotland has useful information of relevance to many of the criteria assessed here. The regulatory system is complex and challenging to understand fully, particularly as it continues to evolve. The industry's producer organization, Salmon Scotland, was open to discussing their production characteristics and their website publishes some useful data on salmon mortality rates, lethal control of seals and on cleaner fish, but these data can be unwieldy to analyze and/or in some cases are heavily aggregated. Impacts to wild salmon and sea trout in Scotland resulting from escapes and particularly from sea lice continue to be poorly understood, and there is minimal monitoring of wild fish (compared to Norway for example). In addition, the impacts of the collection of wild wrasse for use as cleaner fish is uncertain. While in some cases, the data availability lacks the quality and sophistication of that in Norway (particularly the impacts of escapes and disease), Scotland data excels on wildlife mortalities. 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 6.8 out of 10 for all regions of Scotland.

Justification of Rating

In addition to the criteria-specific sections detailed below, two key sources of data and information are highlighted here. The primary source of industry information is "*Scotland's Aquaculture*" website[6], a collaboration between the Crown Estate, Food Standards Scotland, the Scottish Environmental Protection Agency (SEPA), and the Scottish Government. While some data are unwieldy to analyze, 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 5. Secondly, as part of the Scottish Government's 2018 inquiry into salmon farming in Scotland by the Rural Economy and Connectivity Committee and the Environmental Climate Change and Land Reform Committee, the Scottish Association for Marine Science produced the "*Review of the Environmental Impacts of Salmon Farming in Scotland*" (Tett et al., 2018). As it covers many of the same impact areas in the Seafood Watch Aquaculture Standard, the review has been referenced here and updated where possible with more recent references. Additional formats of site-level and mapped results are available from SEPA, for example fish biomass, pesticide use and benthic monitoring[7]. Some data availability was compromised and/or delayed due to a cyber-attack of SEPA in late 2020.

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

[7] https://informatics.sepa.org.uk/MarineFishFarm/

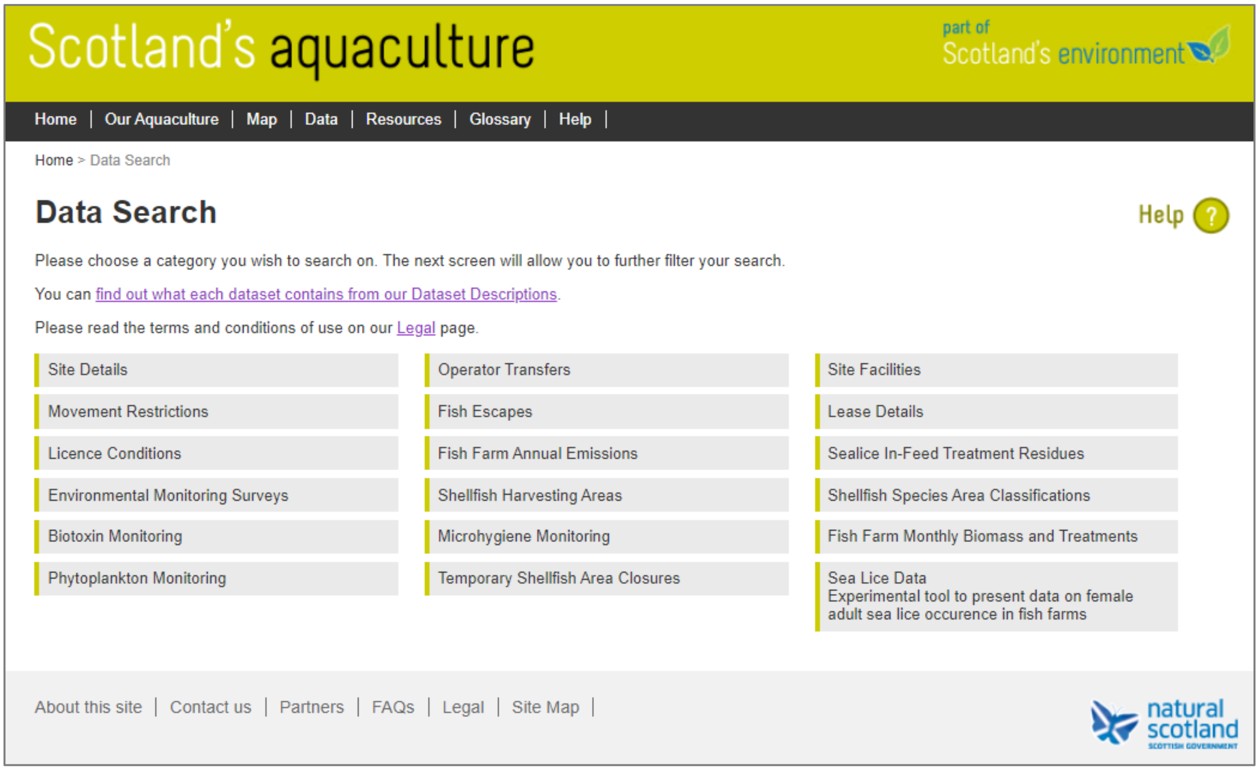

Figure 5: Screenshot of *Scotland's Aquaculture* website.

Industry and Production Statistics

The primary source of general production information is the annual Scottish Fish Farm Production Survey[8], produced by the Scottish Government through Marine Scotland Science. The latest available is for 2019 (as of September 27, 2021), in Munro and Wallace, (2020). The survey includes detailed information on production tonnage, production numbers (ova, smolts, harvested fish), aggregated company information, site numbers (freshwater and marine), site sizes (biomass), and site locations (map). It also includes data on hatchery production of cleaner fish.

Scotland's Aquaculture website includes information on every site with regard to 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[9] includes a large amount of information on the regulatory process for establishing aquaculture facilities in Scotland. The "Independent Review of Scottish Aquaculture Consenting" (Nimmo et al., 2016) provides a comprehensive review of the

[8] https://www.gov.scot/collections/scottish-fish-farm-production-surveys/
[9] https://www.gov.scot/policies/aquaculture/

regulatory process, but given the recent reviews of the industry, it is important to use more recent information (e.g., from the Scottish Environmental Protection Agency - SEPA[10], regarding the new Depositional Zone Regulations) and to search the industry media which in this assessment highlighted recent changes to regulations covering lethal control of seals and new regulatory processes considering wild capture of cleaner fish. The two-year update report from the government's Rural Economy and Connectivity Committee following the 2018 enquiry provides a useful review of the ongoing dynamics (RECC, 2020). In addition, the Scottish Code of Good Practice for Scottish Finfish Aquaculture is available in full online[11]. Given the complexity of the regulatory system and the challenge of finding clear information on current or recent regulatory initiatives, the data score for Management and Regulations is 7.5 out of 10.

Effluent

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 (updated quarterly). In addition, the benthic monitoring method and results are available for every site for more than ten years. SEPA also provide a mapped database of fish biomass and benthic monitoring results[12]. Salmon Scotland'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. The review by Tett et al. (2018) provides a useful review of the academic literature and other evidence. The data score for Effluent is 7.5 out of 10.

Habitat

Locational data available for all regions in addition to readily available satellite images allows a simple overview of salmon farm locations and habitats, but there are few specific data on the impacts of the infrastructure or their operation (other than the discharge of nutrient wastes addressed in Criterion 2 – Effluent). The review of McKindsey (2011) provides a useful list of potential impacts associated with the infrastructure, and other academic studies provide additional information on the attraction or repulsion of wildlife, hydrodynamics, and other operational activities such as the use of submerged lights. In general, these potential impacts have been poorly studied and are difficult to quantify. Information on the general regulatory system for site licensing is available from the Scottish Government website, and from reviews such as Nimmo et al. (2016), but the system continues to evolve, particularly as a result of the 2018 government enquiry into salmon farming, and the most recent developments are discussed in a November 2020 update meeting published in RECC (2020); however, it is not clear how thoroughly the regulatory system governs the relevant impacts described by McKindsey (2011). The data score for the habitat impacts of the floating net pen farming system is 5 out of 10.

[10] https://www.sepa.org.uk/regulations/water/aquaculture/

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

[12] https://informatics.sepa.org.uk/MarineFishFarm/

Chemical Use

Aggregated antimicrobial data for UK fish farming (all species) are available from the Veterinary Medicines Directorate (UK-VARSS, 2019), but salmon-specific data by site are only available on request from SEPA under Freedom of Information regulations (and were initially obtained as such for this assessment, but an updated request was declined due to a data hack in SEPA). For pesticides, *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 available on request from SEPA (but was not returned under a FOI request for this assessment[13]). The same data are mapped by SEPA[14]. Data on sediment residue testing are available from Scotland's Aquaculture for all sites using in-feed sea lice treatments but can be delayed in publication by more than a year. Data on copper and zinc discharges are also available on Scotland's Aquaculture database, but the publication lag is currently long (2019 data as of July 9, 2021). A substantial body of literature is available on the fate and potential impacts of antimicrobials and sea lice treatments, but some gaps remain, and the data score for Chemical Use is 7.5 out of 10.

Feed

Data on the types of feeds used across Scotland in addition to the inclusion levels and sources of marine ingredients for each feed type were provided by the Salmon Scotland. Few data were available for other non-marine ingredients, and these were supplemented by specific ingredients in each category from the reference diets of Mørkøre et al. (2020) and Aas et al. (2019). As such, a best-fit feed composition was created that is considered to adequately represent the Scottish feeds for the purposes of this assessment. Scotland's Aquaculture website has the monthly feed inputs per site, and with production figures from the annual survey, the economic Feed Conversion Ratio (eFCR) can be calculated. Performance results (e.g., FFER) could be checked against data from one Scottish company reporting through the GSI. The Global Feed Lifecycle Initiative (GFLI) database was used for the feed footprint calculations. The data score for Feed is 7.5 out of 10.

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 amongst wild catches is available from the Scottish salmon fisheries statistics. While the review by Tett et al. (2018) covers escapes and is useful, it confirms that studies on the impacts of escaped farmed salmon in Scotland are limited (compared to Norway for example). Norwegian research and monitoring efforts, often publicly

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[13] It appears this was a clerical error, and further attempts are being made. A later data hack at SEPA further prevented access to this data. Some partial data (to 2018) was found in SEPAs disclosure log of previous Freedom of Information requests (https://www2.sepa.org.uk/disclosurelog/#)

[14] https://informatics.sepa.org.uk/MarineFishFarm/

available as peer reviewed journal articles, were used to demonstrate (and support the presence of such risks in Scotland) the potential for both escape and impact. 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 primary source of disease information in Scotland is the government's Fish Health Inspectorate (FHI)[15] with disease cases, mortality rates, causes, and partial data on sea lice counts. Scotland's Aquaculture has site-level mortality data in a spreadsheet format, and as of March 2021, also publishes industry-reported weekly sea lice counts. Salmon Scotland previously reported monthly average sea lice numbers by site, but no longer does following the transition to the new layer in the Scotland's Aquaculture database. The FHI also publishes self-reported sea lice data from farms[16], but with a reporting threshold of >2 adult female lice per fish (previously >3 from July 2017 - June 2019), the data do not reflect the industry as a whole.

Information on pathogen or parasite impacts to wild fish is also limited in Scotland; the review by Tett et al. (2018) is useful, as is the report from the government's Salmon Interactions Working Group (SIWG), yet a comparison with other regions, particularly Norway (which has extensive annual monitoring) is largely necessitated (e.g., Thorstad et al., 2020; Grefsrud et al., 2021a,b, Vollset et al., 2020). 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 information on the sources of salmon eggs (ova) used in Scotland and the wild/domesticated nature of their broodstock. Data on the production of cleaner fish are also available in the annual survey, but the data for wild caught wrasse are poor. Salmon Scotland has initiated reporting of the first 20 traps hauled per week, but this provides minimal useful data on the fishery as a whole. Fishery landing data are available from the UK Government's Marine Management Organisation (MMO), and the Sustainable Inshore Fisheries Trust[17] (SIFT) has produced a paper highlighting the uncertain status of the wrasse fishery's sustainability. There are no data with which to assess the proportion of Scottish farms using wild-caught wrasse, but Salmon Scotland provided an estimate for the purposes of this assessment. As the scoring is based on this estimate, the data score for Source of Stock is 5 out of 10.

Wildlife Mortalities

The Scottish Government provides information on lethal seal control in terms of license numbers and (industry self-reported) mortality records[18]. These are aggregated with fisheries

[15] https://www.gov.scot/policies/fish-health-inspectorate/
[16] https://www.gov.scot/publications/fish-health-inspectorate-sea-lice-information/
[17] https://www.sift-uk.org/
[18] http://www.gov.scot/Topics/marine/Licensing/SealLicensing

licenses and have a publication delay of approximately 18 months, but detailed figures allow an estimate of the proportions killed on salmon farms. There are no requirements to report (and therefore no data on) accidental mortalities due to entanglement. Detailed information on seal population estimates and trends for the relevant species are available from the Marine Mammal Research Unit at the University of St Andrews, and in annual reports published by the Scientific Committee on Seals (e.g., SOC, 2020[19]). These include indicators of population impacts (Potential Biological Removal values) that can be used to assess the likely impact of both deliberate and accidental salmon farm mortalities. Information on recent regulatory changes to seal control licenses are available from the Scottish Government. With unknown accidental (unreported) mortalities, the data score for Wildlife Mortalities is 7.5 out of 10.

Introduction 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. For cleaner fish, the data are more limited but sufficient to indicate that movements of wild caught wrasse occur, particularly from Riley et al. (2017) from the Scottish Government. The data score for Introduction of Secondary Species is 7.5 out of 10.

Conclusions and Final Score

There is a large amount of data readily available on salmon farming in Scotland, particularly through "*Scotland's Aquaculture*" database and the annual Scottish Fish Farm Production Survey, in addition to the Scottish Government website. Most data are published in a reasonable timeframe, but there are often substantial delays of more than a year in some datasets (noting the difficulties caused by a cyber-attack of SEPA in late 2020). The review of the Environmental Impacts of Salmon Farming in Scotland conducted by the Scottish Association of Marine Science as part of the Scottish Government's 2018 Inquiry into Salmon Farming in Scotland has useful information of relevance to many of the criteria assessed here. The regulatory system is complex and challenging to understand fully, particularly as it continues to evolve. Salmon Scotland was open to discussing their production characteristics and their website publishes some useful data on salmon mortality rates, lethal control of seals and on cleaner fish, but these data can be unwieldy to analyze and/or in some cases are heavily aggregated. Impacts to wild salmon and sea trout in Scotland resulting from escapes and particularly from sea lice continue to be poorly understood, and there is minimal monitoring of wild fish (compared to Norway for example). In addition, the impacts of the collection of wild wrasse for use as cleaner fish is uncertain. While in some cases, the data availability lacks the quality and sophistication of that in Norway (particularly the impacts of escapes and disease), Scotland data excels on wildlife mortalities. 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 6.82 out of 10 for all regions of Scotland.

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[19] Cited with permission

Criterion 2: Effluent

Impact, unit of sustainability and principle

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

Criterion 2 Summary

All Regions of Scotland

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0-10)	**5**	Yellow

Brief Summary

Scottish salmon farms have gradually increased their nutrient waste discharges as the industry has grown, with approximately 13,000 mt of nitrogen, 1,800 mt of phosphorous and 42,000 mt of organic carbon discharged in 2019. Salmon farms are thus substantial contributors of soluble and particulate wastes into the lochs, voes, and coastal waters of Scotland, but the review by the Scottish Association for Marine Science considers it unlikely that they would lead to a detectable change in amounts of phytoplankton, or that nutrient ratio changes would be large enough to appreciably perturb the balance of organisms. Benthic impacts are apparent, and while over 60% of sites are in satisfactory condition (according to the regulations), nearly 40% are borderline or unsatisfactory. With aggregated footprints only exceeding 4% of total seabed area in a few lochs and voes, there is a minor potential for cumulative impacts at the waterbody level. While there is no direct monitoring of soluble effluents and the results of the transition to a new Depositional Zone Regulation in 2019-20 remain to be seen at the time of writing, the substantial literature combined with the site-level benthic monitoring data provide a robust understanding of the nutrient-related impacts of the Scottish salmon industry; as such, the Evidence-Based Assessment method is used. The final score for Criterion 2 - Effluent is 5 out of 10 for all production regions.

Justification of Rating

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

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

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

Figure 6 shows the total discharges of nitrogen, phosphorous and organic carbon from Scottish salmon farms have gradually increased over the last ten years with the most recent (2019 – as of September 27th, 2021) annual values of approximately 13,000 mt of nitrogen, 1,800 mt of phosphorous and 42,000 mt of organic carbon. This broadly reflects the gradual increase in farmed salmon production. These wastes represent a substantial loss of the ecologically costly and globally sourced feed ingredients, and their discharge at farm sites represents a substantial point source of nutrients. There is a substantial body of literature on the fate and impact of nutrient wastes from net pen fish farms, particularly salmon farms, and in their review of the environmental impacts of salmon farming in Scotland, Tett et al. (2018) provide a comprehensive review of the discharge of waste nutrients and their interaction in the wider marine environment. Only key details are repeated here.

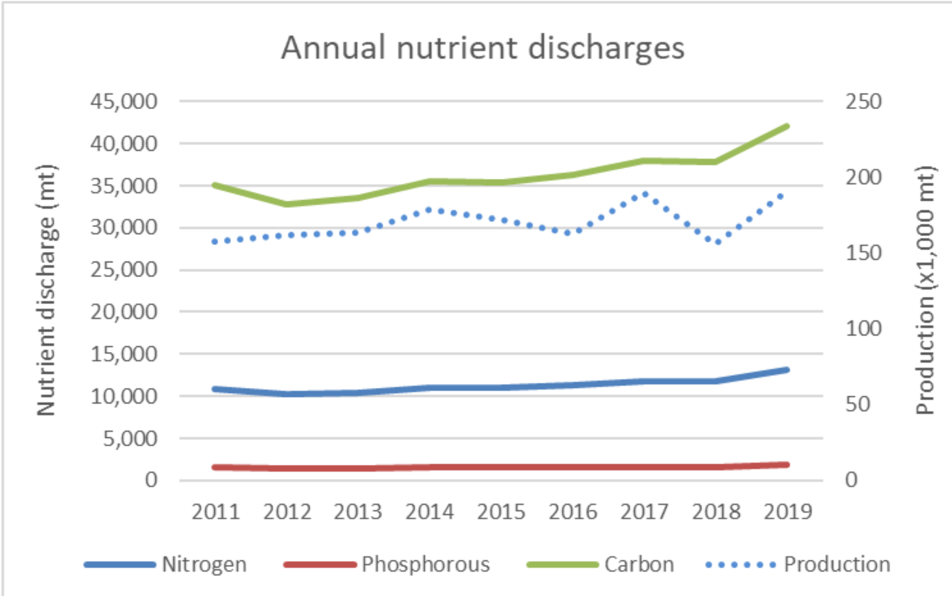

Figure 6: Annual nutrient discharge (solid lines – primary axis) and total farmed salmon production (dotted line – secondary axis). Data from SEPA in "*Scotland's Aquaculture*" database.

Soluble effluent

In relation to eutrophication, Tett et al. (2018) considered the following questions at three spatial scales: local (close to fish farms), sea-loch basins, and larger areas of coastal waters:

- Does salmon farming increase nutrient concentrations in seawater?
- Do such increases lead to increased growth, production, and biomass of seaweeds or phytoplankton?
- Do increases in production and biomass lead to undesirable disturbance of the 'balance of organisms' and the 'quality of water'?

Tett et al. (2018) note that due to the rapid dispersion and dilution of the nutrients emitted by salmon farms, observations of increased concentrations of ammonium (containing nitrogen) and phosphate are limited to within a few tens of meters from farm sites. Due to this rapid dispersal and dilution of nutrients, Tett et al. conclude it is unlikely that increases in phytoplankton will be seen close to farms, as an algal cell requires a few days (depending on illumination) to use N and P in its metabolism and reproduce.

At the waterbody scale, the Scottish Government's "Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters[20]" predict the cumulative effect of fish farms within a

[20] A list of waterbody classifications can be found here, along with links to supporting documents on the models themselves: https://www.gov.scot/binaries/content/documents/govscot/publications/advice-and-

loch or voe and advise where new farms can be sited without overloading nutrient assimilative capacities. The water exchange with the open sea is the main process controlling nutrient levels in most lochs and voes, and according to various simulations, the absolute amount of nutrients contributed by fish farms in summer (when peak feeding rates occur) is not particularly large. However, in a small number of locations and in specific circumstances, the amounts can be more substantial; for example, in 10% of lochs and voes, Tett et al. (2018) noted that salmon farming contributed more than one-third of the Dissolved Available Inorganic Nitrogen (DAIN) during the summer of the second year of the production cycle (when both the biomass in the farm and the feeding rate peaks) with the potential to significantly increase summer amounts of phytoplankton.

Such changes to absolute nutrient levels in addition to changes in relative nutrient ratios can lead to changes in phytoplankton communities, but Tett et al. (2018) report that data allowing an assessment in the changes in plankton communities over time are not available in most cases. Nevertheless, Tett et al. (2018) reviewed long term studies in Loch Creran and Loch Ewe, in addition to the earlier extensive program of monitoring and assessment between 2002 and 2006 carried out by OSPAR (2009). These studies point to the conclusion that Scottish sea-lochs have not been rendered eutrophic by fish farming, but in one example (Loch Creran) Tett et al. (2018) note changes in the balance of phytoplanktonic organisms (despite a decrease in phytoplankton biomass during recent decades) that are hard to explain and might be influenced by farm-derived nutrients. Also, in a limited number of lochs with poorly flushed basins, Tett et al. (2018) suggested organic waste from farms could add to the risk of deoxygenation in deep water that is trapped behind sills, and also noted that enhanced growth of opportunistic green seaweeds in surface waters can occur near farms, but these are not seen as an ecosystem problem if localized and not significant when assessed over lochs as a whole.

At a larger scale (i.e., beyond individual lochs or voes), Tett et al. (2018) considered the Minch (the area of water between the west coast of mainland Scotland and the Western Isles). Depending on the estimate for the volume of water within the flow of the Minch, nutrients derived from fish farming were estimated to represent between 5% and 10% of the total N within the Minch in summer, and between 3.5% and 6% of the total P. It was thought unlikely that such changes would lead to a detectable change in amounts of phytoplankton, or that nutrient ratio changes would be large enough to appreciably perturb the balance of organisms.

Overall, there is evidence that nutrient wastes are rapidly diluted and dispersed from farms, and are therefore a low risk of impact in the immediate farm area, other than occasional localized increases in opportunistic seaweeds. At the waterbody scale, any concern is limited to a small number of lochs or voes where cumulative discharges can be more substantial when the relative biomass of farmed salmon is large. Nevertheless, there are limited observations or data

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guidance/2020/07/authorisation-of-marine-fish-farms-in-scottish-waters-locational-guidelines/documents/locational-guidelines-for-the-authorisation-of-marine-fish-farms-in-scottish-waters-june-2020/locational-guidelines-for-the-authorisation-of-marine-fish-farms-in-scottish-waters-june-2020/govscot%3Adocument/Locational%2BGuidelines%2BJune%2B2020.pdf on significant impacts at the waterbody scale. Similarly, at the coastal scale, while salmon farm nutrients may contribute up to 10% of the total nitrogen, they are considered unlikely to cause significant perturbations to the phytoplankton – or higher trophic – communities at this scale.

Particulate effluent

The particulate waste that is discharged from net pen salmon farms consists of fish feces and uneaten feed. These particulates sink through the water column and settle onto the benthos, where they can alter the chemistry and microbiology of the sediment and alter the community of organisms that live there (Mente et al., 2010; Keeley et al., 2014). The impacted zone is referred to as the farm's 'footprint' and the review in Tett et al. (2018) considered four key questions concerning the fate of solid waste from fish farms:

- What happens within a farm's footprint?
- Does the environment recover when farm operation ceases, and if so, how quickly?
- How big is the footprint?
- What is the contribution of salmon waste to marine ecosystems on scales larger than that of a farm?

Particle deposition is controlled largely by the settling speed of the particles, the water depth, and the current speed; as a result, they generate a localized gradient of organic enrichment in the underlying and adjacent sediments (Black et al., 2008; Keeley et al., 2013, 2015). Keeley et al. (2013) describe the major pathways of bio-deposition from a typical net pen salmon farming system, showing that of the total particulates leaving the net pen, some will dissolve or release nutrients before reaching the seabed; of the portion settling on the seabed in the primary area of deposition, some will be consumed directly by benthic organisms, some will accumulate and consolidate, and some will be re-suspended and transported to far-field locations. During that transport, further nutrients will be dissolved, diluted, and assimilated, and the remainder will finally settle in far-field locations. With a production cycle of approximately 18 months, during which biomass increases to a maximum prior to harvest, SEPA notes that impacts begin to be seen in the second year (RECC, 2020), but typically, the production and deposition of particulate waste generated by fish farms markedly exceeds natural inputs to the seabed in proximity to farm sites, particularly at peak biomass. The degree of effect depends on the magnitude and distribution of particulate settling and the type of sediment. The highest impacts are likely to be seen in areas that have low current speeds, soft sediment, and a high flux of carbon to the seabed. These effects on benthic fauna have been well-studied and have led to a variety of indicators used to describe the extent of benthic disturbance, including the AZTI[21] Marine Biotic Index (AMBI) and the Infaunal Trophic Index (ITI), and the Infaunal Quality Index (IQI) used for regulation in Scotland (Tett et al., 2018).

The footprint of a 1,500 mt farm[22] occupies about half a square kilometer, and the aggregated footprints of the Scottish salmon industry are estimated to be no more than 4% of total seabed area in all but a few lochs and voes, but a lack of recent research in Scottish lochs and a failure

[21] AZTI-Tecnalia - https://www.azti.es/

[22] Munro and Wallace (2019) report 82% of sites in Scotland are licensed for >1,000 mt biomass.

to synthesize monitoring data gives rise to some concerns about long-term sustainability of some sites affected by organic waste (Tett et al., 2018).

In the Environment, Climate Change and Land Reform (ECCLR) Committee report on the environmental impacts of salmon farming (ECCLR, 2018), the committee queried the siting of fish farms in relation to Marine Protected Areas (MPAs), Special Areas of Conservation (SACs) and Priority Marine Features (PMFs). The committee confirmed that 22% of Scottish salmon farms were within MPAs, 18% were in SACs, and 2% were in SPAs; in total, 32% were within some form of protected area. The ECCLR review noted that while site licensing also aims to avoid the risk of farm organic waste falling on protected habitats (e.g., seagrass beds, maerl beds of slow-growing calcareous red seaweeds, and reefs of serpulid tubeworms) there is some evidence of impact to maerl beds in Scotland (based on research from 2003 showing 16 of 346 salmon farm sites were situated over maerl beds, of which a study of three sites showed reduced maerl coverage and changes in the associated fauna up to 100 m from the cage edge (Tett et al., 2018)). In November 2020 (in a 2-year update of the Scottish Government's 2018 Salmon Farming Enquiry) it was noted that NatureScot (formerly Scottish Natural Heritage) has done an enormous amount of work to update and improve mapping information on where priority marine and sea-bed features are that can be considered in the planning of new or expanding salmon farming sites (RECC, 2020).

The Scottish regulatory system for aquaculture's nutrient wastes is based on site-specific maximum biomass limits set according to predicted (modelled) and on-site sampling of the benthic impacts in a defined area around the net pens. 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".

The regulatory system is well developed, but continues to evolve as the industry increases production, and as part of the Scottish Environment Protection Agency's (SEPA) 2018 review of the aquaculture sector, a new regulatory regime was instituted in mid-2019[23]. Under this revised regulatory framework, a depositional mixing zone is used (Figure 7) and defined as an area equivalent to that lying within 100 meters of the pens in all directions (the shape of the zone does not have to be symmetrical; it can extend more than 100 meters from the pens in some directions provided its total area does not exceed that of the equivalent symmetrical area). Benthic samples taken in transects from the farm (Figure 8) must show that the impact area (i.e., the area where the seabed is not in "Good" condition at the time of peak biomass in every production cycle) is smaller than the equivalent permitted mixing zone area. "Good" condition for the benthic samples is dictated by the standards set by the European Water Frameworks Directive. Benthic samples taken under the edges of the net pen arrays must show that the seabed is maintaining the biological processes necessary to break down and assimilate the wastes (i.e., they are not overloaded with wastes to the extent that these biological recovery processes cease).

[23] https://www.sepa.org.uk/media/433439/finfish-aquaculture-annex-2019_31052019.pdf

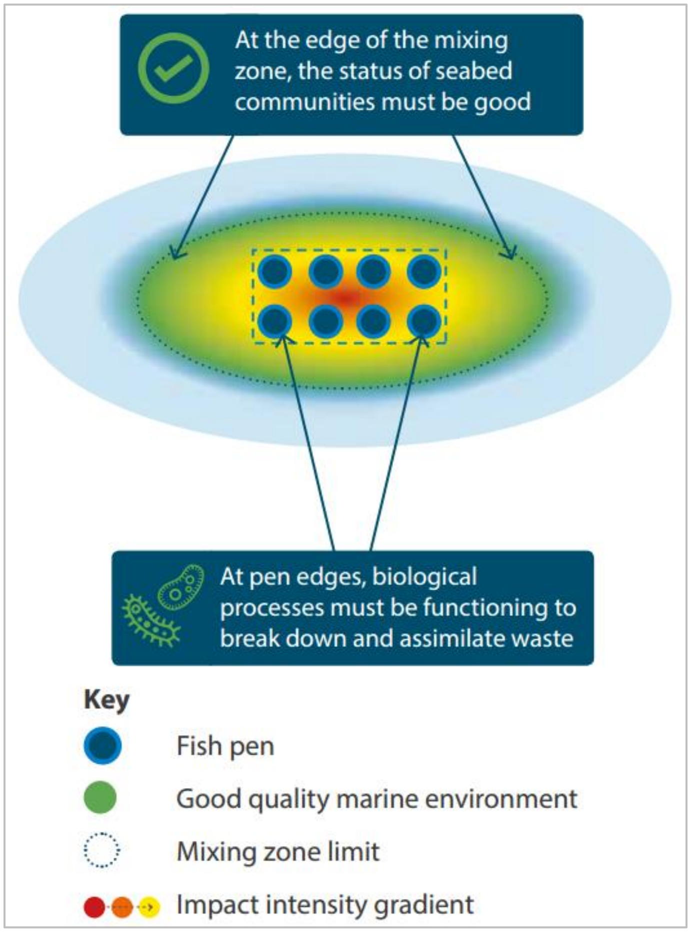


Figure 7: Mixing zone controls on the discharges of fish farm waste under SEPA's regulatory framework for organic wastes. Image copied from SEPA[24].

[24] https://www.sepa.org.uk/media/433439/finfish-aquaculture-annex-2019_31052019.pdf

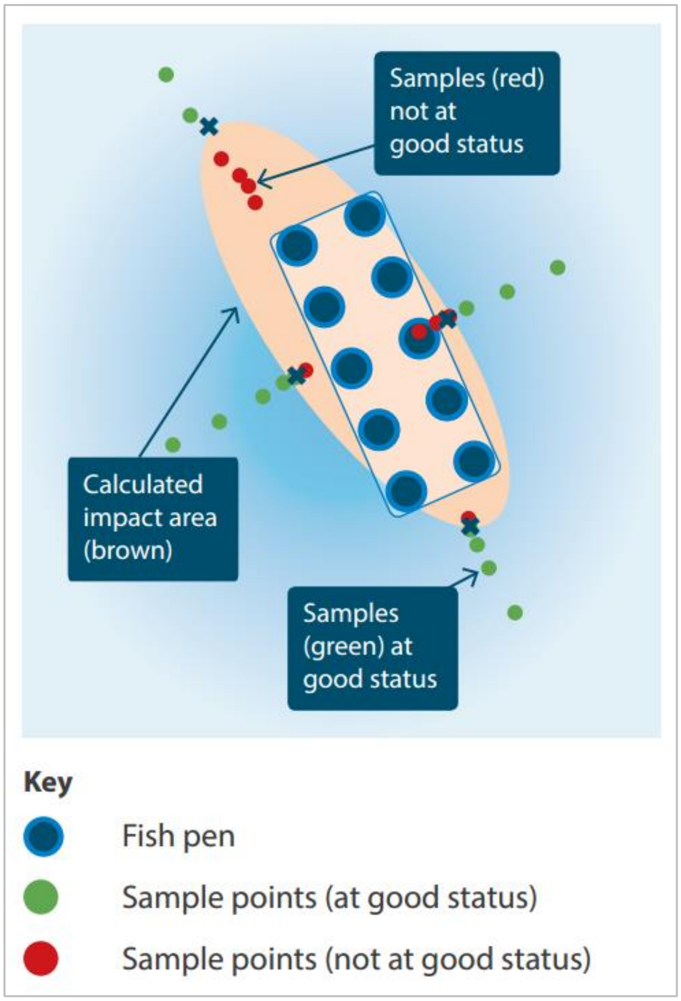


Figure 8: Monitoring transects under SEPA's regulatory framework for organic wastes. The calculated impact area (i.e., equivalent to the area occupied by red samples) must be smaller than the permitted total area equivalent to 100 m from the net pens in all directions. Image copied from SEPA (reference as in Figure 7)

With a transition period to the new DZR regulation starting in 1st Quarter 2020, there are not sufficient results available in the Scotland's Aquaculture database (as of September 27th, 2021) with which to consider the outcomes. Previous benthic monitoring results for all Scottish sites in 2019 (under the former regulatory system based on an Allowable Zone of Effect) show 62% of sites were in "Satisfactory" condition, while 20% of sites were deemed "Borderline" and 18% of sites deemed "Unsatisfactory". The proportion of Satisfactory results had been steadily increasing (Figure 9)[25]. As part of the new regulatory system, SEPA also began its first ever program of unannounced environmental surveys and inspections of marine farms in 2019 (RECC, 2020).

[25] As of November 20, 2020, there were only two sites with 2020 benthic monitoring results in Scotland's Aquaculture database.

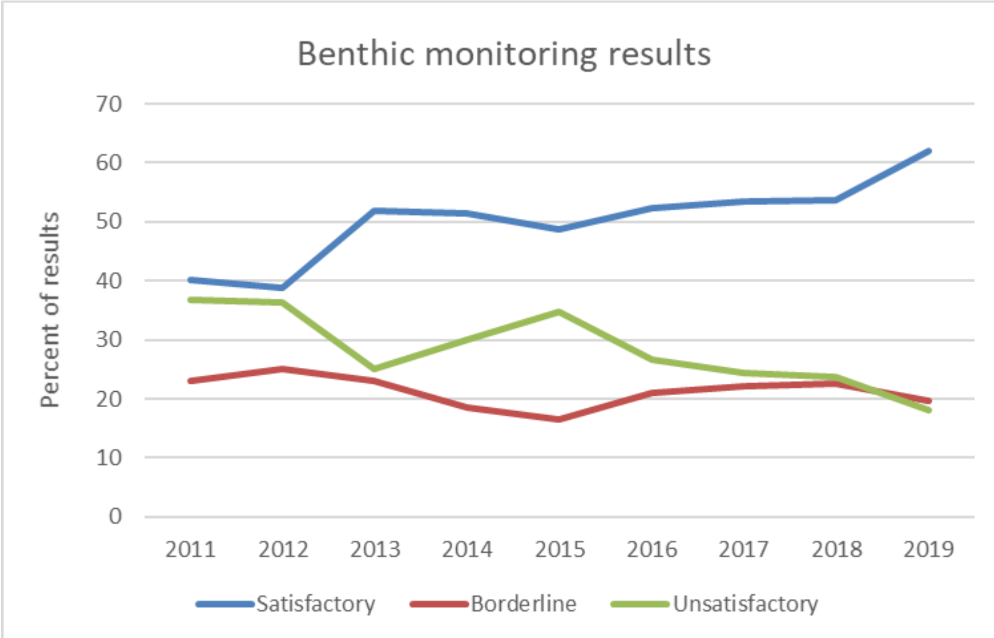


Figure 9: Benthic monitoring results in Scotland from 2011 to 2019. Data from Scotland's Aquaculture.

Research on the direct habitat impacts to benthic communities below the net pens show they are relatively rapidly reversible and could be recovered by fallowing and/or moving the farm (Keeley et al., 2015) but the recovery rate varies with local conditions and full recovery may take substantially longer (Tett et al., 2018). 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, and data in Munro and Wallace (2020) show the most common period is between 9 and 26 weeks. Nevertheless, Keeley et al. (2015) note that after fallowing, impacts begin on the resumption of production and therefore there is an ongoing, cyclical pattern of impacts.

With further regard to potential cumulative impacts, in addition to the broader waterbody nutrient carrying capacity predictions in the "Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters", the new SEPA regulatory framework is intended to address potential cumulative impacts of organic wastes in areas beyond individual farms, and in addition to impacts resulting from other industries (Figure 10). It is not immediately clear how such cumulative impacts will be assessed or monitored, but SEPA states "Fish farm operators will be required to demonstrate, and then manage their sites so that, where waste accumulation does occur, the degree of that accumulation is sufficiently limited to prevent it having a significant adverse impact on the biodiversity of sea life."

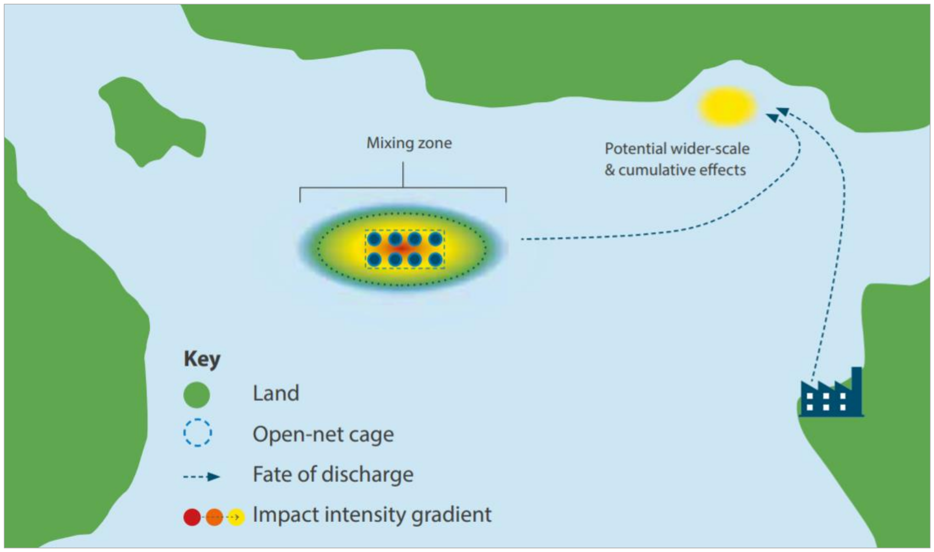


Figure 10: Graphic indicating SEPA's approach to cumulative risks to the wider marine environment. Image copied from SEPA (reference as in Figure 7).

Conclusions and Final Score

Scottish salmon farms have gradually increased their waste discharges as the industry has increased in scale, with approximately 13,000 mt of nitrogen, 1,800 mt of phosphorous and 42,000 mt of organic carbon discharged in 2019. Salmon farms are thus substantial contributors of soluble and particulate wastes into the lochs, voes, and coastal waters of Scotland, but the review by the Scottish Association for Marine Science considers it unlikely that they would lead to a detectable change in phytoplankton biomass, or that nutrient ratio changes would be large enough to appreciably perturb the balance of organisms. Benthic impacts are apparent, and while over 60% of sites are in satisfactory condition (according to the regulations), nearly 40% are borderline or unsatisfactory and there is minor evidence of impacts to maerl beds (a coralline algae). The occurrence of these impacts is considered to be more than occasional, but with aggregated footprints only exceeding 4% of total seabed in a few lochs and voes, there is considered to be a minor potential for cumulative impacts at the waterbody level. While there is no direct monitoring of soluble effluents, the substantial literature (reviewed by Tett et al. 2018) combined with the site-level benthic monitoring data allow for use of the Evidence-Based Assessment method. The final score for Criterion 2 - Effluent is an intermediate 5.0 out of 10 for all production regions.

Criterion 3: Habitat

Impact, unit of sustainability and principle

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

Criterion 3 Summary

All Regions of Scotland

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

Brief Summary

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

The regulatory system for siting and impact assessment in Scotland is robust, but it is unclear how the range of potential impacts associated with the infrastructure of the net pen systems are managed, including from a cumulative perspective. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness is robust. The final score for Criterion 3 – Habitat is of 6.93 out of 10 for all production regions.

Justification of Rating

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

Factor 3.1. Habitat conversion and function

Scotland's Aquaculture mapped database provides a location, map and aerial (satellite) images of all aquaculture sites in Scotland, and these readily allow an overview of general salmon farm habitats. An example of a Scottish salmon farm (picked at random) is shown in Figure 11. A closer image is shown in Figure 12. These images show the number and type of net pens (twelve circles), the feed barge and floating feed distribution pipes, and the surface components of the mooring grid. It is apparent from such images that the floating net pen containment system does not result in any gross functional conversion of surface habitats compared to (for example) the construction of ponds, but that is not to say there are no habitat impacts.

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

Figure 13 shows a typical mooring pattern of anchor lines (at a Norwegian salmon farm randomly selected from the Directorate of Fisheries mapped database), and the positioning of the anchors (notably at approximately 1 km from southeast end of the net pen array in this example) shows the extent of the structures.

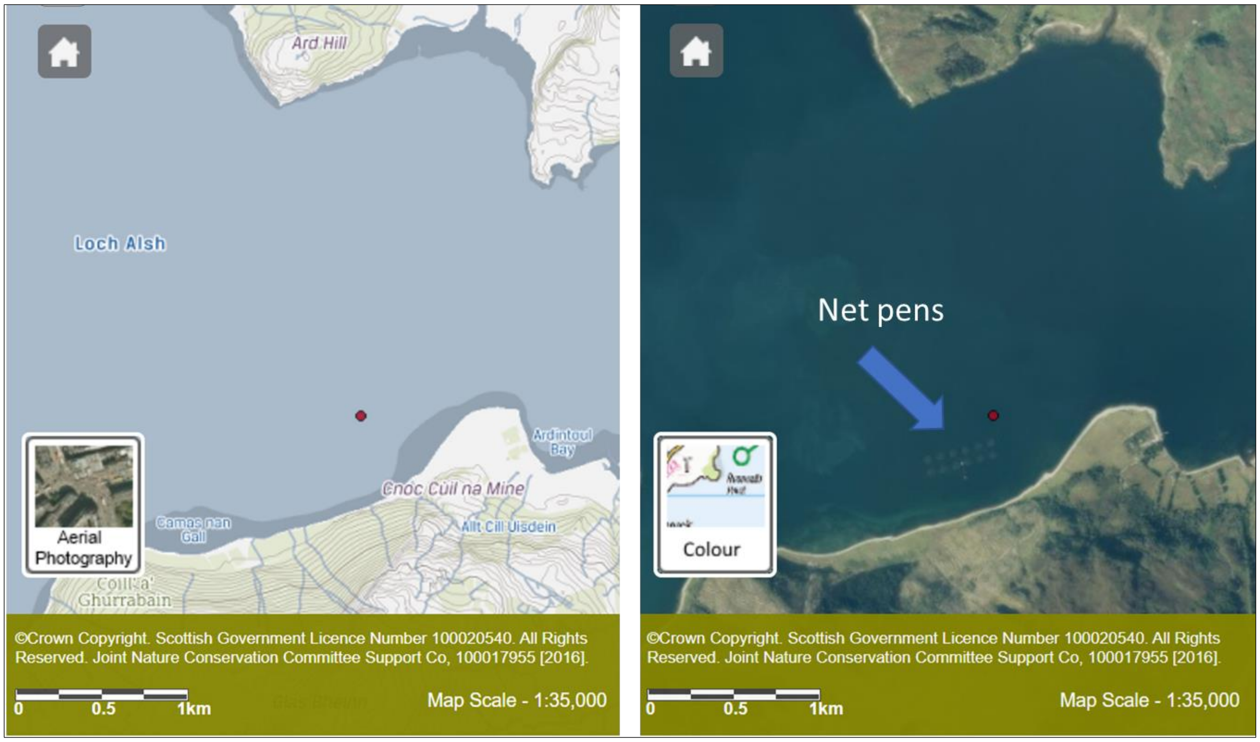


Figure 11: Map and satellite image for a twelve-pen salmon farm in Scotland. Images copied from Scotland's Aquaculture database.

Figure 12: Closer view of the same Scottish salmon farm showing the feed barge at the bottom of the picture, the floating feed distribution pipes leading to each of the twelve net pens, and the surface components of the mooring

system (white buoys). The image also allows the determination that the site is stocked, and that each net pen is fitted with a bird deterrent net. Image copied from Scotland's Aquaculture database.

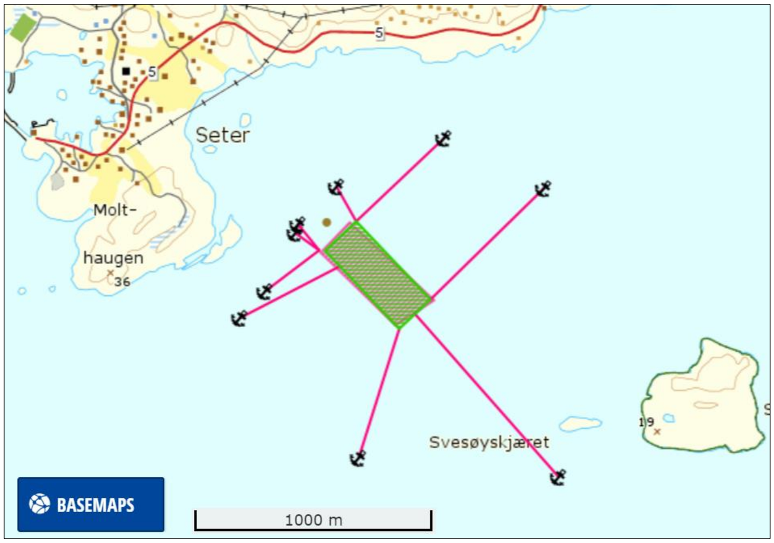


Figure 13: Illustration of the anchoring array of a salmon farm (in Norway). Image copied from the Directorate of Fisheries' mapped database (https://kart.fiskeridir.no/).

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

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

McKindsey (2011) noted an overriding issue in all discussions of these potential stressors is the fact that most proposed effects due to the addition of structure related to fish cage aquaculture are confounded by the addition of large quantities of feed to the environment (and thereby the soluble and particulate fecal wastes discussed in Criterion 2 – Effluent), and any observable impacts may be due, at least in part, to this factor. McKindsey also noted that the effects related to the addition or modification of physical structure are not well studied, most effects have not been quantified, and the discussion of effects in the scientific literature is largely based on extrapolations from other systems. Noting the publication date of 2011, McKindsey also noted that major recent reviews on aquaculture-environment interactions (at that time) did not discuss the implications of these structures or did so only in a very limited way.

A brief search for relevant literature since 2011 adds additional potential impacts; for example, the Canadian Department of Fisheries and Ocean (DFO - in a 2017 information webpage on the Alteration of Habitats[26]) also notes the use of underwater lights may influence the behavior of wild fish by attracting them to—or causing them to avoid—farm sites, but also notes the lights do not penetrate more than a few meters beyond marine nets, suggesting that their use has minimal effect on the surrounding environment. Floerl et al. (2016) note a large number of fish (and mussel) farms in North America, Europe, and New Zealand support extensive populations of biofouling invasive species, and the in-situ cleaning of fouled net pens may inadvertently support the persistence and distribution of such species within aquaculture regions by the localized dispersal of non-indigenous propagules and fragments, or by the use of farm structures as stepping stones for range expansion (Bloecher and Floerl, 2020). In New Zealand, MPI (2013) also note the potential for impacts to benthic habitats due to shading, but in keeping with McKindsey (2011), they note that no studies exist that separate the effects of shading from that of benthic enrichment; presumably because they occur concurrently, and the latter is thought to be the dominant stressor.

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

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

Uglem et al. (2020) also note salmon farms attract large amounts of wild fish which consume uneaten feed pellets, and as specific examples, Otterå et al. (2014) and Skilbrei et al. (2016), note saithe (*Pollachius virens*) are by far the most numerous fish visitors to fish farms (on the

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

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

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

For the industry in Scotland, there do not appear to be any focused research efforts or other similar data to indicate the degree of impact resulting from the placement or presence of net pen arrays. Overall, however, the floating net pen salmon farm containment system is unusual amongst food production systems in that the “construction” of the farm has a relatively low direct habitat impact, yet the addition of the physical infrastructure and the site operations still have a variety of potential impacts on the habitats of the farm site. In addition, it is important to note that the inshore subtidal habitats in which salmon farms are located are important for the early marine stages of endangered wild salmon populations and sea trout in Scotland (see Criterion 6 – Escapes and Criterion 7 - Disease). The evidence reviewed above emphasizes both the complexity and uncertainty regarding the scale of the impacts and the appropriate level of concern, but the examples cited do not indicate the loss of any critical ecosystem services from the affected habitats. As such, the habitats are considered to be maintaining functionality with minor-moderate impacts, and the score for Factor 3.1 Habitat conversion and function is 8 out of 10.

Factor 3.2. Habitat and farm siting management effectiveness

<u>Factor 3.2a – Content of habitat management measures</u>

The Scottish Government website includes a large amount of information on the aquaculture consenting process under various layers of policy including the National Planning Framework, the Scottish Planning Policy (which guides the development of aquaculture to coastal locations that best suit industry needs with due regard to the marine environment, and includes the Town and Country Planning (Environmental Impact Assessment) (Scotland) Regulations 2011), the National Marine Plan, the Scottish Marine Regions, and the UK’s Operational Programme (Nimmo et al., 2016). The Independent Review of Scottish Aquaculture Consenting (Nimmo et al., 2016), commissioned by the Scottish Government, identifies many measures and relevant organizations, though these continue to evolve following the government's review of salmon farming in 2018. 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 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. If a proposed site is close to an area with a nature conservation designation (e.g., Marine Protected Areas, Special Protection Areas, Special Areas of Conservation, Natura sites, Ramsar sites) – which, as discussed in Criterion 2, 32% of sites are within such areas – consultation with NaturScot[27] and other relevant stakeholders is mandatory in order to protect the specific features of these designated areas.

In addition, under the Habitats Regulations (European Union Council Directive 92/43/EEC), it must be considered whether a development will have a 'likely significant effect' on a Natura site, which includes Special Areas of Conservation (SAC), Special Protection Areas (SPA) and Ramsar Sites (this is known as Habitats Regulations Appraisal).

Overall, the dominant aspects of the site-level regulatory system are benthic impacts from nutrient wastes, and given the uncertainty attributed to the impacts described in Factor 3.1, and the apparent dominance of benthic impacts, this is perhaps not surprising. The management system is considered to require farms to be sited according to ecological principles or environmental considerations at the site level, and while there appears to be limited consideration of potential cumulative habitat impacts associated with the combined infrastructures of the industry, the industry does have a broader cumulative management system in place. With consideration of the uncertainties in the scale of the impacts described in Factor 3.1 and the comprehensive nature of the site licensing process, the score for Factor 3.2a is 3 out of 10.

Factor 3.2b – Enforcement of habitat management measures

The regulatory bodies involved in enforcing the various policies and regulations surrounding fish farm siting in Scotland are identifiable and reviewed in Nimmo et al. (2016). The complexity of the system is highlighted by Nimmo et al.'s (2016) review and the report of the ECCLR Committee (ECCLR, 2018), such that the enforcement process is a little less transparent in

[27] NaturScot (formerly Scottish Natural Heritage) is a non-departmental public body funded by the Scottish Government through Grant-in-Aid, and advises the Scottish Government's on issues relating to nature and landscape

terms of the siting of farm infrastructure (in contrast to the enforcement of operational regulations, which can be observed in the benthic monitoring results published in Scotland's Aquaculture database).

Examples of salmon farm EIA reports in Scotland are available online and one selected at random (SSC, 2019) for a large site of twenty pens shows that a comprehensive EIA was undertaken, with consultation from nine stakeholder organizations including NaturScot, Marine Scotland Science, SEPA, the local Council and fishery and recreational representatives. The report describes the infrastructure (number of pens and mooring system, etc.) and operational activities such as the use of lights or acoustic deterrent devices and disturbances from vessel usage but does not address all the potential impacts in Factor 3.1 above, nor is there comment on them all by the stakeholders. The assessment considered the priority marine features within the site area and considered several designated areas within 50 km of the proposed site, including as part of the Habitats Regulations Appraisal. The EIA report notes the consideration of cumulative effects (both the combination of individual impacts at the site level and the combination of impacts from multiple developments) for all aspects of the assessment, although again, these do not specifically cover all the potential impacts described in Factor 3.1.

Following the establishment of a site such as that proposed in SSC (2019), NaturScot (In addition to advising the government on the application process) also undertakes periodic site condition monitoring within Marine Protected Areas (MPAs) which focuses on biological aspects such as the extent and condition of a habitat to determine whether or not the site is in favorable condition (SNH, 2018).

The example EIA report in SSC (2019) is comprehensive and represents an important part of the verification of the regulatory enforcement process. While this example cannot be extrapolated to all new or existing sites in Scotland, nor to all the potential impacts identified in Factor 3.1, it is considered here to be additional evidence of robust enforcement and the score for Factor 3.2b is 4 out of 5.

Final score for Factor 3.2

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) resulting in a Factor 3.2 score of 4.8 out of 10.

Conclusions and Final Score

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

The regulatory system for siting and impact assessment in Scotland is robust, but it is unclear how the range of potential impacts associated with the infrastructure of the net pen systems are managed, including from a cumulative perspective. Overall, the habitats in which salmon farms are located are considered to be maintaining functionality with minor or moderate impacts and the management effectiveness is robust. The final score for Criterion 3 – Habitat is of 6.93 out of 10 for all production regions.

Criterion 4: Chemical Use

Impact, unit of sustainability and principle

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

Criterion 4 Summary

Orkney Isles

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	**7.00**	
Critical?	NO	Green

Northwest, Southwest, Western Isles, and Shetland Isles

Chemical Use parameters	Score	
C4 Chemical Use Score (0-10)	**2.00**	
Critical?	NO	Red

Brief Summary

Scotland's antimicrobial use declined to 2015 when total use that year was less than 0.15 mt and relative use was 0.84 g/ton, but it has since increased with nearly 2.1 mt total and 10.94 g/mt used in 2019. Similarly, the number of sites treated increased from five in 2015 to 55 in 2019. While this is a concerning trend, the current use is considerably less than one treatment per site per year on average across Scotland. From a regional perspective, the Orkney Isles and the southwest region have the lowest antimicrobial use in Scotland.

Pesticide use is variable by treatments, with the in-feed treatment emamectin benzoate used most frequently and the bath treatment azamethiphos used in the greatest quantities by weight. Hydrogen peroxide is also used in large quantities with 5.3 million liters used in 2018. The total number of pesticide treatments per year has generally declined over the last ten years, but the industry still uses over three treatments per site on average each year, or over five treatments per 18-month growout cycle. On a regional basis, the Orkney Isles have a much lower reliance on pesticides, with only seven treatments in 2020 plus additional hydrogen peroxide treatments (six in 2018) equating to slightly less than one treatment per site per year.

The detection of these chemicals in the environment does not directly imply harm, and the number of sites exceeding the Environmental Quality Standards (EQS) for in-feed pesticide treatments (emamectin benzoate and teflubenzuron) is now low (and zero in Orkney in the last ten years). However, while azamethiphos and hydrogen peroxide treatments may have some acute impacts in the water column in the immediate site area, the comprehensive review by SEPA of emamectin benzoate impacts on the seabed added substantial weight of scientific evidence that the existing EQS in Scotland were not adequately protecting marine life. Resistance to emamectin benzoate is widespread, further indicating its overuse. New regulations have been adopted by SEPA but with ongoing multiple treatments per site in open production systems each year and coordinated treatments across multiple sites, the cumulative impacts are uncertain, and the efficacy of the new regulation is as-yet unknown. As such, the final score for the Northwest, Southwest, Western Isles and Shetland Isles for Criterion 4 – Chemical Use is 2 out of 10. With a much lower lice pressure experienced by farm sites in the Orkney Isles, the need for chemotherapeutants is approximately once per site per year and considered a demonstrably low need for chemical use. Consequently, the final score for the Orkney Isles for Criterion 4 – Chemical Use is 7 out of 10.

Justification of Rating

This assessment focuses on antimicrobials and sea lice pesticides as the dominant veterinary chemicals applied in salmon farming. While other types of chemicals may be used in salmon aquaculture (e.g., antifoulants, anesthetics), the risk of impact to the ecosystems which receive them is widely acknowledged to be less than that for antimicrobials and pesticides. Tett et al.'s (2018) Review of the Environmental Impacts of Salmon Farming in Scotland provides a comprehensive review of the important characteristics of the various treatment chemicals used in fish farming in Scotland. Given the importance of this issue and the specifics of the Seafood Watch Aquaculture Standard, additional data collection, research and analysis have been conducted here.

<u>Antimicrobials</u>

Figure 14 shows the quantities of antimicrobials (in kg of active ingredient) used in Scottish salmon aquaculture between 2006 and 2019, and Figure 15 shows the recent period 2015 to 2019 in more detail (all data were obtained at the site-level by a Freedom of Information request from SEPA, but a request for 2020 data was not available due to a data hack at SEPA). Oxytetracycline was the dominant antimicrobial used until 2015, but the use of florfenicol has increased steadily since then. Both oxytetracycline and florfenicol are listed by the World Health Organization as highly important for human medicine (WHO, 2019).

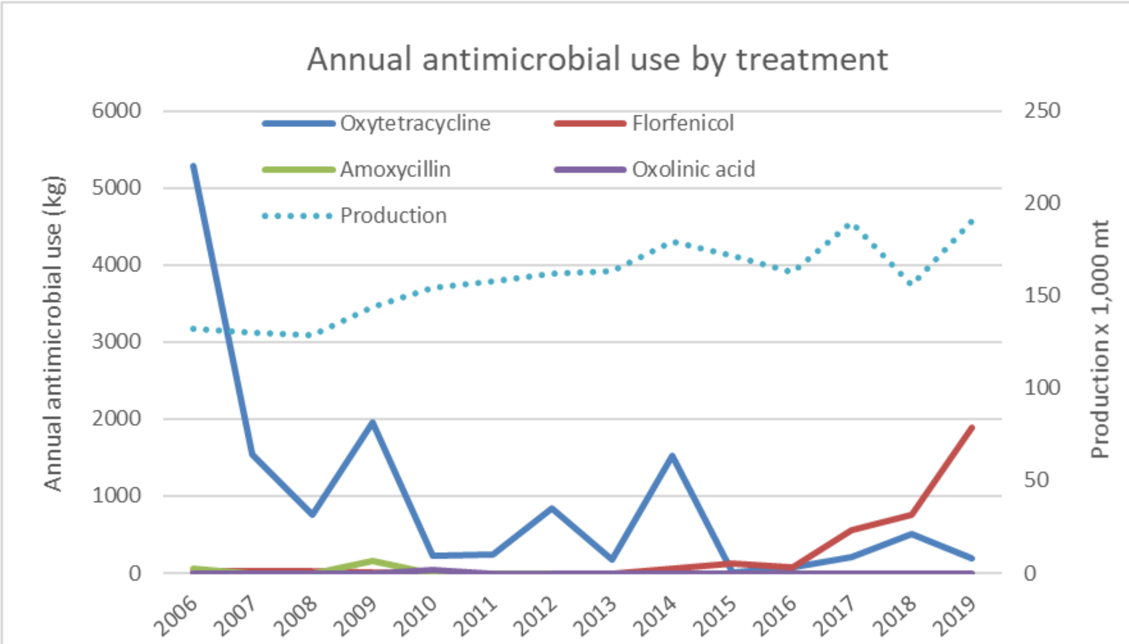


Figure 14: Antimicrobial use in Scotland from 2006 to 2019 (solid lines and primary y-axis) and total salmon production (dotted line and secondary y-axis). Antimicrobial use data from SEPA (FOI request), production data from Munro and Wallace (2019).

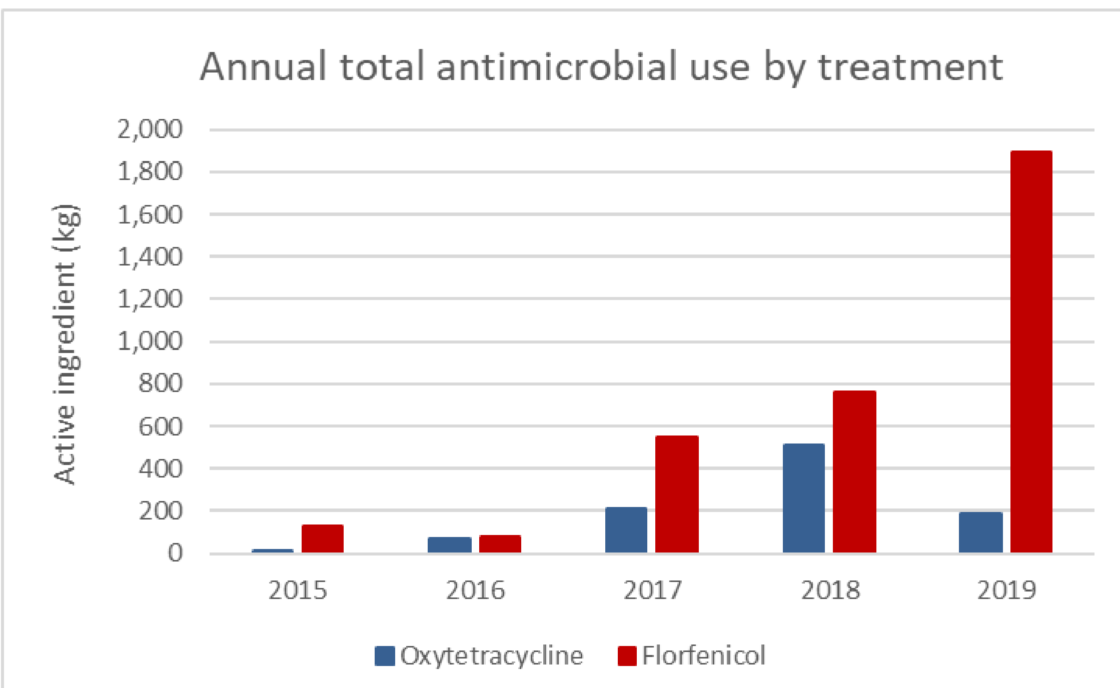


Figure 15: Antimicrobial use in Scotland from 2015 to 2019. Antimicrobial use data from SEPA (FOI request).

Figure 16 shows the number of sites treated each year has increased from 5 in 2015 to 55 in 2019 (note this is not the same as the number of treatments, as the data do not define if each site was treated once or multiple times each year). Over the same period, the relative use in the unit of grams of antimicrobial active ingredient per mt of production (g/mt) increased from 0.84 in 2015 to 10.94 in 2019. This is many times higher than the value of 0.17 g/mt in Norway for 2020 (data from Sommerset et al., 2021), but much lower than the approximately 444 g/mt for Atlantic salmon grown in Chile in 2020 (data from Sernapesca, 2021). The reason for the increase observed in Scotland is not immediately apparent, and the UK's Fish Health Inspectorate (FHI) simply lists "bacterial challenges" (see Criterion 7 – Disease).

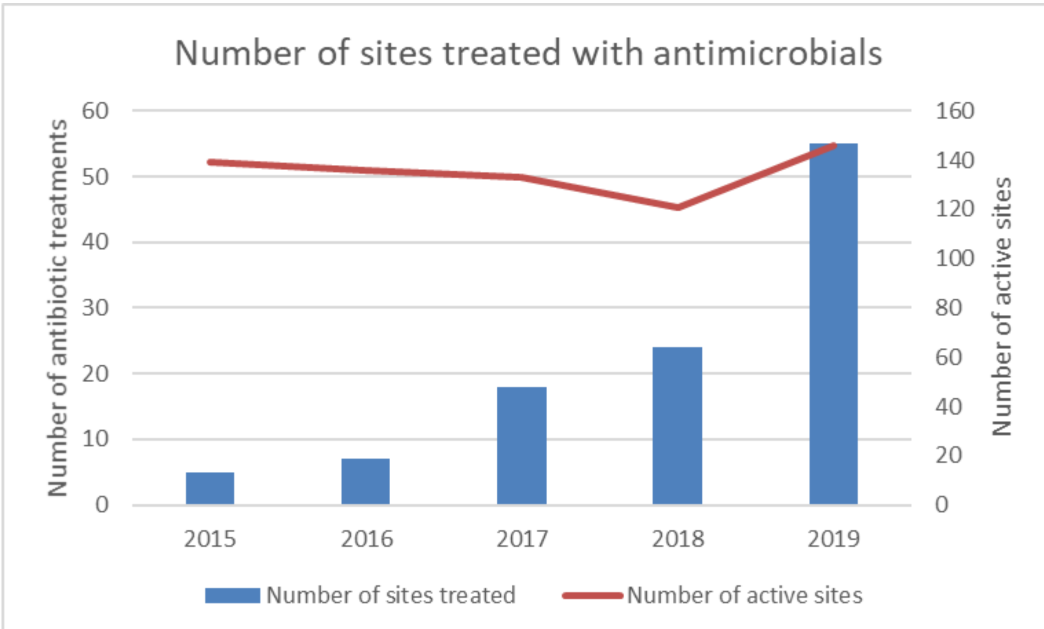


Figure 16: Number of sites treated in Scotland from 2015 to 2019. Antimicrobial use data from SEPA (FOI request).

The number of treated sites is highly variable by region[28] (Figure 17), and while this mirrors production tonnage to some extent (and largely therefore the number of sites), Orkney (with one treated site in 2019) and the southwest region (with 5 treated sites in 2019) had low antimicrobial use in 2019. Orkney in particular has not shown an increase in the number of sites being treated over this time period (Figure 17).

[28] The annual Scottish Fish Farm Survey (e.g., Munro and Wallace, 2020) and Scotland's Aquaculture database report in different regional units. For this Seafood Watch analysis, the separate Argyl & Bute and N. Ayr regions in Scotland's Aquaculture database have been combined into the Southwest region as used by the annual survey.

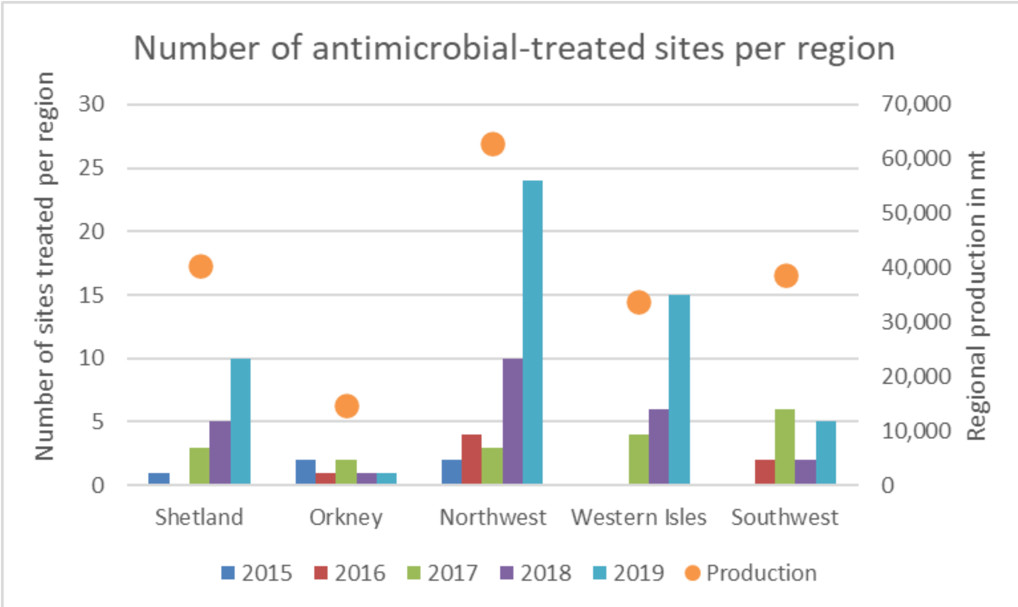


Figure 17: Number of antimicrobial-treated sites per region per year from 2015 to 2019. Production (orange dots) is shown on a secondary axis. Antimicrobial use data from SEPA.

Without specific data on the number of antimicrobial treatments per site (as opposed to the number of sites treated, as presented above), it is not possible to accurately determine the frequency of antimicrobial use, i.e., the average number of treatments per site per year. Any such estimate is also hampered by the lack of data on the numbers of active sites per region in the annual Scottish Fish Farm Production Survey (Munro and Wallace, 2020). Nevertheless, by using the total number of active sites reported by Munro and Wallace (2020) of 146 in 2019, and by considering the annual production per site to be constant across all regions, a crude estimate of the number of active sites per region can be made using the total and regional annual production figures. From these figures, an estimate of the percentage of sites treated per year in each region can be made, as shown in Figure 18.

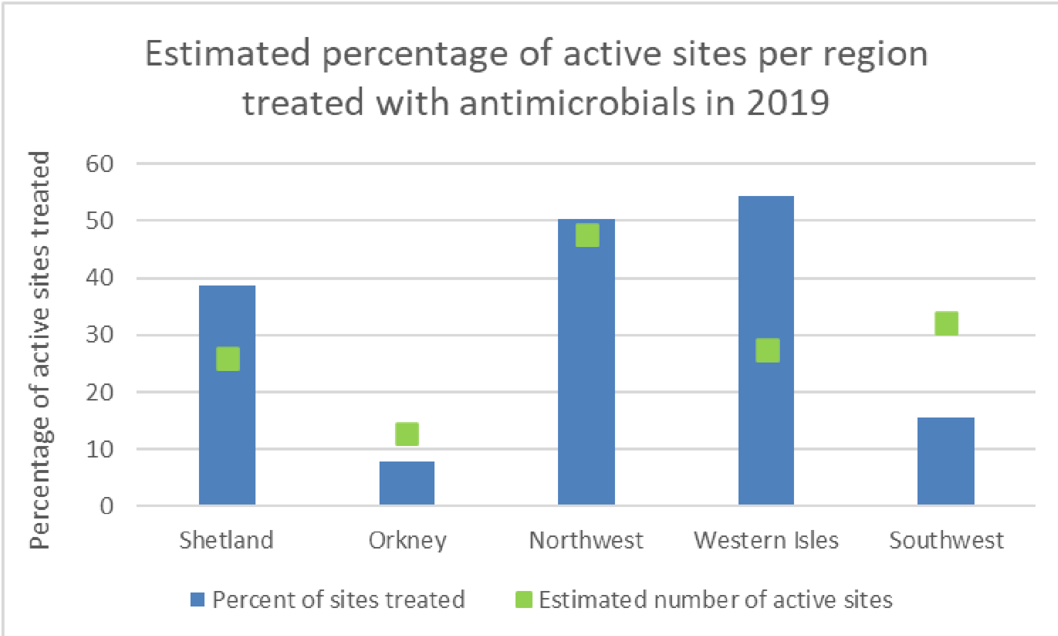


Figure 18: Estimated percentage of active sites in each region that were treated with antimicrobials in 2019. Numbers of active sites (green dots) were estimated from data in Munro and Wallace (2020) and data on the number of sites treated was obtained from SEPA.

While the percentage of sites treated per year per region also does not give any specific indication of treatment frequency, it is clear that Orkney and the Southwest regions have lower frequency of antimicrobial use, and with approximately 10% to 15% of sites treated each year, it is highly likely to be less than one treatment per production cycle[29]. Orkney in particular has also has a consistently low number (and percentage) of treated sites over the 2015 to 2019 time period (Figure 17) and does not show the variability and the rapid increases of antibiotic use for the other regions and for Scotland as a whole (Figures 15 and 16). Nevertheless, even if every one of the 55 treated sites in 2019 was treated twice (in reality, most were likely treated once), the average frequency of treatment over the 146 active sites in 2019 would be 0.75 per year, or 1.1 treatments per site over an 18-month production cycle.

<u>Antimicrobial resistance</u>

The use of antimicrobials in open net pen production systems inherently links salmon farming to global concerns regarding the development of resistance and the passage of resistance genes from aquatic to terrestrial pathogens (Santos & Ramos, 2018; Lilijwa et al., 2019). The WHO (2017) states: extensive research into mechanisms of antimicrobial resistance, including the important role of horizontal gene transfer of antimicrobial resistance determinants, supports the conclusion that using antimicrobials in food-producing animals selects for antimicrobial resistance in bacteria isolated from food-producing animals, which then spread among food-producing animals, into their environment, and to humans. However, in this assessment where

[29] Note, if Orkney has smaller sites than the average across Scotland (which is considered likely), then the estimated number of sites would be higher, and the percentage of sites treated would be lower than the 10% calculated here.

antimicrobial use is relatively low and the frequency of use is likely to be approximately once per year or per production cycle, the concern for resistance development is low.

Pesticide use

Pesticide use as a veterinary medication in Scotland is regulated on a site-specific basis with discharge consents under the SEPA Controlled Activity Regulations. Site-level pesticide data are mostly available from Scotland's Aquaculture database; data on hydrogen peroxide use were requested under a Freedom of Information request to SEPA but were not supplied. Partial hydrogen peroxide data (to 2018) were obtained from SEPA's publication log of previous Freedom of Information data requests[30].

The primary target for pesticides in salmon farming in Europe is the parasitic sea louse *Lepeophtheirus salmonis*, and to a lesser extent *Caligus elongatus*, and Figure 19 shows the annual quantities of five different treatments used in Scottish aquaculture between 2008 and September 2020 (the latest data available as of July 8th, 2021).

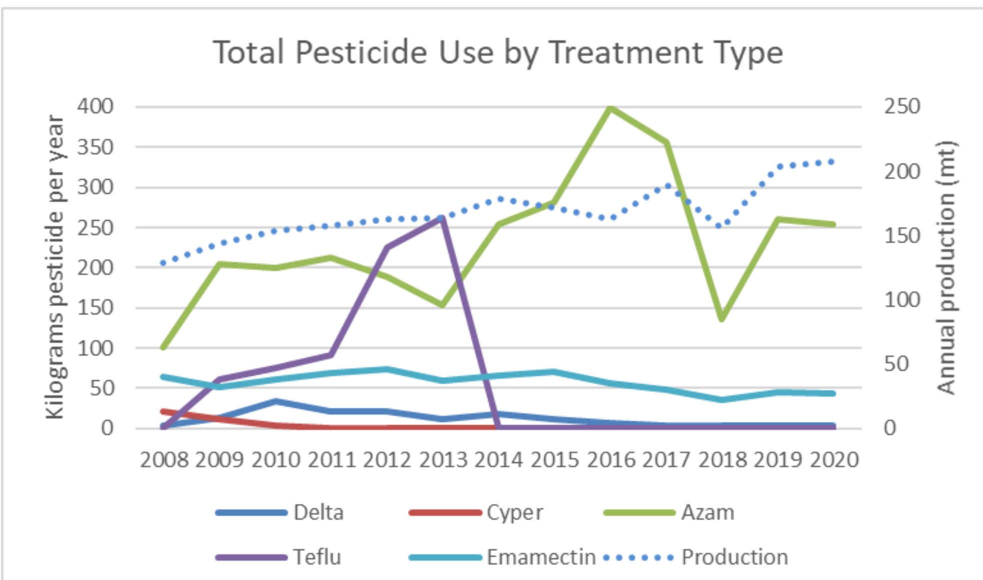


Figure 19: Pesticide use from 2008 to 2020 in kg active ingredient (solid lines and primary y-axis), and annual production in metric tons (dotted line and secondary y-axis). Data from SEPA in "*Scotland's Aquaculture*" database.

Figure 19 shows changing patterns of treatment use. Hydrogen peroxide is not included here due to the greatly different units of use (due to its lower toxicity, large quantities are used in each treatment), and is discussed separately below. Teflubenzuron had a high and increasing use (by weight) until 2013 before dropping to zero in 2014 (and remaining there since). Azamethiphos, the most used from 2008-2011, increased rapidly after 2013, apparently as an alternative to teflubenzuron; its use has subsequently been variable. It is important to use caution with these data as the different pesticides vary greatly in their toxicity and route of

[30] https://www2.sepa.org.uk/disclosurelog/#

administration (in-feed or as a bath treatment), and therefore in their dosage. While the data in Figure 19 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; for example, total teflubenzuron use by weight was high in 2013 but the frequency of treatment was low (5 treatments in total). Previous data obtained from SEPA up to 2015 show the use of hydrogen peroxide was substantial, with 19.5 mt used in 2015. It is considered likely that due to increased resistance to other treatments (discussed below) the use of hydrogen peroxide will still be substantial and has likely increased.

To help clarify the picture of pesticide use in Scotland, Figure 20 shows the frequency of use of each treatment over recent years (in numbers of treatments of each pesticide used each year, not including hydrogen peroxide), and the total number of all treatments. This shows a general decline in the total number of pesticide treatments over the last ten years, with emamectin benzoate (administered in-feed) and azamethiphos (administered as a bath treatment) being the most frequently used chemicals in the last five years.

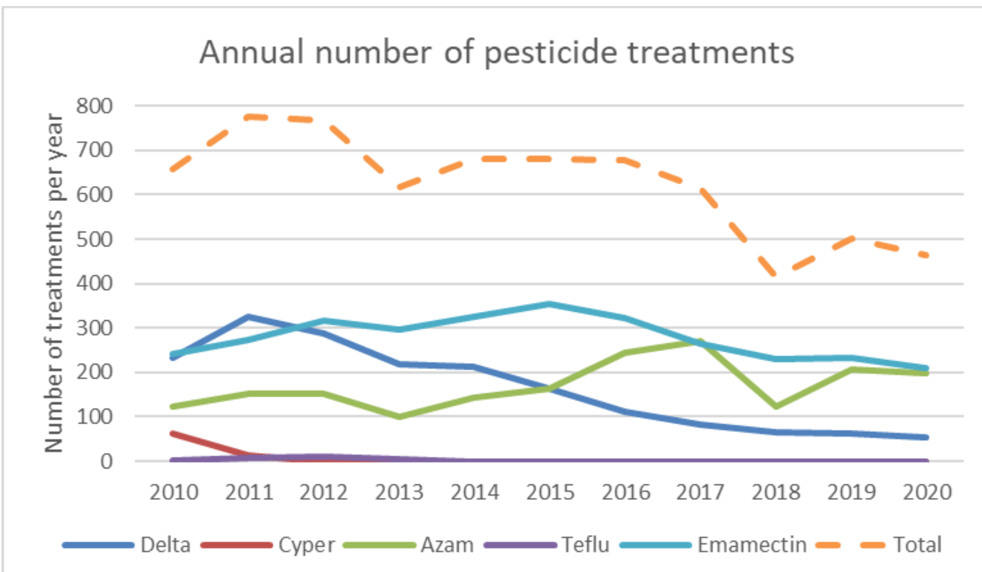


Figure 20: Number of treatments by pesticide type (not including hydrogen peroxide), and total for the years 2010 to 2020. Data from "Scotland's Aquaculture" database.

With 146 active sites (Munro and Wallace, 2020), the total number of sea lice treatments of 461 in 2020 (not including hydrogen peroxide) represents 3.2 treatments per site per year on average. If the growout cycle is approximately 18 months, this means each harvested fish has been treated on average over five times with these chemicals. In 2018, there were 104 hydrogen peroxide treatments, and while this number was decreasing (see Figure 23 below), these treatments will further increase the total number of treatments per site per year.

When considered by region, Figure 21 shows the total weight of each pesticide used in 2019, and Figure 22 shows the number of treatments by region (neither including hydrogen peroxide); both also show the regional production of farmed salmon (orange dots). Figure 21 shows that the Northwest region has the highest use by weight. Figure 22 shows that, despite lower fish production, the Southwest region has the higher number of treatments; the Southwest's greater use of emamectin benzoate (which is used in-feed and has a much smaller weight of active ingredient per treatment than the bath treatment azamethiphos) results in the lower total weight used as compared to the Northwest.

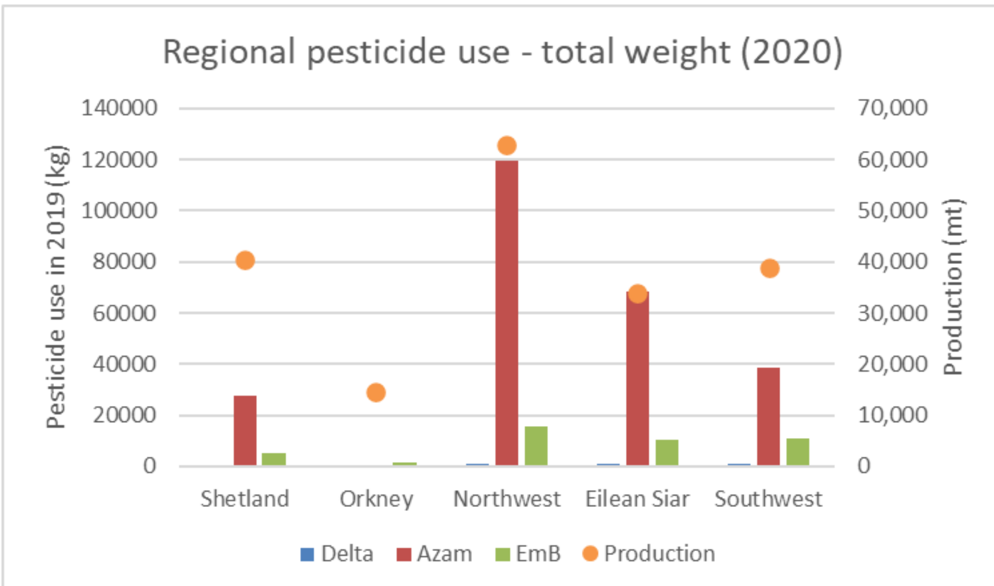


Figure 21: Regional pesticide use by weight in Scotland in 2020 for the three treatments used (not including hydrogen peroxide). Production data (2019) shown in orange dots on secondary axis. Data from Scotland's Aquaculture database.

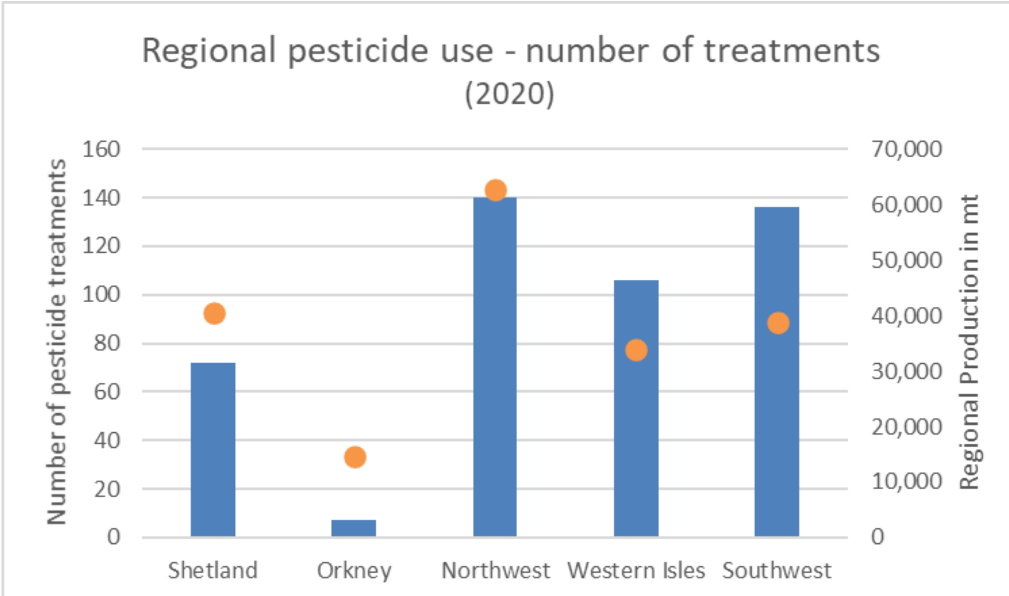


Figure 22: Regional pesticide use showing the total number of treatments (not including hydrogen peroxide) per region in 2020. Production data (2019) shown in orange dots on secondary axis. Data from Scotland's Aquaculture database.

It is notable that the Orkney Isles have very low pesticide use in both total and relative terms. While having the lowest regional production, the seven pesticide treatments (of emamectin benzoate) in 2020 for approximately 13 active sites (estimated for 2019 from Wallace and Munro, 2020) result in an average of 0.5 treatments per site[31].

Hydrogen peroxide

Although previously considered to rapidly break down in the environment with little environmental impact, Grefsrud et al. (2021a,b) reviewed the available information on hydrogen peroxide's presence in the environment (based on the volume used, its spread and dilution, and its decomposition) and its environmental effects on non-target species (based on the sensitivity of the non-target organisms and the seasonal overlap between its use and the presence of those non-target organisms). They concluded that the risk of environmental impact on non-target organisms through the use of hydrogen peroxide was "moderate", and thereby the same as deltamethrin, diflubenzuron and teflubenzuron, emamectin benzoate, and worse than azamethiphos. Treating sea lice with hydrogen peroxide involves considerable volumes; Figure 23 shows the use from 2010 to 2018[32] in millions of liters, with a peak of 19.6 million liters in 2015, declining to 5.3 million liters in 2018. On a regional basis, Figure 24 shows that in 2018, most hydrogen peroxide was used in the Western Isles, with the least in the Orkney Isles (6 treatments in 2018).

[31] If there are in fact more than the 13 active sites in Orkney estimated here, then this value of 0.5 will be lower.

[32] As noted above, only partial data on hydrogen peroxide use could be obtained from SEPA's disclosure log.

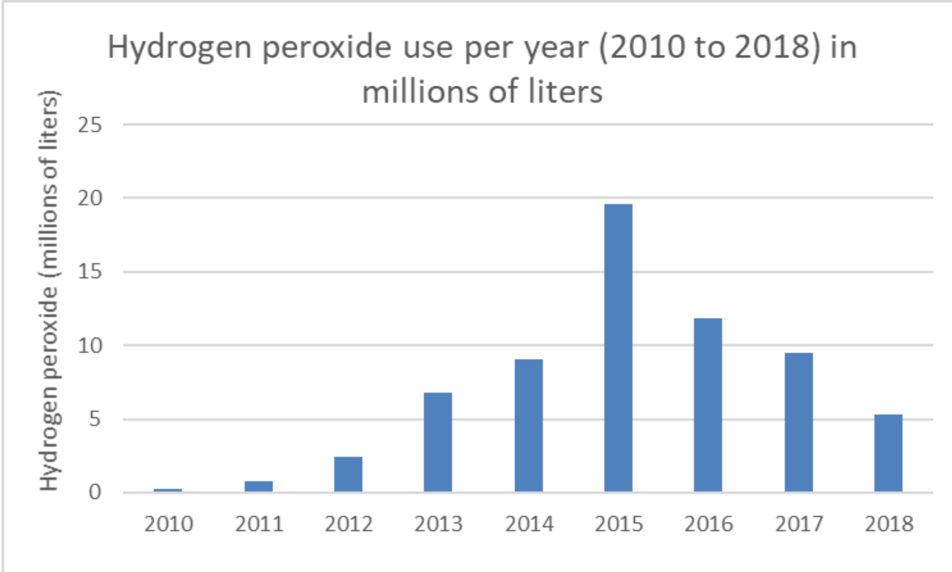


Figure 23: Use of hydrogen peroxide in Scottish salmon farms from 2010 to 2018 in millions of liters. Data obtained from SEPA.

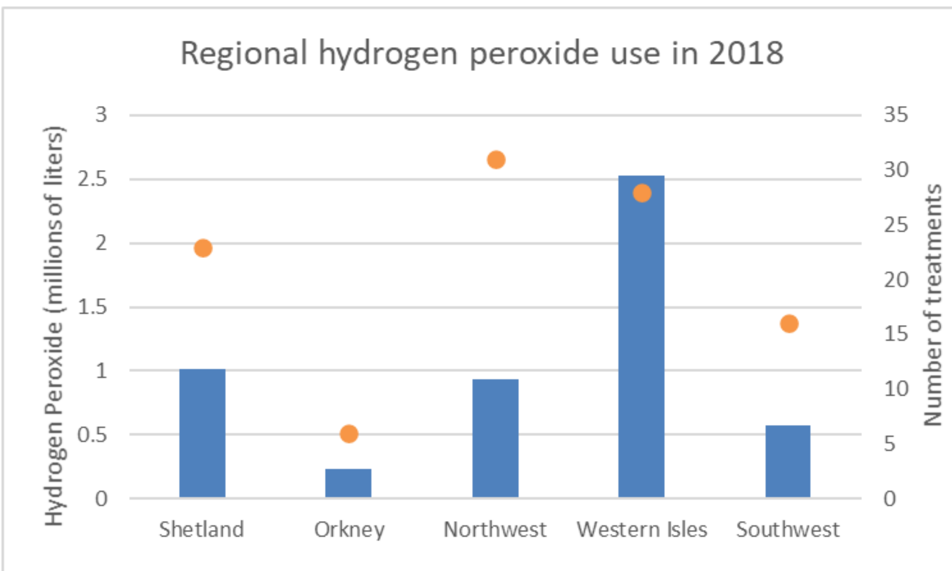


Figure 24: Regional use of hydrogen peroxide in 2018 in millions of liters (blue bars) and the number of treatments (orange dots). Data from SEPA.

<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 water column and on the seabed in the vicinity of treated net pens (Burridge et al., 2010). SEPA note the presence of a chemical in the environment does not necessarily mean that it is causing harm (SEPA, 2018), but while the impacts continue to be studied and reviewed, the real effects of these pharmaceuticals on the marine environment remain largely uncertain (Urbina et al., 2019).

Large proportions of pesticide treatments (in-feed and bath) can be discharged from the farms after treatment. In-feed treatments (emamectin benzoate) tend to be dispersed in small amounts of uneaten feed and, predominantly, in 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). Importantly, Samuelsen et al. (2015) showed that while pesticide residue levels in the sediments are low, particles containing residues have been found as far as 1,100 m from the treatment site.

Sea lice chemicals administered as bath treatments (azamethiphos, deltamethrin, cypermethrin, hydrogen peroxide) are released to the environment as a water column plume. Though some authors contest that such treatments may retain toxicity for a substantial period after release (Burridge et al., 2010), Macken et al. (2015) conclude that, as bath treatments such as azamethiphos, cypermethrin, and deltamethrin have a rapid release, dispersion, and dilution post treatment, they primarily impact non-target organisms in an acute manner with limited potential for chronic impacts. In a study on the epibenthic copepod *Tisbe battagliai* (Macken et al., 2015), azamethiphos was acutely toxic at high concentrations but was found to cause no developmental effects at lower concentrations. More recently, Parsons et al. (2020) report that while azamethiphos is acutely toxic to European lobster larvae (*Homarus gammarus*) at levels below the recommended treatment concentrations, due to the hydrodynamic models of dispersion, the impact zones around farms were relatively small (mean area of 0.04–0.2 km^2). As noted above the (Norwegian) risk assessment and knowledge status review in Grefsrud et al. (2021a,b) considered the risk of environmental impact on non-target organisms of bath treatments to be “good” (i.e. a low risk) for azamethiphos, and “moderate” for hydrogen peroxide, and deltamethrin.

For the in-feed treatments (emamectin benzoate and teflubenzuron), the same Norwegian risk assessment and knowledge status review considered the risk of environmental impact on non-target organisms from in-feed treatments to be “moderate” for diflubenzuron, teflubenzuron, and emamectin benzoate.

In Scotland, detailed seabed pesticide residue data are available on Scotland’s Aquaculture database from samples taken under the edge of the net pens (0 m) and at 100 m distant (Figure 25). Samples are taken at highly variable periods after treatment ends with an average of 138 days but a range of 80 to over 400 days (for samples taken in the last three years). The results show the number of sites exceeding the environmental quality standards (EQS) have declined since 2016. In 2019, no samples exceeded at 0 m, and less than 5% at 100 m, and in the first half of 2020 there were no samples exceeding the EQS.

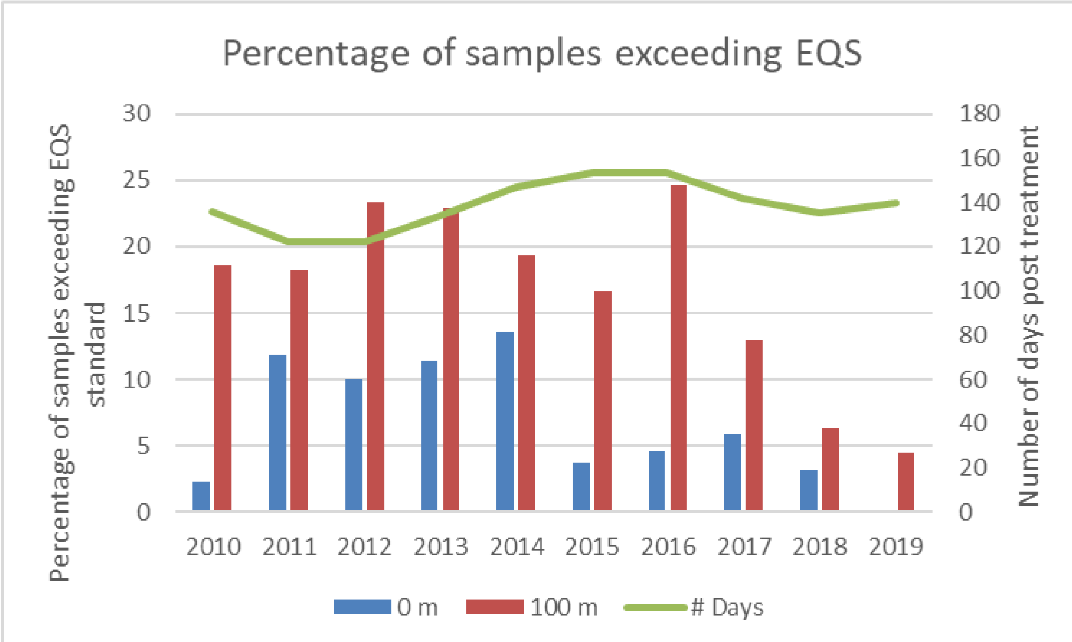


Figure 25: Seabed sampling for emamectin benzoate residues relative to the EQS. Data from Scotland's Aquaculture database.

Using a longer-term dataset from 2010 to July 2020, an indication of the regional share of treatments can be seen. Figure 26 shows the regional share of all the benthic samples that exceeded the EQS in this time period compared to the regional share of production (using 2019 production data). This shows the Northwest region has approximately a third of Scotland's production but half of all samples exceeding the EQS. Shetland and the Western Isles have equivalent shares of exceeded samples and production (approximately 20%), the Southwest has a lower share of exceeded samples than production, while the Orkney Isles are notable for not having any samples exceeding the EQS.

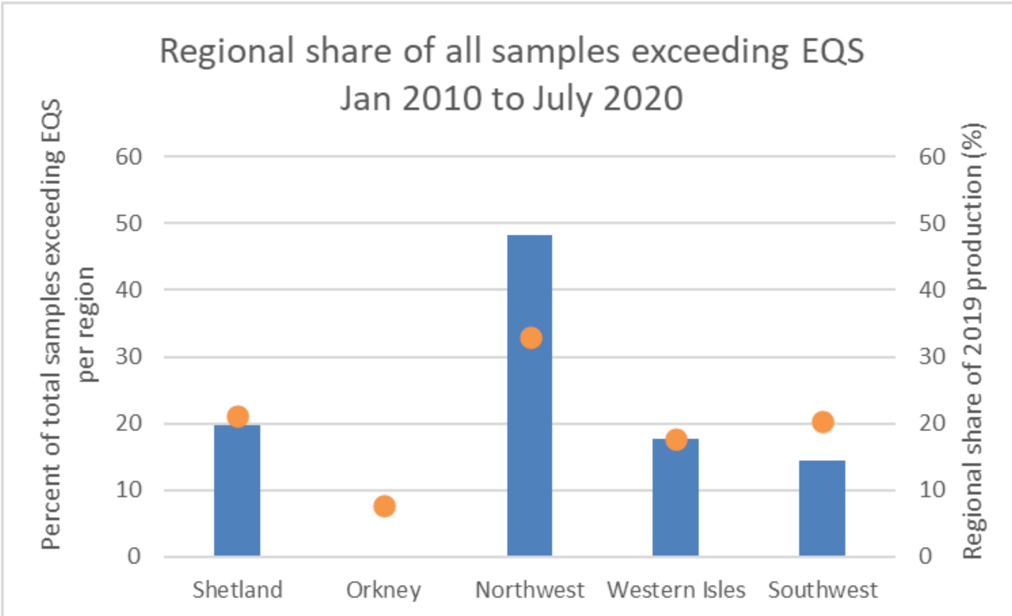


Figure 26: Long term regional share of the seabed samples that exceed the EQS standard from January 2010 to July 2020. The primary y-axis shows the share of all the samples that exceed the EQS standard as a percentage for each region. That is, if there were 100 samples across Scotland exceeding the EQS standard in this time period and half of them occurred in one region, then the share would be 50%. The secondary y-axis shows the regional share of total Scottish farmed salmon production using the 2019 figure. Data from Scotland's Aquaculture database.

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

Eleven years ago, Burridge et al. (2010) highlighted 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*". In their 2018 report, SEPA acknowledges that further work is still required to understand the wider-scale cumulative impacts.

Further, the widespread development of resistance in sea lice to various pesticides, particularly emamectin benzoate, cypermethrin, and deltamethrin, with reports of resistance to azamethiphos and hydrogen peroxide (Aaen et al., 2015; Tett et al., 2018), is a strong indicator that pesticides have been over-used in a veterinary context for many years.

In response to the focused concern on emamectin benzoate, SEPA has established new EQS limits; however, these currently (as of a SEPA position statement, 9 January 2020) apply to new sites only, with existing farms being asked to voluntarily reduce use by 60% (SEPA, 2020). With a somewhat fluid regulatory situation (based on the EQS along with a Total Allowable Quantity and a Maximum Treatment Quantity), concerns inevitably remain regarding the confidence with which local impacts at the site and cumulative impacts at the waterbody level are determined, particularly as the industry grows and the dynamics of pesticide use (and the use of non-chemical alternatives) evolve.

Antifoulants and other metals

Copper use as a net antifoulant in Scotland continues to be significant, but Figure 27 shows the quantity has declined from a peak of over 140 mt in 2012 to 60 mt in 2019 (the latest data year available from Scotland's Aquaculture database as of July 9, 2021). Zinc discharge as a result of feed use has increased slowly from 26 mt in 2008 to 37 mt in 2019.

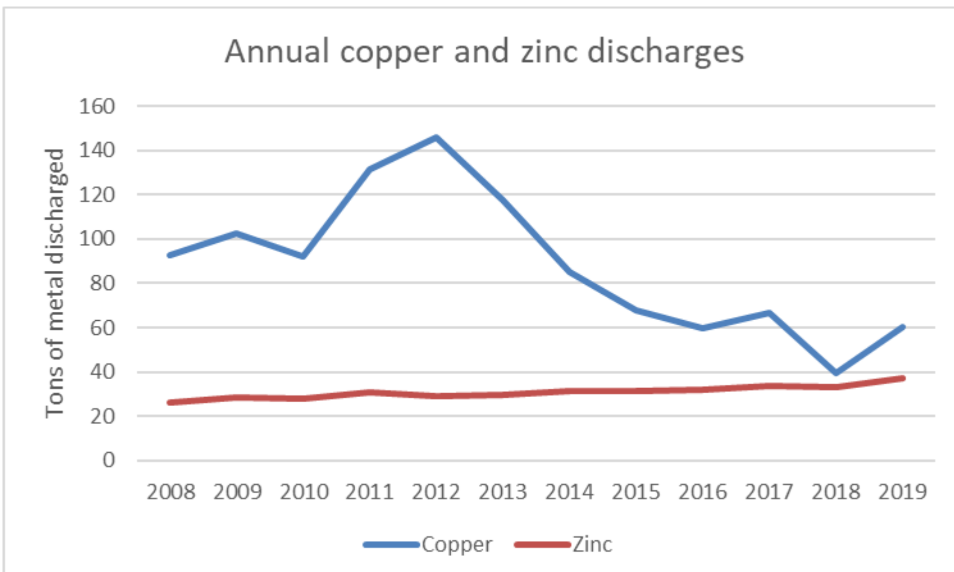


Figure 27: Annual copper and zinc discharge from salmon sites in Scotland. Data from SEPA in "*Scotland's Aquaculture*" database.

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 (Bloecher and Floerl, 2020). While Loucks et al. (2012) reported 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 to 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 which might cause adverse effects in the environment were all within 25 m of the pens, and 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. (2010), several papers have shown that effects reported are not necessarily a consequence of elevated metal concentrations.

Conclusions and Final Score

Scotland's antimicrobial use declined to 2015 when total use that year was less than 0.15 mt and relative use was 0.84 g/ton, but it has since increased with nearly 2.1 mt total and 10.94 g/mt used in 2019. Similarly, the number of sites treated increased from five in 2015 to 55 in 2019. While this is a concerning trend, the current use is considerably less than one treatment per site per year on average across Scotland. From a regional perspective, the Orkney Isles and the Southwest region have the lowest antimicrobial use in Scotland.

Pesticide use is variable by treatment, with the in-feed treatment emamectin benzoate used most frequently and the bath treatment azamethiphos used in the greatest quantities by weight. Hydrogen peroxide is also used in large quantities with 5.3 million liters used in 2018. The total number of pesticide treatments per year has generally declined over the last ten years, but the industry still uses over three treatments per site on average each year, or over five treatments per 18-month growout cycle. On a regional basis, the Orkney Isles have a much lower reliance on pesticides, with only seven treatments in 2020 and few additional hydrogen peroxide treatments (six in 2018), equating to slightly less than one treatment per site per year.

The detection of these chemicals in the environment does not directly imply harm, and the number of sites exceeding the Environmental Quality Standards (EQS) for in-feed pesticide treatments (emamectin benzoate and teflubenzuron) is now low (and zero in Orkney in the last ten years). However, while azamethiphos and hydrogen peroxide treatments may have some acute impacts in the water column in the immediate site area, the comprehensive review by SEPA of emamectin benzoate impacts on the seabed added substantial weight of scientific evidence that the existing EQS in Scotland were not adequately protecting marine life. Resistance to emamectin benzoate is widespread, further indicating its overuse. New regulations have been adopted by SEPA but with ongoing multiple treatments per site in open production systems each year and coordinated treatments across multiple sites, the cumulative impacts are uncertain, and the efficacy of the new regulation is as-yet unknown. As such, the final score for the Northwest, Southwest, Western Isles and Shetland Isles for Criterion 4 – Chemical Use is 2 out of 10. With very low antimicrobial use and a much lower lice pressure experienced by farm sites in the Orkney Isles, the need for chemotherapeutants is approximately once per site per year, and these sites are considered to have a demonstrably low need for chemical use. Consequently, the final score for the Orkney Isles for Criterion 4 – Chemical Use is 7 out of 10.

Criterion 5: Feed

Impact, unit of sustainability and principle

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

Criterion 5 Summary

All Regions of Scotland

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	2.33	
F5.1b Source fishery sustainability score (0-10)		8.00
F5.1: Wild fish use score (0-10)		3.20
F5.2a Protein INPUT (kg/100kg fish harvested)	50.73	
F5.2b Protein OUT (kg/100kg fish harvested)	16.90	
F5.2: Net Protein Gain or Loss (%)	-66.69	3.00
F5.3: Species-specific kg CO2-eq kg-1 farmed seafood protein	7.71	8.00
C5 Feed Final Score (0-10)		**4.35**
Critical?	No	Yellow

Brief Summary

Data on the types of feeds used across Scotland in addition to the inclusion levels and sources of marine ingredients were provided by the Salmon Scotland. The inclusion levels of fishmeal and fish oil from forage fish sources were 19.2% and 8.4% respectively (with an additional 5.7% and 3% of fishmeal and oil from trimmings and byproduct sources). With an eFCR of 1.36, from first principles, 2.33 mt of wild fish must be caught to produce the fish oil needed to grow 1.0 mt of farmed salmon. Information on the source fisheries resulted in a high sustainability score of 8 out of 10 and resulted in a Wild Fish Use score of 3.2 out of 10. There is a substantial net loss of 66.7% of feed protein (score of 3 out of 10) and a low feed ingredient footprint of 7.71 kg CO_2-eq. per kg of harvested protein (score of 8 out of 10). Overall, the three factors combine to result in a final Criterion 5 – Feed score of 4.35 out of 10.

Justification of Rating

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

Feed composition

According to Shepherd et al. (2017), comprehensively understanding feed use in Scotland is complicated by a proliferation of bespoke diets driven by external standards (e.g., organic or Label Rouge). Salmon Scotland requested feed data from their members for this assessment and provided a breakdown of the feed types used in each region. Three main feed types are used in Scotland: firstly, variations around a "Standard Premium" feed, secondly a Label Rouge feed, and finally an organic feed. Table 1 shows their use across the regions.

Table 1: Distribution of the three main feed types in Scotland in 2020 displayed as the percentage of the total feed used per region. Data provided by Salmon Scotland.

Feed	Region				
	Orkney	**Shetland**	**Western Isles**	**Northwest**	**Southwest**
Standard	83.3%	72.0%	93.8%	85.7%	85.0%
Organic	16.7%	8.0%	0.0%	3.6%	0.0%
Label Rouge	0.0%	20.0%	6.3%	10.7%	15.0%

Salmon Scotland data show the Standard feed is dominant and represented approximately 84% of the total Scottish feed input in 2020. Salmon Scotland also provided data from different members on the fishmeal and fish oil inclusions (and the proportion of those ingredients coming from trimmings or fishery byproducts) for each of their feeds. While the Label Rouge feed typically has higher levels of fishmeal and oil, the data showed there is significant variation within each of the three general feed types across different feed companies and producers. As such, while it is possible to consider a weighted fishmeal and fish oil inclusion level for each region based on their use of each of the three feed types, in reality the variability in the feed data blurs any useful distinction or differentiation between the regions. As such, the fishmeal and fish oil inclusion levels (and those of trimmings) for the dominant "Standard" feed are used here for all regions.

Salmon Scotland data provided minimal information on other feed ingredients (e.g., terrestrial crop ingredients, speciality ingredients such as insect or algal products or other functional ingredients, and therefore these were compiled from global and regional data in Mowi's Salmon Industry Handbook (Mowi, 2021) and specific ingredients in two salmon reference diets in Mørkøre et al. (2020) and Aas et al. (2019); the latter two both based on Norwegian feeds. Shepherd et al. (2017) note detailed feed formulation data are often lacking in Scotland but also note a great similarity of the Scottish and Norwegian industries such that Norwegian feed data provide a good approximation to feed use in Scotland. Therefore, the available data sources, including some focused on Norway, have been used to create a best-fit feed composition for Scotland as shown in Table 2, along with each ingredient's Global Feed Lifecycle Institute (GFLI) climate change (CCI/mt value; see Factor 5.3). While this composition might not reflect the exact ingredients and their inclusions in practice, it is considered to be sufficiently representative of a typical Scottish salmon feed for this assessment.

Table 2: Best-fit feed composition and GFLI values from the available data.

Feed Ingredient	Inclusion (% of total feed)	GFLI value
Fishmeal	19.2	1.1764
Fishmeal byproducts	5.7	1.1764
Fish oil	8.4	0.7891
Fish oil byproducts	3.0	0.7891
Wheat	7.4	0.7813
Wheat gluten	7.5	3.9989
Soy protein concentrate	14.2	6.417
Fava (broad) beans	2.8	0.7080
Sunflower meal	1.3	0.8766
Corn gluten	3.0	1.5647
Pea protein concentrate	1.1	1.3535
Pea starch	1.5	0.4732
Rapeseed (canola) Oil	17.0	2.9154
Vitamin/minerals	7.9	No data
Total	100	

<u>Economic feed conversion ratio (FCR)</u>
A general eFCR value from the academic literature for Atlantic salmon (i.e., not specific to any region) is 1.3 (Tacon et al., 2021; Naylor et al., 2021, Tacon, 2020). Salmon Scotland provided an average 2020 value of 1.24 (varying from 1.18 to 1.36 across six producers), but an analysis of feed input data from Scotland's Aquaculture database in combination with annual production figures from Munro and Wallace (2020) generates an eFCR value of 1.36 for 2020 (based on the estimated production for 2020). The four-year average (2017-2020) is also 1.36 (varying from 1.24 to 1.50) and this value is used in the feed calculations below.

Factor 5.1. Wild Fish Use
<u>Factor 5.1a – Feed Fish Efficiency Ratio (FFER)</u>
Using the data in Table 1 along with the eFCR value of 1.36 and the standard yield values for fishmeal and fish oil (22.5% and 5% respectively), the Forage Fish Efficiency Ratio (FFER) is 1.18 for fishmeal and 2.33 for fish oil. These calculated values are slightly higher for fishmeal and lower for fish oil than average 2020 values of two Scottish companies that report through GSI (average 1.08 for fishmeal and 2.36 for fish oil).

Discrepancies in these FFDR values are likely due to minor variations in the values used for eFCR and/or the inclusion level and yield of fishmeal or fish oil, and the value of 2.33 for fish oil is used here based on SSPO data and its similarity to the GSI value. This means that from first principles, 2.33 mt of wild fish would need to be caught to supply the fish oil needed to produce 1.00 mt of farmed salmon.

Factor 5.1b –Sustainability of the Source of Wild Fish

Salmon Scotland provided data on source fisheries for fishmeal and oil both from forage fisheries and trimmings/byproduct sources (Table 3). These fisheries have a combination of certifications from the Marine Stewardship Council (MSC) certification and the International Fishmeal and Fish Oil Organisation Responsible Sourcing scheme (IFFO RS), but the FishSource[33] scores have largely determined the Seafood Watch sustainability score.

Table 3: Source fisheries for fishmeal and fish oil in Scottish salmon feeds (2020). Atlantic Mackerel and Herring were sources of trimmings/byproduct fishmeal and oil sources. Data from Salmon Scotland.

Common name	FAO Fishing Area	Certification	Sustainability score (0-10)
Peruvian Anchovetta	FAO87	IFFO RS	8
NE Atlantic Blue Whiting	FAO27	MSC	6
European Sprat	FAO27	IFFO RS	8
Gulf and Atlantic Menhaden	FAO31	MSC	8
Atlantic Mackerel (trimmings)	FAO27	IFFO RS	8
NE Atlantic Herring (trimmings)	FAO27	IFFO RS	8
North Sea Sand Eel	FAO27	IFFO RS	8
North Sea Norway Pout	FAO27	MSC	8

With all but one fishery having a sustainability score of 8 out of 10 (where all Fishsource scores are >6 and the Stock Health score >8), the score for Factor 5.1b is 8 out of 10, and in combination with the FFER value of 2.33, results in a final score for Factor 5.1 - Wild Fish Use of 3.2 out of 10.

Factor 5.2. Net Protein Gain or Loss

Values for the total protein content of typical salmon feeds from the suite of references stated above average to 35.9% (with a small range of 35% to 36.4%), and data provided from Salmon Scotland for the "Standard Premium" feed type is similar with an average of 37.3% (varying from 36% to 38.5%). The higher SSPO value of 37.3% is used here. Aas et al. (2019) specify a whole-body composition of farmed salmon of 16.9% crude protein, and this value is used here.

Therefore, one ton of feed contains 373 kg of protein; 1.36 tons of feed are used to produce 1.00 tons of farmed salmon (eFCR), so the net protein input per ton of farmed salmon production is 491.8 kg. With only 169 kg of protein in one ton of harvested whole salmon, there is a net loss of 65.7% of protein. This results in a score of 3 out of 10 for Factor 5.2.

Factor 5.3 Feed Footprint

This factor is an approximation of the embedded climate change impact (kg CO_2-eq) of the feed ingredients required to grow one kilogram of farmed seafood protein. The calculation is performed by mapping the ingredient composition of a feed used against the Global Feed

[33] https://www.fishsource.org/

Lifecycle Institute (GFLI) database[34] to estimate the climate change impact (CCI) of one metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested salmon. If an ingredient of unknown or unlisted origin is found in the GFLI database, an average value between the listed global "GLO" value and worst listed value for that ingredient is applied; this approach is intended to incentivize data transparency and provision. Detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

Calculations based on the GFLI values presented in Table 1 above and following the methodology in the Seafood Watch Aquaculture Standard, the CCI is 7.71 kg CO_2-eq per kg of farmed salmon protein. This equates to a score of 8 out of 10 for Factor 5.3.

Conclusions and Final Score

The final score is a combination of the three factors with a double weighting for the Wild Fish Use factor. Factors 5.1 (3.2 out of 10), 5.2 (3 out of 10), and 5.3 (8 out of 10) combine to result in a final score of 4.35 out of 10 for Criterion 5 – Feed for all production regions.

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

Criterion 6: Escapes

Impact, unit of sustainability and principle

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

Criterion 6 Summary

Orkney Isles

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

Shetland Isles

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

Northwest and Western Isles

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

Southwest

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

Brief Summary

Despite the presence of a Scottish Technical Standard for Finfish Aquaculture, large escape events where several thousand fish are reported lost from marine net pens, are less frequent than in decades past. However, they do occur annually in Scotland. Such events occur for a variety of reasons, almost all associated directly or indirectly with human error (including insufficient design, construction, or maintenance of containment equipment to cope with extreme weather events). Very large-scale escape events, such as the loss of 154,549 fish in 2014 and, most recently 73,684, 48,834 and 52,000 fish in 2020, continue to occur sporadically. Additional undetected or unreported trickle losses may also cumulatively be substantial. The survival of escapees to maturity and therefore their potential to spawn with wild salmon is likely to be highly variable depending on the size, location, and time of year of escape. Extensive monitoring of escapee presence in rivers – such as that conducted in Norway and Atlantic North America – does not occur Scotland.

Quantifying the impacts to wild salmon populations is complex. As for escapee monitoring, the focused research on farm-to-wild genetic introgression that occurs in other salmon-farming regions has thus far been limited in Scotland. The research that does exist shows evidence of farm-origin genetic material within wild Scottish salmon populations; notably, though, some observed genetic introgression may have come from deliberate stocking attempts. Ultimately, there is great cause for concern for the health of native salmon populations – whose vulnerability is clear and seemingly increasing – based on comprehensive research and monitoring efforts in Norway and agreement amongst international experts that a risk of population-level impacts could occur in Scotland without highly effective fish containment going forward. There are some notable regional variations; for example, the Orkney Isles have low reported escapes over the last ten years (and zero since 2012) and both the Orkney and Shetland Isles do not have local wild salmon populations. Nevertheless, escapes here could migrate to rivers in other areas, but the risk of reaching spawning grounds is likely somewhat lower, particularly in Shetland. The final score for Criterion 6 – Escapes for the Orkney Isles is 4 out of 10, but with more frequent escapes, the final score for the Shetland Isles is 3 out of 10 and Shetland Isles is 4 out of 10. For the Southwest, Northwest and Western Isles, there continue to be substantial escapes in areas that have vulnerable wild salmon populations, and without data to demonstrate a low rate of introgression or impact, the final score for Criterion 6 – Escapes is 0 out of 10 and a critical conservation concern.

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

Factor 6.1 Escape risk
The UK (including Scotland) is a signatory to the North Atlantic Salmon Conservation Organization (NASCO), of which one of the commitments is that 100% of all farmed fish will remain in the production site[35], but (Glover et al., 2017) note that 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. This inherent risk results in the occasional release of a large number of individuals (massive escape events) and/or the recurrent release of a small number of fish (chronic or leakage escapes) (Atalah & Sanchez-Jerez, 2020).

With approximately 50 million smolts put to sea each year for growout in Scotland (53.0 million in 2019 according to Munro and Wallace, 2020), 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). The salmon industry in Scotland (and elsewhere) has gone to significant lengths to reduce escapes, and as a result of the Scottish Government's Containment Working Group[36], a "Technical Standard for Scottish Finfish Aquaculture"[37] was published in June 2015. In addition to the Code of Good Practice for Scottish 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.

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*"[38]. 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. While media reports typically report large escape events within days, official data (e.g., in Scotland's Aquaculture database) are typically delayed by at least six months. Figure 28 shows the Scottish industry's self-reported escape numbers between 2002 (when reporting escapes first became mandatory) and 2020.

[35] https://nasco.int/conservation/aquaculture-and-related-activities/
[36] http://www.gov.scot/Topics/marine/Fish-Shellfish/MGSA/Containmentwg
[37] http://www.gov.scot/Resource/0047/00479005.pdf
[38] http://www.gov.scot/Resource/0040/00403925.pdf

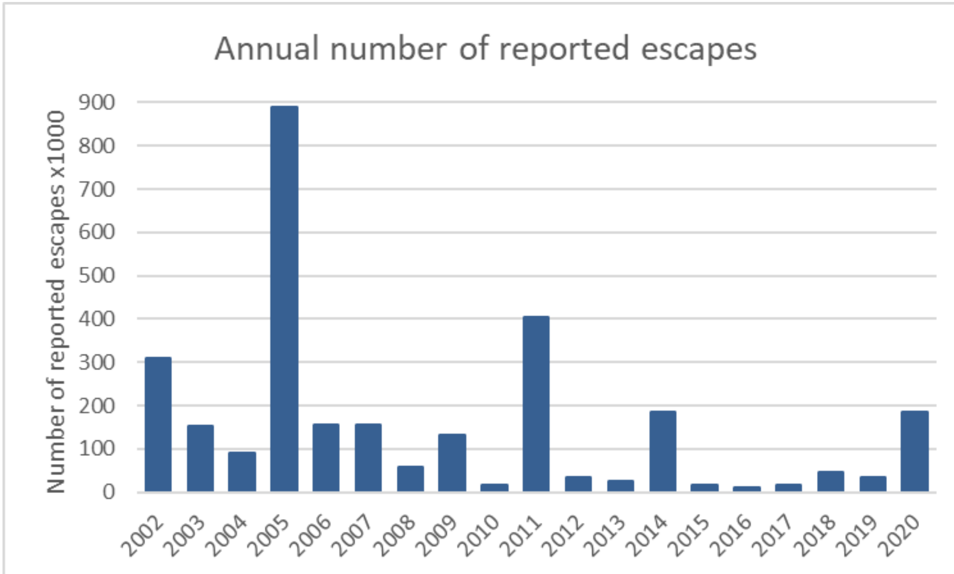


Figure 28: Scottish farmed salmon escape numbers (in thousands of fish) from 2002 to 2020. Data from Marine Scotland in "*Scotland's Aquaculture*" database.

The data show the number of reported events industry-wide each year is low, with an average of five reported escape events per year from 2017 to 2020; however, there have been large escape events every year since these records began in 2002. The most recent data show that approximately 24,752 fish escaped in one event in 2018, 23,970 in 2019, and most recently, there have been four large escapes in 2020 of 13,952, 48,834, 73,684 and approximately 50,000[39] fish. In 2014, there was a single escape event of 154,000 salmon. The cause of these escapes is typically equipment failure due to weather or human error, holes in nets caused by predators or human error, and other undefined aspects of human error (data from Scotland's Aquaculture database). It is important to note that all these recent escape events (i.e., 186,470 escapes in 2020) occurred on farms that met the Technical Standard for Scottish Finfish Aquaculture.

Regional escape events and numbers

The basic net pen production system is the same in all regions, but escapes can vary particularly with regard to storm exposure in different areas. Figure 29 shows the number of reported escape events of any size (>0 fish) over the last ten data years (2011 to 2020) with the annual production (in 2019) shown as an indicator of the relative nature of the escapes compared to the size of the industry or number of sites. The number of events largely reflects the scale of the industry, such that escape events appear approximately proportional to the number of sites. While reporting practices may have changed over this period, the number of events in the last five years (2016 to 2020) is less than half of the ten-year total.

[39] 50,000 is estimated for an escape on December 31st 2020 reported by FMS on January 15 2021. http://fms.scot/significant-escape-from-scottish-salmon-company-portree-farm/
As of June 18 2021, this event is not reported in Scotland's Aquaculture database.

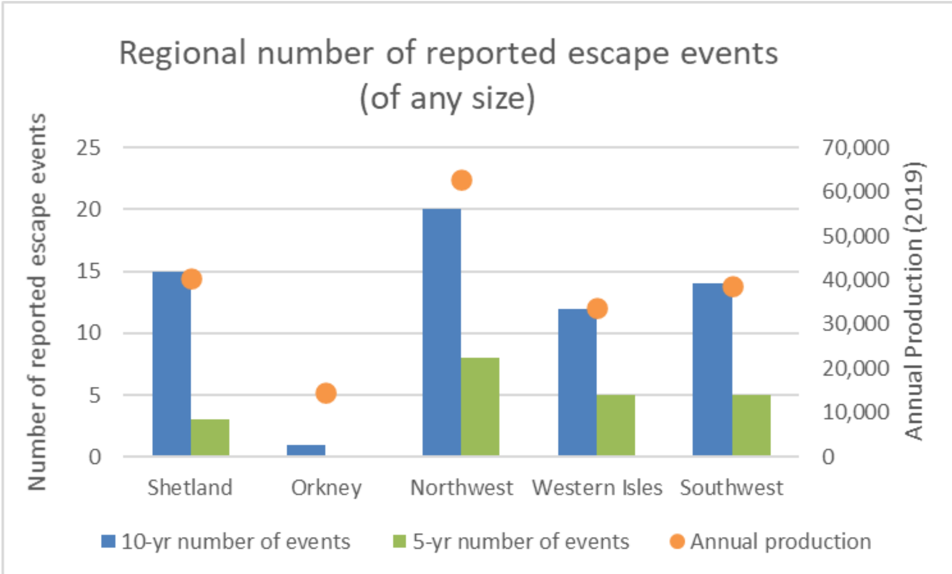


Figure 29: Number of reported escape events (of any number of fish) in each region from 2011 to 2020 (blue bars) and 2016 to 2020 (green bars). Regional production (2019) is also shown (orange dots). Data from Scotland's Aquaculture database, and production figures from Munro and Wallace (2020).

The number of reported escaped fish per reported escape event can vary dramatically from one fish to hundreds of thousands of fish. Figure 30 shows the total number of reported escaped salmon over the same 2011 to 2020 time period with Shetland having by far the largest total of 576,474 fish. Although the Northwest region had the greatest number of reported escape events (Figure 29), the total escape number was smaller (37,067). The Orkney Isles had the smallest number of reported escape events (one in the last ten years and none in the last five, shown in Figure 29) and the smallest total escapes (25,623, shown in Figure 30). The last reported escape event in Orkney was in 2012. By comparing this 2011-2020 ten-year period with the last five years (2016-2020) in Figure 30 (red versus green bars in Figure 30), it can be seen that almost all of Shetland's escapes in the last ten years happened more than five years ago, whereas most of the escapes in the Northwest, Western Isles and Southwest occurred within the last five years.

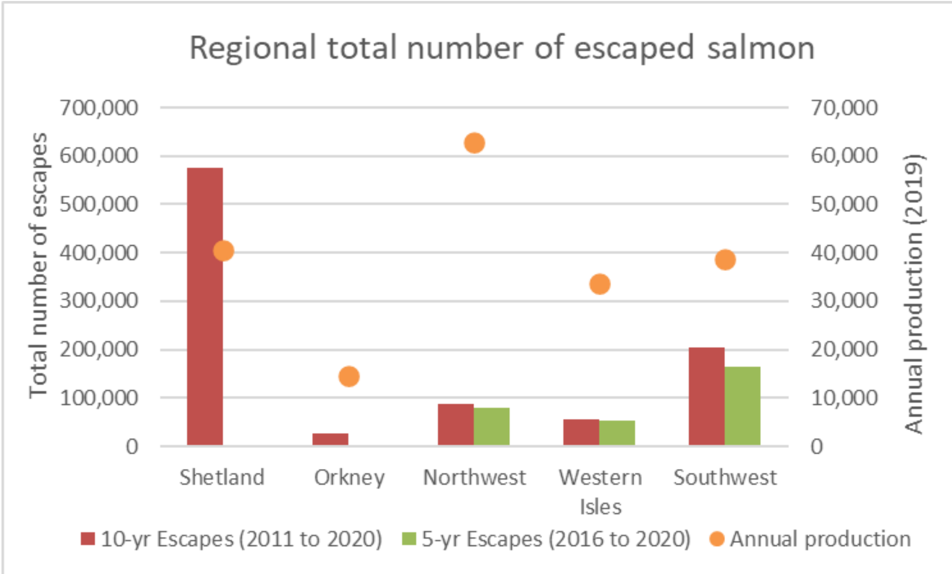


Figure 30: Total reported escape numbers from 2010 to 2020 in each region (red bars) and from 2016-2020 (green bars). The regional scale of production indicated by the orange dots (2019 data). Data from Scotland's Aquaculture database, and production figures from Munro and Wallace (2020).

Trickle losses

While these isolated catastrophic escape events are limited to a small number and proportion of the salmon farms in Scotland, it is considered that lesser-reported trickle losses can also be significant and potentially not detected or reported (Grefsrud 2021b). For example, Sistiaga et al. (2020) noted the escape of small smolts through farm cage netting is a major challenge when the smolts placed in the net pens are smaller than the size estimated by the farmers. 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 small-scale undetected or unreported escape events may make up a large portion of the total escaped farmed fish, and a modelling analysis by Skilbrei et al. (2015a) 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.

Freshwater Escapes

In addition, Scotland is unusual amongst the leading salmon farming nations[40] in using net pen systems in freshwater for the production of smolts; according to Munro and Wallace (2020), 45.2% of smolts were produced in cage systems (as opposed to tanks and raceways), carrying a similar risk of escape as those used for ongrowing in the sea. The data in Scotland's Aquaculture database indicate none of the recent large-scale escapes have happened in freshwater. However, a similar potential for undetected and/or unreported escapes is present in freshwater

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

systems too, and these have been noted in the past in Scotland with identification of escaped fish through vaccination marks (Franklin et al., 2012).

Until the Technical Standard can be shown to be fully effective (e.g., by eliminating large escape events), the repeated large losses highlight the vulnerability of the production system and the ongoing high risk of structural failure and escape from any farm. Therefore, the combination of very high numbers of fish held in any one net pen and an inherently vulnerable 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. The Technical Standard in combination with the existing Code of Good Practice is considered to be evidence of emerging best practices, but 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).

<u>Recaptures</u>
The "Scotland's Aquaculture" database shows escapes are not 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)

Following the escape of 48,834 in 2020 (at Carradale in the Southwest region), Fisheries Management Scotland (FMS) along with the local authorities and the industry initiated a study to understand the distribution of escaped farmed salmon entering freshwater (Burns et al., 2021). The fish were due to be harvested imminently, and though not sexually mature, they were of a size and life-stage where they could head for freshwater. Of 466 reports received of farmed salmon in 22 rivers, 95-97% from 17 rivers were verified as being farmed according to scale sampling (Burns et al., 2021). Therefore, in this case, given the rapid dispersal and entry into freshwater with the potential for recapture by anglers, only approximately 450 escapees were recaptured – this amounts to less than 1% of the total escape number.

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. Overall, there is insufficient evidence to robustly justify a recapture and mortality score.

<u>Factor 6.1 score</u>
Large escape events of farmed salmon continue to occur in Scotland each year, with approximately 186,000 escapes in 2020. Large escapes are limited to a small number of farms, but undetected or unreported trickle escapes may be significant in a greater number of farms. Regionally, the Orkney Isles have only had one reported escape event since 2010, and the total reported number of escapes since 2010 is also the lowest (25,623). In contrast, the Shetland Isles have had the largest number of escapes in the same 10-year period (576,474) but only 1,946 were in the last five years. The Northwest and Western Isles have larger numbers of

reported events (19 and 12 respectively) from 2010 to 2020, but the total escape numbers are still relatively low (37,067 and 56,502 respectively). The Southwest region had 14 escape events from 2010 to 2020 and relatively high total escapes of approximately 205,000, most of which (165,000) were in the last five years. The score for Factor 6.1 Escape Risk for the Orkney Isles is 4 out of 10 for an open system with a documented track record of low escapes (but still with a potential for trickle losses). For the Shetland Isles, the Northwest and the Western Isles, the score for Factor 6.1 is 2 out of 10, recognizing the open system and the presence of best management practices for escape prevention. For the Southwest, the score is 0 out of 10 due to the repeated and high total escapes over the 2010 to 2020 period including in the last five years. There are no recapture adjustments to these scores.

Factor 6.2 Competitive and Genetic Interactions

Atlantic salmon are native in Scotland, but farmed salmon have undergone domestication 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; Skaala et al., 2012). 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 are found 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). It must also be noted that the majority of salmon that escape from farms will not survive to interact with wild salmon populations (Tett et al., 2018, and references therein).

Aronsen et al. (2020) noted that the escape history of farmed Atlantic salmon will influence the likelihood of escapees reaching maturity and entering the rivers to spawn (with wild salmon or other escapees). These authors reported escaped farmed salmon caught in coastal waters and in fjords in Norway came from multiple escape events over several years, and approximately 50% of the escapees had spent one or more winters at sea after escape (with some spending up to 3 years at sea). The higher proportion of escapees captured on the coast compared to within fjords suggested there is a reservoir of immature farmed salmon in coastal waters, and individuals may enter rivers to spawn with wild salmon when they reach sexual maturity (Aronsen et al., 2020). Therefore, while predation and starvation will continue to reduce the numbers in this coastal population, when investigating the risk of genetic introgression from escapees to wild salmon populations, Aronsen et al. (2020) note that escape events from the last four years will have to be considered.

In this regard, it is interesting to consider again the FMS study following the August 2020 Carradale escape of 48,834 salmon in the Southwest region of Scotland (Burns et al., 2021), in which it is stated that while there is variation in the catch efficiency of anglers both geographically and throughout the angling season, it is generally accepted that anglers catch in order of 10% of the wild salmon entering Scotland's rivers. After applying this capture efficiency of 10% to the Carradale escape, FMS estimated that a minimum of 3,000 farmed salmon entered Scottish rivers following this escape event. Given the findings of Aronsen et al. (2020), it is important to consider that the farmed salmon from the Carradale site were not sexually mature, and therefore were unlikely to breed in winter of 2020 (Burns et al., 2020). The impact of those fish immediately entering rivers therefore appears minimal, and the survival of remaining fish in coastal waters with the potential to enter rivers in subsequent years is unknown but considered likely to be low. Burns et al. (2021) concluded that the vast majority of the 48,834 escapees from the Carradale site remain unaccounted for.

With the exception of the FMS Carradale study, Scotland lacks a robust monitoring program for escaped farmed salmon (for context, Norway's national monitoring program surveys approximately 200 rivers each year using a variety of methods) and overall, Tett et al. (2018) confirm that studies on genetic introgression in Scotland are limited. With consideration of the similarities between Scotland and Norway in producing the native Atlantic salmon in net pens, it is relevant to note that of Norway's tested wild stocks, 30% are classified as having "moderate" genetic status, 7% classified as "poor", and 30% classified as "very poor"; only the remaining one-third of stocks were in "good" or " very good" condition (Grefsrud et al., 2021). According to Grefsrud et al., the available knowledge indicates that genetic changes in wild salmon stocks as a result of spawning with escaped farmed salmon will lead to changes in important biological properties in wild stocks such as age at sexual maturity and changes in migration time for smolts, ultimately resulting in reduced production of wild salmon. Looking ahead, Grefsrud et al. (2021a) concludes that of the 13 production regions along the Norwegian coast, only three have a low risk of further genetic change as a result of escaped farmed salmon. Seven are considered to have a high risk of further genetic change as a result of escaped farmed salmon. While Norway has a different scale of industry and ecosystem intricacies that differ from Scotland, these results mean that the lack of robust data on the fate and impact of Scottish escapees and the broad similarity between Norwegian and Scottish salmon farming and environments generate a high concern for the genetic integrity of salmon populations native to Scotland's coastal and riverine habitats.

For well-studied Norway, the escape of farmed salmon is considered (along with sea lice – see Criterion 7 - Disease) to be the greatest current threat and a critical issue influencing the environmental sustainability of salmon aquaculture (Forseth et al., 2017; Glover et al., 2019; Grefsrud et al., 2021a, Thorsted et al., 2020), and Tett et al. (2018) note that the available evidence from outside Scotland provides a strong basis for concluding that the negative consequences of introgression, when it occurs, will alter wild populations. In the short term, the genetic character of wild populations will change, and their abundance will reduce. In the long term, introgression will result in wild populations that are less resilient and less adaptable to environmental change. It is also 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 (SSPO, pers. comm. 2021); therefore, it is likely that these actions played at least some part in the alteration of genetic profiles in Scottish salmon (e.g., Sinclair, 2013).

Regional differences

The most important regional characteristic here is the lack of recognized local salmon breeding populations in the Orkney and Shetland Islands (e.g., no rivers are listed in the Marine Scotland assessment and grading of salmon rivers for 2021[41]. While it is still possible (depending on the size and time of year of escape) that escapees in these regions will return to rivers in other parts of Scotland that do contain wild salmon populations, the likelihood of surviving to reach the spawning grounds is lower for Orkney and substantially lower for the Shetland Isles.

Status of wild Atlantic salmon populations

Atlantic salmon populations have declined across the Atlantic Ocean (including in areas with and without salmon farms). The North Atlantic Salmon Commission (NASCO) considers Atlantic salmon to be a species in crisis; between 1983 and 2016 the numbers of wild Atlantic salmon in the North Atlantic prior to any fishing taking place in the year (known as the pre-fishery abundance), fell by more than half (NASCO, 2019). While the recent decline has been steep, the decline began prior to salmon aquaculture in Scotland (and elsewhere), after the commercial catch reached its peak in 1973. As noted in Criterion 7 – Disease, populations of sea trout have also been in decline in Scotland with a long-term decline prior to the start of salmon farming. According to the European Red List of Marine Species (Nieto et al., 2015), Atlantic salmon are listed as "Vulnerable" at the European level, and Atlantic salmon 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.

Within the European Vulnerable classification, Nieto et al. (2015) note the variability of the status of salmon populations in different regions of the North Atlantic, and between individual rivers. In Scotland, the Scottish Parliament also reports[43] the number of wild salmon has been in steep decline since 2010, with numbers (indicated by angler rod catches) reaching their lowest level in 2018. The Scottish Government introduced the Conservation of Salmon (Scotland) Regulations in 2016, which state that an assessment of the conservation status of salmon must be carried out for all rivers, based on both the number and condition of salmon. The grade of rivers is determined by the percentage chance that the egg requirement has been reached for the previous five years.

These are defined as:

- Grade 1: >80% chance the egg requirement has been met over the past 5 years

[41] https://www.gov.scot/publications/salmon-fishing-proposed-river-gradings-for-2021-season/

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

[43] https://spice-spotlight.scot/2019/07/12/assessing-the-conservation-status-of-scotlands-salmon-rivers/

- Grade 2: 60-80% chance the egg requirement has been met over the past 5 years
- Grade 3: <60% chance the egg requirement has been met over the past 5 year

The river grade determines the management required, as set out by Marine Scotland:

- Grade 1: Exploitation is sustainable. No additional management action is currently required.
- Grade 2: Catch and release should be promoted strongly to reduce exploitation.
- Grade 3: Catch and release is mandatory as exploitation is unsustainable.

The assessment for the 2019 fishing season categorized Scotland's rivers as follows:

- 49 rivers as grade 1 (28.3% of rivers)
- 30 rivers as grade 2 (17.3% of rivers)
- 94 rivers as grade 3 (54.3% of rivers)

Over the last decade, the conservation status for wild salmon according to these grades has been declining (Figure 31) with an increasing number of Grade 3 rivers (and decline in Grade 1 rivers).

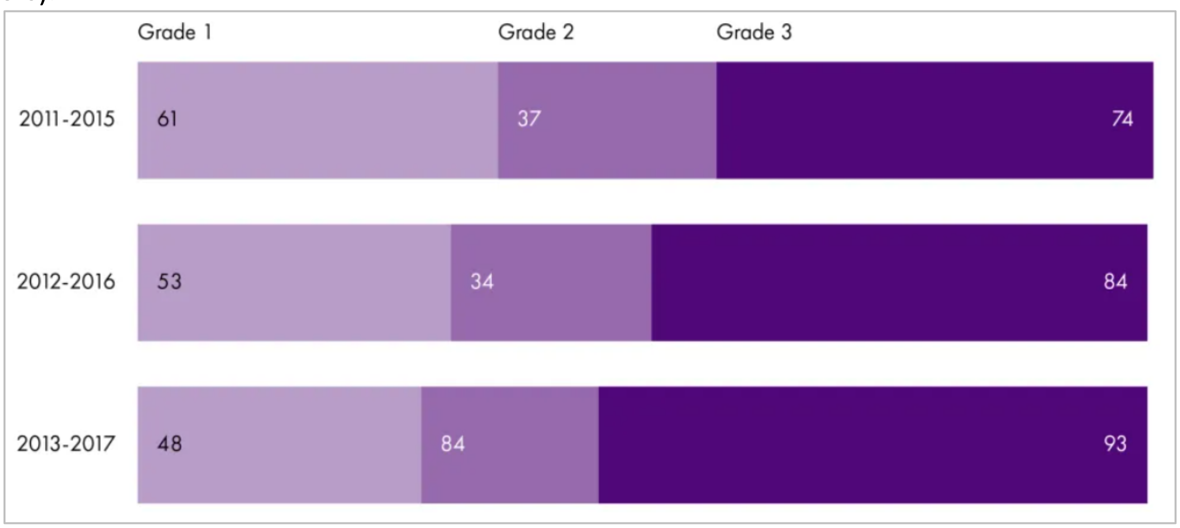


Figure 31: Review of the conservation status of wild Atlantic salmon populations assessed under the Conservation of Salmon (Scotland) Regulations in 2016 using fiver year periods of egg counts. Image copied from the Scottish Parliament (https://spice-spotlight.scot/2019/07/12/assessing-the-conservation-status-of-scotlands-salmon-rivers/).

Factor 6.2 score

The survival to maturity of escapees and therefore their potential to spawn with wild salmon is likely to be highly variable depending on the size, location, and time of year of escape. Quantifying the impacts to wild salmon populations is complex, but in contrast to the extensive monitoring and research efforts in other salmon-farming regions like Norway and Atlantic North America (US and Atlantic Canada), monitoring of escapee presence on spawning grounds and studies on genetic introgression are limited in Scotland. The research that does exist shows evidence of farm-origin genetic material within wild Scottish salmon populations; notably, though, some observed introgression may have come from deliberate stocking attempts. Ultimately, there is great cause for concern for the health of native salmon populations – whose vulnerability is concerning and seemingly increasing – based on the impacts demonstrated through comprehensive research and monitoring efforts in other regions and agreement amongst international experts that a risk of population-level impacts could occur in Scotland without highly effective fish containment going forward. Overall, there is a high concern for impact, namely for the regions of Scotland which host native spawning populations. For those – the Northwest, Southwest and Western Isles –the score for Factor 6.2 – Competitive and Genetic Interactions is 0 out of 10. For the Orkney and Shetland Isles, where there are no wild salmon populations, the risk of genetic interaction is substantially lower (due to expected mortality prior to any potential arrival at a spawning ground elsewhere (e.g., the east coast of Scotland) and a moderate concern with a score of 4 out of 10 for the Orkney and Shetland Isles.

Conclusions and Final Score

Despite the presence of a Scottish Technical Standard for Finfish Aquaculture, large escape events where several thousand fish are reported lost from marine net pens, are less frequent than in decades past. However, they do occur annually in Scotland. Such events occur for a variety of reasons, almost all associated directly or indirectly with human error (including insufficient design, construction, or maintenance of containment equipment to cope with extreme weather events). Very large-scale escape events, such as the loss of 154,549 fish in 2014 and, most recently 73,684, 48,834 and 52,000 fish in 2020, continue to occur sporadically. Additional undetected or unreported trickle losses may also cumulatively be substantial. The survival of escapees to maturity and therefore their potential to spawn with wild salmon is likely to be highly variable depending on the size, location, and time of year of escape. Extensive monitoring of escapee presence in rivers – such as that conducted in Norway and Atlantic North America – does not occur Scotland.

Quantifying the impacts to wild salmon populations is complex. The research that does exist shows evidence of farm-origin genetic material within wild Scottish salmon populations; notably, though, some observed genetic introgression may have come from deliberate stocking attempts. Ultimately, there is great cause for concern for the health of native salmon populations – whose vulnerability is clear and seemingly increasing – based on comprehensive research and monitoring efforts in Norway and agreement amongst international experts that a risk of population-level impacts could occur in Scotland without highly effective fish containment going forward. There are some notable regional variations; for example, the Orkney Isles have low reported escapes over the last ten years (and zero since 2012) and both the Orkney and Shetland Isles do not have local wild salmon populations. Nevertheless, escapes here could migrate to rivers in other areas, but the risk of reaching spawning grounds is likely somewhat lower. The final score for Criterion 6 – Escapes for the Orkney Isles is 4 out of 10, but with more frequent escapes, the final score for the Shetland Isles is 3 out of 10. For the Southwest, Northwest and Western Isles, there continue to be substantial escapes in areas that have vulnerable wild salmon populations, and without data to demonstrate a low rate of introgression or impact, the final score for Criterion 6 – Escapes is 0 out of 10 and a critical conservation concern.

Criterion 7. Disease; pathogen and parasite interaction

Impact, unit of sustainability and principle

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

Criterion 7 Summary

Northwest, Southwest, Western Isles and Shetland Isles

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

Orkney Isles

C7 Disease parameters		Score
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**6**
Critical	No	Yellow

Brief Summary

Bacterial and viral pathogens infect farmed salmon in Scotland and negatively impact production, and their on-farm presence represents a reservoir of potential spillback to wild organisms. Their beyond-farm impact appears low yet remains uncertain (possibly due to the challenges of detecting diseased wild fish). 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 individuals, are recognized as a concern by the Scottish Government and by their Salmon Interactions Working Group (SIWG). While sea lice are not considered to be responsible for the long-term declines in wild salmon and sea trout (and there are many ongoing non-aquaculture pressures on the populations), there is a concern that the added pressure of sea lice transmission from salmon farms is a significant impactor on the health and recovery of wild salmonid populations.

In contrast to Norway, which has long term comprehensive monitoring and modelling of lice on farms and on wild salmon and sea trout, there is very little monitoring of sea lice on wild fish in Scotland. While the available research in Scotland indicates the mortality of sea trout due to sea lice has declined since the late 1990s and is now perhaps in the range of 10-20% per annum, the Scottish Government still defers to examples from Norway, where sea lice are considered to have the greatest negative impact on wild salmon and sea trout and are regarded as an expanding population threat. Without clear evidence on the impacts in Scotland and accepting that evidence in Norway cannot be fully representative of the situation in Scotland, the Risk-Based Assessment method has been used. The score is based on the open nature of the production system, the common exceedance of (recommended) lice limits that were established for the protection of wild fish, the high susceptibility of wild salmon and sea trout to lice, and the apparent high potential for population impacts to discreet wild sea trout populations in Scotland (due to their longer coastal residences in areas with increased sea lice infection pressures). With consideration of the vulnerable conservation status of both Atlantic salmon and sea trout in Scotland, the final score for the Northwest, Southwest, Western Isles, and Shetland Isles for Criterion 7 – Disease is 0 out of 10. In contrast, data indicate very low prevalence of sea lice on the farms in the Orkney Isles region are recognized here as posing a distinctly different level of risk of impact. Using the Risk-Based Assessment method, the score for Criterion 7 – Disease for the Orkney Isles is 6 out of 10.

Justification of Rating

The open nature of net pen salmon farms means the fish are vulnerable to infection by pathogens from the surrounding waterbody, from wild fish, or from other natural infection routes, and can act as a temporally unnatural reservoir for a variety of pathogens and parasites that have the potential to be transmitted or re-transmitted to wild resident organisms, including native salmon species (Hammell et al., 2009).

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

The primary source of disease information in Scotland is the government's Fish Health Inspectorate (FHI)[44] with disease cases, mortality rates, causes, and partial data on sea lice counts. Scotland's Aquaculture has site-level mortality data in a spreadsheet format and as of March 2021, also publishes industry-reported weekly sea lice counts. Salmon Scotland previously reported monthly average sea lice numbers by site, but no longer does following the transition to the new layer in the Scotland's Aquaculture.

<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 hematopoeitic necrosis (IHN), infectious salmon anemia (ISA), and viral hemorrhagic septicemia (VHS). According to Tett et al. (2018), about a dozen pathogens and parasites are economically important for salmon farming in Scotland and approximately one-third of marine fish mortalities are attributed to infectious diseases.

[44] https://www.gov.scot/policies/fish-health-inspectorate/

Figure 32 shows the annual mortality by weight of dead fish on salmon farms has increased from 7,859 mt in 2010 to 27,368 mt in 2020, increasing much faster than production (which increased from 154,000 mt to 207,630 (estimated) mt over the same period), and the mortality as a percentage of production has also increased from 5% in 2010 to 13.2% in 2020 (data from *Scotland's Aquaculture).* Although Tett et al. (2018) attribute approximately one-third of marine fish mortalities to infectious diseases, a large part of the increasing mortality is considered to be due to handling and treatment stress during non-chemical sea lice treatments (based on "treatment" labels for mortality events recorded in the government's FHI data).

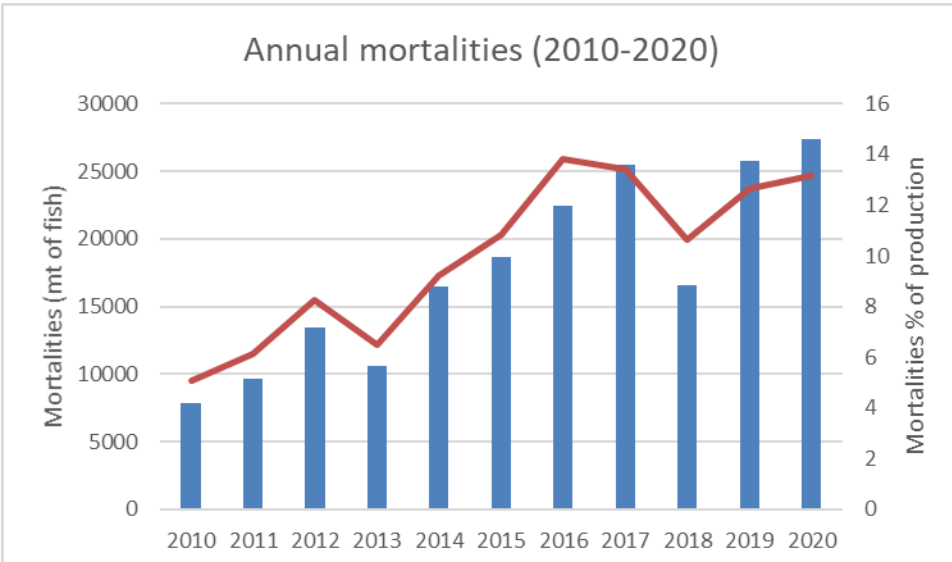


Figure 32: Annual mortalities in mt (blue bars and primary y-axis) and mortality as a percentage of annual production (red line and secondary y-axis). Data from "*Scotland's Aquaculture*" database.

Sommerset et al. (2020) consider the consumption of antibacterial agents to be a good indicator of the occurrence of bacterial diseases on salmon farms (in Norway), and with increasing antimicrobial use since 2016 in Scotland (see Criterion 4 – Chemical Use), an increase in bacterial pathogens is likely (and indicated by the "bacterial challenges" label in the FHI data). With regard to viruses, pancreas disease (PD) and cardiomyopathy syndrome (CMS) are the primary viral diseases listed in both the FHI and SSPO data.

It must be noted that on-farm mortality as one endpoint of the disease cycle in farmed fish (e.g., as opposed to treatment and recovery) is an imperfect indicator to evaluate the potential transfer of pathogens from farms to wild fish throughout the pathogen cycle. Novel research in British Columbia highlights the fact that despite low mortality rates at the farm-level, the fish may continually in varying degrees of disease status and can act as chronic reservoirs of pathogens (Di Cicco et al., 2018).

Grefsrud et al. (2021b) also provide a theoretical scenario in Figure 33 showing how migrating salmon may be affected after passing through an area of infection such as a farm, and also caution that a) the presence of a pathogen does not mean infection, b) infection does not mean the development of disease or the spread of infection, and c) illness does not mean death.

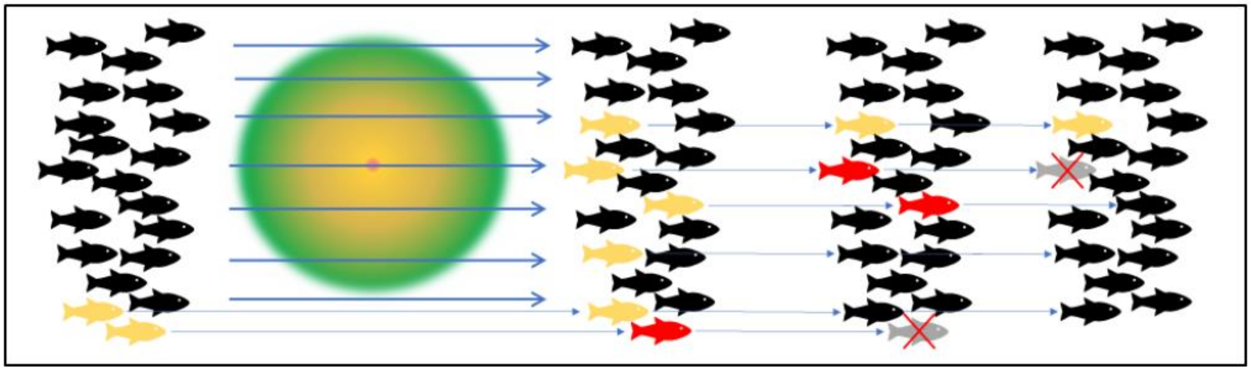


Figure 33: A theoretical scenario of migrating salmon smolts or sea trout passing through areas with infection from farming. In such an area the exposure varies a lot. Upon exposure, some individuals may become infected (yellow fish). Some infected individuals may become ill (red fish). Some sick fish may die (grey fish), some may recover, and some may become chronically infected (carriers). Some of the wild fish may be naturally infected regardless of farming, and some of them may also become ill and die. Image copied from Grefsrud et al. (2021b)

While Norway produces an "Annual report on health monitoring of wild anadromous salmonids in Norway" (e.g., Madhun et al., 2021), Wallace et al. (2017) noted there have been few long-term Scottish wild fish disease surveys and therefore it is difficult to assess temporal changes in the prevalence of these disease agents in populations of wild fish. But, after their systematic review of six key pathogens, Wallace et al. concluded that despite many reported cases in farmed fish, there were a limited number of positive samples from wild fish. Similarly, although they did note evidence for interactions between wild and farmed fish (e.g., elevations in the levels of some pathogens in wild fish caught near infected salmon farms), the same pathogens were detected in wild marine fish caught distant to aquaculture sites. For reference in Norway, Madhun et al. (2021) also showed the absence or low prevalence of viral infections in the migrating salmon smolts they tested in 2019, and the authors note this is consistent with previous findings in wild salmonids that showed no apparent relationship to the fish farming intensity or the frequency of disease outbreaks.

By genetically screening seawater samples (in British Columbia), Shea et al. (2020) reported that the probability of encountering a pathogen was significantly higher in the vicinity of active salmon farms when compared to inactive sites, and that fish farms increase the likelihood that juvenile salmon will encounter an infectious agent during their outward migration. Nevertheless, Madhun et al. (2021) conclude that wild salmon (in Norway) are exposed to a low infection pressure from fish farming, but they also caution that the possibility that infection may lead to rapid disappearance, altered behavior, or biased sampling of the infected fish. While these studies are considered broadly applicable to Scotland, studying diseases in wild populations is exceedingly complex; in the ocean, mortality events are rarely observed, sampling efforts solely capture live fish, and weak and dying fish are probably predated before the disease progresses to mortality (Miller et al., 2014)

This assessment considers potential impacts from all pathogens and parasites, but although the information from Norway and British Columbia has uncertain direct applicability 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*).

<u>Sea lice</u>

For a comprehensive review of sea lice dynamics assessment and management from a global perspective, see Groner et al. (2016), and Tett et al. (2018) for a Scottish focus. In Scotland, according to Salmon Scotland: "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 [Farm Management Areas] 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 treatment thresholds 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 (note, as treatment thresholds, once these levels of lice are reached, a treatment must be initiated, but the numbers of lice can continue to increase above these values).

Despite the rapidly increasing use of non-chemical sea lice removal methods, the 461 chemical pesticide treatments (not including hydrogen peroxide) in 2020 – equating to approximately 3.2 treatments per site in the year as an industry-wide average – indicates the challenge of controlling sea lice in Scotland (see Criterion 4 – Chemical Use).

Until recently, there have been two main sources of sea lice data in Scotland, but both had limitations. The government's FHI publishes reported sea lice data from farms[45], but with a reporting threshold of >2 adult female lice per fish (previously >3 from July 2017 - June 2019), the data do not reflect the industry as a whole (particularly considering the recommended lice limits mentioned above). Until May 2021, Salmon Scotland reported monthly average sea lice counts for each site[46] in a monthly sea lice report, but this aggregation hid the weekly variability at each site. Since March 2021, weekly sea lice counts for all farms have been made available in a mapped and tabular format in Scotland's Aquaculture database. As these data accumulate over time, it will be a useful resource to further study sea lice dynamics. All sea lice datapoints are collected and reported by the industry and have not been independently verified.

SSPO summary data for annual average sea lice levels from 2013 to 2020 are shown in Figure 34 (blue bars). These values are the average of all sea lice counts on every Scottish salmon farm for each year, and are therefore highly aggregated and hide substantial temporal and regional variations. Nevertheless, there is substantial annual variation in these numbers, with the value in 2016 nearly three times (2.9) that of 2018 The data from 12 monthly SSPO sea lice summary

[45] https://www.gov.scot/publications/fish-health-inspectorate-sea-lice-information/

[46] https://www.scottishsalmon.co.uk/reports

reports from 2019[47] were analyzed separately here and the value (green bar in Figure 34) is somewhat higher (35%) than the Salmon Scotland annual value. The reason for this difference is not apparent.

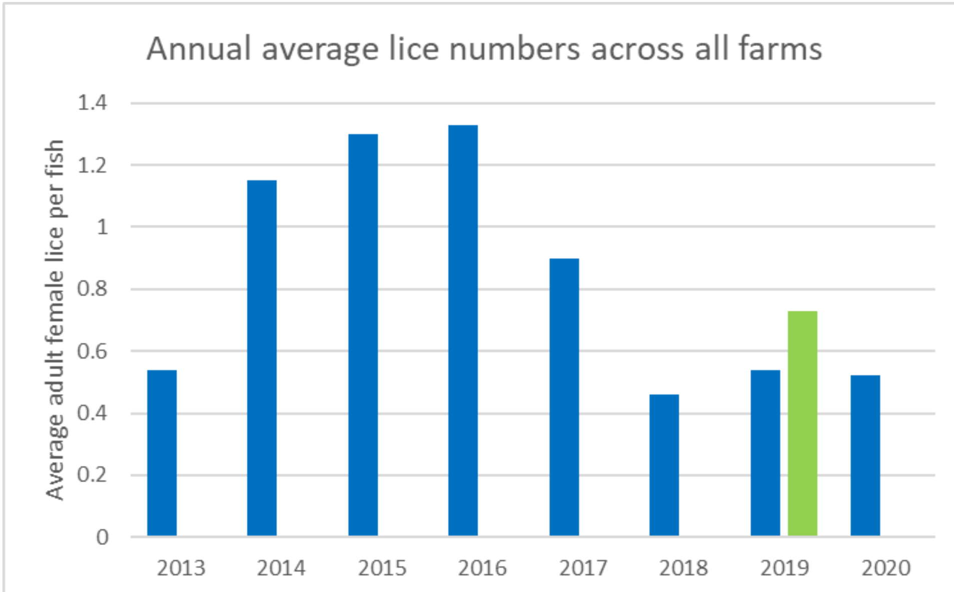


Figure 34: Annual average sea lice data from SSPO summary reports (blue bars). The green bar for 2019 shows the value calculated separately from each of SSPO's monthly sea lice reports for 2019.

Salmon Scotland data for each month of 2019 are presented in Figure 35. These data show the average lice numbers in January and from July to December were below the thresholds of 1.0 adult female lice per fish (red dotted line in Figure 35) set by the industry's Code of Good Practice. In contrast, they were above the 0.5 limit in every month from February to June (also shown by the red dotted line) during the peak outmigration period for wild salmon and sea trout. It is important to note that the data analyzed here from SSPO's monthly reports differs from the organization's summary reports[48] as shown by the grey line in Figure 35, in which the lice numbers are substantially lower across every month than their summary data.

[47] 2019 was the most recent complete data year at the time of the analysis in July 2021.
[48] Sea lice averages and trends in Scottish salmon farming. https://www.scottishsalmon.co.uk/sites/default/files/2020-07/Insight%20Lice%20Report%20May%202020.pdf

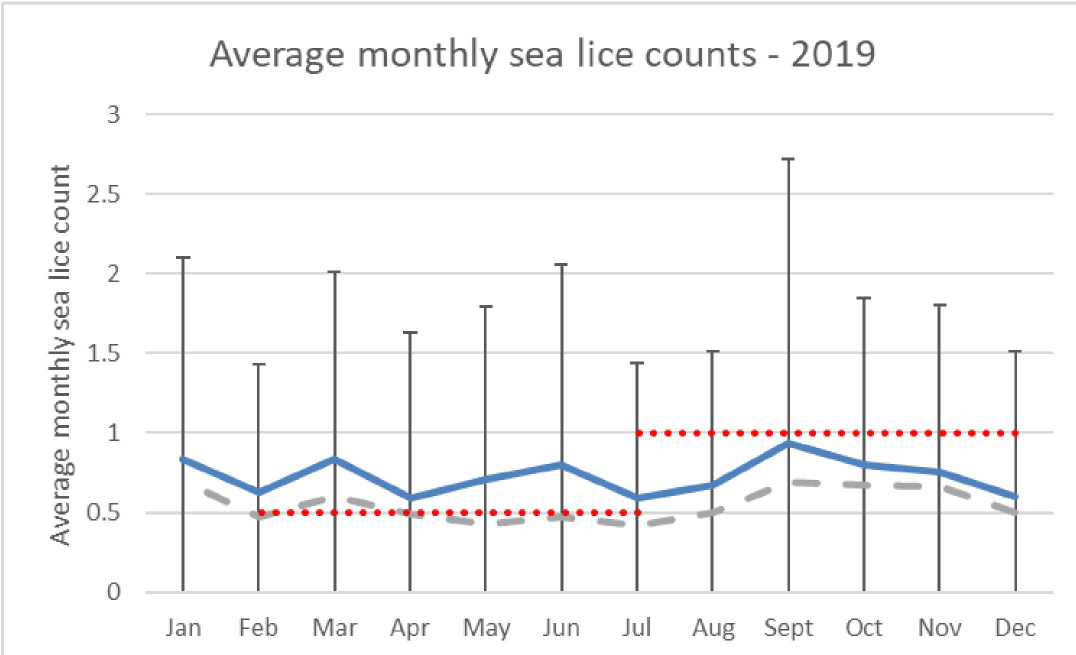


Figure 35: Average monthly sea lice counts with standard deviation bars (set to 1 SD) in 2019 calculated from SSPO monthly data (blue line). The grey dashed line is data from SSPO's multi-year summary report for 2019. The dotted red lines show the treatment thresholds set in the CoGP.

The standard deviation bars in Figure 35 show there is considerable variation in the lice numbers across farms, and while many sites have low lice levels (particularly in the early part of the production cycle), many sites will have lice numbers much higher than the averages. Due to the fact that these thresholds are recommendations for treatment action and not a hard ceiling on actual on-farm lice numbers per fish, it is perhaps not surprising that sites exceed this level as treatment is arranged and carried out. The maximum number of adult female lice per fish reported for each month in 2019 shows values ranging from 3.2 in February to 16.7 in September (average 6.3 for all months in 2019). As these values represent a monthly average for that site, the peak weekly counts are likely to be higher again.

Salmon Scotland also provides data on the average monthly sea lice numbers (adult female lice) from 2013 to August 2020 (as of June 2021), as shown in Figure 36, and in many recent years, the numbers of lice have been well above the CoGP treatment thresholds during the outmigration period of wild salmonids. Only in 2017 and 2018, and partially in 2019 do these data show compliance with the thresholds (again noting that the values calculated here for 2019 were above the thresholds). While the lower levels in the most recent years are encouraging, annual variability due to a variety of factors is likely to continue.

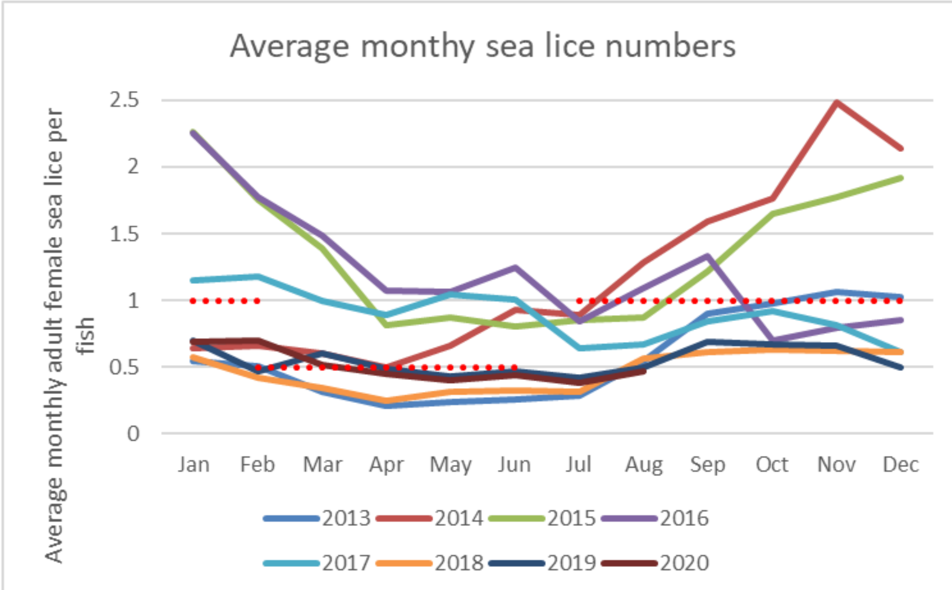


Figure 36: Average monthly sea lice numbers (adult females per fish) on Scottish salmon farms from 2013 to August 2020. The dotted red lines show the treatment thresholds set in the CoGP. Data from SSPO's "Sea lice averages and trends in Scottish salmon farming", but it must be noted that these numbers may underrepresent the values calculated from SSPO's monthly reports.

From an enforcement perspective, the government's FHI has an evolving series of reporting and enforcement thresholds, updated in 2017 and again in 2019. The current thresholds are shown in Figure 37 and show the reporting threshold is currently double the recommended treatment threshold in Salmon Scotland's CoGP (four times the threshold during the February to June wild salmon outmigration period) and enforcement does not begin until lice reach six adult females per fish (i.e., 6 or 12 times the CoGP levels depending on the time of year).

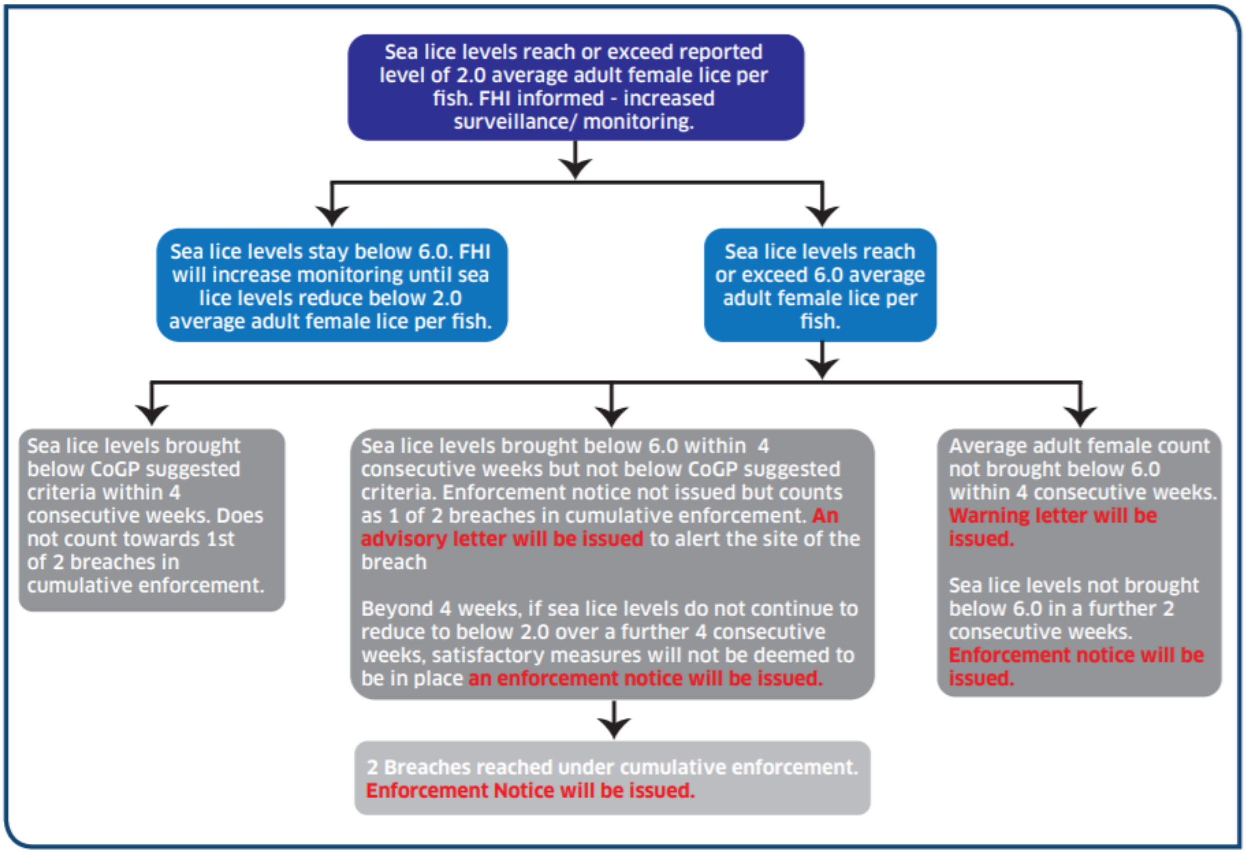


Figure 37: Scotland's Fish Health Inspectorate Sea Lice Policy - Enforcement Regime. Image copied from FHI Topic Sheet #71v3.

Sea lice count data are not reported on a regional basis (in theory, the site-level monthly data could laboriously be attributed by site to each region by cross-referencing other data in Scotland's Aquaculture database but would be impractical in reality). As noted in Criterion 4 – Chemical Use, the Orkney Isles use very little sea lice pesticide treatment in terms of total quantities and frequency of use, and this is assumed here to be due to lower lice levels (rather than an alternative explanation such as higher use of non-chemical sea lice treatments). Several academic studies have developed 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), and according to Salmon Scotland (SSPO, pers. comm., January 2021), the difference is due to the geographic nature of Orkney's separate small islands with high tidal flushing in the channels between them which disperses sea lice larvae rather than allowing them to proliferate on farms (as opposed to the larger island landmasses and more enclosed bays and sea lochs elsewhere in Scotland). Importantly, however, SSPO data in the 2016 Fish Health Management Report provided 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 was only one month (July 2015) when the average sea lice count was above zero across all of Orkney's active sites (it was an average of 0.05 adult female lice per fish in July 2015, with approximately 15 to 18 active sites at any one time). These data confirm that alternate reasons for low reported sea lice chemotherapeutants (e.g., the greater use of non-chemical treatments) are highly unlikely.

The analysis of the potential for sea lice transmission between Scottish finfish aquaculture management areas conducted by Rabe et al. (2020) also confirms the Orkney Isles (along with the Shetlands due to their northeastern-most location) are low sources of sea lice dispersion to other fish farming areas in the same region or elsewhere in Scotland (Figure 38). The same comparison using the 2014 and 2015 data in the 2016 SSPO Fish Health Management Report show Shetland had lice levels largely typical of the rest of the industry (in those two years), despite its remote location beyond Orkney.

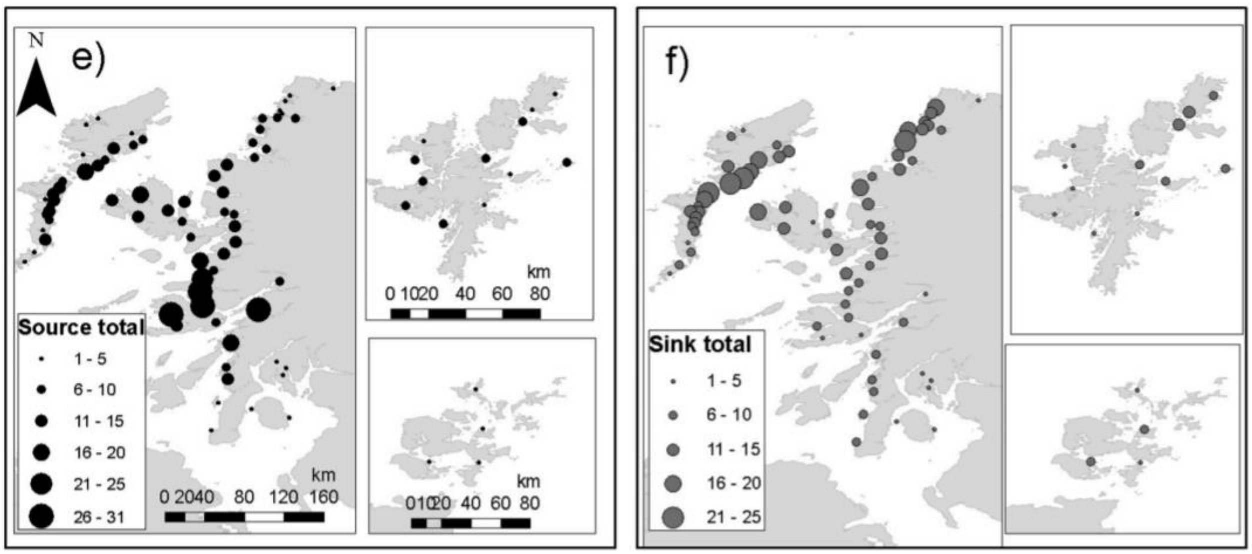


Figure 38: Map of sources of lice dispersion to other fish farming areas (left) and sinks (right) of sea lice in different regions of Scotland. Panels e) and f) shown here show the worst-case modelling approach with the total sources and sinks. In each panel, three regions are shown; the west coast (Northwest, Southwest and Western Isles) is on the left and the right side shows Shetland on the top and Orkney on the bottom, on different scales. Image copied from Rabe et al. (2020).

Impacts of sea lice to wild fish

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 where the predicted mortality of wild salmon due to sea lice from salmon farms is the only variable controlling the industry's scale of production within the country's "traffic light" system. While the Scottish aquaculture industry's most vocal critics are apparently conservation organizations (e.g., Salmon and Trout Conservation Scotland[49]), they are primarily angling bodies with their own specific agendas (and represent part of the exploitation impacts on wild salmon populations). An analysis of catch statistics in Scotland's aquaculture zone compared to other regions without salmon farms, Middlemas et al. (2016), reported (for the Scottish Government) that the catch statistics are consistent with an impact of salmon farming on wild salmon (of which sea lice may be one component). However, it is important to note that Middlemas et al. (2016) did not prove a

[49] https://www.salmon-trout.org/countries/scotland/

causative link, and it is clear from Scottish Government catch data[50] that the declines particularly in sea trout were well underway prior to the establishment of salmon farming in Scotland.

Sea lice (as part of the Fish Health category) are one of twelve high level pressure groups identified by the Scottish Government as having contributed to the decline of wild Atlantic salmon[51] (Table 4). There are currently few data with which to robustly quantify or scale these impacts (other than a comparison to Norway, which may not be relevant for all impact categories). This is similar to the situation in the northeast Atlantic where in the US, Atlantic salmon were once native to almost every coastal river northeast of the Hudson River in New York, but overfishing, dams, habitat damage and pollution caused the populations to decline since the late 19th century until the fisheries closed in 1948, decades before the start of salmon farming (NOAA, 2020)

Table 4: List of 12 high level pressures on wild Atlantic salmon in Scotland. Sea lice are included under Fish Health.

High level pressures on wild Atlantic salmon (in no particular order)		
Exploitation	Invasive non-native species	Habitat – water quantity
Predation/competition	Habitat – water quality	Habitat – riparian
Fish Health	Habitat – thermal	Barriers to migration
Genetic Introgression	Habitat – instream	Coastal and marine

In the Scottish Government's Rural Economy and Connectivity Committee's 2-year update on the 2018 enquiry into salmon farming (RECC, 2020), the following question from Stewart Stevenson (REC Committee member) and answer from Peter Pollard (Head of Ecology at SEPA) are noteworthy:

> Stewart Stevenson: "Who is responsible for monitoring that interaction between farmed fish facilities and the wild fish population? Of course, I am not necessarily assuming that there is a meaningful interaction because on the east coast, we have seen as big declines as we have on the west coast and there are no farms on the east coast. Is there an interaction that matters and who is responsible for monitoring and reacting to it?"
>
> Peter Pollard: "I will start with the big picture. Do we think that sea lice from farmed fish are responsible for the declines that we have seen over the decades in wild fish? No. There is a complex range of reasons, some of which are probably to do with high seas changes. The issue is whether the state of the populations at the moment can be affected by the added pressure of further sea lice as they migrate to sea. That is not to suggest that the declines over the past few decades are due to fish farming. The concern

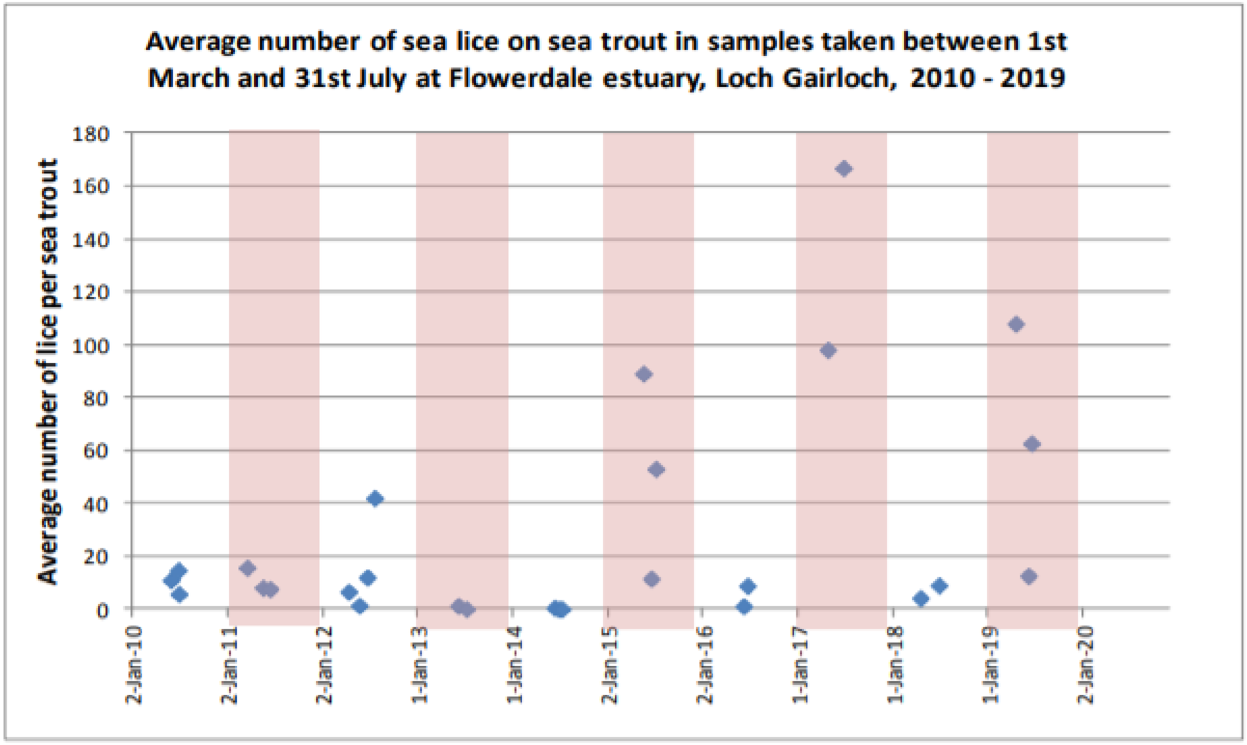
[50] Catch statistics for sea trout: https://www.gov.scot/publications/sea-trout-fishery-statistics-2020/
Catch statistics for salmon: https://www.gov.scot/publications/salmon-fishery-statistics-2020/
[51] High Level Pressures on Atlantic Salmon shown in Appendix 2. https://www2.gov.scot/Topics/marine/Salmon-Trout-Coarse/fishreform/licence/status/Pressures

> is whether the additional pressure of sea lice is now significant, as wild stocks are at such low levels"

Accepting SEPA's statement that farmed salmon are not responsible for the declines of wild salmon, the challenge becomes determining "whether the additional pressure of sea lice is now significant, as wild stocks are at such low levels". The review by Tett et al. (2018) noted that a clear relationship between the increased abundance of sea lice due to salmon farming and presence on wild hosts in the sea has been demonstrated outside Scotland, but unlike Norway which has a comprehensive annual monitoring program for lice on wild salmonids (salmon, trout, and Arctic char), Tett et al. note there are no published accounts of systematic counts of sea lice levels on wild salmon and its association with salmon farming in Scotland. In a minor contradiction to Tett et al.'s review, the Skye and Wester Ross Fisheries Trust (SWRFT) has conducted annual sea lice counts on a modest number of wild sea trout in several estuaries and lochs in their region since at least 2010, with data published in annual or biennial report.

Thorstad et al. (2015) (in Norway) and Shephard et al. (2016) (in Scotland) note sea trout are particularly vulnerable to sea lice impacts because they normally remain for extended periods in near-coastal waters where the majority of salmon farms are located (as opposed to salmon, which migrate offshore). As one example of the SWFRT monitoring, the results from 2010 to 2019 within Loch Gairloch are shown in Figure 39a and b. Figure 39a shows the sea lice abundance on sea trout between March and July inclusive (i.e., the average number of lice per trout in the sample, calculated as the total number of lice on all fish in the sample divided by the total number of fish in the sample). Figure 39b shows the average numbers of lice per gram of fish weight (all data and graphs from SWRFT, 2020). According to Taranger (et al., 2014), if the lice per gram are greater than 0.3, then there could be up to 100% mortality of the fish experiencing that level of infection; when the lice per gram are between 0.2 and 0.3, then there is greater than a 50% risk of mortality, and this reduces to 20% when the figures are between 0.1 and 0.2 lice per gram of fish. If the number is below 0.1 lice per gram, then Taranger perceives no risk (note these are the same mortality brackets used by Norway's "traffic-light system" to manage the scale of production based on the estimated lice-induced mortality of wild juvenile salmon, and also in the annual risk assessment conducted by Norway's Institute of Marine Research). The pink shading in Figure 39a,b denotes years when the nearest salmon farms in Loch Torridon (26 km away) were in the second year of the two-year production cycle (i.e. larger fish and a large total biomass of fish).

These figures from SWRFT (2020) show highly variable lice levels on wild sea trout at the Gairloch location, with low lice levels in many years, but extremely high levels in others (noting the highest abundance numbers likely reflect very small larval lice). SWRFT (2020) concludes that there is a clear association with the higher lice loads on wild sea trout when the nearest farm is in the second year of production. With consideration of the lice levels quoted above (from Taranger et al., 2014), 16 out of the 25 fish sampled by SWRFT at Loch Gairloch had <0.1 lice per gram of fish (no risk), and 7 fish had >0.3 lice per gram (up to 100% mortality). These results appear similar to those of Gargan et al. (2017).



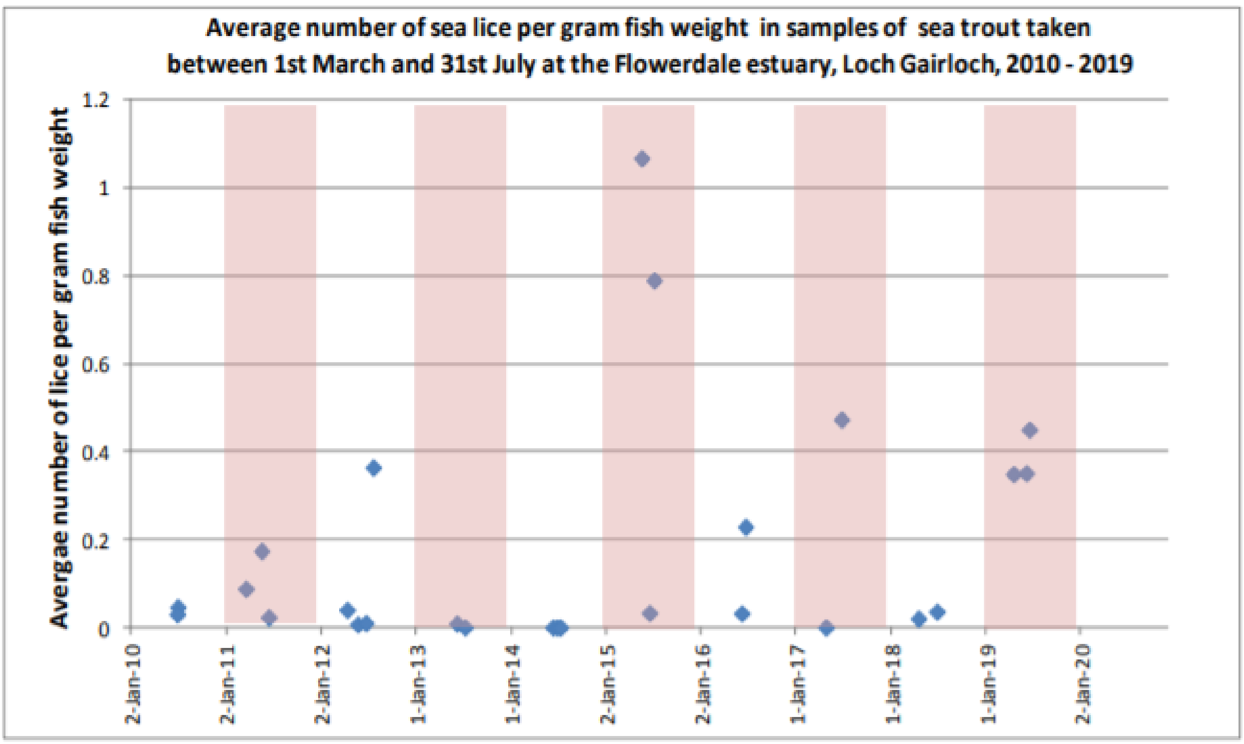


Figure 39: 2. Sea lice abundance on sea trout samples between March and July (inclusive) at Flowerdale, Loch Gairloch from 2010 to 2019, shown as (top graph) average numbers of lice per fish; and (bottom graph) average numbers of lice per gram fish weight. Pink shading denotes years when the nearest salmon farms in Loch Torridon (26km away) were in the second year of the 2-year production cycle. Figure taken from SWRFT (2020).

Gargan et al. (2017) sampled a large number of sea trout in Scotland (and Ireland) from 1997 to 2015 and concluded the increased mortality risk of sea trout due to salmon lice infections was in the 50-100% risk category for much of the early 1997-2001 period. Over the period 2002-2008, the risk of lice-related sea trout mortality decreased and generally was in the 20% risk category, after which the risk of lice-related mortality has been further reduced to between approximately 10 and 20% per year.

While there are 25 regional fisheries trusts in Scotland, with nine on the west coast, there do not appear to be similar studies to the SWRFT monitoring conducted elsewhere. Though the SWRFT data show the impact of sea lice to sea trout (and potentially juvenile salmon) may be substantial in some years and in some locations, the conclusion of Tett et al. (2018) – that the consequences of increased sea lice levels for wild salmonid populations are unclear – remains largely valid for Scotland as a whole (note further regional analysis below with regard to Orkney).

The Scottish Government's *Summary of Science*[52] (updated March 2021) considers that:

- Salmon farms have been shown to be a much more important contributor than wild fish to the total numbers of sea lice in the Scottish coastal zone.
- Concentrations of larval lice sampled in areas near farms relate to the local farm lice loads.
- The numbers of lice found on salmon maintained in sentinel cages relate to lice numbers reported on the nearest farms.
- The proportion of individual sea trout with stress-inducing sea louse burdens increased with the mean weight of salmon on the nearest fish farm and decreased with distance from that farm.
- Levels of lice on wild sea trout also relate to fluctuations on farms associated with stage of production cycle.

The Summary of Science also notes the potential for sea trout in the wild in coastal environments to return to freshwater, a behavior that may act to remove lice but with physiological costs, including reduced growth, but it concludes overall that no information has yet been published to provide a quantitative estimate of the impact of lice on sea trout populations in Scotland.

It is important to note that one of the main problems in measuring or predicting the scale of impact on salmon or sea trout is that the effect of lice on wild salmonids is context-sensitive; that is, the effect of lice is directly correlated with the overall survival in the ocean, so that in years of poor baseline survival the effect of lice is large, while in years of good baseline survival the effect of lice is almost not measurable (Vollset et al., 2015, 2019b; Bøhn et al.,2020).

[52] https://www2.gov.scot/Topics/marine/Salmon-Trout-Coarse/Freshwater/Research/Aqint/troutandlice

Similarly, Bøhn et al. (2020) highlight that timing is crucial. In years with little overlap between lice blooms and Atlantic salmon smolt migration, only minor effects can be expected; conversely, in years with a strong overlap in timing, serious mortality effects can be expected.

Responding to the Scottish Government's identification of twelve high level pressure groups that have contributed to the decline of wild Atlantic salmon, and in response to two government enquiries into Scotland's salmon farming industry[53], a Salmon Interactions Working Group (SIWG) was established. The SIWG acknowledged the potential hazard that salmonid aquaculture presents to wild salmonids (Atlantic salmon and sea trout), even if it is largely impossible to quantify that risk or to put it into context with the remaining eleven high pressure groups. The working group's report (SIWG, 2020) makes 42 recommendations to the Scottish Government to improve the research and data availability and improve the management of wild fish and their interactions with salmon farms.

Accepting that any quantification of the impact in Scotland is currently impossible (either directly, or in relation to other high-level impacts), the Scottish Government's recognition of the similarity with Norway is adopted here. With a useful summary graph, the Norwegian Scientific Advisory Committee for Atlantic Salmon show sea lice (along with escaped farmed salmon) have the greatest negative impact on wild salmon in Norway, and sea lice particularly are regarded as an expanding population threat (see Figure 40). This means they are affecting populations to the extent that populations may be critically endangered or lost in nature with a high likelihood of causing even further reductions (Thorstad et al., 2020; Grefsrud et al., 2021a,b).

[53] In 2018, the Scottish Parliament's Environment, Climate Change and Land Reform Committee (ECCLR) and Rural Economy and Connectivity (REC) Committees held two inquiries into Scotland's salmon farming industry. The focus of the first ECCLR inquiry was to investigate the environmental impact of the salmon farming industry, whereas the second REC inquiry focused on identifying opportunities for the future development of the industry and explore the fish health and environmental issues identified in the ECCLR inquiry.

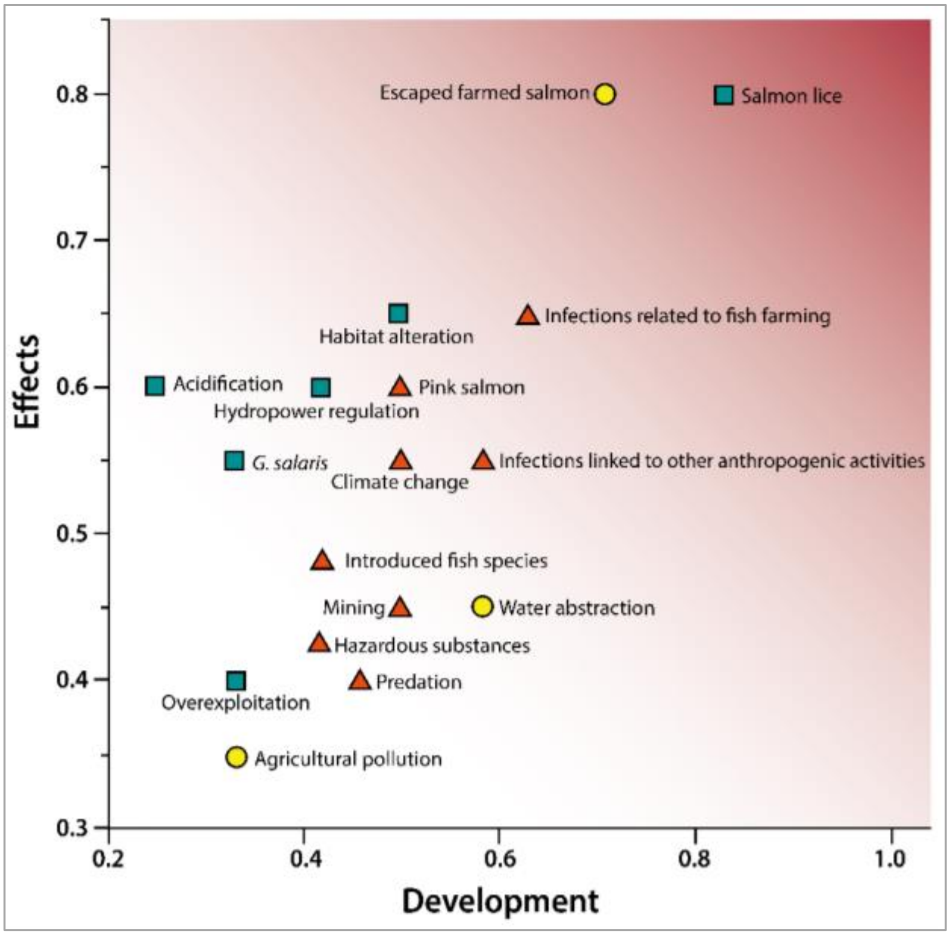


Figure 40: Ranking of 17 impact factors considered in 2019, according to the magnitude of their effects on wild Atlantic salmon populations in Norway and the likelihood of a further negative development. The knowledge of each impact factor and the uncertainty of future development is indicated by the color of the markers. Green squares = Extensive knowledge and small uncertainty, yellow circles = moderate knowledge and moderate uncertainty, and red triangles = poor knowledge and high uncertainty. Image from Thorstad et al. (2020).

The same committee (in Thorstad et al., 2020) calculated the annual loss of adult wild salmon returning to Norwegian rivers due to salmon lice[54] to be 39,000 in 2019 (noting that the corresponding number of out-migrating salmon smolt killed by sea lice will be much larger than this number of returning adult salmon). Catch data from Statistics Norway[55] shows 131,258 salmon (and 34,857 sea trout and Arctic char) were caught and killed by anglers in Norwegian rivers in 2019, with a further 32,189 (all species) caught and released. While it appears the anglers have a greater impact, the reality is that with robust fishery regulations, the angling catch is strictly limited to those rivers where the management system considers there to be sufficient numbers of returning salmon to support a fishery; fishing is currently closed in 110 rivers due to reduced populations and restricted in others (Thorstad et al., 2020). Therefore, overexploitation is a low concern in Norway (Figure 40).

[54] This loss is estimated by comparing the number of adult salmon returning in practice to the predicted number of returns had their out-migrating juveniles experienced only natural background lice levels.
[55] https://www.ssb.no/en/jord-skog-jakt-og-fiskeri/statistikker/elvefiske

The concern for on-farm sea lice impacting wild salmonids in Norway is such that in 2017, the Norwegian government ratified a new regulation, commonly referred to as the traffic-light system, in which farmed salmon production volumes are governed by the single indicator of (estimated) salmon lice-induced mortality in wild salmonids (Vollset et al., 2020). In this system (which is supported by long term detailed sea lice monitoring and modelling data, and extensive monitoring of lice levels on wild salmon and sea trout), a high mortality means >30% of wild salmon or sea trout are estimated to be killed by sea lice each year, moderate means 10-30%, and low means <10% mortality. With regard to sea trout, the impacts are currently addressed in the same way as salmon in the traffic light system, despite the differences in vulnerability to sea lice reported by Vollset et al. (2020), but the annual risk assessment for Norwegian aquaculture conducted by the Institute of Marine Research (Grefsrud et al. 2021a) considers there to be a high risk of lice-induced mortality to wild sea trout in six of Norway's 13 Production Areas, moderate in three Areas, and low in four Areas (in the extreme south and north of the country). These Norwegian examples clearly identify the potential risk to salmon and sea trout in Scotland in the years and locations where sea lice are high.

As described in Criterion 6 – Escapes, the European Red List of Marine Species (Nieto et al. 2015) classifies Atlantic salmon in Europe as Vulnerable, and the majority of Scottish salmon rivers are in the Scottish Government's worst grade of conservation status. Both Atlantic salmon and brown trout are listed in the UK as Biodiversity Action Plan priority species[56]; identified as being the most threatened and requiring conservation action under the plan.

Conclusions and Final Score

Bacterial and viral pathogens infect farmed salmon in Scotland and negatively impact production, and their on-farm presence represents a reservoir of potential spillback to wild organisms. Their beyond-farm impact appears low yet remains uncertain (possibly due to the challenges of detecting diseased wild fish). 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 individuals, are recognized as a concern by the Scottish Government and by their Salmon Interactions Working Group (SIWG). While sea lice are not considered to be responsible for the long-term declines in wild salmon and sea trout (and there are many ongoing non-aquaculture pressures on the populations), there is a concern that the added pressure of sea lice transmission from salmon farms is a significant impactor on the health and recovery of wild salmonid populations.

In contrast to Norway, which has long term comprehensive monitoring and modelling of lice on farms and on wild salmon and sea trout, there is very little monitoring of sea lice on wild fish in Scotland. While the available research in Scotland indicates the mortality of sea trout due to sea lice has declined since the late 1990s and is now perhaps in the range of 10-20% per annum, the Scottish Government still defers to examples from Norway, where sea lice are considered to have the greatest negative impact on wild salmon and sea trout and are regarded

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

as an expanding population threat. Without clear evidence on the impacts in Scotland and accepting that evidence in Norway cannot be fully representative of the situation in Scotland, the Risk-Based Assessment method has been used. The score is based on the open nature of the production system, the common exceedance of (recommended) lice limits that were established for the protection of wild fish, the high susceptibility of wild salmon and sea trout to lice, and the apparent high potential for population impacts to discreet wild sea trout populations in Scotland (due to their longer coastal residences in areas with increased sea lice infection pressures). With consideration of the vulnerable conservation status of both Atlantic salmon and sea trout in Scotland, the final score for the Northwest, Southwest, Western Isles, and Shetland Isles for Criterion 7 – Disease is 0 out of 10. In contrast, data indicate very low prevalence of sea lice on the farms in the Orkney Isles region are recognized here as posing a distinctly different level of risk of impact. Using the Risk-Based Assessment method, the score for Criterion 7 – Disease for the Orkney Isles is 6 out of 10.

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

Impact, unit of sustainability and principle

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

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

Criterion 8X Summary

Orkney and Shetland Isles

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

Northwest, Southwest, and Western Isles

C8X Source of Stock – Independence from wild fish stocks	Value	Score
Percent of production dependent on wild sources (%)	54.4	-5
Use of ETP or SFW "Red" fishery sources	No	
Lowest score if multiple species farmed (0-10)		-5
C8X Source of stock Final Score (0-10)		**-5**
Critical?	No	Yellow

Brief Summary

As is common throughout the global salmon aquaculture industry, Scottish salmon farming production is based on hatchery-raised broodstocks of Atlantic salmon selectively bred over many generations. As such, it is considered to be independent of wild salmon fisheries for broodstock, eggs, or juveniles. With increasing use of non-chemical alternatives to sea lice treatment, large numbers of cleaner fish are used on in the Northwest, Southwest and Western Isles regions (not in the Orkney and Shetland Isles), and while hatchery production is increasing and provides all the lumpfish used in Scotland, approximately one million wild caught wrasse are used each year. Wrasse are a keystone species in inshore waters that are unusually vulnerable to over-exploitation, and despite the establishment of "*Voluntary control measures* *for the live capture of Scottish wild wrasse for salmon farms"* and an in-progress government consultation on making them mandatory, there are no substantive stock assessments; as such, the fishery is considered here to be, at best, of unknown sustainability, and perhaps demonstrably unsustainable. According to, 40% of the total Scottish farmed salmon production involves the use of wild caught wrasse, which equates to 54.4% of the production in the three western regions that use them. Therefore, the final score for Criterion 8X is a deduction of -5 out of -10 for the Northwest, Southwest, and Western Isles regions. With no use of wild caught wrasse in the Orkney and Shetland Isles, the final score for these regions in Criterion 8X – Source of Stock is a deduction of 0 out of -10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Justification of Rating

<u>Source of Atlantic salmon</u>
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., 2015; Gutierrez et al., 2016). As such, of the finfish species farmed for food, Atlantic salmon is among those that have been subject to the longest and most intense domestication regimes (Skaala et al., 2019). For example, farmed salmon in Norway have undergone approximately 15 generations of targeted breeding and are now considered to be partially domesticated and adapted to a life in captivity (Grefsrud et al., 2020). Due to the industry-wide use of domesticated broodstocks globally, 100% of eggs, juveniles and smolts are considered to be independent of wild salmon populations.

<u>Source of cleaner fish</u>
Following laboratory trials in the late 1980s, several species of wrasse and lumpfish 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 lumpfish as cleaner fish increased rapidly in Scotland in recent years (SAIC, 2015). According to Powell et al. (2017), cleaner fish are now being used for delousing by all major salmon farming companies in Scotland (though not at all sites or in all regions, as discussed below). When they are used, Riley et al. (2017) suggested the ratio of cleaner fish to salmon is 1:25, and a variety of species are utilized from hatchery-raised and wild sources. As discussed below, the large majority of hatchery-raised wrasse and lumpfish come from wild-caught broodstock.

The annual Fish Farm Production Survey (Wallace and Munro, 2020) shows 660,000 lumpfish were produced in hatcheries in the UK in 2018 (down from 925,000 in 2017 – see Figure 41) and Salmon Scotland states all the lumpfish used in Scotland are produced in hatcheries. 59,000 wrasse were produced in hatcheries in 2019, down from 103,000 in 2018, and according to Fletcher (2020), one large salmon company (Mowi) has established a hatchery in the UK capable of producing one million wrasse annually (when operating at full capacity).

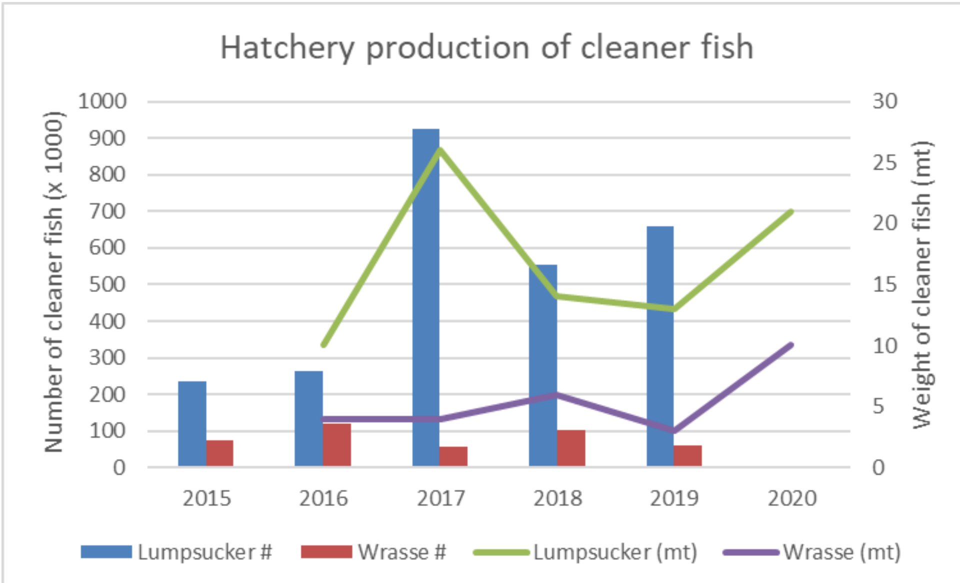


Figure 41: Production of cleaner fish in the UK in numbers (bars) from 2015 to 2018 and weight (lines) from 2016 to 2020 (2020 projected). Data from Wallace and Munro (2020).

All hatchery reared wrasse are currently raised from wild-caught broodstock, and although F1 captive broodstocks are now being retained by commercial hatcheries, they have a long generation time (reaching maturity at ~6 years for females and 12 years for males) and hatchery production is likely to be dependent on wild caught broodstock for some time (Brooker et al., 2018). With regard to lumpfish, nearly all hatchery-reared lumpfish derive from wild caught broodstock and as such pressure is put upon wild populations to supply the demand for broodstock (Saraiva et al., 2019; Powell et al., 2018, Brooker et al., 2018). For the Scottish salmon farming industry, the numbers of wild caught lumpfish broodstock are considered to be low (for example it was estimated to be 300 in 2014) and a small fraction of the established fisheries for human consumption (of the lumpfish roe) (Powell et al., 2018). In addition, with a much shorter generation time, the potential for rapid ongoing domestication of lumpfish is much higher.

Despite the increasing hatchery production of cleaner fish, it does not meet the national demand, and around one million wrasse are currently considered to be caught in Scottish fisheries[57], with a further estimated one million caught in fisheries in southwest England (Powell et al., 2018, Riley et al. 2017). As such, the capture fishery for wrasse is the focus of this criterion.

<u>Wrasse Fishery sustainability</u>
Wrasse are considered to have low resilience and a moderate to high vulnerability to fishing exploitation (Riley et al., 2017). In the United Kingdom, fisheries for wrasse have expanded exponentially since 2013, with more than a 481% increase in landings from 2005 to 2019 (MCS, 2020; referencing data from the UK Marine Management Organisation). This increase has been

[57] https://www.fishfarmingexpert.com/article/wrasse-catch-figures-show-commitment-to-sustainability/

driven by high demand which in turn has led to them being the most valuable fisheries species in Europe[58] (MCS, 2020).

In 2018, Salmon Scotland and the Scottish Government established the "Voluntary control measures for the live capture of Scottish wild wrasse for salmon farms", and in December 2020, the Scottish Government proposed that the voluntary measures become mandatory[59]. The measures include seasonal closures, minimum and maximum landing sizes, reporting requirements, details on trap design (e.g., otter excluders), limits on the total number of traps, and other aspects associated with wrasse welfare. In the English fisheries, there are both voluntary guidance and mandatory management measures implemented by the southwest Inshore Fisheries and Conservation Authorities (IFCAs), but there is a similar lack of appropriate data necessary (e.g., stock assessments) (MCS, 2020).

The establishment of these management measures is to be supported, but the UK's Sustainable Inshore Fisheries Trust (SIFT)[60] and the Marine Conservation Society (MCS, 2020) note wrasse are a keystone species in inshore waters that are unusually vulnerable to over-exploitation, and whose local populations in the UK frequently collapse following the commencement of commercial fisheries that target them. SIFT and MCS consider there to be inadequate substantive stock assessments, in addition to other concerns. Therefore, despite the new measures, the fishery is considered here to be, at best, of unknown sustainability, and possibly demonstrably unsustainable.

Proportion of Scottish farmed salmon dependent on wild caught wrasse

According to Salmon Scotland, wrasse are not used in the Orkney or Shetland Isles, but with total production dominated by the three western regions, there are no public data on the numbers of Scottish salmon farms using cleaner fish, and specifically on the number using wild caught wrasse which are the focus of this assessment. Latham (2015) describes the number of Scottish farms using wrasse as "small", but Salmon Scotland has more recently estimated that 40% or Scottish production has utilized wrasse (Salmon Scotland, personal communication, December 2020). By considering 40% of the total Scottish salmon production (81,552 mt in 2019) with the total production in the three regions using wrasse (149,982 mt in the Northwest, Southwest and Western Isles), it is calculated that 54.4% of production in these regions involves the use of wild caught wrasse.

Conclusions and Final Score

As is common throughout the global salmon aquaculture industry, Scottish salmon farming production is based on hatchery-raised broodstocks of Atlantic salmon selectively bred over many generations. As such, it is considered to be independent of wild salmon fisheries for broodstock, eggs, or juveniles. With increasing use of non-chemical alternatives to sea lice treatment, large numbers of cleaner fish are used on in the Northwest, Southwest and Western

[58] https://salmonbusiness.com/scottish-salmon-producers-organisation-publishes-wild-catch-wrasse-data/
[59] https://consult.gov.scot/marine-scotland/wild-wrasse-harvesting/
[60] https://www.sift.scot/projects/save-wrasse/

Isles regions (not in the Orkney and Shetland Isles), and while hatchery production is increasing and provides all the lumpfish used in Scotland, approximately one million wild caught wrasse are used each year. Wrasse are a keystone species in inshore waters that are unusually vulnerable to over-exploitation, and despite the establishment of "*Voluntary control measures for the live capture of Scottish wild wrasse for salmon farms"* and an in-progress government consultation on making them mandatory, there are no substantive stock assessments; as such, the fishery is considered here to be, at best, of unknown sustainability, and perhaps demonstrably unsustainable. According to Salmon Scotland, 40% of the total Scottish farmed salmon production involves the use of wild caught wrasse, which equates to 54.4% of the production in the three western regions that use them. Therefore, the final score for Criterion 8X is a deduction of -5 out of -10 for the Northwest, Southwest, and Western Isles regions. With no use of wild caught wrasse in the Orkney and Shetland Isles, the final score for these regions in Criterion 8X – Source of Stock 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: Wildlife mortalities

Impact, unit of sustainability and principle

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

This is an "exceptional" 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

Orkney Isles, Shetland Isles, Northwest, Southwest

C9X Wildlife Mortality parameters		Score
Single species wildlife mortality score		-2
System score if multiple species assessed together		n/a
C9X Wildlife Mortality Final Score		**-2**
Critical?	No	Green

Western Isles

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

Brief Summary

The number of seals controlled by lethal means in Scotland (by salmon farming companies and fisheries managers) is low in comparison to the Potential Biological Removal (PBR) for Grey and Common (Harbour) seals (where PBR is defined by the Marine Mammal Research Institute as the number of individual seals that can be removed without causing a decline in the population). Seal mortality management and licensing in Scotland is based on seven management areas, each with an area-specific PBR value. The maximum number of single-species salmon farm mortalities of 21 Common seals in the Western Isles in 2019 represented 6.6% of that species' regional PBR (plus 1.6% of the PBR of Grey seals). In other areas, the percentage of PBR for Common seals varied from 0% in Shetland and Orkney, to 1.4% in the southwest, and for Grey seals, the percentage of PBR varied from 0.2% in Orkney to 2.2% in Shetland with intermediate values in other areas. Recently introduced regulations to align with the US Marine Mammal Act should limit future mortalities of seals to cases of accidental entanglement (i.e., the same as for birds). Entanglement mortalities are not required to be reported in Scotland and while the numbers are not known, they are considered to be uncommon. With good data availability on lethal control from the Scottish Government and robust information on the status of seal populations in each region, it can be seen that deliberate mortality is not routine, and in addition to entanglements, the total mortality does not significantly affect the population size. As such the final score for Criterion 10X – Wildlife Mortalities is a small deduction of -2 out of -10 for the Orkney and Shetland Isles, the Northwest and Southwest. For the Western Isles where the mortalities are higher and reach 6.6% of PBR of common seals, the populations are still not considered to be significantly impacted, but the Final Score for Criterion 10X – Wildlife Mortalities is -4 out of -10.

Justification of Rating

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 may be lethally controlled, and can also become entangled in nets and other farm infrastructure resulting in mortality. In Scotland, although accidental mortalities of birds and otters occur, lethal control is aimed primarily at two species of seals: common (or harbour - *Phoca vitulina)* and Grey (*Halichoerus grypus).* All data in this section are from the Scottish Government seal licensing records, available online at the Scottish Government website[61].

In 2020, the Scottish Government granted 47 lethal control licenses allocated across fisheries and fish farms. The 47 licenses allowed a total of 228 grey and 102 common seals to be killed in 2020, but figures from recent years (Figure 42) show that the actual numbers killed are much lower. In 2019 (the most recent data year as of July 2021), a total of 97 seals were shot by both fisheries managers and salmon farms of which 46 grey seals and 19 common seals (65 total) were killed by salmon farming companies. These data do not include accidental mortalities (such as those resulting from entanglement) and these are not required to be reported in Scotland (SCOS, 2020; cited with permission). The Scottish Scientific Committee on Seals (SCOS, 2020) notes anecdotal reports of entanglement mortalities in Scotland, but with reference to Canadian reported data from the salmon farming industry in British Columbia which shows an average of eight entanglement mortalities per year from 2011 to 2020, the impression is that entanglement mortalities in Scotland are unlikely to approach the numbers deliberately killed.

Figure 43 shows the regional composition of the lethal control mortalities in 2019 with the largest numbers killed in the Western Isles (28) and the Northwest (21). Regional farmed salmon production is also shown to give an indicator of mortalities in relation to the scale of the industry in each region.

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

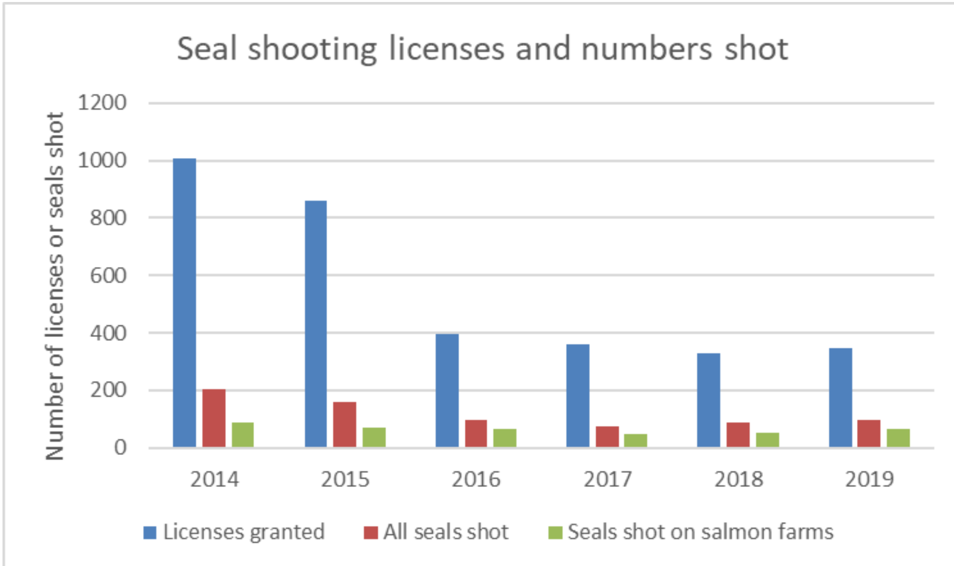


Figure 42: The number of lethal seal control licenses and seals shot from 2014 to 2019. Data are from the Scottish Government website.

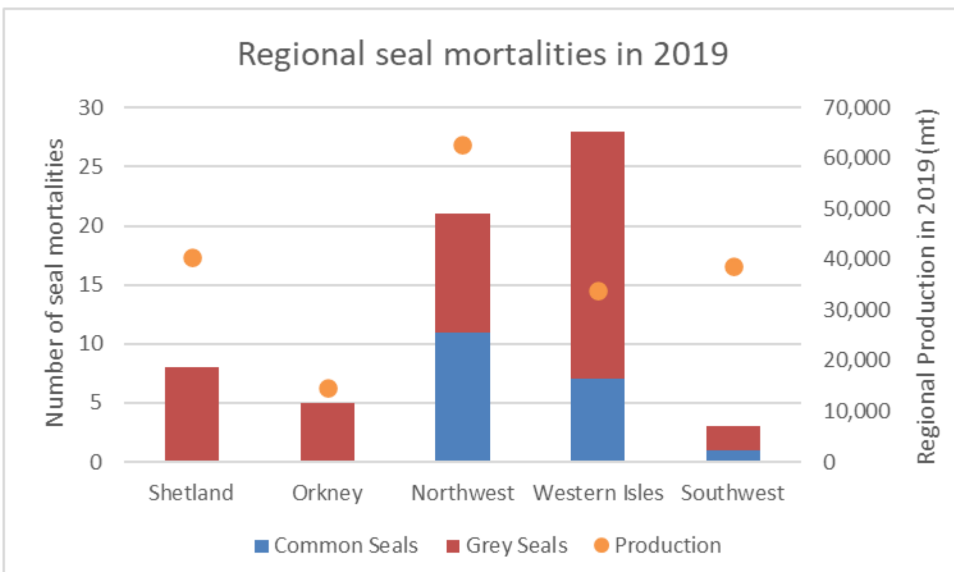


Figure 43: Regional seal mortality in 2019 (blue and red bars) compared to regional annual production (orange dots) in 2019 in mt. Seal data from the Scottish Government, and production data from Munro and Wallace (2020).

<u>Management and Potential Biological Removal (PBR)</u>

In 2011, Part 6 of the Marine (Scotland) Act 2010 came into force which "seeks to balance seal conservation with sustainable fisheries and aquaculture". Figure 44 shows seven seal management areas around Scotland, within which are large seal conservation areas (for common seals) and smaller Special Areas of Conservation mostly also for common seals. The salmon farming industry in the Western Isles, Shetland and Orkney thus operate within common seal conservation areas. According to the Scientific Committee on Seals (SCOS) at the University of St Andrews, Grey seal populations in the UK are increasing in all areas, but while the total UK population of Harbour seals is also increasing, there is considerable regional variation. In the Northwest, Southwest and Western Isles regions, the populations are increasing, but in the Orkney and Shetland Isles (and on the east coast of Scotland where there are no salmon farms) they have substantially decreased since the late 1990s.

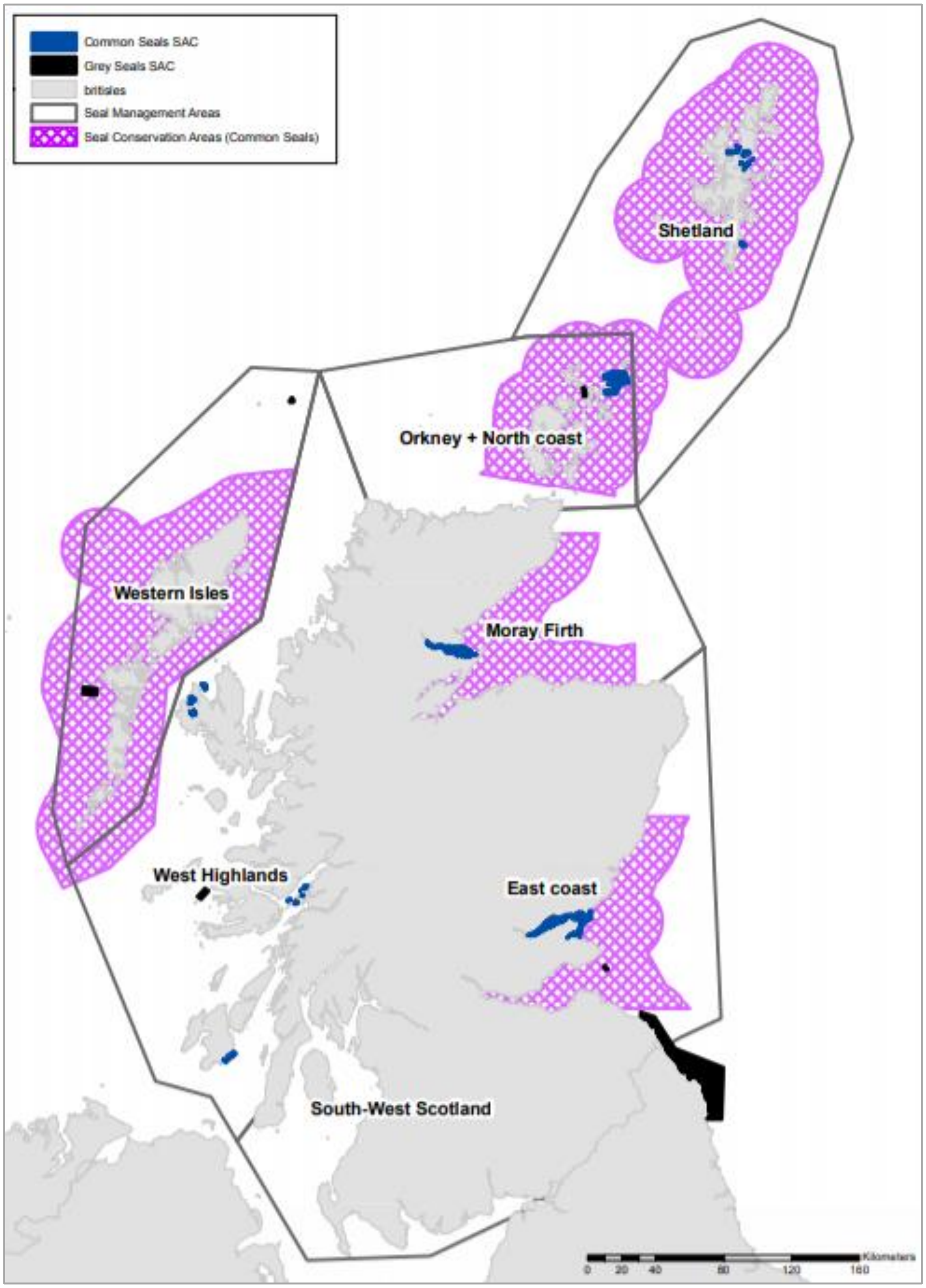


Figure 44: Seal management areas around Scotland. SAC in the legend refers to Special Area of Conservation. Image copied from the Scottish Government.

The Scottish Government's seal licensing system is based on the concept of Potential Biological Removal (PBR – defined as the number of individual seals that can be removed from a population without causing a decline in the population) which is calculated annually by the Sea Mammal Research Unit (SMRU) for each of the seal management areas using the latest seal counts. The population status and the trends noted above are fundamental components of the PBR analysis.

According to figures referenced to the SMRU, the Scottish Government[62] shows the maximum licensed mortality in 2020 for Scotland as a whole (228 grey and 102 common seals) represents 0.21% of the total Grey seal population of 106,250 and 0.38% of the Common seal population of 26,565. The Potential Biological Removal (the number of individual seals that can be removed from a population without causing a decline in the population) was 6,079 grey and 1,147 common seals respectively in 2020. Figure 42 above shows there has been a long-term downward trend in the licensed number of mortalities and the number of seals shot as a percentage of PBR is very low overall. Data on the actual mortalities in 2020 are not yet available (as of July 2021).

On a regional basis, there is greater variability, and Figure 45 shows the 2019 mortality numbers as a percentage of each management area's 2019 PBR. The maximum number of single-species mortalities of 21 Common seals in the Western Isles in 2019 represented 6.6% of that species' regional PBR (plus 1.6% of the PBR of Grey seals). In other areas, the percentage of PBR for Common seals varied from 0% in Shetland and Orkney, to 1.4% in the southwest, and for Grey seals, the percentage of PBR varied from 0.2% in Orkney to 2.2% in Shetland with intermediate values in other areas.

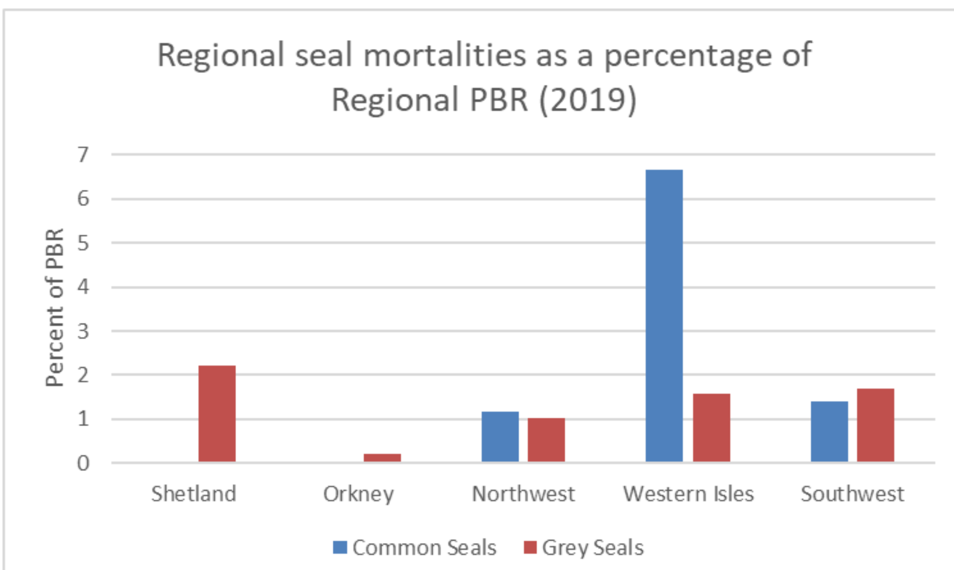


Figure 45: Regional seal mortalities in seal management areas that include salmon farms. Mortality data are from 2019 (the most recent available as of July 2021) with matching 2019 PBR values. All data from the Scottish Government.

[62] https://www2.gov.scot/Topics/marine/Licensing/SealLicensing

A recent (and second) review of the operation of the seal licensing system conducted by the Scottish Government in 2020[63] concluded that the licensing system operates effectively, but the review did not mention potential mortalities from entanglement (other than the lethal control of seals that have managed to enter the net pens). The review did note that entanglements are rare, and post-mortem results of all carcasses recovered showed lethal control.

In June 2020, the Scottish Government approved the Animals and Wildlife (Penalties, Protections and Powers) (Scotland) Bill which amends the Marine Scotland Act (2010), repealing the provision to grant licenses for the shooting of seals on the grounds of protecting fisheries and fish farms[64]. The timing of the ban is linked to the US Marine Mammal Protection Act that comes into effect in January 2022, meaning that Scotland would not be permitted to export to the US after 2022 if it continued to allow seal shooting. As such, and if enforced effectively, it appears seal mortalities will soon be limited to accidental entanglements.

Conclusions and Final Score

The number of seals controlled by lethal means in Scotland (by salmon farming companies and fisheries managers) is low in comparison to the Potential Biological Removal (PBR) for Grey and Common (Harbour) seals (where PBR is defined by the Marine Mammal Research Institute as the number of individual seals that can be removed without causing a decline in the population). Seal mortality management and licensing in Scotland is based on seven management areas, each with an area-specific PBR value. The maximum number of single-species salmon farm mortalities of 21 Common seals in the Western Isles in 2019 represented 6.6% of that species' regional PBR (plus 1.6% of the PBR of Grey seals). In other areas, the percentage of PBR for Common seals varied from 0% in Shetland and Orkney, to 1.4% in the southwest, and for Grey seals, the percentage of PBR varied from 0.2% in Orkney to 2.2% in Shetland with intermediate values in other areas. Recently introduced regulations to align with the US Marine Mammal Act should limit future mortalities of seals to cases of accidental entanglement (i.e., the same as for birds). Entanglement mortalities are not required to be reported in Scotland and while the numbers are not known, they are considered to be uncommon. With good data availability on lethal control from the Scottish Government and robust information on the status of seal populations in each region, it can be seen that deliberate mortality is not routine, and in addition to entanglements, the total mortality does not significantly affect the population size. As such the final score for Criterion 10X – Wildlife Mortalities is a small deduction of -2 out of -10 for the Orkney and Shetland Isles, the Northwest and Southwest. For the Western Isles where the mortalities are higher and reach 6.6% of PBR of common seals, the populations are still not considered to be significantly impacted, but the Final Score for Criterion 10X – Wildlife Mortalities is -4 out of -10.

[63] https://www.gov.scot/publications/second-review-operation-seal-licensing-system-under-marine-scotland-act-2010/

[64] https://www.legislation.gov.uk/asp/2020/14/pdfs/asp_20200014_en.pdf

Criterion 10X: Introduction of Secondary Species

Impact, unit of sustainability and principle

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

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

Criterion 10X Summary

Orkney and Shetland Isles (scores based on salmon movements)

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	87.0	1
Biosecurity score of the source of animal movements (0-10)		8
Biosecurity score of the farm destination of animal movements (0-10)		0
Species-specific score 10X Score		-1.8
Multi-species assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score		**-1.8**
Critical?	No	Green

Northwest, Southwest, and Western Isles (scores based on cleaner fish movements)

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on transwaterbody movements (%)	54.4	4
Biosecurity score of the source of animal movements (0-10)		0
Biosecurity score of the farm destination of animal movements (0-10)		0
Species-specific score 10X Score		-6.0
Multi-species assessment score if applicable (for salmon)		-1.8
C10X Introduction of Secondary Species Final Score		**-6.0**
Critical?	No	Yellow

Brief Summary

Movements of live fish are a characteristic of the Scottish salmon farming industry with a high dependence on international shipments of salmon eggs, movements of smolts from freshwater hatcheries to marine growout farms, and movements of cleaner fish from wild fisheries to those farms that use them. Assessing the risk of introducing a secondary species during those movements is complex given the different source and destination characteristics and the risk of infection and dissemination during transfers.

For Atlantic salmon, with an estimated 87% reliance on international movements of eggs from a relatively biosecure hatchery source, Factors 10Xa and 10Xb combine to result in a minor deduction of -1.8 out of -10. For movements of wild-caught cleaner fish, the lower reliance of the industry on their movements (estimated to be 40% of total Scottish production and 54% of production within the regions that use them) but seemingly absent biosecurity measures, means Factors 10Xa and 10Xb combine to result in a moderate deduction of -6.0 out of -10 for the three western regions that use them (Northwest, Southwest and Western Isles). For the Orkney and Shetland Isles, whose sites are not considered to use wild caught wrasse, the final score reflects the use of egg movements, and is -1.8 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Justification of Rating

Factor 10Xa International or trans-waterbody live animal shipments

Movement of Atlantic salmon

Data from Munro and Wallace (2020) show that in 2019, 89.7% of the 71.2 million salmon eggs hatched in Scotland were imported. This is part of a longer-term trend of increasing use of overseas sources that has stabilized in the last five years (Figure 46). While Norway has been dominant source for at least ten years up to 2018 (supplying 73.6% of the imported eggs in 2018), Iceland became the largest supplier in 2019 with 43.8% of the imports (Norway supplied 39.2%). In addition, 297,000 parr and smolts were imported from EU member states but these represent a small proportion of the 52.9 million smolts put to sea in 2019 (Munro and Wallace, 2020).

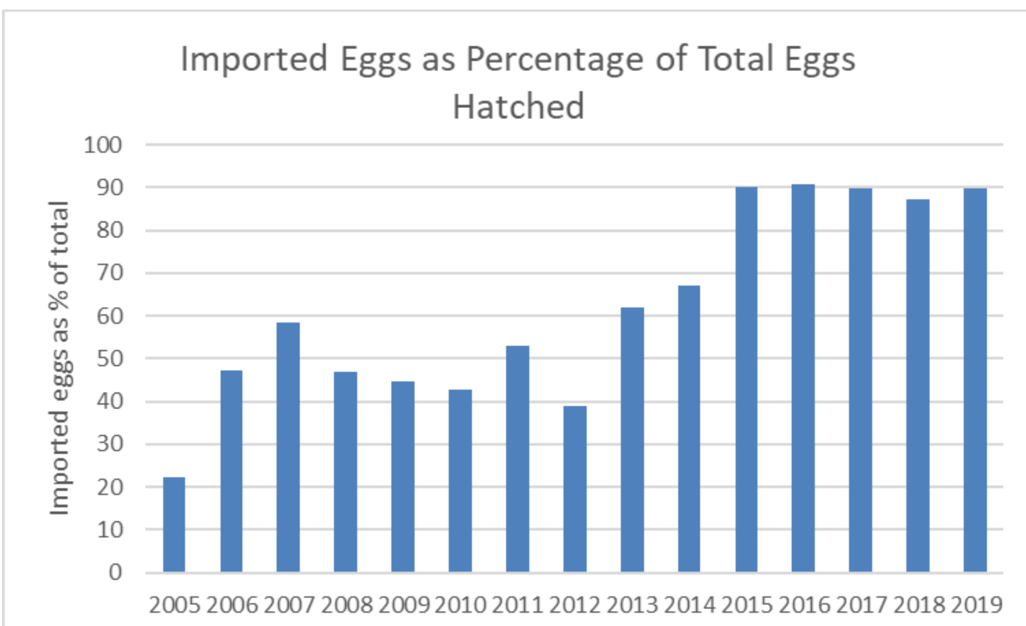


Figure 46: Percentage of salmon eggs coming from imported sources. Data from Munro and Wallace (2019).

The movement of salmon smolts from freshwater hatcheries to coastal growout sites is also a feature of the production cycle, but the data showing Scottish salmon farming is largely dependent on international shipments of eggs drives the score, and with a calculated 89.7% of production based on imported eggs, the score for Factor 10Xa for Atlantic salmon is 1 out of 10.

Movements of cleaner fish

There is currently no official reporting on the location of the source fisheries for wrasse, but the Scottish Government's "Summary of commercial use, fisheries and implications for Management" for northern European wrasse notes that while Scottish salmon farms used locally-caught wrasse initially, the supply could not meet the demand, so fishing of wrasse moved further afield including along the south coast of England where the wrasse fishing season is longer due to warmer sea temperatures (Riley et al., 2017). The same authors consider that fishing in the southwest of England has increased so much that is thought up to one million wrasse (mixed species but thought to be primarily ballan wrasse) are caught for live transfer to Scottish salmon farms annually. In Criterion 8X – Source of Stock, it was calculated that the 40% of total Scottish salmon production that uses wild caught wrasse equates to 54% of production in the three western regions that use them (Northwest, Southwest and the Western Isles), and while some wrasse are still considered to come from fisheries in the same waterbody as the salmon farms, without specific data and on a precautionary basis, all of the wild wrasse are considered to be moved across waterbody boundaries such that there is a risk of unintentionally transferring a "hitchhiker" species during the movements. The score for Factor 10Xa for cleaner fish is 4 out of 10.

Factor 10Xb Biosecurity of source/destination

Biosecurity of Atlantic salmon movements

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. The potential introduction of other organisms (e.g., bacteria or viruses) during ova movements is a concern, but in addition to European Union Fish Health Regulations (to which Scotland complies), the widely practiced ability to disinfect ova is an effective biosecurity measure. Nevertheless, an Icelandic strain of the virus PRV 1a has been identified in escaped farmed fish in British Columbia (BC) and is assumed to be present due to the 2017 Cypress Island escape of farmed salmon just south of BC – fish which were raised from Icelandic broodstock (Miller et al., 2020). This demonstrates that a complete elimination of transfer risk is impossible. For the movements of live parr and smolts, 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, and as a result, some salmon stocks have been lost completely[65].

Movements into Scotland must be accompanied by an appropriate health certificate granting specific assurances with respect to *Gyrodactylus* where appropriate. In general, the source

[65] Scottish Government. http://www.gov.scot/Topics/marine/Fish-Shellfish/aquaculture/diseases/notifiableDisease/g-salaris

hatcheries of both eggs and smolts are typically tank-based, contained systems with high biosecurity measures, and smolts are transferred directly to sea water sites (full salinity sea water is lethal to *Gyrodactylus).* The further requirements for health certificates mean that the score for Factor 10Xb is 8 out of 10.

Biosecurity of cleaner fish movements
For the movement of cleaner fish, there is no evidence of fish health diagnostic or screening procedures or regulations prior to movements, and the source of the fish is open coastal fisheries. The destination of movements (i.e., net pen salmon farms) is also an open system. Therefore, with little or no biosecurity, the source and destination of cleaner fish movements scores 0 out of 10 for Factor 10Xb.

Conclusions and Final Score
Movements of live fish are a characteristic of the Scottish salmon farming industry with a high dependence on international shipments of salmon eggs, movements of smolts from freshwater hatcheries to marine growout farms, and movements of cleaner fish from wild fisheries to those farms that use them. Assessing the risk of introducing a secondary species during those movements is complex given the different source and destination characteristics and the risk of infection and dissemination during transfers.

For Atlantic salmon, with an estimated 87% reliance on international movements of eggs from a relatively biosecure hatchery source, Factors 10Xa and 10Xb combine to result in a minor deduction of -1.8 out of -10. For movements of wild-caught cleaner fish, the lower reliance of the industry on their movements (estimated to be 40% of total Scottish production and 54% of production within the regions that use them) but seemingly absent biosecurity measures, means Factors 10Xa and 10Xb combine to result in a moderate deduction of -6.0 out of -10 for the three western regions that use them (Northwest, Southwest and Western Isles). For the Orkney and Shetland Isles, whose sites are not considered to use wild caught wrasse, the final score reflects the use of egg movements, and is -1.8 out of 10 (see the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations).

Acknowledgements

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

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Appendix 1 - Data points and all scoring calculations

All Regions

Criterion 1: Data	
Data Category	**Data Quality**
Production	10.0
Management	7.5
Effluent	7.5
Habitat	5.0
Chemical Use	7.5
Feed	7.5
Escapes	5.0
Disease	5.0
Source of stock	5.0
Wildlife mortalities	7.5
Escape of secondary species	7.5
C1 Data Final Score (0-10)	**6.818**
	Green

All Regions

Criterion 2: Effluent	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0-10)	**5**
Critical?	NO

All Regions

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0-10)	8
F3.2 – Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	3
3.2b Enforcement of habitat management measures	4
3.2 Habitat management effectiveness	4.800
C3 Habitat Final Score (0-10)	**6.930**
Critical?	No

Northwest, Southwest, Western Isles, Shetland

Criterion 4: Chemical Use	
All-species assessment	**Data and Scores**
Chemical use initial score (0-10)	2

Trend adjustment	0
C4 Chemical Use Final Score (0-10)	**2**
Critical?	No

Orkney

Criterion 4: Chemical Use	
All-species assessment	**Data and Scores**
Chemical use initial score (0-10)	7
Trend adjustment	0
C4 Chemical Use Final Score (0-10)	**7**
Critical?	No

All Regions

Criterion 5: Feed	
5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	11.700
Fishmeal from byproducts, weighted inclusion %	2.800
Byproduct fishmeal inclusion (@ 5%)	0.140
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	8.300
Fish oil from byproducts, weighted inclusion %	2.800
Byproduct fish oil inclusion (@ 5%)	0.140
Fish oil yield value, weighted %	5.000
eFCR	1.370
FFER Fishmeal value	**0.721**
FFER Fish oil value	**2.313**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	5.000
Critical Source fisheries?	No
SFW "Red" Source fisheries?	No
FFER for red-rated fisheries	n/a
Critical (SFW Red and FFER >=1)?	No
Final Factor 5.1 Score	**1.650**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	35.900
Protein INPUT kg/100kg harvest	49.183
Whole body harvested fish protein content	16.900
Net protein gain or loss	-65.639

Species-specific Factor 5.2 score	**3**
Critical (Score = 0)?	No
Critical (FFER>3 and 5.2 score <2)?	No

5.3 Feed Footprint	**Data and Scores**
CCI (kg CO2-eq kg-1 farmed seafood protein)	**7.587**
Contribution (%) from fishmeal from whole fish	14.701
Contribution (%) from fish oil from whole fish	3.518
Contribution (%) from fishmeal from byproducts	6.984
Contribution (%) from fish oil from byproducts	2.356
Contribution (%) from crop ingredients	72.441
Contribution (%) from land animal ingredients	0.000
Contribution (%) from other ingredients	0.000
Factor 5.3 score	**8**
C5 Final Feed Criterion Score	**3.6**
Critical?	**No**

Northwest, Western Isles

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	2
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	2.000
F6.2 Invasiveness score	0
C6 Escape Final Score (0-10)	**0.0**
Critical?	Yes

Southwest

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	0
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	2.000
F6.2 Invasiveness score	0
C6 Escape Final Score (0-10)	**0.0**
Critical?	Yes

Shetland Isles

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	2
Percent of escapees recaptured (%)	0.000

F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	2.000
F6.2 Invasiveness score	4
C6 Escape Final Score (0-10)	**3.0**
Critical?	Yes

Orkney Isles

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	4
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	2.000
F6.2 Invasiveness score	4
C6 Escape Final Score (0-10)	**4.0**
Critical?	Yes

Northwest, Southwest, Western Isles, Shetland

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

Orkney

Criterion 7: Disease	**Data and Scores**
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0-10)	**6**
Critical?	No

Northwest, Southwest, Western Isles

Criterion 8X Source of Stock	**Data and Scores**
Percent of production dependent on wild sources (%)	54.4
Initial Source of Stock score (0-10)	-5
Use of ETP or SFW "Red" fishery sources	No
Lowest score if multiple species farmed (0-10)	n/a
C8X Source of stock Final Score (0-10)	**-5**
Critical?	No

Orkney and Shetland Isles

Criterion 8X Source of Stock	**Data and Scores**
Percent of production dependent on wild sources (%)	0.0
Initial Source of Stock score (0-10)	0.0
Use of ETP or SFW "Red" fishery sources	No

Lowest score if multiple species farmed (0-10)	n/a
C8X Source of stock Final Score (0 to -10)	**0**
Critical?	No

All Regions

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

Northwest, Southwest, Western Isles

Criterion 10X: Introduction of Secondary Species	Data and Scores
Production reliant on transwaterbody movements (%)	50
Factor 10Xa score	5
Biosecurity of the source of movements (0-10)	0
Biosecurity of the farm destination of movements (0-10)	0
Species-specific score 10X score	-6.000
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-6.000**
Critical?	n/a

Orkney and Shetland Isles

Criterion 10X: Introduction of Secondary Species	Data and Scores
Production reliant on transwaterbody movements (%)	87
Factor 10Xa score	1
Biosecurity of the source of movements (0-10)	8
Biosecurity of the farm destination of movements (0-10)	0
Species-specific score 10X score	-1.800
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**-1.800**
Critical?	n/a

Appendix 2 – High-level Pressures on Wild Salmon

High level pressures on wild Atlantic salmon Scottish Government, Marine Scotland May 2019. https://www2.gov.scot/Topics/marine/Salmon-Trout-coarse/fishreform/licence/status/Pressures

Pressure	Components	Key Current Activities as at May 2019
Exploitation	Illegal exploitation	• Annual conservation regulations continue to laid.

	Legal commercial (which includes coastal netting) Rod and line	• Scottish Ministers have agreed to the River Tweed Commission's application to extend the Spring closure period from 1 April to 1 June. • Prohibition of the retention of salmon in coastal waters continues. • Illegal gill netting, very close to the shore, remains a recurrent issue, because the existing regulation allows illegal operators to claim that they are targeting species other than Atlantic salmon and sea trout. Our aspiration is to introduce legislation to prohibit the deployment of gill nets within 0.5 miles of the shore, where the method of deployment and/or depth of water where deployed would result in a high risk of a salmon and/or sea trout bycatch. • A Marine Scotland funded, 3 yr Phd on rod & line catch and release mortality commenced in October 2018.
Predation / Competition	Piscivorous birds Piscivorous fish Seals Other	• On-going tracking of smolts research work with the River Dee will continue during the 2019 smolt run to assess losses in relation to sawbill ducks. We have also procured expert bird stomach analysis services, from within an EMFF fund of £750k, for scientific bird kills, licensed by SNH, across 4 rivers in Scotland from March 2019 to February 2020. Depending on the outputs of this research, we intend to use the majority of the remaining EMFF fund to enable field testing, over the 2020 and 2021 seasons, of new management options to reduce the predation impact, whilst continuing to protect bird populations • The current Seals and Salmon Interaction's (SSI) work the Sea Mammal Research Unit (SMRU) will conclude their analysis of photo-id and behavioural observation data by March 2020. This will address the number of seals using the Dee system and provide estimates of potential salmon removals from the Dee by seals. MS also purchased surface cameras earlier this year, in order for SMRU to trial their ability to record seal movements both upstream and downstream in the River Dee, as a case study. We hope that there will be an opportunity to deploy the cameras and conduct some testing by March 2020. Within the next SSI, from April 2020, we will also explore the possibility of trialling a sensor triggered startle device to keep seals out of rivers. • A joint research project between Marine Scotland, the Ness DSFB and Aberdeen University to identify the impact of dolphin predation on returning adult salmon in the Moray Firth, successfully acoustically tagged 109 adult grilse (MS funding to be finalised, but £20k forecast) in 2018. We aim to publish the results of the research later this year.

		• Marine Scotland policy and science colleagues met Hans Christian Holst on 6 November 2018 to discuss and debate his theory that an explosion in mackerel stocks is having a significant detrimental impact of the marine survival of wild salmon. Conclusions on whether and what further research and/or management action should be taken by end of 2019.
Fish health	Disease Sea lice Other parasites	• The SG's response to the Rural Economy Committee's inquiry, which considered the current state of salmon industry in Scotland, identified opportunities for its future development and explored how the various fish health and environmental challenges it currently faces can be addressed, is now available at: https://www.parliament.scot/parliamentarybusiness/CurrentCommittees/107585.aspx • Post-smolt, west coast sweep netting and a continued work programme at the Shieldaig site to provide data to investigate potential links between sea lice, farms and sea trout.
Genetic introgression	Stocking Escapees	• Marine Scotland initiated a national introgression project in July 2018 that seeks to quantify levels of introgression of genetic material from farm escapees into wild Scottish Atlantic salmon populations. • A review and potential consultation on changes to the current licensing process which permits salmon introductions (stocking) will be completed in advance of 2020 season.
Invasive non-native species	Crayfish Fish – including pink salmon Other	• Pink salmon: experiments by MSS in 2018 using eggs deposited in Scottish rivers indicate that the young fish can survive initially, but will emerge and leave the river in winter rather than spring (which is the normal season in the native range) and are unlikely then to survive. MS intends to issue new pink salmon guidance, via a topic sheet, by mid-June. • The Scottish Invasive Species Initiative is a priority project in the Scottish Biodiversity Strategy's route map to 2020. The route map sets out the major steps needed to improve the state of nature in Scotland and halt the loss of biodiversity by 2020. It highlights the spread of invasive species as one of the key pressures on biodiversity.
Habitat - Water quality	Acidification Point-source pollution Diffuse pollution Other pollution	• DSFBs are working closely with SEPA to address acidification and diffuse pollution. SEPA's work to ensure compliance with 'General Binding Rules' requirements to reduce diffuse pollution from agriculture is being scaled up, with visits to more catchments to be undertaken.

	Changing rainfall patterns Eutrophication Oligotrophication	• MSS has undertaken significant research to improve understanding of the effects of flow regime on Atlantic salmon. • We have an on-going collaboration with Glasgow University, Cromarty Fisheries Trust and the US Forest Service regarding the potential for nutrient enrichment to improve the size and therefore marine survival of smolts. Early research in this area is in peer review, but indicates benefit from adding nutrients to upland streams to counteract reduced numbers of spawning salmon and simulate the presence of adult carcasses. Work to date indicates that this leads to faster growth of juveniles and earlier migration to sea. Further research will seek to confirm this and assess benefits or otherwise over the entire life cycle.
Habitat - Water quantity	Abstraction Flow regulation Upland / agriculture land-use and drainage Changing rainfall patterns Forestry drainage	• SEPA has put in place a programme of work to ensure that fish passage is provided by major operators such as Scottish and Southern Energy and Scottish Water. • Scottish Water is investing, in the current investment programme 2015-21, to improve abstraction regimes in nine water resource zones to ensure that there is sufficient water remaining in the water bodies during periods of low rainfall.
Habitat - Thermal	Loss of shading Over-shading Changing temperature patterns Thermal discharge Impoundment modification Other	• MSS established the Scotland River Temperature Monitoring Network in collaboration with FMS members and University of Birmingham. • Data collected from SRTMN has been used to produce models that can map the regions of rivers that are most vulnerable to further temperature change. These can be used by local managers to plan tree planting and have been made available as online tools through the National Marine Plan Interactive (NMPi) website. • A number of DSFBs and Trusts have undertaken extensive tree planting, particularly in head waters, to provide shade and reduce water temperatures
Habitat - Instream	Sedimentation Loss of sediment transfer Lack of, or excessive, large woody debris Canalisation / dredging/boulder removal	• Reductions in morphological impacts will be achieved through the controlled activity regulations (CAR) and associated “General Binding Rules” and adherence to other guidelines such as the forest and water guidelines. GBRs include requirements for buffer strips to reduce fine sediment and nutrient delivery and encourage the growth of riparian vegetation • DSFBs and Trusts survey their rivers for sedimentation issues leading, in some cases, to gravel being introduced upstream to produce better spawning areas.

Habitat - Riparian	Loss of natural riparian vegetation Conifer afforestation	• The UK Forestry Standard (UKFS) and its supporting Forests and Water Guidelines require that: 'Where new planting or restocking is proposed within the catchments of water bodies at risk of acidification, an assessment of the contribution of forestry to acidification and the recovery process should be carried out; details of the assessment procedure should be agreed with the water regulatory authority'.
Barriers to migration	Upstream passage (consider cumulative impacts) Downstream passage Other	• Scotland's River Basin Management Plans (RBMPs), published in 2015, set objectives for the protection and improvement of our water environment, with the aim of 87% of water bodies achieving a classification of 'good ecological status' by 2027. Fish passage is recognised as one of the three main priorities of RBMP2, including the challenges faced by smolts in their downstream migration, particularly in relation to hydro schemes. • SEPA is leading on work to remove or ease redundant barriers in rivers, utilising circa £5m annual funding from the Scottish Government. For example, work to install fish passes on barriers on the Lugton Water, North Ayrshire was completed in February this year. These passes enable fish species passage at redundant, post-industrial structures on Garden Weir Eglington country park, a popular recreation destination for the local community and Sevenacres weir, east of Kilwinning. The Lugton Water rises in Loch Libo and flows into the River Garnock. The Lugton and its tributaries extend 82 km with approximately 69km of habitat inaccessible to fish species. • In 2018, Marine Scotland published work to prioritise removal based on the expected impact of barriers on salmon production. The work was completed as part of a PhD project with the University of Aberdeen and makes use of the most recent Juvenile Salmon density modelling.
Coastal and Marine	Inshore commercial fisheries Developments – including wind/wave/ energy projects Other	• MS renewables colleagues are working with AST regarding the latter's delivery of a circa £1m smolt acoustic tagging project across 7 rivers in the Moray Firth in 2019 which will contribute to the objectives of the salmon renewables strategy. • Marine Scotland is part of the expert consortium examining factors impacting variation in marine survival of Atlantic salmon over time and in different geographical areas, in a research programme entitled 'SeaSalar'.