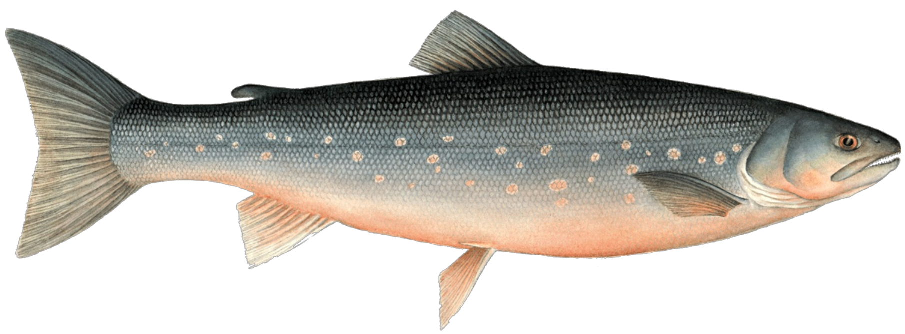
Farmed Arctic Char

Salvelinus alpinus



Iceland

Land-based flow-through systems

Report ID 27825

August 7, 2023

Seafood Watch Standard used in this assessment: Aquaculture Standard v4

Table of Contents

About Seafood Watch

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

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

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

Guiding Principles

Seafood Watch defines sustainable seafood as originating from sources, whether fished[1] or farmed that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

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

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

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

Criterion	Score	Rating	Critical?
C1 Data	8.182	GREEN	n/a
C2 Effluent	8.000	GREEN	No
C3 Habitat	7.600	GREEN	No
C4 Chemicals	8.000	GREEN	No
C5 Feed	5.900	YELLOW	No
C6 Escapes	6.000	YELLOW	No
C7 Disease	8.000	GREEN	No
C8X Source	0	GREEN	No
C9X Wildlife Mortalities	–2.000	GREEN	No
C10X Introduction of Secondary Species	0	GREEN	
Total	49.682		
Final score (0–10)	**7.097**		
OVERALL RATING			
Final Score	**7.097**		
Initial rating	GREEN		
Red criteria	0		
Interim rating	GREEN		**FINAL RATING**
Critical Criteria?	0		**GREEN**

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

Summary
The final numerical score for farmed Arctic charr cultured in Iceland in land-based flow-through systems, sometimes with partial recirculation, is 7.1 out of 10, which is in the Green range, with two Yellow criteria (Feed and Escapes); the final recommendation is Green, or “Best Choice.”

Executive Summary

Iceland, which accounts for approximately three-quarters of global Arctic charr production, is the world's predominant producer of this species. This report focuses on the environmental impacts of Arctic charr production in Iceland. All of the production presently occurs in land-based systems, most of which are flow-through.

The majority of Iceland's aquaculture production comprises salmonids: Arctic charr, Atlantic salmon, and rainbow trout. Since Iceland started to farm Arctic charr commercially in the 1980s, the sector has experienced steady growth, and production volumes now average around 6,000 mt annually. The majority of this production comes from two principal producers, who account for around 80% of Iceland's total production of Arctic charr. Both producers are located on the Reykjanes peninsula in southwest Iceland, and the three farms they operate are all certified by the Aquaculture Stewardship Council (ASC).

In comparison to Arctic charr production, the growth of Iceland's Atlantic salmon sector has been much less stable: within the combined national production volumes of both species in 2021, 90% was Atlantic salmon, but Arctic charr production predominated between 2007 and 2014. In recent years, many of Iceland's smaller Arctic charr facilities have been purchased by salmon farmers and converted to smolt production.

Most of the Arctic charr farmed in Iceland is exported, primarily to North America and Europe; the export volume of the two main producers typically makes up around 90–95% of their total production. Other countries that farm this species mainly sell their produce into domestic markets; thus, most Arctic charr in global markets has been farmed in Iceland.

This Seafood Watch assessment involves a number of different criteria covering impacts associated with effluent, habitats, wildlife and predator interactions, chemical use, feed production, escapes, introduction of nonnative organisms (other than the farmed species), disease, the source stock, and general data availability. The following is a summary of the determinations for each of these criteria, which are explored in more detail in the body of this report.

The volume of peer-reviewed literature pertaining to the Icelandic Arctic charr sector—and more specifically to its environmental impacts—is somewhat limited; however, this is in keeping with the relatively small size of the sector. Those peer-reviewed data that were identified were found to be of high quality, and provided valuable insight into the various production criteria considered. The aquaculture sector in Iceland has been on a growth trajectory in recent years and, to keep abreast of this expansion, the governance framework and mechanisms that oversee it have been evolving accordingly. The laws and regulations that apply to the sector are readily available online, and the agencies responsible for their implementation and enforcement are easy to identify and contact. Under Icelandic law, the principal agencies involved in governance of the aquaculture sector provide a wide array of farm-level data on their respective websites. These online data, together with personal communications with agency representatives, provided a clear overview of the sector and greatly helped to inform the criteria considered.

Other experts and farm personnel were also easy to identify and communicate with, which helped elucidate the environmental impacts of the sector as they relate to the Seafood Watch Aquaculture Standard criteria. Industry publications were also a valuable data resource, particularly in terms of providing a clear overview of the developmental timeline of the Arctic charr sector in Iceland. Of the 11 different data categories considered in this data criterion, 4 scored 10 out of 10, 6 scored 7.5 out of 10, and 1 scored 5 out of 10. Together, these result in an overall score of 8.182 out of 10 for Criterion 1—Data.

Land-based Arctic charr farms in Iceland typically access water for their operations via onsite boreholes or wells. With an abundance of water, high flow rates can be maintained in ongrowing units, which are generally operated as flow-through systems—although one major producer operates a partial reuse aquaculture system (PRAS). High water usage means that effluents are well diluted, and most farms discharge the untreated effluent via pipe directly into a dynamic ocean environment. The receiving waterbody, the Atlantic Ocean, is a complex waterbody as a result of the interactions of many currents and the surrounding ocean bathymetry. These waterbodies have demonstrated the ability to quickly dilute, assimilate, and transport effluents because of the swift currents and the relatively deep nearshore environments. Furthermore, at a cumulative level, water quality monitoring of Iceland's coastline has found zero indication or concern for eutrophication.

The government body responsible for regulatory oversight and monitoring of fish farm effluents is the Environmental Agency, Umhverfis Stofnun (UST), from whom each farm must obtain a license to operate. Such licenses stipulate how effluents must be handled; this varies somewhat between farms, depending on their specific environmental characteristics. The amount of phosphorus a farm is permitted to discharge is clearly specified in each license; although the threshold on some older licenses is higher, the threshold that is stipulated on all new licenses is in the range of 7–10 kg P-total/mt of production per year. UST requires all fish farms to submit an annual summary that includes feed usage and farm discharge water quality data—the latter must be compiled from samples analyzed by an approved independent entity. To ensure that all farms remain within regulatory compliance, UST conducts regular audits. A review of the farm-level effluent monitoring data that is available on UST's website, plus related inspection reports and communications with UST personnel, show no evidence of environmental impacts arising as a result of effluent emissions from Arctic charr farms. Furthermore, it is evident that Iceland's general aquaculture governance framework is attentive to the need for area-based management in situations where effluent emissions are greater in quantity and the receiving body in question is more sheltered, as evidenced by the implementation of a cumulative management strategy in the fjords where Atlantic salmon is farmed in ocean cages.

In conclusion, while the Arctic charr sector's production volumes are increasing, the volumes currently produced are still relatively small, and the effluents produced are well diluted and readily assimilated once discharged into a dynamic ocean environment. A review of government monitoring data coupled with personal communications with UST inspectors and personnel show no evidence that effluent discharges from Arctic charr farms in Iceland cause or contribute to cumulative impacts at the waterbody or regional scale, and any impacts within the vicinity of farms are temporary. The final score for Criterion 2—Effluent is 8 out of 10.

The majority of Arctic charr production takes place in Reykjanes, a lava-covered region in southwest Iceland. Although production volumes of Arctic charr have increased somewhat in recent years, this is mainly due to intensification occurring on existing farms, rather than the development of new sites. According to the data available, the habitats where these farms are sited are maintaining ecosystem functionality, with minimal impacts arising from farm activities.

The Icelandic aquaculture sector, particularly that of Atlantic salmon, has grown significantly in recent years; this rapid growth has prompted a review of aquaculture regulations. Such legislative review focuses a great deal on ocean-based culture of salmon but is also applicable to land-based farming, a sector in which Arctic charr is still the predominant species for full-cycle production. The three principal laws governing aquaculture in Iceland are the Environmental Impact Assessment of Projects and Plans Act, the Act on Aquaculture, and the Law on Hygiene and Pollution Prevention, which are implemented primarily by three discrete agencies: the Icelandic National Planning Agency, the Icelandic Food and Veterinary Authority (MAST), and the Environmental Agency (UST), respectively. These principal laws have been revised and updated in recent times and/or supported by additional new regulations, with the intent of keeping the regulatory framework abreast of sector growth. These laws also provide each respective agency with the necessary enforcement tools to ensure that farm operators adhere to all regulations in a timely and appropriate manner. Insights from industry stakeholders indicate that land-based farming, particularly of Atlantic salmon, is likely to continue to increase, so the potential for cumulative habitat impacts at the regional scale will become increasingly important to address for the land-based sector moving forward. But at present, the content and enforcement of habitat management measures in Iceland is considered to be moderate and effective, particularly regarding the current, relatively small scale of the land-based Arctic charr sector.

In conclusion, and according to the data available, although the presence and operation of Arctic charr farms inevitably affect the habitats in which they operate to some degree, such impacts would appear to be minimal, and habitat functionality is being maintained. Thus, the score for Factor 3.1—Habitat Conversion and Function is 9 out of 10. The content of habitat management measures for land-based fish farms in Iceland is considered moderate, particularly regarding the current, relatively small size of the land-based aquaculture sector, from which the main species harvested is still Arctic charr. The score assessed for Factor 3.2a is a moderate 3 out of 5. In consideration of the efficacy of the enforcement of habitat management measures, the score for Factor 3.2b is 4 out of 5, which ranks this Factor as "effective." Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 7.6 out of 10.

The legislative framework governing chemical usage in Iceland is closely aligned with those adhered to by other Nordic nations and the European Union (EU). For the aquaculture sector, both the Icelandic Environmental Agency (UST) and the Icelandic Food and Veterinary Authority (MAST) are designated as the competent authority for different aspects of this governance framework. Farms are required to report their use of chemical products to both agencies. Government officials contacted at both UST and MAST confirm that chemical usage is quite low in the Arctic charr sector, which is echoed in communications with those companies responsible for the majority of production. The most comprehensive, public-facing data source concerning the use of medicines in Icelandic aquaculture is the Annual Veterinary Report of Fish Diseases, which is published by MAST. Although the 2020 report stated that no antibiotics had been used in the production of salmonids for a continuous period of 9 years, this track record was interrupted in 2021 when one Arctic charr facility with some unvaccinated fish onsite required an antibiotic intervention of oxytetracycline to treat an outbreak of atypical furunculosis.

In addition to monitoring antibiotics, annual reports also document the aggregated quantities of other medicines that have been used to support fish health across the aquaculture sector. A breakdown of the specific quantities of chemicals used by the Arctic charr sector was obtained directly from MAST; these data show that chemical usage during the ongrowing phase is minimal and is limited to anesthetics and formaldehyde: the former is used to facilitate fish handling and the latter to treat external parasites. There is a robust legislative framework in place to govern the appropriate dispensation and use of veterinary medicines in Iceland, and all medicinal drugs used on fish farms must be prescribed by a licensed veterinarian. Furthermore, MAST has access to a database of veterinary prescriptions, which is maintained by the Directorate of Public Health. These officially collected data are evidently used in the preparation of MAST's public-facing annual reports. In terms of chemical usage, the most recent report highlights the exceptional usage of oxytetracycline on one Arctic charr farm as the incident of most concern for the sector during the last decade. The final numerical score for Criterion 4—Chemical Use is 8 out of 10, which reflects the low environmental concern presented by the Arctic charr sector's use of chemicals.

Data used to assess the feed criterion are based on information received directly from Iceland's principal Arctic charr producers, as well as related materials from feed manufacturers. These data have been aggregated and weighted, to provide an overview of the average ongrowing diet used to culture Arctic charr in Iceland. The average inclusion levels and sources of fishmeal and fish oil used in typical ongrowing diets were found to be 32.7% (27.96% from by-products) and 20.38% (17.36% from by-products), respectively. The FFER for fishmeal and fish oil are 0.33 and 0.93, respectively, with the higher of the two values used to assess Factor 5.1a—Feed Fish Efficiency Ratio; as a result, it is estimated that 0.93 mt of wild fish are required to produce 1.0 mt of farmed Arctic charr. A review of data pertaining to the status of the fisheries from which these marine inputs are sourced results in a score of 6 out of 10 for Factor 5.1b—Sustainability of the Source of Wild Fish. These two scores produce a final Factor 5.1 score of 7 out of 10. With an estimated weighted average feed protein content of 38.5%, there is a substantial net protein loss of 58.66%, which leads to a Factor 5.2 score of 4 out of 10. The Feed Footprint (Factor 5.3), which is an assessment of the global warming potential of production as it relates to feed use, is 14.96 kg CO_2 eq per kg of farmed Arctic charr protein, which equates to a low to moderate impact score of 6 out of 10 for Factor 5.3.

The final score for this criterion is a combination of the three factors with a double weighting for the Wild Fish Use factor. Factor 5.1 (7 out of 10), Factor 5.2 (4 out of 10), and Factor 5.3 (6 out of 10) combine to provide an overall score of 5.9 out of 10 for Criterion 5—Feed.

Although no escape events have been documented in the Icelandic Arctic charr sector, it is evident that there is still some potential escape risk inherent during production. The land-based systems employed by the Arctic charr sector predominantly utilize brackish water obtained via boreholes, and it is later discharged to the ocean. Escape risk is mitigated by the installation of multiple screens and secondary capture devices, which places such systems into a low to moderate risk category according to the Seafood Watch Standard for Aquaculture. Thus, the score for Factor 6.1 is 6 out of 10. The score for Factor 6.2—Competitive and Genetic Interactions is driven by Iceland's centralized breeding program, which has differentiated the genetics of farmed Arctic charr those of wild native Arctic charr, and scores 6 out of 10. Factors 6.1 and 6.2 combine to give a final numerical score of 6 out of 10 for Criterion 6—Escapes.

Both communications with experts and a review of literature on the sector indicate that Arctic charr is typically a quite robust species. The occurrence of on-farm diseases is low, and average mortality rates are in the range of 5–8% for the majority of production, which takes place in brackish water; a small balance of production is raised for the full cycle in freshwater, for which the mortality rate is 1–3%. The principal disease encountered by farmers is atypical furunculosis, a bacterial infection for which vaccine control across the sector is generally good, although the commercially available vaccines currently in use have been primarily developed for Atlantic salmon, not for Arctic charr. A gradual and incremental decline in the efficacy of these vaccines has been observed, which has prompted the development of a bespoke vaccine for the specific strain of furunculosis that affects Icelandic stocks. Bacterial kidney disease can also present a challenge to farmers; the bacterium that causes this condition is endemic in Iceland, as is the bacterium that causes furunculosis. These pathogens can enter facilities from the environment via the water intake if biosecurity measures are insufficient. A range of other diseases can also affect the sector, and a review of these, their severity, and the number of instances of each is detailed in each year's Annual Veterinary Report of Fish Diseases. These reports are compiled and published by the Icelandic Food and Veterinary Authority (MAST), which is Iceland's competent authority in the fields of food safety and animal health and welfare. Although disease transmission into natural waterbodies may occur via culture water being discharged from farms, the monitoring data concerning wild species do not indicate that pathogens or parasite numbers on wild species are amplified above background levels by such aquaculture activities. As a result, the level of concern for this criterion is low, and the final numerical score for Criterion 7—Disease is 8 out of 10.

Hólar University runs Iceland's only Arctic charr breeding program, which supplies 90–95% of the eggs stocked by the sector; overseas egg sales are not permitted. When the breeding program commenced in 1992, a variety of Icelandic Arctic charr strains were interbred to optimize traits of fast growth and delayed maturation in cultured fish. The breeding program is now working with fish that have been domesticated for approximately 10 generations; thus, there is no reliance on wild populations for broodstock. Although all Arctic charr farms in Iceland utilize eggs from the Hólar breeding program, two of these farms also maintain broodstock at their own facilities. The broodstock kept at one of these farms also belong to the Hólar strain, and this serves as a back-up facility for the breeding program. The other farm maintains broodstock from a different local strain of Arctic charr, called the Litlaá strain; these were initially introduced to the farm about 15 years ago, and no further wild collection has occurred since—it is noted that eggs from these fish are only used on-site. Because 100% of the Icelandic Arctic charr sector maintains its production independent of wild stocks, there is no deduction applicable, and the score for Criterion 8X—Source of Stock is 0 out of –10.

Wildlife interactions in the Icelandic Arctic charr sector appear to be minimal, and any mortalities that do occur are limited to exceptional cases that do not significantly affect wild populations in any way. The final score for Criterion 9X—Wildlife Mortalities is –2 out of –10.

The Icelandic Arctic charr sector does not require any international or trans-waterbody live animal shipments. Thus, no deduction is applicable, and the score for Criterion 10X—Introduction of Secondary Species is 0 out of –10.

Overall, the final numerical score for farmed Arctic charr cultured in Iceland in land-based, flow-through systems, sometimes with partial recirculation, is 7.1 out of 10, which is in the Green range, with two Yellow criteria (Feed and Escapes); the final recommendation is Green or Best Choice.

Introduction

Scope of the analysis and ensuing recommendation

Species
Arctic charr (*Salvelinus alpinus*)

Geographic Coverage
Iceland

Production Method(s)
Land-based flow-through, sometimes with partial recirculation

Species Overview

Arctic charr, which is found farther north than any other freshwater fish, is a circumpolar species belonging to the Salmonidae family (DFO 2014, Klemetsen 2010). Native to the Arctic and sub-Arctic zones, its distribution incorporates Canada, Finland, Greenland, Iceland, Norway, the Russian Federation, Saint Pierre and Miquelon, Svalbard and Jan Mayen, Sweden, and the United States, plus some landlocked populations in Europe, including the United Kingdom.

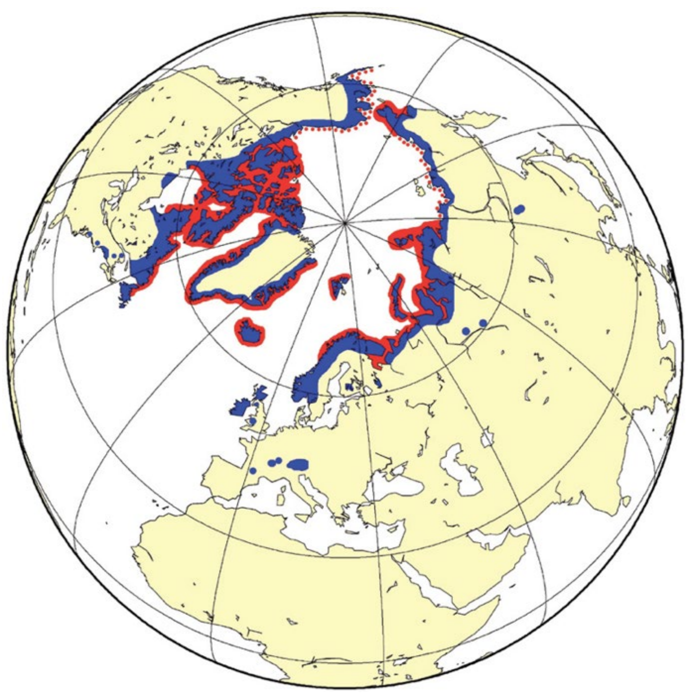


Figure 1: The wide, circumpolar distribution of Arctic charr, the world's northernmost freshwater and diadromous fish (red zones indicate anadromy). From (Klemetsen 2010).

Although spawning always takes place in freshwater, Arctic charr is differentiated into lacustrine (lake-dwelling) freshwater residents or anadromous, sea-run (ocean-going) individuals, which spend their summer months at sea before migrating back inland to overwinter in lakes (Flack 2019)(Weileder 2019)(DFO 2014). Lacustrine residents, which complete their lifecycle in freshwater, grow much more slowly than do anadromous stocks. The longest documented migration of anadromous Arctic charr is 940 km, and individuals do not necessarily always return to the same freshwater body when they migrate from the sea. Anadromous stocks, which are only found north of around 65 °N (Flack 2019)(Freyhof & Kottelat 2008), have migration routes in all three oceans in the Holarctic region (the Arctic, Atlantic, and Pacific Oceans) (Klemetsen 2013). South of this latitude, nonmigratory populations exist exclusively within the confines of post-glacial, landlocked lakes and in river drainage systems (Jeuthe 2015)(Fraser 2013)(AD 2012).

Figure 2: Arctic charr (*Salvelinus alpinus*). Source: U.S. Fish and Wildlife Service, Jim Gaither.

Although salmonids in general are renowned for their phenotypic plasticity and polymorphism, this is particularly true of the *Salvelinus* genus, to which Arctic charr belongs (Árnason et al. 2022)(Gudbrandsson et al. 2019)(Sæther et al. 2015)(Jónsson 2002). It has been estimated that there are over 50,000 extant populations in the world, with most diversification evident in Scandinavia (Imsland et al. 2019). Around 9,000 to 12,000 years ago, during the Northern Hemisphere's last glacial retreat, Arctic charr migrated into the myriad of emergent rivers, streams, and lakes that appeared as the ice sheets melted. The unique ecological variables inherent in these evolving waterbodies gave rise to many distinct, independent, isolated populations of Arctic charr. Multiple morphs can be found across these northern landscapes, often even within the same waterbody, such as in Iceland's Lake Þingvallavatn, where four morphs have been identified (Gudbrandsson et al. 2019). The extent of polymorphism exhibited by Arctic charr is such that it has been referred to in the literature as "the most variable vertebrate on earth after Man" (Klemetsen 2013). The differences identified between some populations have been so significant that biologists initially thought to describe them as distinct species, although they are generally considered together as one species in modern classification (Guardian 2017)(Fraser 2013).

Although the maximum recorded age of this species is 40 years, the average life expectancy is around 20 years. The age at which sexual maturity is attained varies widely between stocks: from 2 to 15 years, depending upon their environmental niche. Lacustrine residents notably spawn earlier than do anadromous individuals (Flack 2019)(Freyhof & Kottelat 2008). Marine fish, krill, and copepods compose the primary diet of anadromous individuals; feeding is reportedly reduced or absent when they re-enter the freshwater environment. The diet of lacustrine Arctic charr comprises small fish, insects, mollusks, plankton, and benthic organisms, with different morphs exploiting discrete feed niches (Flack 2019)(DFO 2014)(Freyhof & Kottelat 2008). The largest Arctic charr on record was 15.9 kg; documented in 1935, it was caught off the northwestern Russian Arctic archipelago of Novaja Zemlya. There are also stocks of dwarf Arctic charr; the smallest recorded were collected in Fjellfrøsvatn, a subarctic lake in northern Norway; there, mature adults of both sexes weigh between 4 and 17 g. Among Arctic charr populations, there is also a high degree of variation in form and coloration; the latter also changes seasonally (Weileder 2019)(Klemetsen 2013).

Lake acidification, caused by anthropogenic pollutants, has long been noted as a significant threat to Arctic charr populations in northern lakes and lochs across their range (Maitland et al. 1987). Data from the International Union for the Conservation of Nature (IUCN) indicate that Arctic charr is a species of "Least Concern"; however, this status was last assessed in 2008, and the entry notes that an update is needed (Freyhof & Kottelat 2008).

The Development of Arctic Charr Aquaculture and Status of the Sector

The first time that cultivation of Arctic charr was officially recorded was in 1900, when Norway initiated restocking efforts (Sæther et al. 2013). Shortly thereafter, in 1910, Iceland also started to culture this species, although it was not until the 1980s that significant commercial production commenced (Troell et al*.* 2017)(Sæther et al. 2015)(Heimisson 2016)(Eurofish 2020); by the early 1990s, there were around 40 Arctic charr farms operating in Iceland (Solar 2009). Statistics from the Food and Agriculture Organization of the United Nations (FAO) show Sweden to be the first country to report farmed production in 1983, followed in 1987 by Iceland, which has remained the world's foremost producer since 1991. France, Austria, Ireland, and the United Kingdom all subsequently reported some production volumes in the 1990s, as did the United States in 2000. Although Canadian researchers started working with Arctic charr in the late 1970s,[2] it was not until 2008 that Canada reported any commercial production of this species to FAO. Italy and Norway also reported their first volumes of farmed Arctic charr to FAO

[2] https://northernaquafarms.blogspot.com/p/arctic-char-farming.html#.Ya9tXy-l1ap

in 2008. The only other countries to ever report any farmed production of this species were Denmark and Latvia, both of which reported small amounts for a few years only (FAO 2022a).

Arctic charr is noted in the literature as being a good aquaculture candidate for a number of reasons, including its high fillet yield of around 50–60% (ANA 2015)(UWSP 2011), a feed conversion ratio close to 1:1, and good growth rates (1 kg < 17 months) in cold temperatures and at high altitudes (Smárason et al. 2017)(Olk et al. 2015)(Sæther et al. 2013)(Brännäs et al. 2011)(UWSP 2011)(Summerfelt et al. 2004). But early maturation, which males are more prone to than females, has been a major challenge to Arctic charr farmers because both flesh quality and yield decline if fish reach sexual maturity before harvest. This is due to the heightened energy requirements of gametogenesis (ANA 2020)(Brännäs et al. 2011). Researchers also note that the sector has been held back by poor reproductive success, resulting in unreliable egg quality and juvenile production (Olk et al. 2015).

The first selective breeding program for this species commenced in Sweden in the early 1980s (Brännäs et al. 2011)(Nilsson et al. 2010). Similarly, in 1992, a government-sponsored genetic selection program was initiated at Iceland's Hólar University.[3] This program, which primarily sought to improve growth rates and delay sexual maturation, reportedly led to a doubling of Icelandic Arctic charr production within 5 years of the project's inception (Heimisson 2016)(Solar 2009). In recent years, Norway has also introduced a breeding program (pers. comm., Bjørn-Steinar Sæther, UiT The Arctic University of Norway February 2020).

Figure 3: Farmed Arctic charr (*Salvelinus alpinus*) in an Icelandic land-based flow-through system. Source: Samherji (IFS 2019).

[3] http://www.holaraquatic.is/breeding-program.html

Although the growth rate of Arctic charr is comparable to that of Atlantic salmon, harvesting typically takes place earlier, to avoid the flesh quality issues brought about by early maturation. Harvest-sized fish average around 1.5 kg, which yields a smaller fillet than is typical in the Atlantic salmon sector (Towers 2016). It should be noted that Arctic charr generally commands a considerably higher selling price than does Atlantic salmon (MFA 2013). In recent years, a great deal of progress has been made in overcoming the problem of early maturation (pers. comm., Bjarni K. Kristjánsson December 2021). So, if this constraint were removed, the average harvest size for Arctic charr may increase in the future. Even so, despite its evident desirability in the marketplace as well as the considerable attention that it has received from researchers and commercial producers, global production volumes of Arctic charr have never been high, equating to just 0.3% of Atlantic salmon production in 2020 (FAO 2022a).

Industry statistics and the Scale of the Arctic Charr sector

According to FAO data, global production of farmed Arctic charr amounted to 7,629 mt in 2020 (FAO 2022a). Iceland's dominance in the sector is evident in Figure 4: in 2020, Iceland accounted for 72% of total production, followed by Sweden (14%), Norway (7%), Austria (4%), Canada (3%), and Italy (1%), with the balance of production (< 1%) reported by Denmark and the United Kingdom.

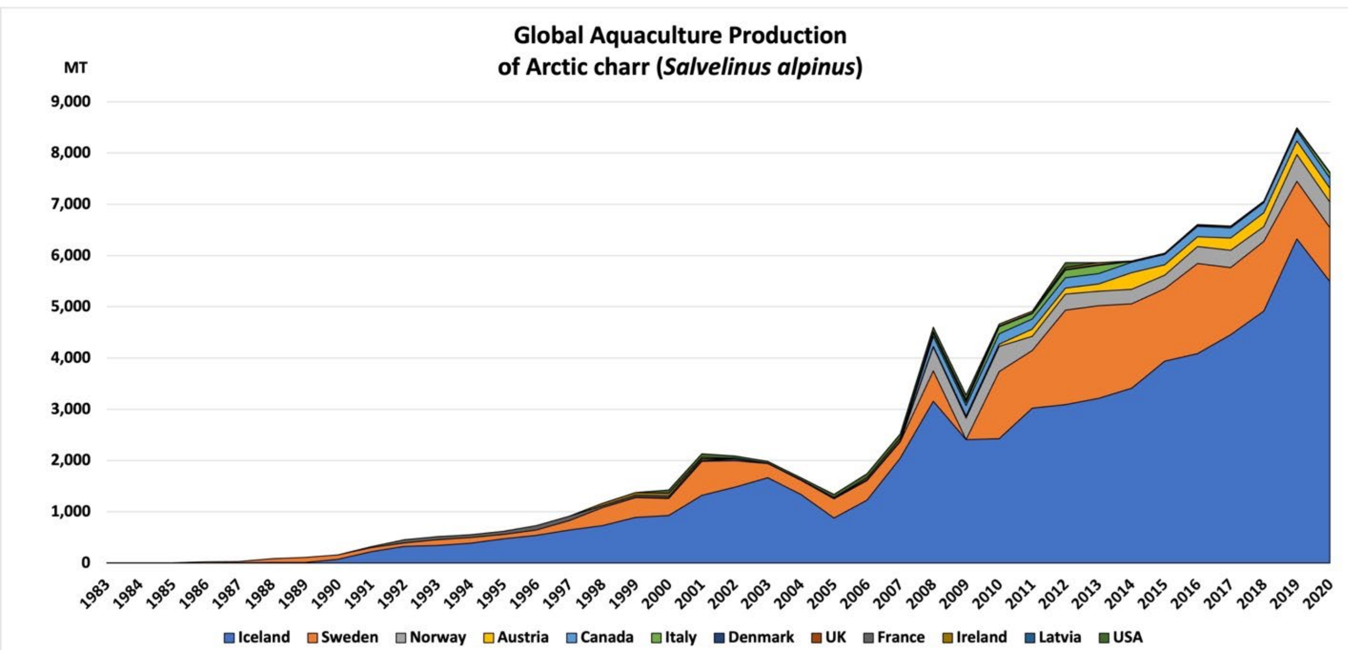


Figure 4: Global production volumes of cultured Arctic charr, 1983–2020. From (FAO 2022a).

Although these FAO data provide a good overview of global production, various literature sources on farmed Arctic charr concur that accurate statistics on this sector are challenging to determine (Yossa 2017)(Sæther et al. 2013), particularly for those countries that have quite low production volumes. The historic growth trajectory of Arctic charr production in Iceland is shown in Figure 5.

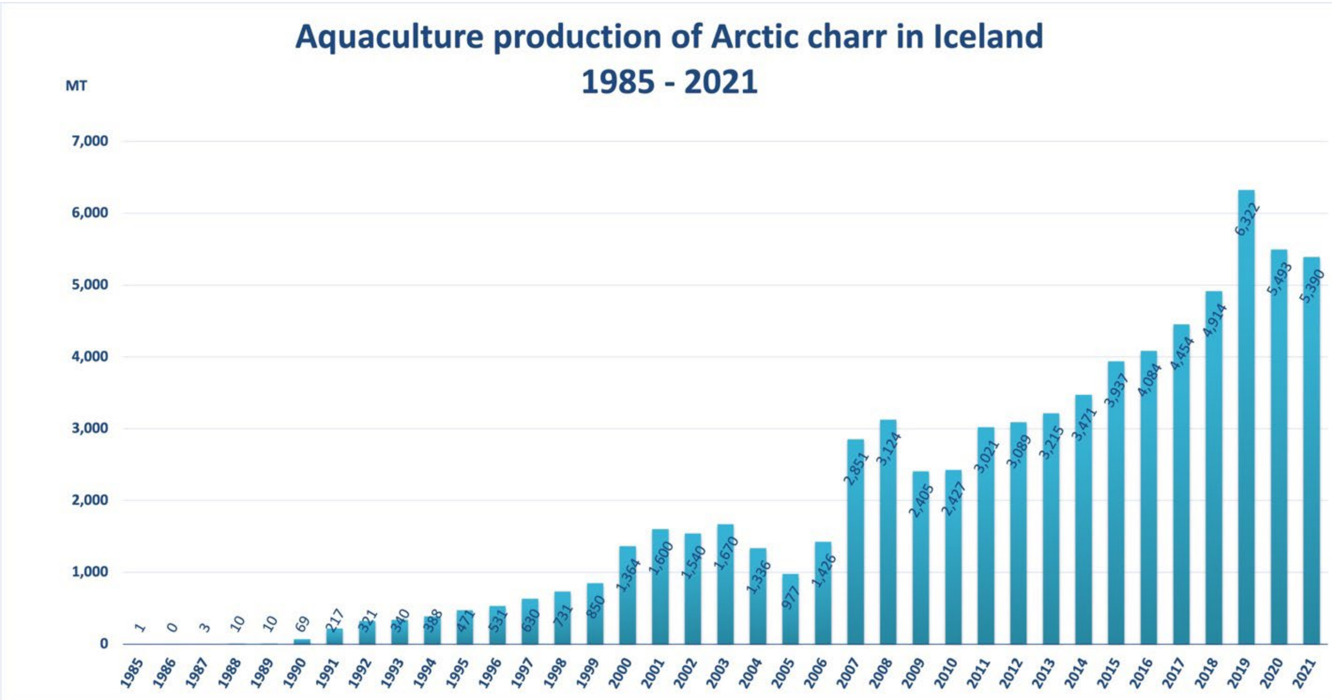


Figure 5: The growth of Arctic charr production in Iceland from 1985 to 2021. Data source: Icelandic Food and Veterinary Authority, Matvælastofnun (MAST 2021a).

While nearly three-quarters of the world's farmed Arctic charr comes from Iceland, almost two-thirds of this Icelandic production comes from just one producer: Samherji fiskeldi.[4] Samherji has two farms that focus on Arctic charr production, located in the Reykjanes peninsula in the southwest of Iceland. Matorka,[5] the country's second-largest Arctic charr producer, is also located in this region. All three of these farms are certified by the Aquaculture Stewardship Council (ASC),[6] and their combined production makes up ≈80% of Iceland's total Arctic charr production. Both Samherji and Matorka are fully integrated operations, so these companies control all aspects of their production from hatchery through processing. The third- and fourth-largest producers, which are significantly smaller, are the only other farms in Iceland currently harvesting >100 mt Arctic charr per year: Fiskeldið Haukamýri,[7] in the northeast, and Tungusilungur,[8] in Talknafjordur in the Westfjords. Although these companies are Iceland's principal Arctic charr producers, there are also a number of quite small producers, which are mainly situated in the south of Iceland close to Kirkjubaejarklaustur.[9] [10] Figure 6 provides an

[4] https://www.samherji.is/en/fishfarming
[5] https://matorka.is
[6] https://www.asc-aqua.org/find-a-farm/
[7] https://haukamyri.is
[8] https://tungusilungur.is
[9] https://www.klausturbleikja.is/en/klaustur-char
[10] https://lindarfiskur.com

overview of the number and location of fish farms in Iceland at the end of 2021, as well as the respective species that are permitted to be grown at each site.

At present, the majority of Arctic charr production in Iceland occurs in coastal, land-based facilities (MAST 2022). Until quite recently, there was also a significant quantity produced by one farm operating a net-pen system in a semi-salted lake in the northeast (beside Kópasker); however, this facility has now been taken over by an Atlantic salmon producer. Evidently, because interest and investment in Atlantic salmon farming has been renewed in Iceland, this sector has been acquiring and repurposing numerous aquaculture facilities, some of which had been used to produce Arctic charr. One trade publication recently noted that, while Icelandic Atlantic salmon production increased by over 35% in 2021, Arctic charr production stagnated somewhat (IM 2022).

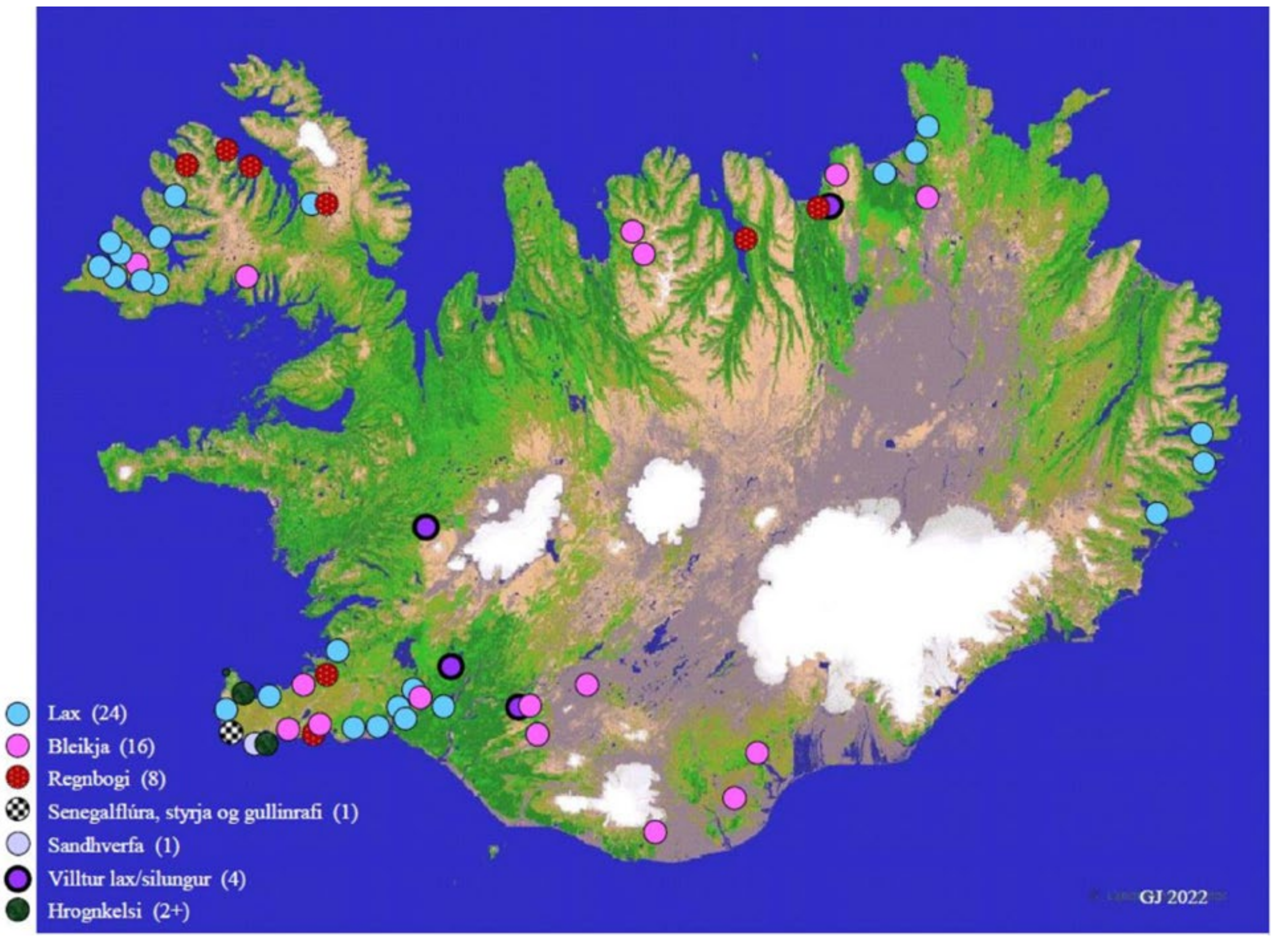


Figure 6: Overview of the number and location of fish farms in Iceland at the end of 2021. From (MAST 2021a). Legend translation: **Lax:** Atlantic salmon; **Bleikja:** Arctic charr; **Regnbogi:** rainbow trout; **Þorsksur:** Atlantic cod; **Senegalflúra:** Senegalese sole; **Styrja:** sturgeon; **Gullinrafi:** greater amberjack; **Sandhverfa:** turbot; **Villtur lax/silungur:** wild salmon/trout; **Hrognkelsi:** lumpfish.

The Icelandic Food and Veterinary Authority, Matvælastofnun (MAST), maintains a publicly available database of licensed farms,[11] which includes details of the species covered by each license, the applicable life stage, and the tonnage permitted on each site at any one time. At the time of writing this report, Iceland has a total of 48 licensed land-based farms, the majority of which are now focused on Atlantic salmon smolt production. Over 20 stations are permitted to grow Arctic charr, but fewer than 10 are actively producing this species at present (pers. comm., Karl Steinar Óskarsson January 2022), even though 16 Arctic charr farms are identified in the map in Figure 6. The unique geology and climate in Iceland mean that fresh and saline water is not a limiting factor, so there has been no incentive for farmers to invest in full recirculating aquaculture systems (RAS);[12] all these land-based facilities are flow-through systems, sometimes with a degree of partial water reuse.

Although Sweden is the world's second-largest producer of Arctic charr, accounting for 14% of the global total in 2020, it is notable that production there has been in decline over the last decade (FAO 2022a). The country's main producer is Umlax,[13] which was established in 1986. Most Arctic charr farms in Sweden use net-pen systems, which are typically situated in oligotrophic, nutritionally depleted water reservoirs that have arisen as a result of hydroelectric developments (Bergheim 2015)(Eriksson et al*.* 2010). Individual producers in Norway, which accounted for 7% of global production in 2020, and Austria (4%) are challenging to identify, possibly because of the low-volume output of the individual farms involved, although it is evident that some Norwegian Arctic charr production takes place in RAS[14] [15] (Skybakmoen et al. 2009) as well as in lakes (Helgadóttir et al. 2021).

In North America, it is evident that a number of commercial farms that were previously in operation have now ceased production, such as Aqua Terra Farms in Wisconsin and Urban Organics, which was based in Minnesota. For a number of years, the University of Wisconsin has run an Arctic charr research program at its Northern Aquaculture Demonstration Facility[16] (UWSP 2011); however, this project has recently been suspended. Although some Arctic charr production is still ongoing in Wisconsin, output is limited (pers. comm., Gregory Fischer, University of Wisconsin November 2021). Of note, 2012 is the last year that any U.S. Arctic charr production is evident in FAO aquaculture production statistics, when a volume of 100 mt was reported (FAO 2022a). Likewise, the number of operational Arctic charr farms in Canada appears to have declined in recent years. Icy Waters,[17] which is located in the Yukon, accounts for the majority of production (pers. comm., Sheri Beaulieu, Canadian Aquaculture Industry

[11] https://www.mast.is/is/maelabord-fiskeldis/fiskeldisstodvar

[12] Note that Matorka utilize a partial recirculating aquaculture system (PRAS), which is designed to reuse as much water as possible without the need for biofiltration – the maximum reuse possible with this system is around 70% (pers. comm. Árni Páll Einarsson Einarsson, Chief Commercial Officer, Matorka, December 2021).

[13] https://www.umlax.se

[14] https://babordgroup.com/products/arctic-char/

[15] http://www.arcticfishnorway.com/AFN/no/Aquaculture/page1/index.html?a22=65

[16] https://www.uwsp.edu/cols-ap/nadf/Pages/UWSP%20Northern%20Aquaculture%20Demonstration%20Facility%20Home%20Page.aspx

[17] https://www.icywaters.com

Alliance November 2021); in addition to selling harvest-sized Arctic charr, Icy Waters also supplies ova internationally to third-party farmers. Other producers in Canada include Ridgeland Aqua Farms, in Manitoba, and Raymer Aquaculture, in Quebec;[18] these two RAS facilities produce around 35 mt and 45 mt of Arctic charr per year, respectively,[19] [20] whereas Icy Waters reportedly produce around 120 mt each year (GoC 2019). Of note, FAO data indicate that Canada has consistently produced 200 mt of Arctic charr each year since 2008 (FAO 2022a).

It is also interesting to consider the wild-caught volumes of Arctic charr that have been reported to FAO over the years; these have never been particularly high (Solar 2009). The first country to report wild capture of this species was Greenland, for which a volume of 28 mt was recorded in 1963. During the past two decades, global landings have averaged around 200 mt annually, although considerably higher volumes were reported in 2012 (449 mt), 2015 (498 mt), and 2020 (559 mt) (FAO 2022a). It is noted with concern that there are indications that wild Arctic charr populations are in decline from an array of anthropogenic impacts as well as climate change (Helgadóttir et al. 2021)(Troell et al. 2017). Anadromous stocks are particularly vulnerable to the effects of rising water temperatures (pers. comm., Dr. Bjarni K. Kristjánsson December 2021).

Cultured production of Arctic charr: An overview of production systems

Regarding production systems, a major consideration for farmers is this species' variable tolerance to saltwater, which differs both seasonally and among stocks (Imsland et al. 2019)(Brännäs et al. 2011). This makes farming in ocean net pens challenging or unviable, especially at lower temperatures, and can result in slow growth and high mortality rates. Conversely, it is also challenging to produce Arctic charr in freshwater lakes because summertime temperatures can become too high for its tolerance (Gunnarsson 2011). As a result of these constraints, the majority of global production, through to harvest, takes place in land-based systems, which are substantially more expensive to operate than net-pen systems (Imsland et al. 2019)(Brännäs et al. 2011). Most of these land-based systems in Iceland are flow-through, although one of the major producers operates a partial recirculating aquaculture system (PRAS). These land-based farms primarily rely on borehole-sourced water, which delivers water of a stable temperature and quality year-round (Gunnarsson 2011)(Summerfelt et al. 2004).

Arctic charr is a schooling fish that thrives in high stocking densities; in fact, researchers note that low stocking densities should be avoided because this can have welfare ramifications: negatively affecting the cohort by increasing social interactions, which can lead to aggressive behavior and the formation of hierarchies (Gaffney & Lavery 2022)(Sæther & Siikavuopio 2015). Higher stocking densities also appear to be positively correlated with better growth performance, assuming that adequate feed is provided. In tank systems, quite high stocking

[18] https://raymeraquaculture.ca/en/
[19] https://www.aquaculturenorthamerica.com/ridgeland-aqua-a-model-for-business-success-1398/
[20] https://www.aquaculturenorthamerica.com/egg-to-plate-model-works-for-arctic-char-farmer-1879/

densities of 100 kg/m^3 apparently still achieve optimal growth (Brännäs et al. 2011) and a tolerance up to 150 kg/m^3 is noted in the literature (Sæther et al. 2015). Researchers in the U.S. have documented success with densities up to 120 kg/m^3 in land-based systems (ANA 2015)(UWSP 2011). The maximum stocking density employed by Samherji is 50 kg/m^3 (IFS 2019), whereas Matorka typically does not exceed 80 kg/m^3 (pers. comm., Árni Páll Einarsson, Matorka December 2021). Stocking densities used in Swedish and Norwegian net-pen systems are reportedly around 50–60 kg /m^3, which is comparably higher than the densities at which cage-reared rainbow trout are stocked (30–40 kg/m^3) (Brännäs et al. 2011).

Since this report focuses on the production of Arctic charr in Iceland, the following provides an overview of the land-based, flow-through production systems that are typically in use here. Icelandic farmers rely exclusively on hatchery-raised fry that are derived from local Arctic charr stocks. Although a few farms still maintain their own broodstock, the sector is increasingly (≈90–95%) reliant on eggs from Hólar University, which hosts the country's only Arctic charr breeding program—an initiative that officially commenced in 1992 (pers. comm., Bjarni K. Kristjánsson December 2021).

Figure 7: Aerial view of a land-based PRAS Arctic charr farm on Iceland's southwest coast near Grindavík. (Photo credit: Matorka.)

Like Atlantic salmon, cultured Arctic charr start their lifecycle in freshwater. To begin with, eggs are stocked in the hatchery at 4–6 °C, where they will remain for around 8–10 weeks until they hatch; once hatched, alevins weigh ≈0.1 g. Next, they are transferred to a freshwater nursery unit, where the temperature is 7–9 °C. Once they attain a weight of 60–70 g, they are vaccinated, and when they reach 100–150 g, they are ready to be transferred to an ongrowing unit (pers. comm., Heiðdís Smáradóttir November 2021). Depending on the system setup, the ongrowing phase may involve an interim period in indoor tanks where fish stay until they reach around 300g,[21] after which they are moved to outdoor tanks, where they will remain until they attain harvest size (800 g to 2 kg) (IFS 2019). Circular concrete, fiberglass, or steel tanks are most often utilized, although raceways are also used (Gunnarsson VI 2011). Typically, salinity and temperature during the ongrowing phase are between 10–24 ppt and 6–10 °C, respectively. Depending upon the desired final harvest weight, the length of time from egg to harvest ranges from 18 to 28 months (pers. comm., Heiðdís Smáradóttir, November 2021)(pers. comm., Árni Páll Einarsson December 2021).

Figure 8: An Icelandic land-based Arctic charr farm on the southwest coast. (Photo credit: Samherji.)

Although juvenile production always takes place in freshwater, most Arctic charr farms in Iceland pump brackish groundwater to facilitate the ongrowing phase, and this method accounts for the majority of production. Although Arctic charr can complete their lifecycle in freshwater, only a few of the smaller producers employ this method, by using fresh spring water for ongrowing (Eurofish 2020). Besides this difference, the production practices adhered to by land-based farms in Iceland are quite similar (pers. comm., Heiðdís Smáradóttir February 2020).

Slightly salty groundwater is available in abundance in many parts of Iceland; when extracted via a borehole, this water has the advantage of having been naturally filtered through volcanic lava rock (Eurofish 2020)(Gunnarsson 2011). Although Arctic charr can tolerate full salinity for a

[21] https://www.samherji.is/en/fishfarming/samherji-fishfarming

few months in the summer, the optimal year-round range is 15–20 ppt; if Arctic charr are subject to sustained salinities ≥25 ppt, health issues will arise as the fish struggle to deal with this biological challenge (pers. comm., Bjarni K. Kristjánsson December 2021). Because of this, care must be taken when preparing boreholes for Arctic charr farming: the water on top is fresh, but the salinity increases the deeper the borehole penetrates into the rock—as does the water temperature. Warmer water encourages faster growth, but this must be judiciously balanced with optimal salinity for the fish to thrive (pers. comm., Heiðdís Smáradóttir November 2021).

Arctic charr import and export statistics

Trade publications note that Icelandic aquaculture export volumes have risen considerably in recent years; although Atlantic salmon accounts for the majority of this growth, Arctic charr is identified as the country's second main export species.[22]

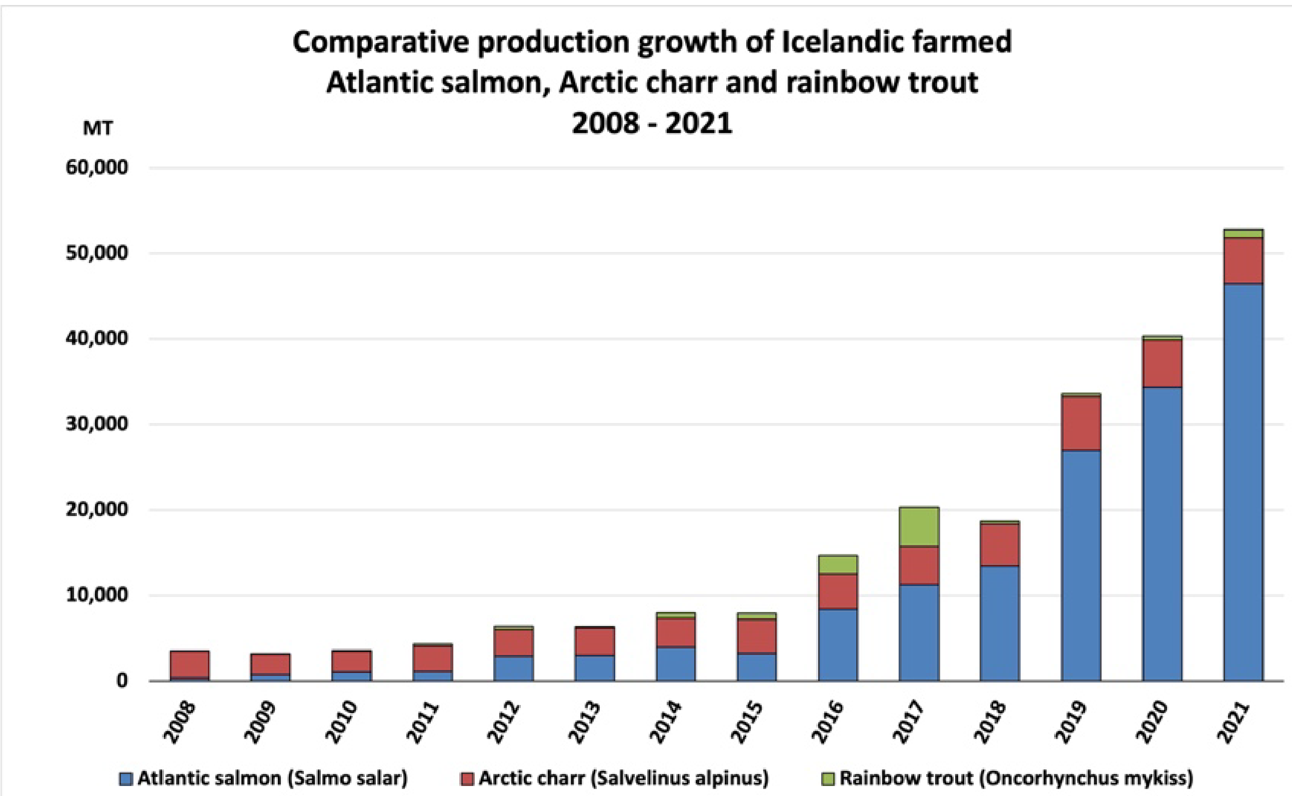


Figure 9: Comparison of the cultured production volumes of Atlantic salmon, Arctic charr, and rainbow trout farmed in Iceland between 2008 and 2021. Data from (FAO 2022a)(MAST 2021a).

Iceland's national center for official statistics, Statistics Iceland, states that Arctic charr exports have primarily been traded into the United States, Poland, Japan, and Germany.[23] But, because

[22] https://www.fishfarmermagazine.com/news/iceland-on-track-to-break-record-for-farmed-fish-exports/
[23] https://statice.is/publications/news-archive/fisheries/aquaculture-in-iceland/

Statistics Iceland[24] combines Arctic charr and rainbow trout together as "Trout" in export data, it is not possible to determine the exact amount of such exports that pertain solely to Arctic charr. In 2021, the entire amount of exports in this "Trout" category was 4,825 mt, of which 1,242 mt (26%) were recorded as being exported to the U.S. (SI 2022). Production of rainbow trout has diminished a great deal in the last few years, as can be seen in Figure 9, so the majority of these "Trout" exports are likely to be Arctic charr. It should be noted that these export volumes pertain primarily to processed fillets and portions, so they cannot be directly compared with FAO aquaculture production volumes, which are based on live weight.

Imsland et al. (2019) note that, though most of the Arctic charr farmed in Iceland is exported—to North America and Europe—other countries that farm this species mainly sell it to their domestic markets; this factor strongly suggests that the majority, if not all, of United States Arctic charr imports come from Iceland. Iceland's main Arctic charr producers describe their typical sales as being around 90–95% for export and around 5–10% for the domestic market (pers. comm., Heiðdís Smáradóttir February 2020)(pers. comm. Árni Páll Einarsson, Matorka December 2021).

At present, Arctic charr trade flows are not specifically defined in any country's official trade statistics. Regarding U.S. trade data, the situation is clarified by NOAA Fisheries as follows: "There is no specific trade category for Arctic charr, so it is grouped in with 'other' species. Our trade categories reflect the categories of the Harmonized Tariff Schedule (HTS) of the U.S. as defined by the U.S. International Trade Commission. If there is no category, it essentially means that there is no regulatory reason to separate out the species, and that the volume is sufficiently low that Customs isn't willing or able to separate it out for statistical purposes. So, the data simply isn't [sic] collected at that level of detail" (pers. comm., NOAA Fisheries agent, February 2020).

Future Projections

It appears likely that Iceland's Arctic charr production will continue on a steady growth trajectory over the coming years, a projection that is further supported by trade literature, which notes ongoing investment in the sector.[25] [26] Icelandic Arctic charr production has approximately doubled over the course of the last decade and, even though harvest volumes dipped somewhat in 2020 and 2021—by 13% and 15%, respectively, compared to 2019—this mirrors the downturn experienced by other food-producing sectors during the COVID-19 pandemic. Given the overall steady rise in Icelandic Arctic charr production, Iceland appears to be on track to retain its dominant position within this global sector and will likely continue to be

[24] https://statice.is/statistics/business-sectors/fisheries/aquaculture/
[25] https://www.fishfarmermagazine.com/news/iceland-company-to-boost-arctic-char-aquaculture-investment/
[26] https://www.seafoodsource.com/news/premium/aquaculture/icelandic-salmon-ceo-sector-s-growth-is-dependent-on-political-will?utm_source=marketo&utm_medium=email&utm_campaign=newsletter&utm_content=newsletter&mkt_tok=NzU2LUZXSi0wNjEAAAGK0Scb4LuWc42OVNejvCB0JbVJpM6Oj9NfQqC5Vy28Z9iRVSvIeSdApaD9-_6n7J6OJiODqZskLpzdeEevYLzFb5ypzQvx546GXGle3-OwK7I5Cw

the United States market's primary supplier. Before 2016, Iceland's total aquaculture production had never exceeded 10,000 mt annually, whereas by 2021 it was over 53,000 mt. Although this increase is primarily due to the rapid rise in Atlantic salmon production, Arctic charr made up 10% of the nation's total aquaculture production in 2021, making it Iceland's second biggest aquaculture product (MAST 2021a).

Product Forms

As depicted in Figure 10, whole fresh fish has tended to be the dominant form of Iceland's Arctic charr exports, with the balance comprised of fresh fillets and, to a lesser extent, whole and frozen fillets. Further examination of these 2014 data indicates that U.S. imports comprised only whole fresh fish (71%) and fresh fillets (29%) (Heimisson 2016).

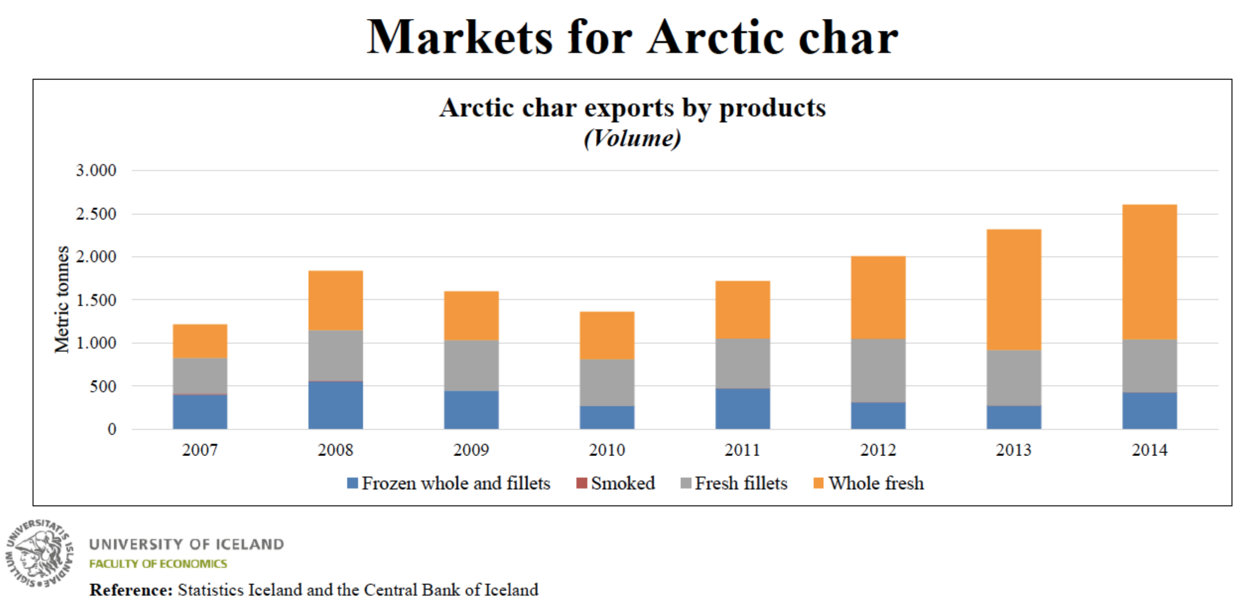


Figure 10: Volume and product category of Icelandic Arctic charr exports (Heimisson 2016).

Common Names

The name "Arctic charr" is sometimes spelled with only one 'r.' Other common names for this species are salmon trout, mountain trout,[27] alpine char, lake charr, sea run trout, and salt-water trout (Fishbase 2008). In Iceland, Arctic charr is known as bleikja.

[27] http://www.eurofishmagazine.com/sections/species?start=10

Criterion 1: Data Quality and Availability

Impact, unit of sustainability and principle

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

Criterion 1 Summary

Data Category	Data Quality
Production	10.0
Management	10.0
Effluent	7.5
Habitat	7.5
Chemical use	7.5
Feed	7.5
Escapes	7.5
Disease	5.0
Source of stock	10.0
Wildlife mortalities	7.5
Escape of secondary species	10.0
C1 Data Final Score (0–10)	**8.182**
	GREEN

Brief Summary

The volume of peer-reviewed literature pertaining to the Icelandic Arctic charr sector—and more specifically to its environmental impacts—is somewhat limited; however, this is in keeping with the relatively small size of the sector. Those peer-reviewed data that were identified were found to be of high quality and provided valuable insight into the various production criteria considered. The aquaculture sector in Iceland has been on a growth trajectory in recent years and, to keep abreast of this expansion, the governance framework and mechanisms that oversee it have been evolving accordingly. The laws and regulations that apply to the sector are readily available online, and the agencies responsible for their implementation and enforcement are easy to identify and contact. Under Icelandic law, the principal agencies involved in governance of the aquaculture sector provide a wide array of farm-level data on their respective websites. These online data, together with personal communications with agency representatives, provided a clear overview of the sector and helped greatly to inform the different criteria considered.

Other experts and farm personnel were also easy to identify and communicate with, which helped further elucidate the environmental impacts of the sector, as they relate to the Seafood Watch Aquaculture Standard criteria. Industry publications were also a valuable data resource, particularly in terms of providing a clear overview of the developmental timeline of the Arctic charr sector in Iceland. Of the 11 different data categories considered in this data criterion, four scored 10 out of 10, six scored 7.5 out of 10, and one scored 5 out of 10. Together, these result in an overall score of 8.182 out of 10 for Criterion 1—Data.

Justification of Rating

Iceland's two largest Arctic charr farming companies account for ≈80% of national production of this species, which for the last few years has averaged ≈6,000 mt annually. Because the Arctic charr sector is relatively small, the volume of peer-reviewed literature that specifically pertains to the sector's activities is comparatively limited; nonetheless, those scientific data that were identified were considered to provide in-depth insights, which greatly helped to inform this assessment. Government officials, farm representatives, and other relevant professionals across the sector were easy to identify and contact. Personal communications with these stakeholders helped to provide an up-to-date overview of the sector and its environmental impacts. Government websites also proved to be an important information resource; recent amendments to Iceland's legal framework for aquaculture have made it mandatory that data pertaining to the sector, including its environmental performance, are made publicly available on the online platforms of relevant authorities. Most of these data are available only in Icelandic. Also of note, as a party to the European Economic Area (EEA) Agreement, Iceland is obliged to adhere to a number of European Union (EU) Directives that deal with environmental management, and these likewise are available online.

Referring to the 11 categories included in the scoring chart, this Data criterion considers the availability and quality of data that have been identified in each case. For the first category, Production, historical and current aquaculture production volumes are readily available on the website of Statistics Iceland, which is the National Statistical Institute of Iceland. These same data are also available in the Fishery and Aquaculture Statistics database that is maintained by the Food and Agriculture Organization of the United Nations (FAO). Other literature that discusses the production output of the Icelandic Arctic charr sector also references these same data. These official production data are considered to be accurate, so this data category scores 10 out of 10.

The category of Management is likewise considered to be robustly informed by the data that are available. The various government departments that administer to the aquaculture sector are explicit in the chain of management command that is adhered to within their organizations, and the management process for the sector is clearly described. Farm permits are also available online and these documents identify the specific individuals that are responsible on each farm. Thus, the availability and quality of data pertaining to this category scores 10 out of 10.

Data pertaining to the Effluent category were primarily obtained from Iceland's Environmental Agency (UST), both via the website and through personal communications with agency staff.

The UST-issued operating licenses of all commercial fish farms are available online, and these specify the discharge limits that are permitted. Farm-level effluent monitoring data are also available on the UST website, as are farm audit inspection reports, which highlight any compliance issues or deviations alongside any corrective actions required or taken. Communications with farm representatives also assisted considerably in assessing the effluent impacts of the Arctic charr sector. The data reviewed are considered to provide a reliable representation of the effluent impacts of the sector, although some data gaps are evident. The data category for Effluent scores 7.5 out of 10.

Regarding the Habitat data category: peer-reviewed literature, personal communications, and industry media all helped to explain and inform a review of the sector's habitat conversion and function impacts during the timeline of its development. Aquaculture production in Iceland has grown considerably in the last few years and, as a result, many aspects of the regulatory framework that governs the sector have recently been revised and updated to keep abreast of this expansion. Thus, data pertaining to the content of habitat management measures were mainly obtained by reviewing current legislation, which is readily available online, as well as through communications with the principal agencies responsible for enforcement of relevant laws and regulations. The National Planning Agency (NPA) is the agency responsible for conducting Environmental Impact Assessments (EIAs) and delivering screening decisions on proposed farm developments, and documentation concerning these deliberations are made publicly available in an online database. The website of the Icelandic Institute of Natural History (IINH) was also a valuable resource for understanding the different terrestrial habitat types that have been defined in Iceland, and the Institute's habitat type mapping data facilitated the identification of the underlying habitat types at the farm sites of the main producers. The data reviewed are considered to provide a reliable representation of the habitat-related impacts of the sector, although some data gaps are evident, such as the specific land footprint occupied by land-based Arctic charr farms and how this has changed over time. This is evidently challenging to define, particularly since some farms may have other species onsite, such as rainbow trout, and also because some facilities that have previously been used for ongrowing Arctic charr have recently converted to salmon smolt production. The data category for Habitat scores 7.5 out of 10.

In addition to personal communications with stakeholders and experts, the principal data sources used to inform the chemical criterion were the Icelandic Food and Veterinary Authority's (MAST) annual reports. MAST is responsible for the oversight and monitoring of all medicines and chemicals used by the aquaculture sector, and the quantities used are published each year in these reports. It is evident from these report data that antibiotics have scarcely been used in Icelandic aquaculture over the past decade, and any instances in which they have been prescribed are documented, including the amount used and the species and condition being treated. The reported volumes of other types of chemicals are aggregated; however, a breakdown of the specific quantities of chemicals used by the Arctic charr sector was obtained directly from MAST. Data pertaining to the governance framework for chemical usage within the sector were easily identified, and the relevant laws and regulations are available online. The data reviewed are considered to provide a reliable representation of the impacts of chemical use by the sector, although some data gaps are evident. The data category for Chemicals scores 7.5 out of 10.

Data used to assess the feed criterion were obtained directly from the main producers, feed manufacturers, and from feed bag labels; these data were then aggregated and weighted to provide an overview of the average ongrowing diet used to culture Arctic charr in Iceland. Feed formulations are typically proprietary, so the precise compositions of diets were not provided; however, the data provided are considered to provide a reliable, average representation of the feeds that are used by the sector. The data category for Feed scores 7.5 out of 10.

Escape prevention is one of MAST's principal concerns, so communications with personnel from this agency were a key source of information for the escape criterion. Before any fish can be stocked in a new facility, a MAST representative will inspect the premises to assess the system and its escape risk potential; thereafter, the agency will follow up with regular inspections to ensure that operators remain in compliance with the terms of their license. MAST has an online portal that provides public access to fish farm operating licenses and inspection reports, and these proved to be an important source of data for assessment of the Escape criterion. Communications with the principal producers also helped to inform this criterion; farmers explained the escape prevention measures that are implemented on farms, and also confirmed that no escape events had ever been documented at their respective facilities. Hólar University's website was also an important source of data that helped to inform this criterion: specifically, the section of the escape criterion that deals with the potential for competitive and genetic interactions to occur, if an escape event were to occur. Information on this website describes the university's breeding program, its duration, and the number of generations for which the broodstock in the program have been domesticated. These data are considered to provide a reliable representation of farm operations with regard to escapes, their likelihood, and their potential to affect wild stocks if an escape event were to occur. Thus, the escape data category scores 7.5 out of 10.

Regarding the data category for disease, a notably greater amount of peer-reviewed literature was identified that was related to this criterion than for other criteria. Personal communications were also immensely helpful in providing a good understanding of this aspect of production, particularly those communications with veterinary and fishery experts, but also discussions with fish farm representatives. MAST's annual veterinary reports on fish diseases include a detailed and transparent overview of the main infectious diseases that have affected national aquaculture production during the preceding year, including which species have been affected, the severity of outbreaks, and the number of instances of these. These reports also discuss the prevalence of disease in wild fish, based on data collected by Iceland's national health control surveillance program, which has been monitoring wild and farmed fish for disease since 1985. Data pertaining to the ongoing activities of Iceland's Fish Disease Committee are available on MAST's website, as are data collected through the surveillance program. Annual reports dating to 2006 are available on the MAST website, and these documents provide a valuable insight into the sector and its progress across this timeframe. Together, these data are considered to give a reliable representation of the disease issues affecting land-based Arctic charr farms in Iceland. Although data quality and availability are good regarding the diseases that affect cultured Arctic charr, and monitoring data concerning the diseases that affect wild fish are also available, data that specifically concern the potential impact of disease transmission from farmed to wild fish are lacking. As a result, the score for the Disease data category is 5 out of 10.

The Source of Stock data category was informed through personal communications, peer-reviewed literature, and by data sourced from Hólar University's website. The university runs Iceland's only Arctic charr breeding program, which supplies 90–95% of the eggs stocked by the sector. The breeding program commenced in 1992, and research to optimize Arctic charr production has been ongoing since; as a result, a range of recent contemporary and historic peer-reviewed literature was available within this data category. Communications with experts also provided valuable insights that helped to explain this aspect of the assessment. These data sources are considered to have provided a complete and full understanding of the source of stock for the requirements of this criterion. Therefore, the score for the Source of Stock data category is 10 out of 10.

Data sources that are referenced in the Wildlife Mortalities criterion are mainly limited to personal communications as well as a review of farm-level environmental impact assessment (EIA) materials and relevant laws. Although few data were identified to directly inform this category, the lack of references available helps to validate the conclusion reached for this criterion: that wildlife interactions would appear to be limited. Thus, the array of materials reviewed to inform this criterion, in addition to those cited, are considered to give a reliable representation of the operational impacts of the Arctic charr sector in Iceland regarding wildlife mortalities, and the score for this category is 7.5 out of 10.

As an exceptional criterion, the Introduction of Secondary Species criterion does not apply to all types of aquaculture production. Data pertaining to the Arctic charr sector in Iceland confirm that international or trans-waterbody live animal shipments are not required to facilitate production of this species. Thus, the score for this data category is 10 out of 10.

Conclusions and Final Score

Of the 11 different data categories considered in this data criterion, 4 scored 10 out of 10, 6 scored 7.5 out of 10, and 1 scored 5 out of 10. Together, this results in an overall score of 8.182 out of 10 for Criterion 1—Data.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.
- Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect.
- Principle: not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Evidence-Based Assessment	
C2 Effluent Final Score (0–10)	**8**
	GREEN

Brief Summary

Land-based Arctic charr farms in Iceland typically access water for their operations via onsite boreholes or wells. With an abundance of water, high flow rates can be maintained in ongrowing units, which are generally operated as flow-through systems, although one major producer operates a partial reuse aquaculture system (PRAS). High water usage means that effluents are well-diluted, and most farms discharge the untreated effluent via pipe directly into a dynamic ocean environment. The receiving waterbody, the Atlantic Ocean, is a quite complex waterbody because of the interactions of many currents and the surrounding ocean bathymetry. These waterbodies have demonstrated the ability to quickly dilute, assimilate, and transport effluents as a result of the swift currents and the relatively deep nearshore environments. Furthermore, at a cumulative level, water quality monitoring of Iceland's coastline has found no indication or concern for eutrophication.

The government body responsible for regulatory oversight and monitoring of fish farm effluents is the Environmental Agency, Umhverfis Stofnun (UST), from which each farm must obtain a license to operate. Such licenses stipulate how effluents must be handled; this varies somewhat between farms, depending on their specific environmental characteristics. The amount of phosphorus that a farm is permitted to discharge is clearly specified in each license; although the threshold on some older licenses is higher, the threshold that is stipulated on all new licenses is in the range of 7 to 10 kg P-total/mt of production per year. UST requires all fish farms to submit an annual summary that includes feed usage and farm discharge water quality data, the latter of which must be compiled from samples analyzed by an approved independent entity. To ensure that all farms remain within regulatory compliance, UST conducts regular audits. A review of the farm-level effluent monitoring data that is available on UST's website, plus related inspection reports and communications with UST personnel, show no evidence of environmental impacts arising as a result of effluent emissions from Arctic charr farms.

Furthermore, it is evident that Iceland's general aquaculture governance framework is attentive to the need for area-based management in situations where effluent emissions are greater in quantity and the receiving body in question is more sheltered, as shown by the implementation of a cumulative management strategy in the fjords where Atlantic salmon is farmed in ocean cages.

In conclusion, though the Arctic charr sector's production volumes are on an upward trajectory, the volumes currently produced are still relatively small, and the effluents produced are well diluted and are readily assimilated after discharge into a dynamic ocean environment. A review of government monitoring data along with personal communications with UST inspectors and personnel show no evidence that effluent discharges from Arctic charr farms in Iceland cause or contribute to cumulative impacts at the waterbody or regional scale and that any impacts within the immediate vicinity of farms are temporary. The final score for Criterion 2—Effluent is 8 out of 10.

Justification of Rating

This Effluent criterion applies to nutrient-related impacts at all locations nearer to and farther from the farm. Because the data availability and quality pertaining to nutrient-related farm impacts is considered to be moderate to high (the score for Criterion 1—Data is 7.5 out of 10), an evidence-based approach to assessing this aspect of production has been employed. These data are explored in some detail, including an overview of the localities where Arctic charr farms in Iceland are sited.

<u>The Reykjanes peninsula</u>

The Reykjanes peninsula lies in the southwest, close to Iceland's capital city, Reykjavik. The three farms belonging to the two main producers are located here (Figure 11). Furthermore, Arctic charr is also the predominant aquaculture species produced in Reykjanes: in 2021, 81% of Icelandic Arctic charr was farmed there, and this amount accounted for three-quarters (76%) of this region's total aquaculture production (MAST 2022). The remaining balance of Icelandic Arctic charr production comes from Suðurland (8%; 448 mt), Norðurland (7%; 401 mt), and Vestfirðir (4%; 202 mt).

Of note, although there are a total of 48 licensed land-based farms countrywide, of which approximately 28 are licensed to produce Arctic charr, only about 10 are actively producing this species, and the three farms operated by the two main producers are the only ones that each produce in excess of 500 mt each year (pers. comm., Karl Steinar Óskarsson January 2022). Much of the Reykjanes peninsula is covered in lava fields, and the farms here were mainly built in the 1980s (pers. comm., Heiðdís Smáradóttir November 2021).

Figure 11: Map of the Reykjanes peninsula, showing the location of Iceland's three principal Arctic charr farms, which account for >80% of production. The inset shows the location of these farms relative to the whole of Iceland. (Map data @2023 Google.)

Farmers access water for their farms by drilling through lava rock to access the groundwater below. The unique geology of this area allows water to easily percolate into the bedrock, creating large aquifers that are continuously replenished by rain and snowmelt and fed by seawater that seeps in beneath the land. On top, there is a freshwater layer, but at greater depths, the water becomes increasingly warmer and more saline. This factor must be considered carefully when new boreholes are drilled to supply ongrowing facilities: the ideal depth will yield water that provides enough warmth to support optimal growth, but with a salinity comfortably within the 25 ppt limit. Groundwater temperatures do not fluctuate much throughout the year; Arctic charr facilities typically use water at 6–7 °C, rising to a maximum of 8–9 °C (pers. comm., Heiðdís Smáradóttir November 2021)(pers. comm., Árni Páll Einarsson December 2021).

The effluent wastes generated from these systems are generally discharged directly into the surrounding environment. Arctic charr farms in Iceland are primarily flow-through, although the most recently developed farm in Reykjanes operates a partial reuse aquaculture system (PRAS),[28] which is designed to reuse the water as much as possible without using biofilters. Because groundwater is available in abundance, the water flow rates used in ongrowing

[28] https://www.rastechmagazine.com/landing-on-ice/

facilities are typically quite high (≈2,000L/second), which means that effluents are well diluted before being discharged (untreated) into the ocean. The volume of water discharged is the same as the volume abstracted. Only small farms situated inland have any kind of settling ponds, but such facilities are uncommon (pers. comm., Guðbjörg Stella Árnadóttir February 2023)(pers. comm., Sigríður Kristinsdóttir February 2023)(pers. comm., Heiðdís Smáradóttir November 2021). The PRAS facility is required to use a drum filter to remove organic wastes before effluents are discharged to the sea, as stipulated in their operating license on the UST website. The recent expansion Environmental Impact Assessment (EIA) for this farm notes that measurements that have been carried out on both the effluent and the receiving waterbody show that quite high and rapid mixing takes place and that no pollutants have accumulated during the expansion of this farm.[29] It can be concluded that the majority of Arctic charr farm effluents are discharged directly into the ocean through a pipe, and while the PRAS facility has some degree of effluent filtration included in its design, other coastal farms do not.

<u>Density of Arctic charr production and the risk of environmental impacts from effluent</u>

The oceanographic characteristics of Iceland and the Reykjanes peninsula are complex primarily due to the interactions of many currents, and the surrounding ocean bathymetry (Logemann, K. et al. 2013). To better understand the potential impacts that Arctic charr effluents may have on the water quality of receiving waters (i.e., eutrophication, or the lack thereof), it is important to understand the characteristics of the receiving waters, as these may ameliorate any such impacts. For Arctic charr effluents, the primary receiving waters are the Atlantic Ocean, and their oceanographic characteristics allow for the quick dilution, assimilation, and transportation of effluents.

As shown in Figure 11, the principal Arctic charr farms are located on the coast, and effluents that are discharged from them flow straight into the Atlantic Ocean—a highly dynamic environment where effluents are quickly dispersed (pers. comm., Guðbjörg Stella Árnadóttir February 2023). Furthermore, Figure 12 shows the demarcation of 72 bodies of water defined in the coastal sea off Iceland, as defined by Iceland's Marine and Freshwater Research Institute (MFRI), which provides the government with scientific advice on the protection and sustainable use of marine and freshwater habitats. As an example of the dynamic characteristics of the receiving waterbodies, the three principal farms on the Reykjanes peninsula lie within region CN2152, which is defined as open coastal seas that are not sheltered but are open to dynamic wave action (Guðmundsdóttir et al. 2022). Here, the ocean depth quickly plunges from around 10 m to greater than 100 m less than 3 nautical miles offshore.[30] The best data readily available to estimate the speed of the speed along the Reykjanes peninsula is from Logemann, K. et al. (2013), who estimated that the mean velocity of marine surface water at 15 m depth was between 0.025 m/sec and 0.05 m/sec from 1996 to 2006 (Logemann, K. et al. 2013). The available information suggests that there are swift currents throughout the surface and

[29] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/nr/939#alit

[30] Reykjavik (Marine Chart : IS_2735_0) accessed from GPS nautical charts https://www.gpsnauticalcharts.com/main/is_2735_0-reykjavik-nautical-chart.html

subsurface within the vertical water column of the receiving waterbodies with significant depth. As an approximation, when net pen aquaculture farms are sited in similar oceanic conditions (of depth and current speed), the effluent has been found likely to be readily dispersed and diluted (Price et al., 2015). This generality is echoed in a recent Icelandic Arctic charr EIA assessment, which states that the likely distribution, dilution, and mixing of nutrients is extremely fast and high, and after the effluents are mixed with the ocean,[31] the amount of discharged effluents becomes a fraction of what it was.

In terms of scale and the risk of cumulative impacts, the risk is generally low because of the limited size of the industry and the relatively significant distance between farms. Although the total number of farms actively growing Arctic charr in Iceland is presently around 10, many of these are quite small producers: their combined production totaled 1,051 mt in 2021 (MAST 2022). Besides the three main farms in Reykjanes, only two other farms produce volumes in excess of 100 mt per year. One of these farms is located in the northeast and the other in the Westfjords; both are located on the coast and discharge effluents into the sea. Overall, there is no information readily available to suggest a causal relationship of effluent waste from aquaculture and an increase in primary productivity in receiving waters. Furthermore, findings of marine coastal water quality monitoring around Iceland have found zero indication or concern for eutrophication (OSPAR Commission, 2017).

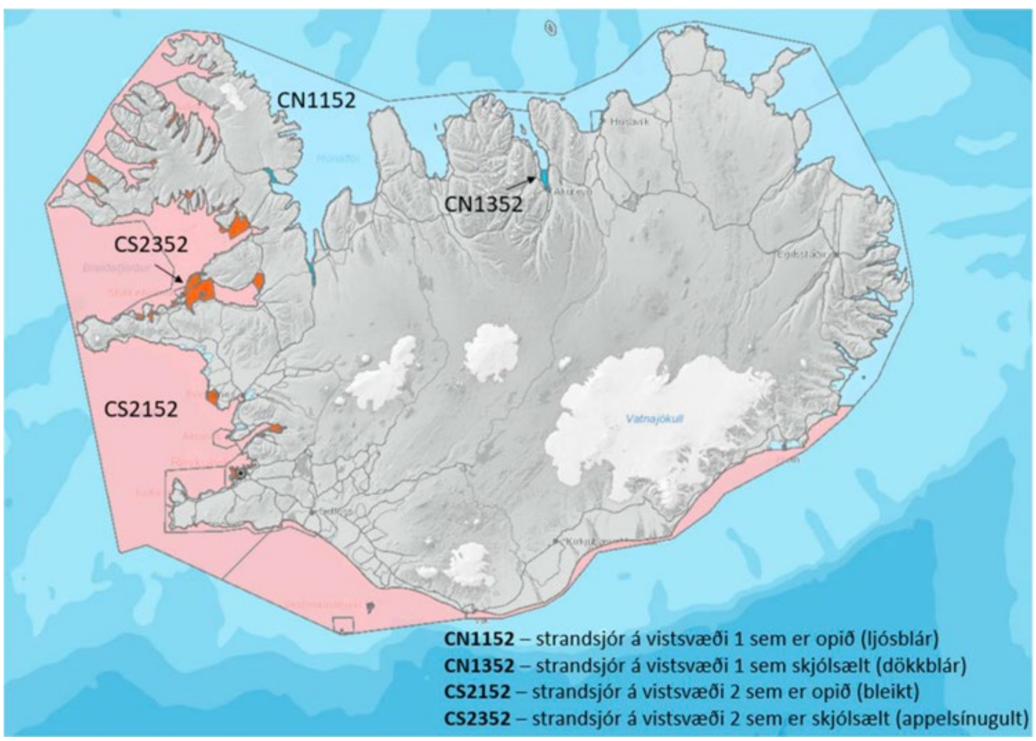


Figure 12: Map showing the division of coastal waters off Iceland into ecological zones and water bodies. Different water body types are colored in light blue, dark blue, pink, and orange. **(Guðmundsdóttir et al. 2022)**

Legend translation: CN1152: open coastal seas in ecozone 1 (light blue); CN1352: sheltered coastal waters of ecozone 1 (dark blue); CN2152: open coastal seas in ecozone 2 (pink); CN2352: sheltered coastal waters of ecozone 2 (orange).

[31] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/nr/939#alit

Lastly, there is a low risk of disturbance of the benthic environment from Arctic charr effluent waste (e.g., fish feces, uneaten food); this is primarily due to the ocean current speed and the ability of receiving waters to transport particulate matter, as well as the ocean bottom type. Figure 13 provides an overview of the distribution of benthic types around Iceland's coast: note that the substrates near coastal areas adjacent to Iceland's principal Arctic charr farms, where the effluents from these farms are discharged, are identified as comprising mud and sand. It is unlikely that any particulate matter would accumulate to such a degree to negatively affect the mud and sand of this area. Hence, the risk of effluent discharge impacts, both soluble and insoluble, appears minimal.

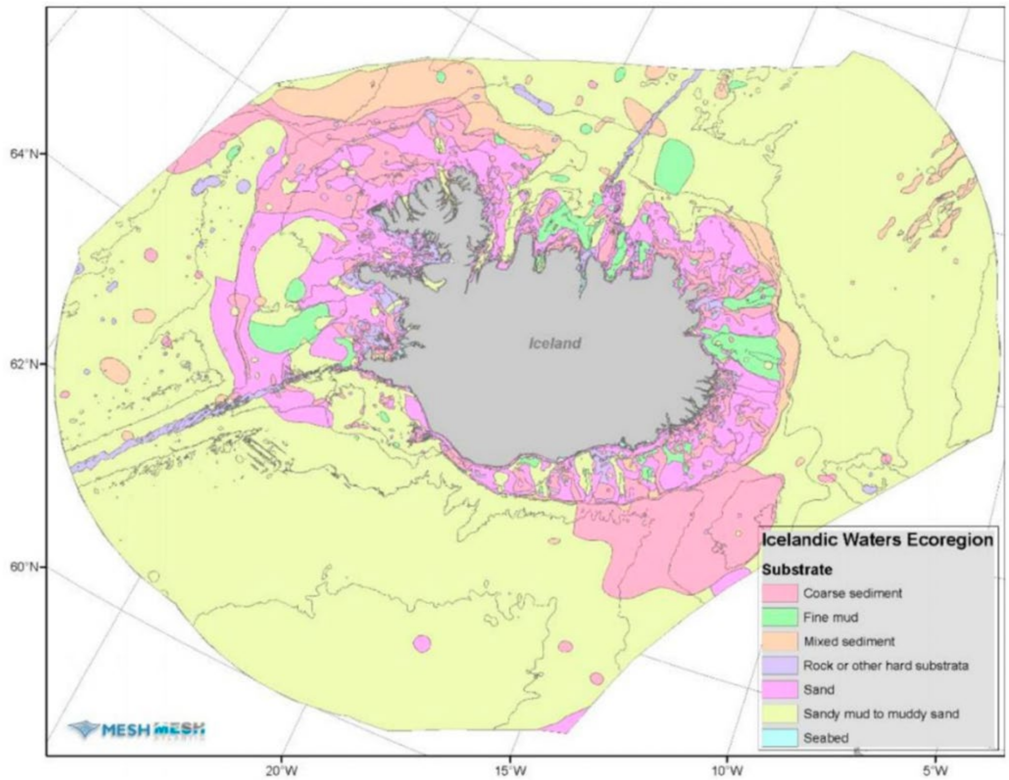


Figure 13: Major substrates in the Icelandic Waters ecoregion (compiled by EMODnet Seabed Habitats; www.emodnet seabedhabitats.eu) (MFRI 2017).

In summary, the risk of effluent impacts to the surrounding oceanic environment appears quite low, considering the low production volume, the oceanographic characteristics of the receiving waters, the benthic characteristics, and the low density of farm effluent discharge locations. But, it is also pertinent to consider the effluent regulations and enforcement mechanisms that are in place, to ensure that there is a low risk of environmental impacts arising from the discharge of effluents associated with Arctic charr production.

Regulatory requirements pertaining to farm effluents

Iceland is a member of the European Economic Area (EEA) and, as such, is legally bound to incorporate many of the measures that are contained in European Union (EU) Directives into national legislation; one of these, which is particularly relevant to this effluent criterion, is the EU's Water Framework Directive (WFD): Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy, is the main law for water protection in Europe. It applies to inland, transitional, and coastal surface waters as well as groundwaters; it ensures an integrated approach to water management, respecting the integrity of whole ecosystems, including by regulating individual pollutants and setting corresponding regulatory standards.[33] In alignment with the WFD, Iceland enacted the Water Management Act (No. 36/2011).[34]

Although MAST is the primary agency responsible for oversight of the aquaculture sector in Iceland, the monitoring of effluents and feed usage falls within the remit of the Environmental Agency, Umhverfis Stofnun (UST).[35] UST, which operates under the direction of the Ministry for the Environment and Natural Resources, is the agency that issues licenses for effluent discharge (pollution prevention permits), without which a fish farm cannot operate.

UST requires all fish farms to submit an annual summary that includes feed usage and effluent discharge water quality data, the latter of which must be compiled from samples analyzed by an approved independent entity. The UST website includes a searchable database of the various reports that each farm is required to submit, including each farm's accrued water quality monitoring data.[36] A review of water quality monitoring test results indicate that samples are typically taken at a range of locations on farms, such as from boreholes, at the exit of ongrowing tanks, and at the point of discharge. Total phosphorus (P-total) must be measured at least twice per year: once at highest biomass and once at lowest biomass, so that a comparison can be made; many farms also choose to monitor total nitrogen (N-total), although this is not mandatory. Farms are also required to measure total suspended solids (TSS) and organic matter (TOC, COD, or BOD5) in accordance with the specific requirements of their operating license and in line with their UST-approved Environmental Monitoring Plan. UST will then review these data in tandem with declared feed inputs and historic water quality monitoring data to ensure that effluent water quality parameters remain within an acceptable range at each farm (pers. comm., Guðbjörg Stella Árnadóttir February 2023)(pers. comm., Sigríður Kristinsdóttir February 2023). Many land-based farms are also required to sample the chemical content of their influent water (pers. comm., Steinar Rafn Beck Baldursson January 2022).

The amount of phosphorus that a farm is permitted to discharge is clearly specified in each UST-issued operating license; although the threshold on some older licenses is higher, the threshold that is stipulated on all new licenses is in the range of 7–10 kg P-total/mt of production per year. UST's threshold evaluation is site-specific and varies between farms, depending upon their particular environmental characteristics and the natural conditions at the location of effluent release (pers. comm., Steinar Rafn Beck Baldursson February 2022). The scientific rationale upon which these evaluations are based is aligned with the Norwegian emissions

[33] https://environment.ec.europa.eu/topics/water/water-framework-directive_en
[34] https://www.informea.org/en/node/687870
[35] https://ust.is/english/
[36] https://ust.is/atvinnulif/mengandi-starfsemi/starfsleyfi/eldi-sjavar-og-ferskvatnslifvera/

model developed by Bergheim & Braaten (2007), which considers feed inputs in conjunction with biomass and the resultant nutrient content of effluents to provide a measurement of the potential eutrophication effects of discharged farm wastes. Though this site-by-site management approach would appear to be appropriate to the relative size and density of the Arctic charr sector, it is not a cumulative management system. But, it is evident that the regulatory framework in Iceland is evolving in this direction, and an area-based approach has already been implemented for the Atlantic salmon sector, which has recently undergone a period of rapid expansion, with production rising from around 3,000 mt in 2015 to over 34,000 mt in 2020 (FAO 2022). In recent years, MFRI has conducted environmental assessments in most of the country's fjords, including carrying capacity assessments in those fjords where salmon farming is permitted; of note, it is integral to the Water Management Act (No. 36/2011) that the condition of water bodies must not be allowed to deteriorate due to polluting activities such as aquaculture (Macrander & Ólafsdóttir 2023)(Ólafsdóttir et al. 2017). Considering the timeliness of the implementation of area-based management for aquaculture in Iceland, it is relevant to note that, before 2016, Iceland's total annual aquaculture production had never exceeded 8,500 mt (FAO 2022).

To ensure that all farms remain within regulatory compliance, UST regularly conduct audits. These audits take place at least once a year, with the frequency increasing if any compliance issues have been detected. Audit inspections may be announced or unannounced (pers. comm., Steinar Rafn Beck Baldursson January 2022). The final reports that are prepared after each audit inspection are made publicly available on UST's website, as are all other reports referred to above.[37] Of note, UST operating licenses specifically state that the public has the right to access information about such licenses, their application process, and related monitoring, in accordance with Article 6 and IV Annex to Regulation no. 550/2018. A review of these publicly available, post-audit inspection reports for Arctic charr farms indicates that operators are mostly found to be compliant; any deviations identified are documented alongside corrective actions required and subsequently taken. If a farm were to consistently fail to comply with the terms of their operating license, UST could apply the provisions of Article 67 of Act No. 7/1998[38] (last updated 2020), which is the law governing Sanitation and Pollution Prevention. This provides UST with a legislative tool that enables them to impose fines upon noncompliant operators until any identified issues have been resolved; or, in extreme cases, to revoke a license. Provisions within the Pollution Prevention Act allow UST to issue daily fines (up to ISK500,000 per day; approximately USD3,500 as of writing this report) to farm operators if they do not comply with orders to rectify regulatory infringements within a certain period. In addition, administrative fines can also be issued (up to ISK25,000,000; approximately USD175,000) for violations such as starting operations before obtaining a valid operating license, failure to report changes in operation, or exceeding the permitted discharge of polluting substances. UST also has the authority to close a farm in extreme cases; however, this has evidently never occurred, based on the information from government personnel who were

[37] https://ust.is/atvinnulif/mengandi-starfsemi/starfsleyfi/eldi-sjavar-og-ferskvatnslifvera/
[38] https://www.althingi.is/lagas/nuna/1998007.html

contacted during research for this report. And, even fines are a rarity, because of the high level of compliance within the sector (pers. comm., Steinar Rafn Beck Baldursson January 2022).

A recent study, which explored the levels of phosphorus and nitrogen present in effluents generated by land-based flow-through systems in Iceland, noted that, over the last 30 years, there has been a roughly 50% reduction in the amount of nutrients generated per mt of fish produced. The authors note that this is largely attributable to a reduction in the protein content of aquafeeds, as well as improvements in feed management and feed conversion efficiency (Mavraganis et al. 2017).

Although the management of land-based Arctic charr farms in Iceland is not yet based on a comprehensive cumulative management system, the detailed farm-level data (e.g., farm operation permit, audit inspection reports, annual summary including feed usage and farm discharge water quality monitoring test results, and green accounting documents) that are provided on the UST website, in conjunction with communications with the agency, show no evidence that effluent discharges from Arctic charr farms in Iceland cause or contribute to cumulative impacts at the waterbody or regional scale. Also, UST inspectors confirm that no ecological impacts have been observed in the field as a result of effluents discharged from Arctic charr farms (pers. comm., Guðbjörg Stella Árnadóttir February 2023)(pers. comm., Sigríður Kristinsdóttir February 2023). Although the regulatory system for land-based Arctic charr farms lacks a cumulative management approach, and the carrying capacities of the bays into which effluents are discharged have not been assessed, it is evident from the oceanographic information available that the receiving waterbodies are well flushed as a result of dynamic wave action. Furthermore, the effluents being discharged are highly diluted, and their quantity is commensurate with the relatively small amount of production involved.

Summary of regulatory framework, enforcement, and environmental impacts

To summarize, the available evidence demonstrates that there is active, site-level monitoring of important effluent-related water quality parameters on Arctic charr farms in Iceland (e.g., phosphorus, total suspended solids, and organic matter [TOC, COD or BOD5], and many farms—including the three largest—also monitor nitrogen). Furthermore, there is evidence that regular farm inspections are conducted by UST and that effluent monitoring requirements are enforced by the agency to ensure compliance across the sector. Although no area-based management system is in place for the Arctic charr sector, it is highly unlikely that effluent discharges from these farms could exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level; this is the result of the relatively small scale and density of the industry and that effluents are discharged into a dynamic ocean environment. This hypothesis is further supported by communications with UST inspectors, who attest that they have never observed any ecological impacts arising from Arctic charr farm effluents—either on coastal or inland farms (there are few of the latter). In addition, it is evident that mechanisms governing the wider aquaculture sector are responsive to change, as evidenced by the recent implementation of a cumulative management strategy for ocean-based Atlantic salmon farming in Iceland, a sector that increased its output more than tenfold between 2015 and 2020 (FAO 2022). It is anticipated that land-based fish farming, particularly that of Atlantic salmon, will grow significantly in the near future; therefore, UST is attentive to monitoring such developments as Iceland's aquaculture sector evolves (pers. comm., Steinar Rafn Beck Baldursson January 2022).

Conclusions and Final Score

Land-based Arctic charr farms in Iceland typically access water for their operations via onsite boreholes or wells. With an abundance of water, high flow rates can be maintained in ongrowing units, which are generally operated as flow-through systems, although one major producer operates a partial reuse aquaculture system (PRAS). High water usage means that effluents are well diluted, and the majority of farms discharge the untreated effluent via pipe directly into a dynamic ocean environment. The receiving waterbody, the Atlantic Ocean, is a complex waterbody from the interactions of many currents and the surrounding ocean bathymetry. These waterbodies have demonstrated the ability to quickly dilute, assimilate, and transport the effluent as a result of the swift currents and the relatively deep nearshore environments. Furthermore, at a cumulative level, water quality monitoring of Iceland's coastline has found no indication or concern for eutrophication.

The government body responsible for regulatory oversight and monitoring of fish farm effluents is the Environmental Agency, Umhverfis Stofnun (UST), from which each farm must obtain a license to operate. Such licenses stipulate how effluents must be handled; this varies somewhat between farms, depending on their specific environmental characteristics. The amount of phosphorus that a farm is permitted to discharge is clearly specified in each license; though the threshold on some older licenses is higher, the threshold that is stipulated on all new licenses is in the range of 7–10 kg P-total/mt of production per year. UST requires all fish farms to submit an annual summary that includes feed usage and farm discharge water quality data; the latter must be compiled from samples analyzed by an approved independent entity. To ensure that all farms remain within regulatory compliance, UST conducts regular audits. A review of the farm-level effluent monitoring data that are available on UST's website, plus related inspection reports and communications with UST personnel, show no evidence of environmental impacts as a result of effluent emissions from Arctic charr farms. Furthermore, it is evident that Iceland's general aquaculture governance framework is attentive to the need for area-based management in situations where effluent emissions are greater in quantity and the receiving body in question is more sheltered, as evidenced by the implementation of a cumulative management strategy in the fjords where Atlantic salmon is farmed in ocean cages.

In conclusion, while the Arctic charr sector's production volumes are on an upward trajectory, the volumes currently produced are still relatively small. And, the effluents produced are well diluted and are readily assimilated once discharged into a dynamic ocean environment. A review of government monitoring data, and personal communications with UST inspectors and personnel, show no evidence that effluent discharges from Arctic charr farms in Iceland cause or contribute to cumulative impacts at the waterbody or regional scale, and that any impacts within the immediate vicinity of farms are temporary. The final score for Criterion 2—Effluent is 8 out of 10.

Criterion 3: Habitat

Impact, unit of sustainability and principle

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

Criterion 3 Summary

Habitat parameters	Value	Score
F3.1 Habitat conversion and function (0–10)		9
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)		4.8
C3 Habitat Final Score (0–10)		**7.6**
Critical?	No	**GREEN**

Brief Summary

The majority of Arctic charr production takes place in Reykjanes, a lava-covered region in southwest Iceland. Although production volumes of Arctic charr have increased somewhat in recent years, this is mainly due to intensification occurring on existing farms, rather than the development of new sites. According to the data available, the habitats where these farms are sited are maintaining ecosystem functionality, with minimal impacts arising from farm activities.

The Icelandic aquaculture sector, particularly that of Atlantic salmon, has grown significantly in recent years; this rapid growth has prompted a review of aquaculture regulations. Such legislative review focuses a great deal on ocean-based culture of salmon but is also applicable to land-based farming, a sector in which Arctic charr is still the predominant species for full-cycle production. The three principal laws governing aquaculture in Iceland are the Environmental Impact Assessment of Projects and Plans Act, the Act on Aquaculture, and the Law on Hygiene and Pollution Prevention, which are implemented primarily by three discrete agencies: the Icelandic National Planning Agency, the Icelandic Food and Veterinary Authority (MAST), and the Environmental Agency (UST), respectively. These principal laws have been revised and updated in recent times and/or supported by additional new regulations, with the intent of keeping the regulatory framework abreast of sector growth. These laws also provide each respective agency with the necessary enforcement tools to ensure that farm operators adhere to all regulations in a timely and appropriate manner. Insights from industry stakeholders indicate that land-based farming, particularly of Atlantic salmon, is likely to continue to increase, so the potential for cumulative habitat impacts at the regional scale will become increasingly important to address for the land-based sector. But as of now, the content and enforcement of habitat management measures in Iceland are considered to be moderate and effective, particularly regarding the current, relatively small scale of the land-based Arctic charr sector.

In conclusion, and according to the data available, although the presence and operation of Arctic charr farms inevitably affect the habitats where they operate to some degree, such impacts would appear to be minimal, and habitat functionality is being maintained; therefore, the score for Factor 3.1 Habitat conversion and function is 9 out of 10. The content of habitat management measures for land-based fish farms in Iceland is considered to be moderate, particularly for the current, relatively small size of the land-based aquaculture sector, in which Arctic charr is still the main species harvested. The score assessed for Factor 3.2a is a moderate 3 out of 5. Considering the efficacy of the enforcement of habitat management measures, the score for Factor 3.2b is 4 out of 5, which ranks this Factor as "effective." Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 7.6 out of 10.

Justification of Rating

This Habitat Criterion applies to ecological impacts within the farm boundary, whereas impacts related to nutrient release, at all locations nearer to and farther from the farm, are addressed in Criterion 2—Effluent. The following considers the typical habitat occupied by land-based Arctic charr farms in Iceland and explores any changes in habitat functionality that may be associated with such production.

Factor 3.1—Habitat Conversion and Function

The first aquaculture endeavors in Iceland focused on the production of salmonid juveniles for stock enhancement in rivers (Rosten et al. 2013). In 2011, literature from the Icelandic Directorate of Fisheries noted that such restocking activities had subsequently increased significantly, with the salmon population of some angling rivers entirely reliant on hatchery-raised smolts at that time (DOF 2011a)(DOF 2011b). In the 1980s, the first substantive efforts toward commercial aquaculture commenced (IF 2014); land-based tank farms were developed to grow Atlantic salmon,[39] including smolt production for sea ranching. But, these initial salmon farming initiatives were largely unsuccessful, and many of these land-based facilities subsequently converted to the production of Arctic charr (Young et al. 2019). Interestingly, in more recent times, the reverse has been occurring; now, Atlantic salmon production is on the rise and numerous land-based Arctic charr facilities are being converted to smolt production (pers. comm., Karl Steinar Óskarsson January 2022). Note that some industry projections suggest that Icelandic salmon production could rise to 170,000 mt annually by 2028[40] and to

[39] https://www.fishfarmingexpert.com/archive/iceland-getting-back-to-salmon-farming/1217456
[40] https://www.fishfarmingexpert.com/iceland/braced-for-icelandic-boom/1188253

234,000 mt by 2032.[41] In this regard, it is important to bear in mind that the full extent of land-based fish farming activities is greater than what is indicated in full-cycle harvest production statistics[42] alone, as a result of land-based smolt production.

Determination of the typical habitat occupied by Iceland’s principal Arctic charr farms

Iceland is one of the world’s most volcanically and geologically active countries. As discussed in Criterion 2—Effluent, most Arctic charr is farmed in Reykjanes, on the southwestern tip of the Reykjanes peninsula. Of note, the topography of this 25 km^2 lava-covered region has been formed by glaciers and volcanism (Figures 14 and 15). Regional geothermal systems supply significant quantities of hot water for domestic use, and a geothermal power plant has been operating in Reykjanes since 2006 (Sæmundsson et al. 2018). These rich, geothermal energy resources can also be tapped by land-based farms, allowing them to access warmer water that can facilitate faster growth during ongrowing.

Figure 14: Lava flows of the Reykjanes volcanic system. Image Credit: Hornstrandir1, CC BY-SA 4.0.

[41] https://www.seafoodsource.com/news/premium/aquaculture/icelandic-salmon-ceo-sector-s-growth-is-dependent-on-political-will?utm_source=marketo&utm_medium=email&utm_campaign=newsletter&utm_content=newsletter&mkt_tok=NzU2LUZXSi0wNjEAAAGK0Scb4LuWc42OVNejvCB0JbVJpM6Oj9NfQqC5Vy28Z9iRVSvIeSdApaD9-_6n7J6OJiODqZskLpzdeEevYLzFb5ypzQvx546GXGle3-OwK7I5Cw

[42] https://radarinn.is/Fiskeldi/Framleidsla

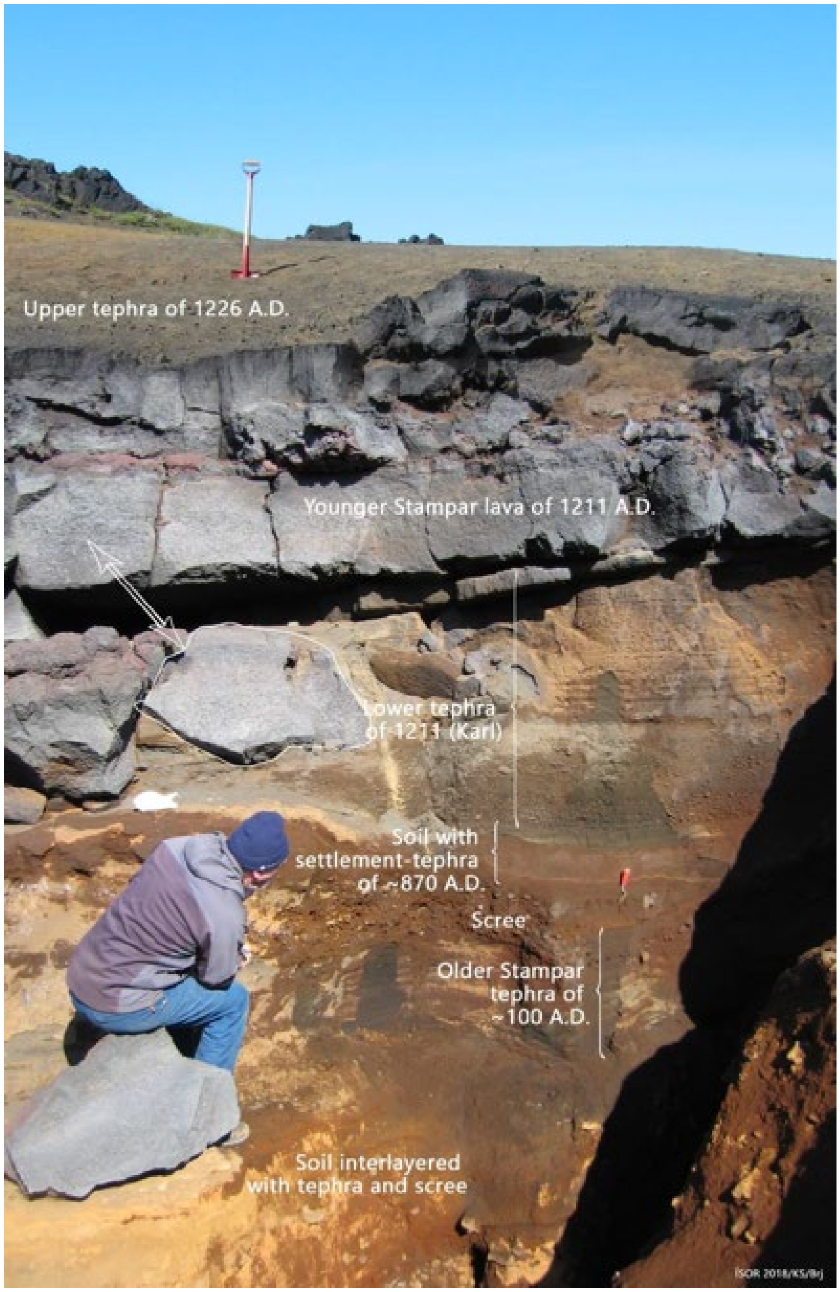


Figure 15: Section of a low coastal cliff on the Reykjanes peninsula (Sæmundsson et al. 2018).

Historically, the site selection process for Iceland's first land-based farms was done in close consideration of each facility's water requirements, in terms of both securing access to an optimal water source for husbandry needs as well as implementation of a wastewater discharge system. As a result of these priorities, early farms were typically sited in coastal areas with good access to high-quality borehole water and where outlet pipes could be directed out into dynamic ocean currents, to facilitate effective dilution and dispersal of effluents. The unique geology of the Reykjanes peninsula, where most Arctic charr farming takes place, is evidently well suited to these siting requirements, particularly for the abundance of brackish water that can be accessed from the aquifers beneath the lava fields.

The typical habitat type occupied by Iceland's principal Arctic charr farms in Reykjanes can be described as "lava field habitat." Although a detailed analysis of the underlying habitat type at each specific fish farm is beyond the scope of this report, the website of the Icelandic Institute of Natural History (IINH) provides an array of data pertaining to the 64 different terrestrial habitat types that have been defined in Iceland. These ,are further classified into 12 main habitat categories, plus an additional 2 groups that include anthropogenic habitat types, glaciers, and unvegetated ice-dominated moraines.[43] By utilizing IINH's habitat type mapping data,[44] it is possible to zone in on specific areas across Iceland, up to a scale of 1:25,000, to determine their underlying habitat type. Implementation of this mapping data confirms that all three of Iceland's main Arctic charr fish farming facilities are sited in lava field habitats, which are categorized as habitat type L6. Within this category, Iceland's lava field habitats are divided into four discrete types: (L6.1) barren Icelandic lava fields; (L6.2) Icelandic lava field lichen heaths; (L6.3) Icelandic lava field moss heaths; and (L6.4) Icelandic lava field shrub heaths (Ottósson et al. 2016). Regarding the underlying habitat type at Iceland's three principal Arctic charr farms, these can be identified as a mix of barren Icelandic lava fields (type L6.1[45]), Icelandic lava field shrub heaths (type L6.4[46]), and Icelandic lava field moss heaths (type L6.3[47]).

<u>Consideration of the overall scale and intensity of Arctic charr production</u>
To date, the footprint of modern, land-based Arctic charr farms has changed little since the 1990s, even though production volumes have increased; this is mainly due to intensification occurring on existing farms—particularly the larger farms in Reykjanes—rather than the development of new facilities (pers. comm., Heiðdís Smáradóttir November 2021). Expansion on a particular farm site may be significant at the farm level, but in terms of the addition of tanks and related infrastructure, the sector overall is still relatively small and there has not been a significant change in the land footprint of the industry over the past two decades (pers. comm., Egill Þórarinsson January 2023).

Though Reykjanes is Iceland's principal Arctic charr growing region, there are a number of smaller producers elsewhere, as shown in the aquaculture overview map in the Introduction (Figure 6). Although a total of 16 registered Arctic charr farms are identified on this map, only about 10 are actively producing Arctic charr at present (pers. comm., Karl Steinar Óskarsson January 2022). Of these 10, only 5 produce volumes in excess of 100 mt—and, at the time of writing, only the 3 farms discussed above produce over 500 mt annually. Arctic charr production on many of the smaller facilities is an adjunct to other agricultural activities; hence, the quantities produced are small and in the range of 20 to 100 mt or less. It should also be noted that some of the smaller Arctic charr producers may also be permitted to produce other

[43] https://www.ni.is/en/flora-funga/habitat-types/terrestrial-habitat-types
[44] https://vistgerdakort.ni.is
[45] https://www.ni.is/is/grodur/vistgerdir/land/eydihraunavist
[46] https://www.ni.is/is/grodur/vistgerdir/land/lynghraunavist
[47] https://www.ni.is/is/grodur/vistgerdir/land/mosahraunavist

species, such as salmon or rainbow trout; therefore, the proportion of their farm's footprint that is directly attributable to Arctic charr production may vary.

Although the Arctic charr sector's overall production volumes are relatively low, this criterion ideally considers the areal coverage of farms, rather than their production volumes, because this is the metric most relevant to evaluating their impact upon the habitats that they occupy. Because licenses are issued based on the maximum standing biomass that is permitted on-site at any one time, not on the actual areal footprint of the farm, the land occupied by each farm cannot easily be extrapolated from these. But, the Environmental Impact Assessment (EIA) for a recent expansion proposal by one of the principal farms notes that the overall plot size of the farm is 15 hectares (i.e., 0.15 km^2).[48] When the farm in question is viewed on Google Earth, the proportion of this plot that is already developed accounts for around one-third of the plot size (i.e., 0.05 km^2), and the EIA notes that the proposed expansion would increase this developed area to 0.065 km^2. Using Google Earth to view the other two principal farm sites, it is evident that all three farms are approximately equivalent in land area. Thus, it can be extrapolated that the farms in Reykjanes occupy a combined total plot size of $\approx$0.45 km^2; this equals around 1.8% of the 25 km^2 Reykjanes peninsula lava field.

<u>Evaluation of the impact of Arctic charr farms on ecosystem functions and services</u>

Most current production of Arctic charr takes place at sites that have been used for fish farming since the 1980s and 1990s, as is the case with the three main farms in Reykjanes. The company that owns two of these larger farms has ambitions to increase their production capacity over the next decade,[49] and the other principal Arctic charr farm, which is owned by a company that was established in 2010,[50] recently secured permission for an increase in production—of note, though this farm is a state-of-the-art facility, it is partly located on a site that has been used for fish farming since 1981 (pers. comm., Árni Páll Einarsson December 2021).

The presence of Arctic charr farms and their related activities inevitably affect the habitats where they operate to some degree. To assess the extent of such impacts, both the habitat type and the areal footprint of farms must be considered. As noted above, the combined areal footprint of the three main producers, which account for over 80% of total Arctic charr production, is approximately 0.45 km^2, although the area actually built on is likely to be considerably less. All this production occurs on the lava fields of Reykjanes peninsula, which features a mix of barren Icelandic lava fields (type L6.1[51]), Icelandic lava field moss heaths (type L6.3[52]), and Icelandic lava field shrub heaths (type L6.4[53]); these are categorized as having a conservation value of "low," "medium," and "medium," respectively, in IINH's habitat type data. Expansion EIAs conducted on behalf of the principal producers discuss the potential

[48] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/nr/939#alit
[49] https://www.intrafish.com/aquaculture/icelandic-giant-samherji-charges-ahead-with-land-based-aquaculture-expansion-plans/2-1-795181
[50] https://linde-stories.com/land-based-fish-farming-for-a-sustainable-future/
[51] https://www.ni.is/is/grodur/vistgerdir/land/eydihraunavist
[52] https://www.ni.is/is/grodur/vistgerdir/land/mosahraunavist
[53] https://www.ni.is/is/grodur/vistgerdir/land/lynghraunavist

impacts to the lava types at each site in some detail, and further describe how construction works can be performed in a manner so that impacts to the functionality of these various lava habitats are minimized.[54] [55]

In summary, Iceland's principal Arctic charr farms are sited in lava fields that are categorized variously by the IINH as being of low and medium conservation value—an evaluation that aligns with the habitat evaluations provided in the Seafood Watch Aquaculture Standard. The areal footprint of these farms is quite small. Given the total extent of the combined footprint of all farms, there is no indication that the conversion of this habitat has led to any loss beyond a minimal impact to the lava field habitat functionality. The score for Factor 3.1—Habitat Conversion and Function, is 9 out of 10.

Factor 3.2—Farm Siting Regulation and Management

<u>Factor 3.2a—Content of habitat management measures</u>
As noted, Iceland's initial attempts to farm Atlantic salmon in the 1980s did not meet with great success. Subsequent endeavors in the early 2000s were also hampered by a range of technical and economic issues (MAST 2021a)(Young et al. 2019): the cumbersome licensing process then in place was identified as a constraint to sector development, as well as the lack of suitable marine sites on Iceland's exposed coastline, and environmental restrictions on licensing (McKillop et al. 2018)(Jonsson 2000). But during the last decade, salmon production in Iceland has grown (see Figure 9), particularly since 2014, when Atlantic salmon production again overtook that of Arctic charr. This expansion has prompted a substantial and ongoing review of the regulatory framework for aquaculture (Young et al. 2019). Though this review has especially been prompted by the growth of the Atlantic salmon sector, particularly in marine environments, many of the regulatory changes underway are equally applicable to the Arctic charr sector, including those pertaining to farm siting and habitat protection. Of note, Arctic charr is still the predominant species grown full-cycle in Icelandic land-based facilities (MAST 2022).

In 2008, Iceland passed an Act on Aquaculture,[56] which was last amended in 2015.[57] After 2015, much of the burden for oversight of fish farms was moved from the municipal to the state level (pers. comm., Steinar Rafn Beck Baldursson January 2022). One of the central, explicit aims of the Aquaculture Act is to ensure minimal disturbance to the ecosystems where farms operate. In the last few years, a number of additional aquaculture regulations have been introduced to support implementation of the Aquaculture Act.[58] Jóhannsdóttir (2016), author of "Iceland: Aspects of the legal environment relating to aquaculture," noted that, at the time of writing, the regulatory process for aquaculture was in a state of transition. Given this evolving

[54] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/nr/939#alit
[55] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/nr/1118#emat
[56] https://www.althingi.is/lagas/nuna/2008071.html
[57] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC177700
[58] https://www.reglugerd.is/reglugerdir/eftir-raduneytum/atvinnuvega--og-nyskopunarraduneyti/nr/0540-2020

regulatory situation, the following governance overview has primarily been informed by direct communications with government personnel.

Regulatory overview

With effect from January 2008, the Icelandic Parliament passed Act No 167/2007, which established the Icelandic Food and Veterinary Authority: Matvælastofnun[59] (MAST). This Act served to merge the various authorities that had provided services dedicated to food and agriculture-related inspection and administration, thus streamlining such tasks under the oversight of one single entity. MAST took over the duties of both the Agricultural Authority of Iceland and the Environmental and Food Agency of Iceland, as well as other related tasks that had been attended to by the Icelandic Directorate of Fisheries.[60] MAST's principal purpose is twofold: the oversight and control of food safety legislation and the oversight and control of the primary production of animal products, including fish and fish products.[61] MAST, which operates under the auspices of the Ministry of Food,[62] is Iceland's competent authority (CA) in the fields of food safety; animal health and welfare; control of feed, seed, and fertilizers; plant health; and water for human consumption.[63]

The aquaculture department of MAST is the main licensing agency for fish. In addition to obtaining a general operating license from MAST, which is aligned with the Act on Aquaculture, farmers must also be in possession of an operation permit for pollution prevention from the Environmental Agency (UST), which is aligned with the Law on Hygiene and Pollution Prevention.[64] To streamline this application process, MAST coordinates these activities so that applicants need only deal with MAST and will receive both types of operating permit from them, if successful.

But before being able to apply for these operating permits, all new farm proposals must have been approved first by the municipalities where the proposed farm development is to occur, and second by the Icelandic National Planning Agency (NPA), Skipulagsstofnun.[65] Initially, it is up to the entity that wishes to develop a farm to identify a suitable site for their farming requirements; in this process, they must be cognizant of the municipality's master plan, which will identify any areas where fish farming is a permitted land use. Although there may be protected areas in a municipality that limit development in general, the municipality may also decide to amend their masterplan to allow for certain types of development. For example, though the three principal Arctic charr farms in the Reykjanes peninsula are sited in lava fields, which are protected by law in Iceland, two of these farms are located in a designated industrial area, and the other is in a designated light industrial area (pers. comm., Egill Þórarinsson January 2023).

[59] https://www.mast.is/static/files/library/Fræðsluefni/Fields_of_work_and_legal_basis.pdf
[60] https://www.fiskistofa.is/english/about-the-directorate/
[61] https://www.mast.is/static/files/library/Fræðsluefni/Fields_of_work_and_legal_basis.pdf
[62] https://www.government.is/ministries/ministry-of-food-agriculture-and-fisheries/organizational-chart/
[63] https://www.mast.is/en/about-mast/operation
[64] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC199599
[65] https://www.skipulag.is/en

Only after the potential farm applicant has successfully discussed planning issues with the municipality will the NPA become involved. This agency is the authority responsible for providing screening decisions on proposed developments and for the administration and implementation of the Environmental Impact Assessment of Projects and Plans Act,[66] the Planning Act,[67] and the Marine Spatial Planning Act[68] (Lehwald 2020). Iceland's first Environmental Impact Assessment Act was passed in 1993 (No. 63/1993), and aquaculture was not included within the scope of the act; later, in 2000, this act was replaced with a new Environmental Impact Assessment Act (No. 106/2000), and at this time aquaculture was incorporated; however, under this act, EIAs were never mandatory for fish farms but were conducted at the discretion of the NPA. More recently, this act was also repealed and replaced by Act No. 111 on Environmental Impact Assessment of Projects and Plans, which entered into force in September 2021. Under this current EIA act, all ocean-based farms producing ≥3,000 mt are subject to mandatory EIAs, and other farms—including land-based farms—may also undergo EIA if this is determined by NPA in a screening decision.

Jóhannsdóttir (2016) noted that surprisingly few fish farms had undergone a full EIA, but also commented that this was likely the result of the small production capacity of most farms at the time of her review. This is echoed in recent communications with NPA and UST, who comment that, because the majority of Arctic charr farms are small, with many producing only 20–100 mt annually, full EIAs have often been considered unnecessary because of the low production volumes involved and the minimal conversion of habitat and land footprint required (pers. comm., Egill Þórarinsson January 2023)(pers. comm., Steinar Rafn Beck Baldursson January 2022). A new regulation has recently entered into force that applies specifically to operators of small, land-based farms that are not subject to EIA. The Regulation on Registration Obligations in Aquaculture (No. 1133/2021)[69] defines such facilities as those where the maximum biomass of fish produced—for either food or research purposes—does not exceed 20 mt at any one time and/or the maximum biomass of juvenile production is no greater than 1,000 kg or 10,000 juveniles at any one time. Such farms must confirm registration of their facilities with MAST, instead of obtaining an operations license from this agency; however, an operating permit from UST is still required. In the years following Jóhannsdóttir's 2016 review, it is evident that production volumes have scaled up somewhat, primarily because of intensification occurring on the three main Arctic charr farms that are operated by the two principal producers. This increase in production is apparent in Figure 5; Icelandic Arctic charr production volumes have approximately doubled over the last decade, and by 2015–16 had reached ≈4,000 mt, increasing to ≈6,000 mt in recent years.

The stated objectives of the recently updated EIA Act (No. 111/2021) are concerned with sustainable development, environmental protection and promotion of a healthy environment,

[66] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC209552
[67] https://www.althingi.is/lagas/nuna/2010123.html
[68] https://www.althingi.is/lagas/nuna/2018088.html
[69] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC209709

efficiency in the delivery of environmental impact assessments, and public participation in the environmental impact assessment process. The act also describes the content of environmental impact assessments, stating that they shall cover the direct and indirect impact on: a) population and human health; b) biodiversity, with special emphasis on protected species and habitats; c) land, landscape, wilderness, geological formations, soil, water, air, and climate; d) material values and cultural monuments; e) sensitivity of a project or plan for the risk of catastrophic accidents and natural disasters; and f) the interplay of the factors listed in the preceding five items. The act further states that development proposals shall be initially categorized by the National Planning Agency into either category A or B. Category A projects, which include those pertaining to heavy industries, are always required to have an EIA, whereas category B projects are considered on a case-by-case basis to determine if a full EIA is required; in such instances, this will be determined via an NPA screening decision. Category A explicitly includes ocean farms that produce in excess of 3,000 mt. Category B includes land-based farms with a maximum biomass of ≥200 mt that drain to the sea, and those with a maximum biomass of ≥20 mt that drain into freshwater; however, farms producing below these thresholds may also be subject to an EIA if their proposed location is within a protected area. The EIA act also states that, once an EIA has been completed by the NPA, the agency must present the proposed project and respective EIA report to the public in a prominent way and make it available online. Thereafter, the public must be given at least 6 weeks to comment on the report. These EIA documents are made available in a database on the NPA website,[70] as are screening decisions.[71]

Though the NPA database contains many EIAs and screening decisions for the aquaculture sector at large, it is evident that these mainly pertain to Atlantic salmon production—a factor that is unsurprising, given the rapid expansion that has recently occurred in Iceland's salmon farming sector. To date, the database contains EIA documentation pertaining to two different established Arctic charr farms that have sought permission to make changes to their facilities (such as increasing production or water abstraction volumes) and one new farm proposal, which is principally for salmon but also includes Arctic charr in its long-term scope. The aforementioned two EIAs that were for expansion pertain to farms operated by the principal producers on Reykjanes peninsula. The database also contains five Arctic charr farm screening decisions, all of which pertain to established farms (and one hatchery) seeking to increase production; in each instance the screening decisions have concluded that the proposed expansion is not anticipated to have a significant environmental impact, and that a full EIA is not required. It should also be noted that the time frame of these online documents spans 2010 to 2021, so some documents pertain to the same farms at different times. As noted, most Arctic charr farms were established in the 1980s and 1990s, before aquaculture was first added into the scope of the EIA act in 2000. As a result, small farms that have been in production since these earlier times, and which have not subsequently applied for permission to increase production, have never been required to go through an EIA, because they were established

[70] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/

[71] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/alit-skipulagsstofnunar/

before fish farms were subject to EIA requirements. In such instances, in Iceland and elsewhere, farms are permitted to continue production under a grandfather clause.

Several acts are in place to protect the public's right to access information pertaining to the potential environmental impacts of fish farms and, beginning in 2020, it is also a legal obligation for MAST and UST to make data concerning aquaculture operations publicly available online, including proposals for new farms, which are advertised simultaneously on the websites of both institutions.[72] These publicly available data also include proposals for biomass expansion on existing farms (pers. comm., Karl Steinar Óskarsson January 2022). An additional part of this process is that, once the National Planning Agency has completed an EIA report, it is passed to UST and MAST for their review and input (pers. comm., Steinar Rafn Beck Baldursson January 2022). In this regard, the updated UST permit of one Arctic charr farm that recently successfully applied for an increase in biomass was noted on the UST website, in which the agency's review of the preceding EIA procedure was also attached.[73]

It should be noted that, although Iceland is not a member of the European Union (EU), it is a member of the European Economic Area[74] (EEA), which unites the EU member states and the three EEA European Free Trade Association[75] (EFTA) states (Iceland, Liechtenstein, and Norway) into an internal market governed by the same basic rules. As a member of the EEA, Iceland is obliged to adhere to a number of EU Directives, as stipulated in the EEA Agreement.[76] Annex XX[77] of the Agreement includes those Directives that pertain to the environment, the essence of which need to be embraced within Icelandic regulations, including those related to habitat protection and EIAs. In January 2022, it was reported that Iceland had been found to be in violation of EEA rules after a review by the EFTA Surveillance Authority (ESA), which monitors the compliance of those EEA members who are not members of the European Union (EU) (ESA 2022). These alleged violations were evidently due to the detection of shortcomings in the implementation of aquaculture-related EIAs, including difficulties experienced by members of the public who wished to participate in these processes. These issues were later rectified with amendments made to the Law on Hygiene and Pollution Prevention.[78]

In addition to these required procedures, farm operators must also secure a license from the National Energy Authority to drill boreholes for water abstraction (pers. comm., Steinar Rafn Beck Baldursson January 2022). Although new land-based farm proposals do not automatically require an EIA, the volume of groundwater that a farm operator proposes to abstract may make an EIA compulsory (pers. comm., Egill Þórarinsson January 2023). After both MAST and

[72] https://www.mast.is/is/um-mast/frettir/frettir
[73] https://ust.is/library/sida/atvinnulif/starfsleyfi-og-eftirlitsskyrslur/02_Starfleyfi%20Matorku%20ehf.%200.8.10.2020.pdf
[74] https://www.europarl.europa.eu/factsheets/en/sheet/169/the-european-economic-area-eea-switzerland-and-the-north
[75] https://www.efta.int/about-efta
[76] https://www.efta.int/Legal-Text/EEA-Agreement-1327
[77] https://www.efta.int/legal-texts/eea/annexes-to-the-agreement
[78] https://www.fishfarmermagazine.com/news/iceland-fish-farm-policy-broke-eea-rules/

UST operating licenses have been approved and issued, the site must be visited and inspected by representatives from both agencies; only upon successful completion of these inspections can fish be stocked and operations begin (pers. comm., Karl Steinar Óskarsson January 2022). The operating permits issued to each farm by MAST and UST, as well as each agency's respective inspection reports, can be found on each authority's website.[79] [80]

Holocene lava fields in Iceland (those less than ≈11,000 years old), such as those in Reykjanes, are all under special legal protection as mandated by Iceland's Nature Conservation Act (No. 60/2013),[81] Article 61, which provides special protections for certain ecosystems and geological features. Though the majority of Iceland's Arctic charr is produced on the lava fields of Reykjanes, the farms there are all sited in designated industrial areas (pers. comm., Egill Þórarinsson January 2023). It is relevant to note that the farm expansion EIA for one of these farms comments that, within the proposed construction area, there is almost no vegetation, and that, although individual surfaces in between have some moss vegetation, by far the largest part of the proposed construction area comprises lava and lava rocks. The EIA also takes a cumulative approach to assessing the planned farm expansion, and contextualizes the potential impacts within the wider scope of other activities and resource users in the area. The EIA discusses designated zoning around the farm area and in the adjacent region, and comments on which areas are for industry, recreation, etc., as well as noting those areas where planning has been suspended (no development is permitted). The EIA also mentions that the master plan of the local municipality emphasizes that, when natural resources are used, care should be taken as much as possible to use areas that have already been disturbed, rather than affecting new areas.

Summary of EIA implementation in the Arctic charr sector

Although it is evident that EIAs are routinely conducted for fish farming development proposals in Iceland, these primarily pertain to the Atlantic salmon sector, which is currently undergoing significant expansion. Few farms in the Arctic charr sector have undergone a full EIA; this is due to both the small size of the sector (only 10 farms, half of which produce <100 mt) and that most of these farms were established before EIAs were required for aquaculture. Only one new farm development proposal that includes Arctic charr in its scope has undergone an EIA;[82] all other EIAs relate to the expansion of existing farms, and these in turn relate to the facilities operated by the main producers on Reykjanes peninsula. Since 2010, there have also been five screening opinions issued by the NPA, all of which pertain to proposals for increased production; in each case, the proposed increase in production volume was deemed not to require an EIA. Per the EIA Act, which was last amended in 2021, all ocean-based farms that produce in excess of 3,000 mt are now subject to a mandatory EIA, whereas other farms, including land-based farms with a maximum biomass of ≥200 mt that drain to the sea and those with a maximum biomass of ≥ 20 mt that drain into freshwater, may be subject to an EIA, and

[79] https://www.mast.is/is/maelabord-fiskeldis/rekstrarleyfi-og-eftirlitsskyrslur
[80] https://ust.is/atvinnulif/mengandi-starfsemi/starfsleyfi/eldi-sjavar-og-ferskvatnslifvera/
[81] https://www.althingi.is/lagas/nuna/2013060.html
[82] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/nr/932#alit

this will be determined via an NPA screening decision. Farms producing below these thresholds may also be subject to an EIA if their proposed location is within a protected area. Because most Arctic charr farms were established in the 1980s and 1990s, before the inclusion of aquaculture in the scope of the EIA act, those farms that have never applied for an expansion in production have not required an NPA screening decision or an EIA. Although the current EIA process takes a cumulative approach to assessing farm development proposals, it is evident that smaller Arctic charr farms have undergone neither an EIA nor a screening decision, and their cumulative impacts have not been assessed because they operate under a grandfather clause.

<u>Justification and score for the content of habitat management measures</u>
The highest score possible for this factor is 5 out of 5, which is applicable in situations in which the content of habitat management measures are considered to be comprehensive. A comprehensive management system, as defined by the Seafood Watch Standard for Aquaculture Version A4.0, is one that implements an area-based, cumulative approach to aquaculture farm siting, which is integrated with the siting of other industries, and which is based on maintaining the ecosystem functionality of the affected habitats. Although this type of comprehensive management system is not yet fully implemented in Iceland, it would appear that management systems are evolving in this direction as the sector grows. Insights from industry stakeholders indicate that land-based farming, particularly of Atlantic salmon,[83] is likely to continue increasing, so the potential for cumulative habitat impacts at the regional scale will become increasingly important to address. Recently, Iceland's Fisheries Minister confirmed her intent to develop a comprehensive aquaculture policy that would accommodate future sector expansion, and that this process would be supported with an administrative audit conducted by the National Audit Office, to help identify the various issues.[84] Also, Iceland recently introduced new regulations for ocean-based farming, which are based on Norway's regulatory framework for this sector.[85]

Thus, the content of habitat management measures in Iceland is considered to be moderate, the management system does require farms to be sited according to ecological principles (such as the use of EIAs), and there are environmental protections that restrict where farms may be sited, but there are limited considerations of cumulative habitat impacts. The score assessed for Factor 3.2a is 3 out of 5.

<u>Factor 3.2b—Enforcement of habitat management measures</u>
As mentioned, the principal laws governing the habitat management measures pertaining to the Arctic charr sector in Iceland are the Environmental Impact Assessment of Projects and Plans Act, the Act on Aquaculture, and the Law on Hygiene and Pollution Prevention. Each of these laws has a clearly designated government agency for the implementation and monitoring of regulations. These are the National Planning Agency, which enforces the EIA process, and

[83] https://fishfocus.co.uk/akva-group-signs-contract-with-icelandic-land-farmed-salmon/
[84] https://www.fishfarmermagazine.com/news/iceland-to-set-out-new-aquaculture-strategy/
[85] https://www.fishfarmingexpert.com/iceland/braced-for-icelandic-boom/1188253

MAST and UST, both of which provide the permits required to operate a fish farm. The three laws provide each agency with the necessary enforcement tools to ensure that regulations are adhered to appropriately by farmers and to ensure that the habitats where they operate are adequately protected along with related ecosystem services. There are nine regional UST offices across Iceland, including the agency's head office in Reykjavík. MAST operates out of four district offices, with an additional central office in Selfoss. The National Planning Agency is based in Reykjavík. Both UST and MAST have more than 100 staff, although MAST has 4 staff working in the aquaculture department. The National Planning agency has over 30 staff, of whom 7 carry out EIAs.

Although EIAs have evidently been conducted infrequently for Arctic charr farms in the past, there is evidence that EIA legislation is being enforced and has recently been used to assess the potential impacts of increased production at individual farms, as well as to assess a new farm development that proposes to initially focus on salmon and to later incorporate production of Arctic charr. Furthermore, a searchable EIA database is now available on the National Planning Agency website, which allows an array of EIA-related documentation to be retrieved.[86] Article 32 of the EIA Act lays out the provisions in place to allow the National Planning Agency to issue administrative fines, if necessary.

For ongoing farm operations, all aquaculture operators are required to report to MAST on a monthly basis to facilitate the agency's ongoing monitoring of farm activities. If any regulatory violations come to light, the Aquaculture Act includes provisions for MAST to implement penalties. In such instances, farmers will initially be given a warning and are granted a period of time to rectify matters. Subsequently, if the license holder does not comply, MAST can decide to implement daily fines (up to ISK500,000 per day; approximately USD3,500) until the issue is resolved. In more extreme cases, licenses can be revoked or operators imprisoned; however, to date, neither of these measures has been deemed necessary, nor have maximum fines ever been levied (pers. comm., Karl Steinar Óskarsson January 2022). UST also has equivalent enforcement tools available, as discussed in the Effluent criterion.

It is evident that these three enforcement organizations are identifiable and are also easily contactable; furthermore, their resources would also appear to be appropriate to the scale of the industry. Area-based enforcement is active, although not comprehensive, and the permitting or licensing process is transparent and publicly available. Therefore, enforcement is considered effective, and the score for Factor 3.2b is assessed as 4 out of 5. Combined with the Factor 3.2a score of 3 out of 5, the final Factor 3.2 score is 4.8 out of 10.

Conclusions and Final Score

Although the presence and operation of Arctic charr farms inevitably affect the habitats where they operate to some degree, such impacts would appear to be minimal and habitat functionality is being maintained, according to the data available. The score for Factor 3.1—

[86] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/

Habitat Conversion and Function is 9 out of 10. The content of habitat management measures in Iceland is considered to be moderate, particularly regarding the current, relatively small size of the land-based Arctic charr sector. The score assessed for Factor 3.2a is a moderate 3 out of 5. For the efficacy of the enforcement of habitat management measures, the score for Factor 3.2b is 4 out of 5, which ranks this Factor as “effective.” Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 7.6 out of 10.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- Impact: Improper use of chemical treatments impacts non-target organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.
- Sustainability unit: non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments
- Principle: limiting 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

Chemical Use parameters		Score
C4 Chemical Use Score (0–10)		**8**
Critical?	No	**GREEN**

Brief Summary

The legislative framework governing chemical usage in Iceland is closely aligned with those adhered to by other Nordic nations and the European Union (EU). Regarding the aquaculture sector, both the Icelandic Environmental Agency (UST) and the Icelandic Food and Veterinary Authority (MAST) are designated as the competent authority for different aspects of this governance framework. Farms are required to report their use of chemical products to both agencies. Government officials contacted at both UST and MAST confirm that chemical usage is quite low in the Arctic charr sector, and that assessment is echoed in communications with those companies responsible for the majority of production. The most comprehensive, public-facing data source concerning the use of medicines in Icelandic aquaculture is the Annual Veterinary Report of Fish Diseases, which is published by MAST. Although the 2020 report stated that no antibiotics had been used in the production of salmonids for a continuous period of 9 years, this track record was interrupted in 2021 when one Arctic charr facility with some unvaccinated fish onsite required an antibiotic intervention of oxytetracycline to treat an outbreak of atypical furunculosis.

In addition to monitoring antibiotics, annual reports also document the aggregated quantities of other medicines that have been used to support fish health across the aquaculture sector. A breakdown of the specific quantities of chemicals used by the Arctic charr sector was obtained directly from MAST; these data show that chemical usage during the ongrowing phase is minimal and is limited to anaesthetics and formaldehyde: the former is used to facilitate fish handling and the latter to treat external parasites. There is a robust legislative framework in place to govern the appropriate dispensation and use of veterinary medicines in Iceland, and all medicinal drugs used on fish farms must be prescribed by a licensed veterinarian. Furthermore, MAST has access to a database of veterinary prescriptions, which is maintained by the Directorate of Public Health. These officially collected data are evidently used in the preparation of MAST's public-facing annual reports. In terms of chemical usage, the most recent report highlights the exceptional usage of oxytetracycline on one Arctic charr farm as the incident of most concern for the sector during the last decade. The final numerical score for Criterion 4—Chemical Use is 8 out of 10, which reflects the low environmental concern presented by the Arctic charr sector's use of chemicals.

Justification of Rating

The expansion of commercial aquaculture has necessitated the routine use of veterinary medicines to prevent and treat disease outbreaks, assure healthy stocks, and maximize production (FAO 2012); however, profiles of chemical use are highly variable, depending upon the species produced and the management characteristics. This Seafood Watch assessment focuses on antibiotics as the veterinary chemicals of most concern applied to Arctic charr flow-through systems in Iceland.

Governance

As stipulated in Article 2 of Icelandic Regulation No. 539/2000, regarding veterinarians' authorizations to prescribe drugs,[87] veterinary drugs may only be prescribed by veterinarians. The Icelandic regulatory framework pertaining to chemical substances and their use is based on related Nordic and European Union (EU) legislation. Such legislation includes consideration of the manufacture, marketing, and export of chemicals, registration of substances, licensing, labeling, usage, restrictions, and prohibitions.[88] Iceland—besides being a member of the Nordic Council,[89] which fosters a commonality of legislation and legal interpretation across its member states—is a party to the Agreement on the European Economic Area (EEA), which was also discussed somewhat in Criterion 3—Habitat. This international agreement requires that Iceland adheres to a number of EU Directives, one of which is Regulation (EC) No. 1907/2006 of the European Parliament and of the Council of 18 December 2006, concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH.)[90] The intent of this regulation is to improve the protection of human health and the environment from the risks that can be posed by chemicals.[91] Iceland's Environmental Agency, UST, is the competent authority (CA) for the implementation and enforcement of REACH.[92] [93]

The REACH Regulation is directly referenced in UST operating permits in the section that discusses chemical usage and safety data sheets. Operators are advised that they must work according to Act No. 61/2013 and Regulation No. 888/2015 on the registration, assessment, licensing, and restrictions of substances (REACH) as well as other regulations that apply to substances and chemical preparations. Permits specify that the safety data sheets of any

[87] https://www.government.is/publications/legislation/lex/2018/06/05/Reglulation-No.-539-2000-on-respecting-veterinarians-authorisations-to-prescribe-drugs/
[88] https://www.government.is/topics/consumer-affairs/chemicals/
[89] https://www.norden.org/en/nordic-council
[90] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32006R1907
[91] https://echa.europa.eu/regulations/reach/understanding-reach
[92] https://ust.is/atvinnulif/efni/reach/
[93] https://ec.europa.eu/environment/chemicals/reach/pdf/reports_2015/Iceland.pdf

chemicals kept on-site must be up-to-date and easily accessible. Furthermore, when such chemicals are stored on-site, access to them must be restricted, and the risk of contamination should be minimized as much as possible. The permit also states that efforts should be made to replace substances that have a harmful effect on humans and the environment with substances that are less harmful. In the event of a spillage of chemicals, farm operators are required by the regulation to have a response plan in place. If any hazardous materials and drug residues need to be disposed of, these must be taken to an approved hazardous waste disposal facility.

As a condition of UST operating permits, in addition to undergoing regular inspections by the agency, all farms are required to submit an annual summary report to UST that must include details of all chemicals used. Farms must also submit detailed, monthly operational reports to MAST, which is Iceland's competent authority (CA) in the field of food safety and animal health and welfare. As such, the veterinary division of MAST is responsible for the oversight and monitoring of all medicines and chemicals used in animal husbandry, including fish farming. For aquaculture, MAST's monitoring activities culminate in the production of a yearly review of the sector, entitled "Ársskýrsla dýralæknis fisksjúkdóma": the Annual Veterinary Report of Fish Diseases, the most recent edition of which (as of this writing) provides an overview of fish farming activity in 2021.[94] This report includes a section that discusses the use of medicines on Icelandic fish farms, in which it is noted that there is a strong emphasis on drug-free disease prevention and minimizing chemotherapeutant use across the sector.

As a party to the EEA Agreement and the convention establishing the European Free Trade Association (EFTA), Iceland has adopted EU guidelines regarding medicinal products, as described in the Medicinal Products Act No. 100/2020.[95] This act states that the Icelandic Medicines Agency shall operate a pharmacovigilance system to monitor the safety of medicinal products and that the Directorate of Public Health shall maintain a medicinal products database of prescriptions and the dispensing of medicinal products, including veterinarians' medicinal product prescriptions. Furthermore, MAST will have access to this database in order to monitor veterinarians' prescriptions and to monitor and promote the rational use of veterinary medicinal products in Iceland. If any violations are detected concerning the use of veterinary medicines, the act stipulates that administrative fines shall be imposed, regardless of whether such violations are committed on purpose or through negligence—and, in extreme cases, there is a provision for imprisonment.

In alignment with EU legislation, Iceland's register of pharmaceutical products that are banned for use in the production of food animals (including hydrobionts) prohibits the use of chloramphenicol, dimetridazole, nitrofurans (nitrofurazolidone and nifurprinol), malachite green, growth hormones, and pesticide agents. Those pharmaceutical products that are permitted for use in Icelandic aquaculture are shown in Table 1.

[94] https://www.mast.is/is/maelabord-fiskeldis/arsskyrslur-fisksjukdoma
[95] https://www.government.is/library/01-Ministries/Ministry-of-HealTh/PDF-skjol/Lyfjalög%20nr.%20100.2020%20-%20ensk%20þýðing.pdf

Table 1: List of approved vaccines, antibiotics, and other important medicinal products used in Icelandic aquaculture. Source: MAST (Icelandic Food and Veterinary Authority—Matvælastofnun).

<table>
<tr><th>Species</th><th>Vaccines</th><th>Anesthetic</th><th>Antiparasitic</th><th>Antifungal</th><th>Antibiotic</th></tr>
<tr><td>Atlantic salmon (Salmo salar)

Arctic charr (Salvelinus alpinus)</td><td>Alpha Ject 5-3

Alpha Ject 3000</td><td rowspan="5">Tricaine methanesulfonate

(Finquel vet.)
(Tricaine Pharmaq)
(MS-222)

Isoeugenol
(Aqui-S vet.)</td><td rowspan="5">General treatment:
Formaldehyde
(Aquacen formaldehyde)

Sea-lice treatment:
Deltametrin
(Alpha Max)

Emamectin benzoate
(Slice)</td><td rowspan="5">Bronopol
(Pyceze vet.)</td><td rowspan="5">Oxolinic acid
Oxytetracycline</td></tr>
<tr><td>Atlantic cod (Gadus morhua)</td><td>Alpha Marine Vibrio</td></tr>
<tr><td>Turbot (Scophthalmus maximus)</td><td>AquaVac ERM vet.</td></tr>
<tr><td>Senegal sole (Solea senegalensis)</td><td>Autovaccine TM Sole Immersion Stolt</td></tr>
<tr><td>Lumpfish (Cyclopterus lumpus)</td><td>Icthyovac Lumpus 5</td></tr>
</table>

Iceland also recently introduced Act No. 14/2022 on Veterinary Medicinal Products,[96] which implements EU Regulation 2019/6 of the European Parliament and of the Council on Veterinary Medicinal Products. This act lays down rules to ensure the quality and safety of veterinary medicinal products while ensuring a high degree of animal welfare and safety. Furthermore, the aim of the act is to ensure the safety and wholesomeness of foods from animal products in Iceland and to strengthen the fight against the resistance of infectious agents.

To summarize, the control structures that govern the availability, access, and use of chemicals for the Icelandic aquaculture sector take a comprehensive spectrum of factors into consideration; together, these seek to ensure the overall safety of medicinal products and their rational use. In this regard, Iceland's regulatory framework is closely aligned with that of other Nordic countries as well as the EU, including which chemicals are approved and which are banned. Icelandic regulations stipulate that only veterinarians are authorized to prescribe veterinary drugs, and a record of all such prescriptions and their subsequent dispensation is recorded in a database maintained by the Directorate of Public Health. In addition to being recorded in this database, any instances of veterinary drug use on fish farms must also be reported to the relevant authorities. The veterinary division of MAST is responsible for the oversight and monitoring of all medicines and chemicals that are used in the aquaculture sector and is legally empowered to enforce the governance measures that are in place.

Antimicrobial use

[96] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC209525

On the topic of antibiotics usage in national aquaculture, the Annual Veterinary Report of Fish Diseases notes that the routine, annual monitoring of antibiotic residues and other contaminants in farmed fish began in 1999, to bring Icelandic regulation into alignment with EU Directive No. 96/23/EEC on the Control of Antibiotics, Hormones and Other Contaminants in Animal Products and Farmed Fish. The most recent analysis in 2021 involved 412 samples, of both juveniles and harvest-sized fish, that were taken from a cross-section of farms and processing plants to be screened for drug residues as part of this routine. This analysis, which was performed by a laboratory in Denmark, found all samples to be drug-free—as has evidently been the case in all preceding years.

Data from the Annual Veterinary Report of Fish Diseases (Figure 16) chart the total quantity of antibiotics used by the entire Icelandic aquaculture sector from 1990 through 2021, per mt of fish harvested.

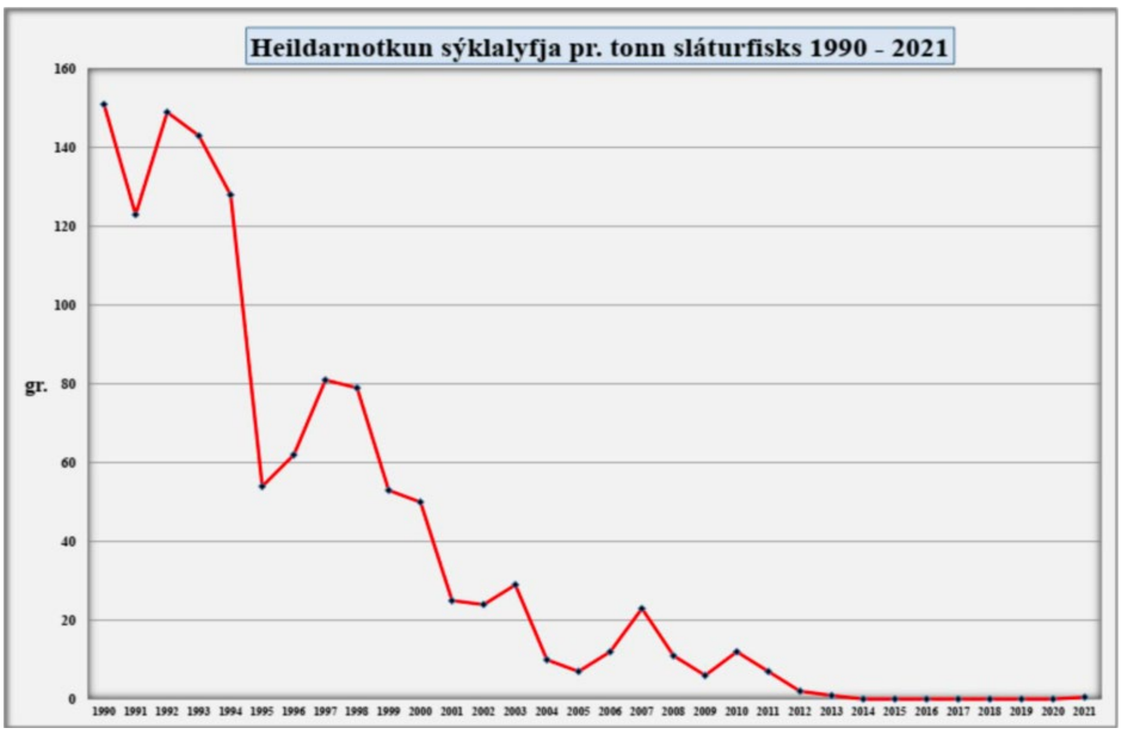


Figure 16: Icelandic aquaculture 1990–2021: Total use of antibiotics per metric ton (mt) of fish harvested (MAST 2021a).

As can be noted in Figure 16, no antibiotic use is documented between 2014 and 2020; however, a tiny uptick is evident in 2021. This resulted from an exceptional incident on an Arctic charr farm at the end of 2021, which will be discussed in this criterion. The annual report for the previous year, 2020, states that no antibiotics had been used in the production of salmonids in Iceland—Atlantic salmon, Arctic charr, and rainbow trout—for a continuous period of 9 years. During this period, the small amount of antibiotics used during 2012 and 2013, as indicated in Figure 16, were employed for R&D activities and for experimental Atlantic cod farming (MAST 2020)(MAST 2012). For several years, the feasibility of cod production in Iceland was explored; this included efforts to farm cod full-cycle using hatchery-raised juveniles, the ongrowing of captured wild cod, and the “ranching” of wild cod in “herds” (Halldórsson et al. 2012). Evidently, these cod farming ventures did not prove viable, and interest in farming of this species declined; no cod farming occurs in Iceland at present (MAST 2020).

It is evident that antibiotics are rarely used in the Icelandic Arctic charr sector, but when they have been prescribed, it has been to treat atypical furunculosis. The causative agent of atypical furunculosis is the pathogenic bacterium, *Aeromonas salmonicida* subsp*. achromogenes*, a pathogen for which there is typically good vaccination control across the sector (MAST 2020). Although vaccination against this disease is not required for fish that are grown full-cycle in freshwater, the majority of Arctic charr completes the ongrowing phase in brackish water—and, as a routine, these fish are always vaccinated as juveniles before being transferred from fresh to brackish water. But, an unusual exception to this protocol arose toward the end of 2021, when unvaccinated adult fish that were close to harvest size were transferred to a saltwater farm from a freshwater farm, because the latter facility ceased Arctic charr production and switched to salmon smolt production. An outbreak of atypical furunculosis was subsequently detected in the unvaccinated fish, which were treated with the administration of 26 kg of oxytetracycline in medicated diets—a treatment that extended into 2022. This exceptional incident interrupted a period of no antibiotic use by the sector from 2012 to 2020 (pers. comm., Dr. Gísli Jónsson January 2023). Before this event, antibiotics had last been used by the Arctic charr sector in January 2011, when 1 kg of oxytetracycline was prescribed to treat atypical furunculosis (MAST 2011).

In summary, it is apparent that antibiotics have been used infrequently by the Arctic charr sector during the past 10 years. From 2011 to 2021, there was only one recorded instance of antibiotic usage, and this was due to unusual circumstances. The antibiotic prescribed to treat this outbreak was oxytetracycline, which is ranked by the World Health Organization (WHO) as an antibiotic that is highly important to human medicine.[97] In light of the preceding analysis, the Seafood Watch Aquaculture Standard considers that, where data show that chemical treatments are used on average less than once per production cycle, or once per year for longer production cycles, this falls into a category of low environmental concern for the sector’s chemical use.

Use of other chemicals

Communications with UST personnel confirm that chemical use on Arctic charr farms is minimal and is typically limited to cleaning products and sometimes formalin (formaldehyde) (pers. comm., Steinar Rafn Beck Baldursson January 2022). This was also echoed in communications with the principal farm operators, who commented that, during ongrowing, the only chemicals utilized besides vaccines are those contained in hand soaps and cleaning products, which are used to disinfect equipment, tools, and nets (pers. comm., Árni Páll Einarsson December 2021) as well as tanks (pers. comm., Heiðdís Smáradóttir November 2021); however, the online

[97] https://www.who.int/publications/i/item/9789241512220

monitoring plan of one farm states that tanks are cleaned by pressure washing only.[98] The main Arctic charr producers commented on the importance of vaccination programs to their operations; these vaccines are used to help protect fish against furunculosis and vibrio (pers. comm., Árni Páll Einarsson December 2021). Farms will also typically adhere to a Veterinary Health Biosecurity Plan, which is updated each year in cooperation with a veterinarian (pers. comm., Heiðdís Smáradóttir November 2021). Though vaccines are typically the only chemicals used in the ongrowing phase, eggs are commonly treated with a fungicidal solution to improve the hatch rate, and a low-dosage formalin bath may be administered at the embryonic and juvenile stages to protect against ectoparasites (pers. comm., Dr. Bjarni K. Kristjánsson December 2021). Annual reports also indicate the usage of anesthetics, which farmers may use to reduce stress when handling or inspecting fish. Vaccines and chemicals used in the hatchery phase of production are not considered in this chemical criterion assessment.

Besides antibiotics, the Annual Veterinary Report of Fish Diseases also documents the quantities of other types of therapeutic chemicals that are used sector-wide, and a general comparison of medicinal usage between years can be made by referring to earlier annual reports.[99] Although a breakdown of the specific quantities used in the production of each species is not provided in these reports, data specific to the Arctic charr sector were provided through personal communications with MAST. Apart from the exceptional use of oxytetracycline described above, the use of other chemicals applied by the Arctic charr sector has remained consistent over the last decade, with no increasing or decreasing trends observed. Annual chemical usage comprises ≈40 liters of formaldehyde, to treat external parasites (Trichodina and costia); ≈40 l of iodophores, to disinfect fish eggs (Buffodine/Ovadine); ≈15 l of the fungicide Pyceze, during the hatchery phase; and 2 kg of anesthetics (Finquel), to facilitate fish handling (pers. comm., Dr. Gísli Jónsson January 2023).

Ecological impact

As previously discussed, land-based farms in Iceland are generally operated as flow-through systems, although one major Arctic charr producer operates a partial reuse aquaculture system (PRAS). The principal Arctic charr farms are located on the coast, and these facilities discharge their wastewater directly into the Atlantic Ocean. Though such systems have the potential to cause negative ecological impacts through the discharge of chemicals in effluents, no evidence of such impacts were identified during a review of UST farm inspection reports or during communications with UST personnel. Furthermore, a review of MASTS' Annual Veterinary Reports of Fish Diseases, together with communications with MAST personnel, indicate that the sector's use of chemicals is minimal. Other than the one intervention with antibiotics noted previously, the Arctic charr sector's use of chemicals in the last decade during ongrowing has been limited to formaldehyde and anesthetics, and the amount of both chemicals used has remained at a consistently low level each year. Formalin is typically used during the hatchery phase, which is not assessed in this criterion; however, if this chemical were to be used on

[98] https://ust.is/library/sida/atvinnulif/starfsleyfi-og-eftirlitsskyrslur/Vöktunaráæltun%20Matorka%20Grindav%C3%ADk%20ágúst%202020.pdf
[99] https://www.mast.is/is/maelabord-fiskeldis/arsskyrslur-fisksjukdoma

occasion to treat fish during ongrowing, it breaks down rapidly when it comes into contact with moisture and air and is not considered to present any significant risk to the environment.[100]

Conclusions and Final Score

From the above analysis, it is evident that the use of chemicals, chemotherapeutants, and antibiotics in the Arctic charr sector is minimal, and that this species has a demonstrably low need for chemical use, particularly from the use of vaccines. There is a robust legislative framework in place governing chemical use in Iceland, and all medicinal drugs used on fish farms must be prescribed by a licensed veterinarian. Furthermore, government officials contacted at both UST and MAST confirm that chemical usage is quite low in the Arctic charr sector, and this is echoed in communications with those companies responsible for the majority of production.

There is a high degree of transparency surrounding the overall use of chemicals in Icelandic aquaculture, and MAST publishes an Annual Veterinary Report of Fish Diseases, which quantifies chemical usage across the aquaculture sector. Regarding antibiotics usage, these annual reports note that, before 2021, no antibiotics had been used in the production of salmonids in Iceland for a continuous period of 9 years. But, this was interrupted in late 2021 when one Arctic charr facility was prescribed oxytetracycline to treat an outbreak of atypical furunculosis in unvaccinated fish, a situation that arose from unusual circumstances. Other than this exceptional use of antibiotics on one farm, chemical usage by the Arctic charr sector has remained consistent over the past decade. During ongrowing, chemical use is limited to the application of minimal quantities of formaldehyde and anesthetics.

In fish farming sectors where chemical treatments have been used on average less than once per year (or once per production cycle for those shorter than 1 year), the Seafood Watch Standard for Aquaculture Version A4.0 considers such production-related chemical impacts to be of low environmental concern. The final numerical score for Criterion 4—Chemical Use is 8 out of 10, which reflects the low environmental concern presented by the Arctic charr sector's use of chemicals.

[100] https://www.chemicalsafetyfacts.org/chemicals/formaldehyde/

Criterion 5: Feed

Impact, unit of sustainability and principle

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

Criterion 5 Summary

Feed parameters		Value	Score
F5.1a: Forage Fish Efficiency Ratio (FFER)		0.93	
F5.1b: Source fishery sustainability score (0–10)			6.0
F5.1: Wild fish use score (0–10)			7.0
F5.2a: Protein INPUT (kg/100 kg fish harvested)		46.20%	
F5.2b: Protein OUT (kg/100 kg fish harvested)		19.10%	
F5.2: Net Protein Gain or Loss (%)		–58.66%	4.0
F5.3: Species-specific kg CO_2-eq kg^{-1} farmed seafood protein		14.96	6.0
C5 Feed Final Score (0–10)			**5.9**
	Critical?	NO	YELLOW

Brief Summary

Data used to assess the Feed criterion are based on information received directly from Iceland's principal Arctic charr producers, as well as related materials from feed manufacturers. These data have been aggregated and weighted to provide an overview of the average ongrowing diet used to culture Arctic charr in Iceland. The average inclusion levels and sources of fishmeal and fish oil in typical ongrowing diets were found to be 32.7% (27.96% from by-products) and 20.38% (17.36% from by-products), respectively. The FFER for fishmeal and fish oil is 0.33 and 0.93, respectively, with the higher of the two values used to assess Factor 5.1a—Feed Fish Efficiency Ratio. As a result, it is estimated that 0.93 mt of wild fish are required to produce 1.0 mt of farmed Arctic charr. A review of data pertaining to the status of the fisheries from which these marine inputs are sourced results in a score of 6 out of 10 for Factor 5.1b—Sustainability of the Source of Wild Fish. These two scores combine to produce a final Factor 5.1 score of 7 out of 10. With an estimated weighted average feed protein content of 38.5%, there is a substantial net protein loss of 58.66%, which leads to a Factor 5.2 score of 4 out of 10. The Feed

Footprint (Factor 5.3), which is an assessment of the global warming potential of production as it relates to feed use, is 14.96 kg CO_2-eq per kg of farmed Arctic charr protein, which equals a low to moderate impact score of 6 out of 10 for Factor 5.3.

The final score for this criterion is a combination of these three factors, with a double weighting for the Wild Fish Use factor. These are: Factor 5.1 (7 out of 10), Factor 5.2 (4 out of 10), and Factor 5.3 (6 out of 10), which combine to provide a final overall score of 5.9 out of 10 for Criterion 5—Feed.

Justification of Rating

This Seafood Watch Feed criterion assesses three core aspects of feed use: the use of wild fish, including the sustainability of the source; the net protein gain or loss; and the "global" impact of feed production (i.e., the feed footprint), which is calculated based on the climate change impact (CCI, in CO_2-eq) of the feed ingredients necessary to grow 1 kg of farmed Arctic charr protein. Further details are available in the Seafood Watch Standard for Aquaculture Version A4.0.[101]

Ongrowing diets are supplied to the Icelandic Arctic charr sector by either of two local feed mills, Laxá[102] and Foðurblandan,[103] which, for the purposes of the following calculations, have been weighted as contributing 75% and 25%, respectively, to the sectors' average feed use. Data used to assess this criterion, including the economic feed conversion ratio (eFCR),[104] the feed composition, and the sources and inclusion rates of marine and terrestrial ingredients, are based on data received directly from Iceland's principal Arctic charr producers, as well as related materials from feed manufacturers.

<u>A note on recent developments in Arctic charr feed formulations</u>

Between 2011 and 2014, a collaborative research project that focused on Arctic charr diets was conducted in Iceland, Norway, and Sweden. This endeavor sought to reduce production costs across the sector by reassessing the protein needs of Arctic charr and identifying the efficacy by which fishmeal inputs could be replaced by plant-based proteins. This evidently led Iceland's Laxá Feed mill, the main global producer of Arctic charr feeds, to revise the formulation of their commercial diets as a result of the project's findings.[105]

In Iceland, the principal research partners for this project were Hólar University[106] and Matís,[107] which is a public limited company specializing in food industry R&D. After initial laboratory trials, commercial trials were conducted on Arctic charr farms using four different diets. One of

[101] https://prod.seafoodwatch.org/globalassets/sfw/pdf/standards/aquaculture/seafood-watch-aquaculture-standard-version-a4.pdf
[102] https://www.laxa.is
[103] https://fodurblandan.is
[104] Note that eFCR = total feed used divided by total harvest of fish
[105] https://www.nordicinnovation.org/programs/profitable-arctic-charr-farming-nordic-countries
[106] https://www.holar.is/en
[107] https://matis.is/en/um-matis/

these was a typical commercial diet containing 42.5% crude protein, which was used as a control, whereas the other three all had a lower protein inclusion level of 34%. Of these three, one contained only plant proteins with zero fishmeal inclusion, whereas the other two included a reduced amount of fishmeal: one formulation focused on reduced protein, whereas the other prioritized low cost, with the former containing more fishmeal than the latter. All diets included fish oil as their primary oil source. The results showed that diets in which fishmeal protein was totally replaced with plant protein resulted in poor growth performance, most likely because of reduced food digestibility; the production time for this group was 64% longer than that of the control group, which researchers estimated would result in production yields 39% lower than the commercial control diet. But, based on results obtained with the other lower protein formulations, it was demonstrated that a high inclusion of plant protein was viable, if some fishmeal was also included. Researchers noted that, although these diets did not compromise on product quality, production yields were anticipated to be 5–9% less than with the commercial control diet, which would likely result in lower profits for farmers when all factors were weighed. Although the optimal protein requirement was found to be related to fish size, a protein content of 34–35% was found to be adequate for ongrowing diets. Researchers also noted that diets with a higher proportion of plant-based ingredients, compared to conventional diets, may result in a higher degree of environmental impacts arising from effluents, because of elevated BOD and nitrogen, and of phosphorous loading (Arnason et al. 2015).

Matís also collaborated with the University of Iceland on a life-cycle assessment (LCA) of Icelandic Arctic charr production, which identified feed manufacturing as the factor of fish production with the most environmental impact. The study considered three different types of feed: one conventional Arctic charr formulation that included fishmeal, one with a higher inclusion rate of agricultural inputs and reduced fishmeal, and one that was based on black soldier fly larvae that did not include fishmeal. Researchers found the black soldier fly-based feed to have the best LCA performance of all three diets and, considering the other two feeds, that improvements were evident when marine inputs were replaced by agricultural ones (Smárason et al. 2017).

Factor 5.1—Wild Fish Use
This factor considers the quantity of wild fish used in Arctic charr diets (Factor 5.1a) combined with the sustainability of the fisheries from which these wild marine inputs are sourced (Factor 5.1b). Together, these metrics are used to calculate a score from 0 to 10 for wild fish use.

<u>Factor 5.1a—Feed Fish Efficiency Ratio (FFER)</u>
The FFER is a measure of the dependency that the production of farmed fish has upon wild fish as a result of the amount of wild fish used in aquafeeds. This is expressed as a ratio between wild fish inputs; i.e., fishmeal (FM) and fish oil (FO) compared to farmed fish outputs. The following methodology also considers whether these marine ingredients are derived from whole wild fish or from by-products. An increasing proportion of global FM and FO supplies are rendered from processing offcuts, such as heads, viscera, skin, bones, and scales, rather than from whole wild caught fish; these by-products are retrieved both from the processing of wild as well as cultured fish. Recent estimates indicate that, globally, >27% of FM and 48% of FO

supplies are derived from by-products (FAO 2022b). Regarding the domestically manufactured ongrowing diets used by Iceland's Arctic charr sector, on average, ≈85% of FM/FO inputs are derived from by-products. By-product availability in Iceland is high because of the country's significant fisheries sector, which landed over 150,000 mt of fish in 2018; as a net exporter of fish and fishery products, Iceland also has a substantial fish processing sector (OECD 2021a)(NSII 2020).

The data used to calculate the FFER for the Icelandic Arctic charr sector are shown in Table 2. To derive a single value for fishmeal and fish oil inclusion levels (e.g., both whole fish and by-products) from multiple feed manufacturers, the weighted average was estimated based on the reported inclusion levels and the estimated use share of each feed type. For example, the total fishmeal and fish oil inclusion levels and the percentage derived from by-products are estimated using the inclusion levels reported by each feed type and how much (as a percentage) relative feed was used in the ongrowing diets (see Appendix 2, Equations 1 and 2). The resulting calculations estimate the total fishmeal and fish oil inclusion levels of 32.7% and 20.38%, respectively, while by-products are estimated as 27.96% and 17.36%, respectively. Whole fish inclusion levels were estimated as the difference between the total inclusion level and the by-product inclusion level (see Appendix 2, Equation 3).

The standard yield values for fishmeal and fish oil (22.5% and 5%, respectively) are estimated from Tacon and Metian (2008). The eFCR values were derived from feed manufacturers and producers. Altogether, the FFER values (see Appendix 2, Equation 4) for fishmeal and fish oil are estimated as 0.33 and 0.93, respectively.

Table 2: Parameters and their calculated values used to determine the use of wild fish in farmed Arctic charr diets in Iceland.

Eq. variable	Parameter	Data
	Fishmeal inclusion level (total)	**32.70%**
a	Fishmeal inclusion level (whole fish)	4.74%
	Fishmeal inclusion level (by-product)	27.96%
b	Assessed fishmeal inclusion level (by-product)[108]	1.40%
e	Fishmeal yield	22.50%
	Fish oil inclusion level (total)	**20.38%**
c	Fish oil inclusion level (whole fish)	3.02%
	Fish oil inclusion level (by-product)	17.36%
d	Assessed fish oil inclusion level (by-product)	0.87%
f	Fish oil yield	5.00%
g	Economic Feed Conversion Ratio (eFCR)	1.20

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

	Calculated values
Fishmeal feed fish efficiency ratio ($FFER_{FM}$)	0.33
Fish oil feed fish efficiency ratio ($FFER_{FO}$)	0.93
Assessed FFER	**0.90**

The Feed Criterion considers the FFER of both fishmeal and fish oil and uses the higher of the two to determine the score. Therefore, the score for Factor 5.1a—Feed Fish Efficiency Ratio is 0.9; based on first principles, this means that approximately 0.9 mt of wild fish are required to obtain the fish oil needed in feeds to produce 1 mt of farmed Icelandic Arctic charr.

<u>Factor 5.1b—Sustainability of the Source of Wild Fish</u>

This factor evaluates the sustainability of the fisheries supplying fishmeal and fish oil for Arctic charr grow-out feed. There are two different feed types, each of which has different fishmeal and fish oil inclusion levels from varying sources (i.e., fisheries and species). To calculate a final weighted score from multiple feed types, several steps are completed:

1. Determine the sustainability score for each source fishery.
2. Calculate whole fish and by-product 5.1b Source Fishery Sustainability scores.
3. Determine the total sustainability scores by combining the whole fish and by-product sustainability scores for fishmeal and fish oil.
4. Calculate a final Factor 5.1b score by weighting the overall fishmeal and fish oil scores by the FFER of each, considering the actual biomass of fish required to produce the ingredients.

The results and summary of each step are presented here, while each calculation and its respective equation is detailed in Appendix 2.

Step 1: Determine the sustainability score for each source fishery

In accordance with the Seafood Watch Standard for Aquaculture, the sustainability of wild fish inputs in aquafeeds are assessed using commonly available metrics developed by FishSource,[109] the Marine Stewardship Council (MSC)[110], Marin Trust[111] (previously IFFO RS), and Seafood Watch wild fisheries assessments, as applicable. The score allocations based on these various assessment methodologies are further defined in the Standard.

Table 3 shows the source fisheries typically used in Arctic charr diets in Iceland and their respective FishSource scores and MSC certification status, which together have been used to determine the assessed sustainability score for each species. If the guidance in the Standard for either of these assessment methodologies (MSC or FishSource) differs for any of the fisheries under consideration, the higher of the two scores has been applied. A more detailed overview of the FishSource score for each species is also provided in Table 4.

[109] https://www.fishsource.org
[110] https://www.msc.org
[111] https://www.marin-trust.com

Table 3: Source fisheries and the resulting Factor 5.1b sustainability scores.

Species	FAO Fishing Area	MSC Certification	FishSource Scores (0–10)	Assessed Sustainability Score (0–10) for Factor 5.1b
Capelin (*Mallotus villosus*)	FAO27	MSC-F-31299 (F-SAI-025) Certified—no conditions	All scores ≥ 6	8
Atlantic herring (*Clupea harengus*)	FAO27	MSC-F-31464 (F-ACO0098) Certified—one condition	All scores ≥ 8	8
Mackerel (*Scomber scombrus*)	FAO27	MSC-F-31331 (F-SAI-027) Effective date of suspension: 3/2/2019; certification withdrawn 5/17/2022	One score < 6 (i.e., "Managers Compliance" scores 3.2)	4
Blue whiting (*Micromesistius poutassou*)	FAO27	MSC-F-31346 (F-DNV-251547) Certification withdrawn 12/30/2020	All scores ≥ 6	6
Atlantic cod (*Gadus morhua*)	FAO27	MSC-F-31301 (F-TUN-1104) Certified—four conditions carried over from the previous certificate[112]	All scores ≥ 6	6

The species shown in Table 3 are Northeast Atlantic fish stocks, which are reviewed and scientifically assessed by the International Council for the Exploration of the Seas (ICES). As indicated, although all five species were previously MSC certified, both mackerel and blue whiting recently had their certifications withdrawn. This situation has arisen due to the inability of coastal states in the region (the European Union, Norway, Iceland, the Faroe Islands, the United Kingdom, Russia, and Greenland) to agree on the allocation of sustainable catch quotas for these species. Collaborative, equitable, and sustainable management of fisheries in multi-jurisdictional areas can present considerable challenges to the parties involved. A complex array of factors must be considered, including fluctuations and shifts in the abundance, distribution, and migratory patterns of these target species, in conjunction with the perspectives of each coastal state. In the absence of mutually agreed-upon quota allocations, coastal states have unilaterally set their own quotas for these species, resulting in combined catch volumes that exceed the limits advised by ICES (ABPmer, 2018).

In response to the withdrawal of MSC certification for these species, European retailers and processors have set up the North Atlantic Pelagic Advocacy (NAPA) group, a supply-chain initiative that seeks to drive improvement in the management of these fisheries by achieving a

[112] https://fisheries.msc.org/en/fisheries/isf-iceland-cod/@@view?about=

formal agreement on catch limits based on scientific advice.[113] [114]. Aquafeed producers have also recently threatened to boycott the use of blue whiting in their formulations unless policy makers in the respective coastal states can implement mutually agreed-upon sustainable catch quotas.[115] An overview of the status of these fisheries in terms of management and stock health is shown in Table 4.

Table 4: Overview of FishSource scores for each fishery considered in Factor 5.1b.

FishSource Scores					
Species	**Management Quality**			**Stock Health**	
	Management Strategy	**Managers Compliance**	**Fishers Compliance**	**Current Health**	**Future Health**
Capelin (*Mallotus villosus*)	≥ 6	10.0	9.8	≥ 6	≥ 6
Atlantic herring (*Clupea harengus*)	≥ 8	10.0	9.2	10.0	8.0
Mackerel (*Scomber scombrus*)	≥ 6	3.2	10.0	10.0	7.2
Blue whiting (*Micromesistius poutassou*)	9.4	10.0	10.0	10.0	7.4
Atlantic cod (*Gadus morhua*)	≥ 8	10.0	9.4	9.4	7.9

Summary of the source fisheries used in Arctic charr feeds and related score allocation

- Capelin is MSC-certified, and this certification applies to catches within Iceland's 200 nm exclusive economic zone (EEZ) using either pelagic trawl or purse seine;[116] in accordance with the Seafood Watch Standard for Aquaculture, this qualifies for a score of 8. Considering the FishSource score for this fishery, all scores are ≥6, including stock health,[117] which in accordance with the Standard qualifies for a score of 6 out of 10. The higher of these two scores has been applied, so the Seafood Watch sustainability score for this fishery is 8 out of 10.

[113] https://www.seafish.org/about-us/news-blogs/north-atlantic-pelagic-advocacy-group-established-to-drive-improvements-in-management-of-fisheries/
[114] https://fishingnews.co.uk/news/mackerel-challenges-head-neafc-agenda/
[115] https://www.fishfarmingexpert.com/biomar-cargill-napa/salmon-feed-makers-threaten-to-boycott-northeast-atlantic-blue-whiting/1483727
[116] https://fisheries.msc.org/en/fisheries/isf-iceland-capelin/
[117] https://www.fishsource.org/stock_page/752#

- Atlantic herring is MSC-certified with one condition, and this certification applies to catches within Iceland's EEZ using midwater trawl mesh size 40 mm, or purse seine mesh with size 31 mm;[118] in accordance with the Seafood Watch Standard for Aquaculture, this qualifies for a score of 6. Considering the FishSource score for this fishery, all scores are ≥8,[119] which in accordance with the Standard qualifies for a score of 8 out of 10. The higher of these two scores has been applied; therefore, the Seafood Watch sustainability score for this fishery is 8 out of 10.
- Mackerel is also caught within Iceland's EEZ and is fished using midwater trawl or purse seines; though this stock was previously certified by MSC, this certification is currently withdrawn.[120] [121] With no MSC certification in place, the score is based on the FishSource assessment, which includes one score that is <6[122] (i.e., Managers Compliance scores 3.2). Based on this, the Seafood Watch sustainability score for this fishery is 4 out of 10.
- Blue whiting is also caught within Iceland's EEZ and is fished using pelagic trawl, bottom trawl, or purse seine; although this stock was previously certified by MSC, this certification is currently withdrawn.[123] With no MSC certification in place, the score is based on the FishSource assessment, for which all scores are ≥6, including stock health.[124] Based on this, the Seafood Watch sustainability score for this fishery is 6 out of 10.
- Atlantic cod is MSC-certified with four conditions carried over from the previous certificate,[125] and this certification applies to catches within Iceland's EEZ using gillnet, hooks and lines, seine nets, Danish seine, demersal otter trawl, pelagic trawl, nephrops trawl, and shrimp trawl. In accordance with the Seafood Watch Standard for Aquaculture, this qualifies for a score of 6. Considering the FishSource score for this fishery, all scores are ≥6,[126] which in accordance with the Standard qualifies for a score of 6 out of 10. The Seafood Watch sustainability score for this fishery is 6 out of 10.

Step 2. Calculate whole fish and by-product 5.1b Source Fishery Sustainability scores

To determine a single Factor 5.1b Source Fishery Sustainability score for fishmeal and fish oil sourced from whole fish and by-products across two separate feed types, a weighted average sustainability score is calculated based on the inclusion level and feed usage (calculated in Factor 5.1a; see results in Table 2). (See Appendix 2, Equation 5, for weighted average calculations and methods). Table 5 summarizes the results of these calculations along with all

[118] https://fisheries.msc.org/en/fisheries/isf-icelandic-summer-spawning-herring-trawl-and-seine/@@view
[119] https://www.fishsource.org/stock_page/1719
[120] https://www.msc.org/media-centre/press-releases/press-release/msc-certificates-suspended-for-all-north-east-atlantic-mackerel-fisheries#fisheries
[121] https://fisheries.msc.org/en/fisheries/isf-iceland-mackerel/@@assessments
[122] https://www.fishsource.org/fishery_page/5076
[123] https://fisheries.msc.org/en/fisheries/isf-iceland-north-east-atlantic-blue-whiting/
[124] https://www.fishsource.org/fishery_page/3058
[125] https://fisheries.msc.org/en/fisheries/isf-iceland-cod/@@view?about=
[126] https://www.fishsource.org/stock_page/689#

the inputs. All data points in the table were provided, except for the Sustainability Scores, which are determined in Step 1.

Table 5: Marine ingredients inclusion levels and sustainability scores

		Feed 1	Feed 2
Marine input	**Sustainability Score**	**Inclusion**	**Inclusion**
Total inclusion of fishmeal from whole fish as a percentage of the total feed		6.32	0
Capelin (*Mallotus villosus*)	8.00	3.17	
Atlantic herring (*Clupea harengus*)	8.00	1.05	
Mackerel (*Scomber scombrus*)	4.00	1.05	
Blue whiting (*Micromesistius poutassou*)	6.00	1.05	
Weighted whole fish FM Inclusion %	4.74		
Weighted whole fish sustainability score	7.00		
Total inclusion of fishmeal from by-products as a percentage of the total feed		25.68	34.8
Capelin (*Mallotus villosus*)	8.00	13.10	17.40
Atlantic herring (*Clupea harengus*)	8.00	2.48	5.80
Mackerel (*Scomber scombrus*)	4.00	2.48	5.80
Atlantic cod (*Gadus morhua*)	6.00	7.62	5.80
Weighted by-product FM Inclusion %	27.96		
Weighted by-product sustainability score	7.01		
Total inclusion of fish oil from whole fish as a percentage of the total feed		4.02	0
Blue whiting (*Micromesistius poutassou*)	6.00	4.02	
Weighted whole fish FO Inclusion %	3.02		
Weighted whole fish sustainability score	6.00		
Total inclusion of fish oil from by-products as a percentage of the total feed		19.98	9.5
Capelin (*Mallotus villosus*)	8.00	16.82	4.75
Atlantic herring (*Clupea harengus*)	8.00	1.58	2.38
Mackerel (*Scomber scombrus*)	4.00	1.58	2.38
Weighted by-product FO Inclusion %	17.36		
Weighted by-product sustainability score	7.59		

These results indicate that the fishmeal sustainability scores from whole fish and by-products are 7.00 and 7.01, respectively, while fish oil sustainability scores from whole fish and by-products are 6.00 and 7.59, respectively.

It is important to note that the ratios of the inclusion level of marine inputs will vary, depending on what the respective fisheries are catching at any given time; likewise, by-product inputs are also dependent on what is being caught and processed. The nutritional profile of these different marine inputs also vary, so the marine components in any given feed run will vary somewhat to ensure that the nutrition provided in each batch of feed remains consistent. Some of the North Atlantic's largest fish stocks, including cod, are found in Iceland's exclusive fisheries zone, an area that is seven times the size of Iceland.[127] Iceland's substantive fisheries necessitate a large volume of processing, which is reflected in the high level of by-product inclusion in domestically produced aquafeeds. Note that the proportion of capelin inputs is somewhat higher than that of the other species indicated, which is reflective of the 2022 fishing season and the relative amounts of each species that were landed.

Step 3: Determine the total sustainability scores by combining the whole fish and by-product sustainability scores for fishmeal and fish oil.

Using the fishmeal and fish oil sustainability score values for whole fish and by-products calculated in Step 2, the weighted overall sustainability scores (in which only 5% of the byproducts' sustainability scores are included; see SFW aquaculture standard p. 38) for total fishmeal and fish oil inputs can be calculated (see Appendix 2, Equation 6). The overall sustainability scores of fishmeal and fish oil are then estimated as 7.00 and 6.08, respectively.

Step 4: Calculate a final Factor 5.1b score by weighting the total fishmeal and fish oil scores by the FFER of each, considering the actual biomass of fish required to produce the ingredients.

The last step is to modify the weighted overall sustainability scores for fishmeal (7.00) and fish oil (6.08) by their respective FFER calculated in Factor 5.1a ($FFER_{FM}$ = 0.33; $FFER_{FO}$ = 0.93). This is done to accurately attribute the sustainability of source fishery scores with the biomass utilized for feed (see Appendix 2, Equation 7). The resulting Factor 5.1b—Source Fishery Sustainability score is estimated to be 6.32 out of 10.

When combined, the Factor 5.1a—Feed Fish Efficiency Ratio score (0.93) and the Factor 5.1b—Source Fishery Sustainability Score (6.32) result in a final Factor 5.1 score of 6.8 out of 10.

Factor 5.2—Net Protein Gain or Loss

Factor 5.2 measures the net protein efficiency of the fish farming process based on the feed protein inputs and the harvested fish protein outputs. The net protein gain or loss is calculated according to Equation 8, with the results presented in Table 6.

$$\text{Net Protein} = \frac{[\text{Harvested fish protein content \%} - (\text{feed protein content \%} \times \text{eFCR})]}{(\text{feed protein content \%} \times \text{eFCR}) \times 100} \quad \text{(Eq. 8)}$$

Where:

- Harvested fish protein content is 19.1% (i.e., the percent of whole harvested fish)
- Feed protein content is 38.5%
- eFCR is 1.2

[127] https://www.iceland.is/trade-invest/fisheries

Table 6: Parameters and respective values used to determine net protein gain or loss in the production of farmed Arctic charr in Iceland.

Parameter	Data
Protein content of feed	38.50%
Economic Feed Conversion Ratio	1.20
Total protein INPUT per mt of farmed Arctic charr	462.00 kg
Protein content of whole harvested Arctic charr	19.10%
Total protein OUTPUT per mt of farmed Arctic charr	191.00 kg
Net protein loss	–58.66%
Seafood Watch Score (0–10)	**4**

There is an overall net protein loss of 58.66% incurred during the production of Arctic charr in Iceland, which leads to a Factor 5.2 score of 4 out of 10.

Factor 5.3—Feed Footprint

Factor 5.3 is an approximation of the embedded global warming potential (GWP) (kg CO_2-eq including land-use change [LUC]) of the feed ingredients required to grow 1 kg of farmed seafood protein. This calculation is performed by mapping the ingredient composition of a typical feed used against the Global Feed Lifecycle Institute (GFLI) database[128] to estimate the GWP (kg CO_2-eq) of 1 metric ton (mt) of feed, which is then multiplied by the eFCR and the protein content of whole harvested fish.

Typical ingredients for Arctic charr feeds include fishmeal and fish oil from whole fish and by-products (as explained in Factor 5.1), and terrestrial crop ingredients. There are no terrestrial animal ingredients used. A summary of the GWP for each feed ingredient category (e.g., fishmeal from whole fish, fishmeal from by-products, fish oil from whole fish, fish oil from by-products, and terrestrial crop ingredients) by feed type (e.g., 1 or 2) can be found in Table 7. To understand how the values for each category's feed type have been calculated in the column "kg CO_2 eq/mt feed," see Appendix 2, Equation 9.

Table 7: Estimated embedded global warming potential of 1 mt Icelandic Arctic charr feed, calculated according to GFLI values for marine and terrestrial inputs.

GWP (incl. LUC) Value				
Feed ingredients (≥2% inclusion)	**Feed item**	**GLFI ingredient name used for calculations**	**Ingredient inclusion %**	**kg CO_2-eq/ mt feed**
Fishmeal from whole fish	Feed 1	Fishmeal, from capelin, at processing/NO Economic S Fishmeal, from Atlantic herring, at processing/NO Economic S *Fishmeal, at processing/NO Economic S	6.32%	67.13

128 https://globalfeedlca.org/gfli-database/

		Fish meal, from blue whiting, at processing/NO Economic S		
Fishmeal from by-products	Feed 1	*Fishmeal, from Atlantic herring by-products, at processing/NO Economic S Fishmeal, from Atlantic herring by-products, at processing/NO Economic S Fishmeal, from mackerel by-products, at processing/NO Economic S Fishmeal, from cod by-products, at processing/NO Economic S	25.68%	156.92
	Feed 2	*Same ingredients as Feed 1*	34.80%	185.16
Fish oil from whole fish	Feed 1	Fish oil, from blue whiting, at processing/NO Economic S	4.02%	99.60
Fish oil from by-products	Feed 1	*Fish oil, from Atlantic herring by-products, at processing/NO Economic S Fish oil, from Atlantic herring by-products, at processing/NO Economic S Fish oil, from mackerel by-products, at processing/NO Economic S	19.98%	106.25
	Feed 2	*Same ingredients as Feed 1*	9.50%	48.04
Terrestrial crop ingredients	Feed 1	**Soybean protein-concentrate, at processing/GLO Economic S & Soybean protein-concentrate, at processing/BR Economic S **Soybean meal (solvent), at processing/GLO Economic S & Soybean meal (solvent), at processing/BR Economic S **Crude rapeseed oil (solvent), at processing/Average of ALL entries Economic S & Crude rapeseed oil (solvent), at processing/BR Economic S **Wheat middlings & feed, at processing/GLO Economic S & Wheat middlings & feed, at processing/US Economic S **Rapeseed meal (solvent), at processing/GLO Economic S &	44.00%	1,370.9

		Rapeseed meal (solvent), at processing/BR Economic S		
	Feed 2	*Same ingredients as Feed 1*	55.70%	3,887.63
		Sum of Total, Feed 1	100.00%	1,800.81
		Sum of Total, Feed 2	100.00%	4,120.83

* Note: Where a GLFI ingredient name for a particular fish input is preceded by an asterisk, this indicates that the GLFI database did not include an exact match for the fish species in question and that the referenced ingredient name has therefore been used as a proxy; clarification of these substitutions is provided below.

** Note: Because the specific origins of terrestrially sourced feed ingredients are unknown, the average value of the two GLFI ingredients shown have been used for GWP calculation purposes; these are further clarified below.

<u>GLFI values selected for GWP including LUC calculations: as shown in Table 7</u>

Fishmeal and fish oil whole fish and by-products

Because the GLFI database does not include any entries specifically for Icelandic fisheries, the country of origin selected from the GLFI database for all fish inputs is Norway. When there was no exact match in the GFLI database for the specific species of fish used in feeds, a similar species has been substituted; all such instances are indicated with a single asterisk in Table 7 and are further clarified as follows:

* **Fishmeal from whole fish:** "Fishmeal, at processing/NO Economic S" has been used as a substitution for mackerel, for which there was no whole fish entry in the GLFI database.

* **Fishmeal from by-products:** "Fishmeal, from Atlantic herring by-products, at processing/NO Economic S" has been used as a substitution for capelin, for which there was no by-product entry in the GLFI database.

* **Fish oil from by-products:** "Fish oil, from Atlantic herring by-products, at processing/NO Economic S" has been used as a substitution for capelin, for which there was no by-product entry in the GLFI database.

Terrestrial ingredients

All terrestrial ingredients are marked with a double asterisk in Table 7. Because the specific origins of terrestrially sourced feed ingredients are unknown, an average value between the GLFI listed "GLO" (i.e., global) value and the worst value for that ingredient has been applied, per the guidance in the Seafood Watch Standard for Aquaculture. The selected GLFI entries for each terrestrial ingredient are clarified as follows:

** **To calculate an average value for Soybean protein concentrate**, the average of the following two GLFI entries have been used: Soybean protein-concentrate, at processing/GLO Economic S & Soybean protein-concentrate, at processing/BR Economic S (note that BR = Brazil).

** **To calculate an average value for Soybean meal**, the average of the following two GLFI entries have been used: Soybean meal (solvent), at processing/GLO Economic S & Soybean meal (solvent), at processing/BR Economic S.

** **To calculate an average value for Rapeseed oil**, the average of the following two GLFI entries have been used: Crude rapeseed oil (solvent), at processing/Average of ALL entries Economic S & Crude rapeseed oil (solvent), at processing/BR Economic S.

** **To calculate an average value for Wheat**, the average of the following two GLFI entries have been used: Wheat middlings & feed, at processing/GLO Economic S & Wheat middlings & feed, at processing/US Economic S (note that US = United States).

** **To calculate an average value for Rapeseed meal**, the average of the following two GLFI entries have been used: Rapeseed meal (solvent), at processing/GLO Economic S & Rapeseed meal (solvent), at processing/ BR Economic S.

As can be seen in Table 7, the total estimated embedded GWP of Icelandic Arctic charr feed is Feed 1: 1,800.81 and Feed 2: 4,120.83 kg CO_2-eq/mt feed (see Appendix 2, equation 10). Considering a whole harvest protein content of 19.1% and an eFCR of 1.2, it is estimated that the feed-related GWP of 1 kg of Arctic charr protein is 11.31 and 25.89 kg CO_2-eq (see Appendix 2, equation 11). The two scores are weighted and combined (see Appendix 2, equation 12) to produce a single value, which equates to a low to moderate 14.96 kg CO_2-eq per kg of farmed Arctic charr protein. This results in a score of 6 out of 10 for Factor 5.3—Feed Footprint.

Conclusions and Final Score

The final score is a combination of the three aforementioned factors, with a double weighting for the Wild Fish Use factor. Factors 5.1 (7 out of 10), 5.2 (4 out of 10), and 5.3 (6 out of 10) combine to provide a final overall score of 5.9 out of 10 for Criterion 5—Feed.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- Impact: competition, genetic loss, predation, habitat damage , spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations
- Sustainability unit: affected ecosystems and/or associated wild populations.
- Principle: preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

Escape parameters	Value	Score
F6.1: System escape risk	6	
F6.1: Recapture adjustment	0	
F6.1: Final escape risk score		6
F6.2: Competitive and genetic interactions		6
C6 Escape Final Score (0-10)		**6**
Critical?	No	YELLOW

Brief Summary

Although no escape events have been documented in the Icelandic Arctic charr sector, it is evident that there is still some potential escape risk inherent during production. The land-based systems employed by the Arctic charr sector predominantly utilize brackish water obtained via boreholes, which is later discharged to the ocean. Escape risk is mitigated by the installation of multiple screens and secondary capture devices, which places such systems into a low to moderate risk category, according to the Seafood Watch Standard for Aquaculture. Thus, the score for Factor 6.1 is 6 out of 10. The score for Factor 6.2, Competitive and Genetic Interactions, is driven by Iceland's centralized breeding program, which has differentiated farmed Arctic charr genetics from wild native Arctic charr, and scores 6 out of 10. Factors 6.1 and 6.2 combine to give a final numerical score of 6 out of 10 for Criterion 6—Escapes.

Justification of Rating

Factor 6.1—Escape Risk

Factor 6.1 assigns a level of risk to each type of production system based on the ability of farmed species to escape the system and enter the surrounding ecosystem. Production system escape risks are categorized from low to high and are evaluated based on the governance, production system type and characteristics (i.e., a measure of the system's openness), farm management practices, escape trends, and vulnerability to environmental factors (e.g., tsunami, flood, predator damage).

Governance

As stipulated in Article 13 of the Act on Aquaculture[129] (Act No. 71 of 2008, as amended last by Act No. 113 of 2015) and Articles 45 and 47, plus Annex IV of Regulation No. 540/2020,[130] all fish farms in Iceland must actively implement operating protocols that minimize the risk of escape and must also have a contingency plan in place to deal with accidental escapes. This legislation requires farm operators to have an escape response plan available on-site that addresses escape prevention and the actions that must be taken, if such an event occurs.

One of the principal concerns of the Icelandic Food and Veterinary Authority (MAST) is escape prevention. Before a new fish farming license can be validated, a representative from MAST will go to the farm to assess the system and its escape risk potential. To identify the risk drivers for escape, such an assessment will involve a review of the farm system design and the placement of all inline drainage barriers, such as tank grids, screens, and secondary capture devices. Operators must receive approval from MAST before fish can be stocked for the first time (pers. comm., Karl Steinar Óskarsson January 2022). Thereafter, MAST will follow up with regular inspections to ensure that operators remain in compliance with the terms of their license and that all mitigation measures to prevent accidental escapes are in place. In recent years, MAST have developed an online "fish farming dashboard" that allows public access to operating licenses and inspection reports.[131]

If an operator believes that an escape event has occurred, it is incumbent upon them to take immediate action to identify the cause and to prevent further accidental release of fish. They must also immediately report the incident to the Directorate of Fisheries and MAST, as well as their local municipality and fishing associations. It is incumbent upon farm operators to do all they can to minimize escape-related ecological damage and to immediately begin efforts to retrieve escapees.

Production system characteristics

Iceland's Arctic charr production takes place in land-based tank farms that are operated as flow-through systems, although one of the main producers has implemented a partial recirculating system (PRAS) in which the maximum water reuse possible is around 70%. The majority of production takes place in coastal farms that discharge directly into the Atlantic Ocean, although a few percent of Arctic charr are also raised full-cycle in freshwater systems that discharge into freshwater. Land-based farms in Iceland are required to incorporate multiple inline security screens in their drainage outlets to reduce the risk of escapes, and freshwater farms typically also incorporate a settling pond into their design. Regarding the physical location of Iceland's Arctic charr farms, there do not appear to be any specific environmental factors that increase the likelihood of an escape event occurring, such as being in a flood-prone region.

[129] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC177700
[130] https://www.reglugerd.is/reglugerdir/eftir-raduneytum/atvinnuvega--og-nyskopunarraduneyti/nr/0540-2020
[131] https://www.mast.is/is/maelabord-fiskeldis/rekstrarleyfi-og-eftirlitsskyrslur

Although the risk of fish escaping from land-based facilities is perceived to be inherently less than, for example, that presented by open net-pen culture, any production system in which effluents are discharged into the natural environment still has the potential for an accidental escape event. On the Reykjanes peninsula, where the majority of production takes place, groundwater is available in abundance; thus, ongrowing facilities typically employ quite high flow rates (or discharge rates) of ≈2,000 l/sec. Although these high flow rates are advantageous for maintaining optimal water quality in tanks, they also elevate the risk of an escape event if there were a mechanical issue with any of the drainage barriers in the system.

Farm management practices

Per the conditions of their operating permits, it is incumbent upon farm operators to implement a range of protocols to mitigate escape risk. To ensure the efficacy of these protocols, training is provided to staff to ensure that they have the skills and competence necessary to implement them. This training assures that workers are familiar with the farm's standard operating procedures, including daily observation of the integrity of standpipes and grids in tanks, top nets, drainpipes, and other screens and secondary capture devices that are incorporated into the farm system design. Training is also provided to staff regarding the farm's emergency escape response plan, which is kept on-site.

Historical perspective on escape trends

A review of MAST's Arctic charr farm inspection reports does not indicate the occurrence of any escape events, a status that was echoed in communications with MAST personnel, who noted that farms have a "double system" in place, with barriers utilized in tank outflows (pers. comm., Karl Steinar Óskarsson January 2022). Likewise, communications with the principal producers concur that escapes have never been recorded or observed, and that they are averted by the implementation of escape prevention protocols and the installation of double or triple defense barriers in land-based systems (pers. comm., Heiðdís Smáradóttir November 2021)(Árni Páll Einarsson December 2021).

Evaluation of escape risk and the compliance of farms with required mitigation measures

Although no evidence of escapes is documented in MAST's online database of inspection reports—indeed, some reports comment on operations being "exemplary"—it is evident that shortfalls in escape prevention protocols have been identified on some farms during some of these visits. The types of deviations commented upon in inspection reports include not having a response plan available on-site, not providing adequate escape response training to staff, not having equipment on hand to recapture fish in the event of an escape, and not having adequate fish-proof barriers present in the drainage system. If a deviation is identified during a periodic inspection, inspectors will assess the scope and severity of the issue; though a simple issue may be fixed immediately, inspectors will specify a deadline by which more challenging issues must be addressed. If a deadline is issued, there will also be a follow-up inspection to ascertain if the issue has been addressed appropriately. By reviewing each farm's inspection reports in chronological order, it is possible to see where any deviations have been identified and the subsequent action taken to rectify the situation. As of this writing, all reported deviations appear to have been marked as rectified in later reports—although not always in a timely manner within the specified deadline—except one deviation noted on the farm of a smaller producer, for which a follow-up inspection report has yet to be posted online.

Summary and evaluation of escape risk

Although no escape events have been documented in the Arctic charr sector, it is evident that there is still some potential escape risk inherent during production, because land-based Arctic charr farms discharge their waste into natural waterbodies. To mitigate the risk of escape, all farmers are required by law to implement a range of measures and strategies. To ensure that farms are compliant with these requirements, MAST routinely conducts inspection visits, and follow-up visits if required. The Seafood Watch Standard for Aquaculture considers that flow-through (i.e., single-pass) tanks or raceways present a moderate risk in terms of this factor. But, where such systems use multiple or fail-safe escape prevention methods, or active best management practices for the design, construction, and management of escape prevention, the escape risk concern for such systems is reduced from moderate to low–moderate. The Standard considers tank-based recirculation systems (any % reuse with multiple screens, water treatment, and secondary capture devices) to present a low level of concern for this escape risk factor; indeed, the PRAS Arctic charr facility falls within this category. But, considering the average Icelandic land-based systems, the score assessed for Factor 6.1 is a low to moderate 6 out of 10.

Factor 6.2—Competitive and Genetic Interactions

As noted in Factor 6.1, no escape events have been documented on land-based Arctic charr farms in Iceland; furthermore, in light of the production systems employed, the escape risk is assessed to be low to moderate. Even so, some degree of escape risk remains, and the potential impact of unobserved or undocumented escapes warrants consideration. This factor is a trait-based measure of the likelihood of genetic and/or ecological disturbance from escapees, based on their native or nonnative status and/or their domestication and ecological characteristics. The likely survival of the species after escape is also taken into consideration.

Overview of wild Arctic charr and its characteristics

Arctic charr is native to Iceland and is the country’s most abundantly occurring salmonid (Gudmundsdóttir et al. 2017). Salmonids are generally renowned for their phenotypic plasticity, and this is particularly true of Arctic charr, for which there are lacustrine, riverine, and anadromous stocks. Although anadromous stocks are present in Iceland, these do not occur at latitudes below roughly 65 °N, so all stocks in continental Europe are resident in freshwater only. Anadromous Arctic charr juveniles remain in freshwater for 1–9 years before migrating to the sea, where they will remain in coastal areas for the short duration of the Arctic summer, before returning to overwinter in frozen lakes. In freshwater, Arctic charr feeds on benthos, plankton, and small fish, whereas at sea, its diet is mainly fish. Anadromous Arctic charr grows considerably faster than lacustrine and riverine stocks. The IUCN Red List of Threatened Species global review of Arctic charr ranks it as a species of “Least Concern” (Freyhof & Kottelat 2008).

Survivability potential of farmed Arctic charr escapees

The majority of Arctic charr production in Iceland occurs in coastal farms that utilize brackish groundwater to facilitate the ongrowing phase, and effluents are subsequently discharged into the sea. Considering the survivability potential of fish escaping these systems, it is important to note that, although Arctic charr can tolerate full salinity for a few months in the summer, farming year-round in full-salinity sea cages is not viable. Literature indicates an upper tolerance of around 27–28 ppt (Imsland et al. 2019); however, the optimal year-round range for this species is 15–20 ppt. If Arctic charr is subject to sustained salinities ≥25 ppt, health issues are likely to arise as the fish struggle to deal with this biological challenge (pers. comm., Bjarni K. Kristjánsson December 2021)(pers. comm., Dr. Bernhard Laxdal, Fish Veterinarian, Aquaculture Innovation, Iceland December 2021). It can therefore be concluded that, if an escape were to occur in a typical farm setting such as this, escapees would be unlikely to survive unless their accidental release occurred during the few summer months when this species can tolerate full salinity (33–35 ppt), after which they lose this ability (Imsland et al. 2019). Such escapees would then also need to find a river to navigate up in order to survive. But a few of the smaller producers complete the entire production cycle in freshwater (Eurofish 2020), and the potential for escapees to survive in freshwater is evidently greater than that of fish escaping into full-salinity seawater. Although data on the exact volume of Arctic charr produced in freshwater were not identified, it is evident that such production is a small minority (<10%) of overall production, so it is not considered in the scoring here.

Evaluation of the potential for genetic introgression occurring as a result of accidental escape

As will be explored further in Criterion 8X—Source of Stock, Hólar University runs a breeding program that provides most of the eggs used by the Arctic charr sector in Iceland. Since its inception in 1992, this breeding program has worked to improve reproductive success, increase growth rates, and overcome early maturation. To prevent inbreeding, the parent fish for each generation are selected out of a minimum of 30 sibling groups. Each generation spans around 3–4 years (Hólar 2022), so the breeding program is now working with fish that have been domesticated for around 10 generations. Any potential farm escapees would demonstrate some degree of genetic differentiation from wild stocks, so there is a potential risk of genetic introgression if escaped farmed stocks survived to breed with wild conspecifics.

Factor 6.2 Conclusion

Although Arctic charr is native to Iceland, the Hólar University breeding program has selected for preferred aquaculture traits, such as increased growth rates and greater reproductive success. As a result of around 10 generations of this selection process, there is evidently some degree of genetic differentiation from wild stocks, which suggests a score of 6 out of 10. The likelihood of farmed stock escaping and surviving appears to be low, due to the receiving waters (the Atlantic Ocean) and this species' varying intolerance to full-strength salinity—suggesting a score of 8 out of 10. The overall score for this factor is determined by the lowest of these conditions, so the score for Factor 6.2—Competitive and Genetic Interactions is 6 out of 10.

Conclusions and Final Score

Although no escape events have been documented in the Icelandic Arctic charr sector, it is evident that there is still some potential escape risk inherent during production. The land-based systems employed by the Arctic charr sector predominantly utilize brackish groundwater obtained via boreholes, which is later discharged to the Atlantic ocean. Escape risk is mitigated by the installation of multiple screens and secondary capture devices, which places such systems into a low to moderate risk category, according to the Seafood Watch Standard for Aquaculture. Thus, the score for Factor 6.1 is 6 out of 10. The score for Factor 6.2 is driven by the breeding program, which has differentiated farmed Arctic charr genetics from wild native Arctic charr and scores 6 out of 10. Factors 6.1 and 6.2 combine to give a final numerical score of 6 out of 10 for Criterion 6—Escapes.

Criterion 7: Disease; Pathogen and Parasite Interactions

Impact, unit of sustainability and principle

- Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body
- Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.
- Principle: preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites.

Criterion 7 Summary

Risk-Based Assessment		
C7 Pathogen and parasite parameters (0–10)	**Score**	**8**
Critical?	No	**GREEN**

Brief Summary

Both communications with experts and a review of literature on the sector indicate that Arctic charr is typically a robust species. The occurrence of on-farm diseases is low, and average mortality rates are in the range of 5–8% during the majority of production, which takes place in brackish water; a small balance of production is raised full-cycle in freshwater, for which the mortality rate is 1–3%. The principal disease encountered by farmers is atypical furunculosis, a bacterial infection for which vaccine control across the sector is generally good, although the commercially available vaccines currently in use have been primarily developed for Atlantic salmon, not Arctic charr. A gradual and incremental decline in the efficacy of these vaccines has been observed, which has prompted the development of a bespoke vaccine for the specific strain of furunculosis that affects Icelandic stocks. Bacterial kidney disease can also present a challenge to farmers; the bacterium that causes this condition is endemic in Iceland (as is the bacterium that causes furunculosis). These pathogens can enter facilities from the environment via the water intake if biosecurity measures are insufficient. A range of other diseases can also affect the sector, and a review of these, their severity, and the number of instances of each are detailed in the Annual Veterinary Report of Fish Diseases. These reports are compiled and published by the Icelandic Food and Veterinary Authority (MAST), which is Iceland's competent authority in the field of food safety and animal health and welfare. Although disease transmission into natural water bodies may occur via culture water being discharged from farms, the monitoring data concerning wild species do not indicate that pathogens or parasite numbers on wild species are amplified above background levels by such aquaculture activities. As a result, the level of concern for this criterion is low, and the final numerical score for Criterion 7—Disease is 8 out of 10.

Justification of Rating
This criterion does not assess the impact that disease has upon the species being farmed; rather, it assesses the ecological risk that on-farm diseases may present to wild species in the surrounding environment. Although the data quality and availability are good for the diseases that affect cultured Arctic charr, and wild fish in Iceland are also monitored for disease, the data specifically concerning the potential impact of disease transmission from farmed to wild fish are lacking. As a result, the disease category of Criterion 1—Data was assessed as 5 out of 10, and the Seafood Watch Risk-based assessment for this criterion has been utilized.

Governance of disease-related issues within the Icelandic aquaculture sector
The Icelandic Food and Veterinary Authority (MAST) is Iceland's competent authority (CA) in the field of food safety and animal health and welfare, which includes the enforcement of related regulations. Specific legislation for the control of fish diseases was first implemented in Iceland in 1957, and the Fish Disease Committee (Fisksjúkdómanefnd), presided over by the Chief Veterinary Officer, was also established at this time (OECD 2021b). In 1985, a national health control surveillance program began to monitor for—and confirm the absence of—exotic and/or other serious diseases.[132] Wild fish are routinely sampled for disease, and all fish farms are obligatory participants in this initiative, in which farms may be randomly selected for routine fish health inspections and disease surveillance. Data pertaining to the ongoing activities of the Fish Disease Committee are available on MAST's website,[133] as are data collected through the surveillance program (MAST 2021b). The fish diseases that are notifiable and reportable by law, as specified in Iceland's Regulation No. 52/2014 on Notifiable and Reportable Animal Diseases,[134] are shown in Table 8.

Table 8: Notifiable and reportable fish diseases per Icelandic Regulation No. 52/2014 (MAST 2021b).

Serious notifiable diseases:	Other notifiable diseases:	Reportable diseases:
• Epizootic haematopoietic necrosis (EHN) • Viral haemorrhagic septicaemia (VHS) • Infectious haematopoietic necrosis (IHN) • Infectious salmon anemia (ISA) • Pancreas disease (PD/SAV) • Infectious pancreas necrosis (IPN) • Oncorhynchus masou virus (OMV) • Cardiomyopathy syndrome (CMS/PMCV) • Koi herpesvirus (KHV) • Spring viraemia of carp (SVC) • Viral nervous necrosis (VNN) / Viral encephalopathy and retinopathy (VER) • Gyrodactylosis	• Furunculosis • Piscirickettsiosis • Bacterial Kidney disease (BKD) • Proliferative kidney disease (PKD) • Whirling disease • Swimbladder nematode of eel • Salmon louse infection (*Lepeophtheirus salmonis*)	• Viral erythrocytic necrosis (VEN) • Ulcerative dermatic necrosis (UDN) • Heart and skeletal muscle inflammation (PRV/HSMI) • Salmon gill poxvirus (SGPV) • Papillomatosis • Atypical furunculosis • Cold water vibriosis • Enteric red mouth (ERM) • Epitheliocystis • Mycobacteriosis • Winter ulcers • Vibriosis • Marine louse infection (*Caligus elongatus*)

[132] https://www.government.is/topics/business-and-industry/fisheries-in-iceland/aquaculture/
[133] https://www.mast.is/is/maelabord-fiskeldis/fisksjukdomanefnd
[134] https://www.government.is/library/04-Legislation/Regulation%20no.%2052%202014%20on%20notifiable%20and%20reprotable%20animal%20diseases-mai-2015.pdf

Act No. 50/1986 on the Research Department of Fish Diseases[135] is also a key piece of legislation that promotes national research on fish diseases. The Research Department of Fish Diseases, whose role is to handle research on fish diseases, is a department within the University of Iceland's Institute for Experimental Pathology at Keldur.[136]

Since 1993, the year that the European Union (EU) was officially created,[137] Iceland has been legally bound to incorporate many of the measures contained in EU Directives into their national legislation; this requirement is due to Iceland's membership in the European Economic Area (EEA). Consequentially, for disease-related governance, Act No. 25 on Animal Diseases and Measures to Control Them was promulgated by the Icelandic parliament in 1993 (and last amended in 2020).[138] Note that the EEA brings together the member states of the EU and three of the European Free Trade Association (EFTA) States—Iceland, Liechtenstein, and Norway—into a single market.[139] Though the conduct of EU member states is overseen by the European Commission, the EFTA Surveillance Authority (ESA) has the responsibility of ensuring that EFTA states respect their obligations under the EEA Agreement.

The Annual Veterinary Report of Fish Diseases for 2021 notes that ESA regulators last conducted an audit inspection in Iceland in 2019, when they evaluated the veterinary health controls that were in place across the aquaculture sector. ESA post-audit reports are published on the ESA website. The report for 2019 notes that, "The mission team found that the official control system put in place by the competent authority generally ensures that the requirements of Directive 2006/88/EC are fulfilled in the area of fish health and that surveillance programmes regarding farmed fish provide sufficient guarantees that a disease would be detected" (EFTA-SA 2019). Iceland's Act No. 60/2006 on the Prevention of Fish Diseases (last amended by Act No. 88/2020)[140] incorporates the relevant measures contained in Directive 2006/88/EC on Animal Health Requirements for Aquaculture Animals and Products Thereof, and on the Prevention and Control of Certain Diseases in Aquatic Animals.[141] Article 10 of Act No. 60/2006 particularly addresses the measures that must be taken if any infectious diseases or parasites are discovered on a fish farm or in a natural waterbody, and authorizes MAST, after consultation with the Fish Diseases Committee and in consideration of Act No. 25/1993, to take the necessary actions to control the situation.

Each month, all fish farmers must submit a detailed report to MAST concerning the progress of their operations, including any health issues and related mortalities that may have occurred (pers. comm., Karl Steinar Óskarsson January 2022). Likewise, such mortalities must also be reported to the Environment Agency (UST) in the annual reports that farms are required to

[135] https://www.althingi.is/lagas/nuna/1986050.html
[136] https://keldur.is/is
[137] https://european-union.europa.eu/principles-countries-history/history-eu/1990-99_en
[138] https://www.informea.org/en/node/657746
[139] https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/iceland_en
[140] https://www.informea.org/en/node/657787
[141] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006L0088&from=EN

submit to this authority, although these mortality data are not made available online (pers. comm., Steinar Rafn Beck Baldursson January 2022). Communications with stakeholders and experts concur that mortality rates in the Arctic charr sector in Iceland are typically low and in the region of 5%. This percentage was broadly confirmed by MAST personnel, who affirm that mortality rates within the sector typically range between 5% and 8% on saltwater farms and from 1% to 3% on freshwater farms (pers. comm., Dr. Gísli Jónsson January 2023).

Aquaculture literature describes Arctic charr as a robust species that has good resistance to many types of disease (Gunnarsson & Rúnarsson 2006). The general hardiness of this species is also confirmed by experts (pers. comm., Dr. Bjarni K. Kristjánsson December 2021)(pers. comm., Dr. Bernhard Laxdal December 2021) and in annual reports published by MAST. These reports, entitled "Ársskýrsla dýralæknis fisksjúkdóma," the Annual Veterinary Report of Fish Diseases, include an overview of the main infectious diseases that have affected aquaculture production over the past year, including which species have been affected, the severity of outbreaks, and the number of instances. Reports dating to 2006 are available on the MAST website,[142]. The following is a synthesis of disease data pertaining to Arctic charr production in Iceland.

<u>Atypical furunculosis</u>

Literature notes, and experts concur, that the infectious disease of most concern to Arctic charr farmers in Iceland is atypical furunculosis, which can cause severe septicaemia and high mortality rates in salmonids (pers. comm., Dr. Bjarni K. Kristjánsson December 2021)(pers. comm., Dr. Bernhard Laxdal December 2021)(Giang & Guðmundsdóttir 2016). There are two declared forms of furunculosis, defined as either typical or atypical, which are caused by the pathogenic bacterium *A. salmonicida*. This species can be divided into five subspecies: *A. salmonicida* subsp. *salmonicida* is the etiological agent of typical furunculosis, whereas the four atypical species, *achromogenes*, *masoucida*, *pectinolytica*, and *smithia*, cause atypical furunculosis. Furunculosis affects many species of marine and freshwater fish worldwide—both wild and farmed—with some species, such as Arctic charr, being susceptible to both forms (Giang & Guðmundsdóttir 2016). The particular strain of atypical furunculosis that affects the Icelandic Arctic charr sector is caused by the bacterium *Aeromonas salmonicida* subsp. *achromogenes* (Asa), which is endemic in Icelandic waters and is present in the surrounding environment of all coastal Arctic charr farms that utilize brackish water (MAST 2021a). Researchers found the transmission and development of Asa to be temperature-dependent, with greater mortalities observed at 12 °C than at 8 °C during trials (Giang & Guðmundsdóttir 2016).

Vaccines against furunculosis in salmonids have been available in Iceland since 1990 and are now routinely used by all coastal-based Arctic charr farms to protect their stocks. Note that this disease does not present a problem to freshwater farms. The vaccines that are commercially available have been developed based on *A. salmonicida* subsp. *salmonicida*, with the principal objective of protecting Atlantic salmon from typical furunculosis (Kristjansdottir et al.

[142] https://www.mast.is/is/maelabord-fiskeldis/arsskyrslur-fisksjukdoma

2022)(Giang & Guðmundsdóttir 2016). The use of these vaccines has significantly reduced the occurrence of atypical furunculosis disease outbreaks But, the protection afforded by these vaccines appears to have diminished somewhat over time, such that mortalities were noted to have increased incrementally from 2010 through 2015 (Figure 17); this is particularly evident in fish during the later stages of ongrowing (Giang & Guðmundsdóttir 2016).

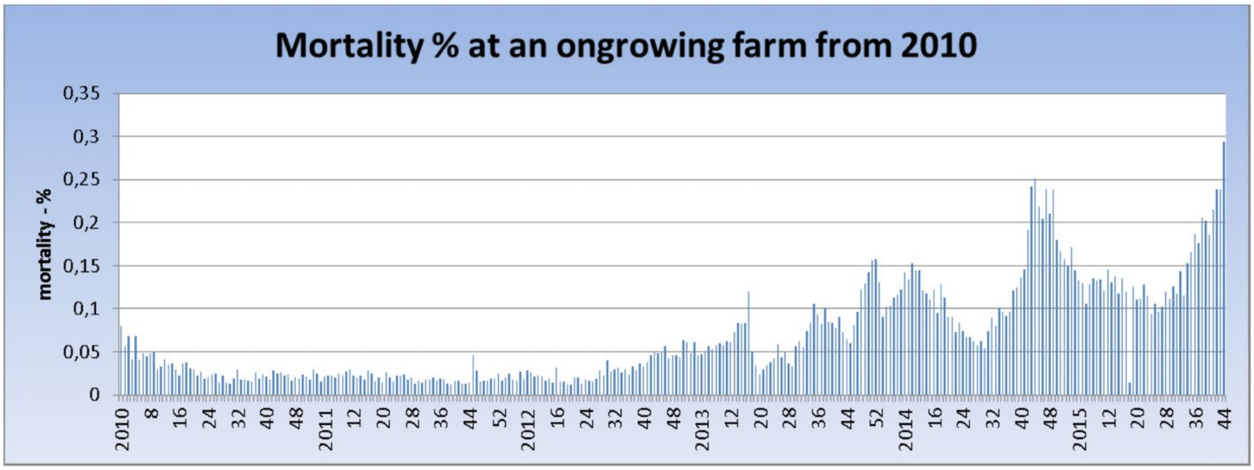


Figure 17: Weekly mortality (%) of vaccinated Arctic charr (0.1_1.6 kg) caused by *A. salmonicida* subsp. *achromogenes* at an ongrowing fish farm in Iceland. Data courtesy of Heiðdís Smáradóttir (Giang & Guðmundsdóttir 2016).

A new vaccine specifically for Arctic charr is currently in development, which is based on *Aeromonas salmonicida* subsp*. achromogenes*. The results of trials so far have been encouraging, demonstrating that the experimental vaccine provides a higher degree of protection against atypical furunculosis in Arctic charr than the commercial vaccines currently in use (Kristjansdottir et al. 2022).

MAST's annual report for 2021 notes that, although few instances of furunculosis were detected across the domestic aquaculture sector during the year, a serious outbreak of this disease occurred on one Arctic charr farm because of unusual circumstances. Though all Arctic charr reared in brackish water are routinely vaccinated against this disease as juveniles, this is not required for fish raised full-cycle in freshwater. On this occasion, unvaccinated fish were transferred from a freshwater farm, which was ceasing Arctic charr production and switching to salmon smolt production, to a saltwater farm. The fish were close to harvest size, and it was anticipated that the lack of vaccination would not be problematic at this advanced stage of ongrowing. But, the severity of the subsequent disease outbreak was such that antibiotics were prescribed, which ended a period of over 10 years when antibiotics had not been used in Icelandic salmonid culture (MAST 2021a). Although the average annual mortality of Arctic charr on brackish water farms is 5–8%, around 80% of this mortality is attributable to atypical furunculosis (pers. comm., Dr. Gísli Jónsson January 2023).

Studies indicate that an increased resistance to atypical furunculosis may be heritable, as is the case with typical furunculosis, so research into the potential to select for this trait is ongoing at Hólar University as part of its Arctic charr breeding program. It is also possible that a genetic relationship exists between resistance to atypical furunculosis and other diseases, such that the success of this initiative could potentially reduce the disease susceptibility of cultured Arctic charr to a wider spectrum of pathogens (pers. comm., Dr. Bjarni K. Kristjánsson December 2021)(Giang & Guðmundsdóttir 2016).

To summarize: although outbreaks of atypical furunculosis occur infrequently on Arctic charr farms because of good vaccine control, this is the disease of greatest concern to the sector, and it accounts for around 80% of overall mortalities.

<u>Other diseases that affect Arctic charr</u>

Although atypical furunculosis is the primary infectious disease of concern to the Arctic charr sector, Giang & Guðmundsdóttir (2016) note that bacterial kidney disease (BKD), proliferative kidney disease (PKD), and winter ulcer disease can also affect this species. Regarding bacterial kidney disease (BKD), which is caused by the bacterium *Renibacterium salmoninarum*, the 2021 MAST report states that routine sampling and analysis of all aquaculture species for this disease returned a 0% rate of infection for Arctic charr (MAST 2021a). Notably, Atlantic salmon is much more vulnerable to this disease than is Arctic charr. Though this bacterium is endemic in Icelandic waters and is commonly found in wild Arctic charr stocks, it generally does not greatly affect this species or cause symptoms and/or mortalities. Because *Renibacterium salmoninarum* is present in the wild, farmers must be diligent about the biosecurity of their incoming water and also ensure that the rearing environment is optimal—suboptimal conditions are stressful for fish, making them much more likely to succumb to any disease challenge. Broodstock are also closely screened for this disease (pers. comm., Dr. Bernhard Laxdal December 2021). Although the natural resistance to BKD in Icelandic farmed Arctic charr stocks is evidently good, an outbreak of this disease caused a decline in production between 2004 and 2006 (Solar 2009)(Bergheim 2015). Good husbandry and monitoring protocols are key to avoiding BKD occurring among stocks, because the available therapeutants have a limited effect in controlling this disease (Gudmundsdóttir et al. 2017).

Although a range of parasites have evidently been identified on and in Icelandic wild Arctic charr (Kristmundsson & Richter 2009)(Johnston 2006), parasites do not present a notable concern to the Icelandic Arctic charr farming sector at present. In North America and Europe, proliferative kidney disease (PKD), which is caused by the myxozoan parasite *Tetracapsuloides bryosalmonae*, has brought about significant mortalities in farmed salmonids. This parasite has also been implicated in the declines of wild brown trout and Atlantic salmon fry in rivers in Switzerland and Norway, respectively—in both cases, it has been suggested that the situation has been exacerbated by warming waters (Okamura et al. 2011). In Iceland in 2008, the presence of *T. bryosalmonae* was confirmed for the first time in Lakes Elliðavatn and Vífilsstaðvatn (Kristmundsson et al. 2010)(Svavarsdóttir 2016). Since then, studies have confirmed that the parasite is widespread in rivers and lakes in Iceland (MAST 2021a). It has been hypothesized that PKD is a potential factor contributing to a decline in wild Arctic charr, possibly because of the increased stress brought on by warming waters, which in turn may make wild populations more susceptible to this disease (pers. comm., Dr. Bjarni K. Kristjánsson December 2021)(Kristmundsson et al. 2010). Some researchers note that an increase in PKD outbreaks is anticipated as climate change impacts intensify (Helgadóttir et al. 2021). Other parasites mentioned in MAST's Annual Veterinary Report of Fish Diseases for 2021 are *Ichthyobodo necator*, an ectoparasite that causes ichthyobodosis (earlier known as costiasis, after the previous name of the parasite, *Costia necatrix*), and *Trichodina* spp. (MAST 2021a).

Gudmundsdóttir & Björnsdóttir (2007) note that winter ulcer disease, which is caused by the bacterium *Moritella viscosa*, can cause significant mortalities in salmonids that are reared in salt or brackish water at temperatures below 10 °C. The first time that this disease was diagnosed in farmed Arctic charr in Iceland was in 2012, as noted in MAST's annual report for that year. This event initiated some use of vaccines against this condition in Arctic charr (MAST 2012), and these vaccines had previously been used only by the salmon sector in Iceland (Gudmundsdóttir & Björnsdóttir (2007). Although winter ulcer disease still affects the Arctic charr sector, it typically occurs as a secondary infection rather than a primary infection (pers. comm., Dr. Bernhard Laxdal December 2021).

Secondary infections can often arise because of husbandry-related issues and suboptimal rearing conditions that could occur if temperature, water flow, or oxygen levels are not appropriate, or if the salinity of the culture water is too high for the biology of the fish. There are multifactorial issues to consider in providing optimal conditions for fish, and a suboptimal environment can result in stress and a greater susceptibility to disease (pers. comm., Dr. Bernhard Laxdal December 2021). In this regard, some MAST annual reports (e.g., MAST 2012, MAST 2011) refer to "opportunistic pathogens" that are occasionally detected in farmed fish without causing actual diseases or significant losses. These are pathogens that are commonly present in the environment but which, on occasion, may flare up and cause infections under certain conditions. For Arctic charr, bacteria such as *Aliivibrio wodanis*, *Vibrio anguillarum*, and *Flavobacterium psychrophilum* are mentioned. Annual reports comment that, although *Flavobacterium* spp*.* are more closely associated with freshwater environments, they have recently become more evident in saline and marine environments. Another husbandry-related condition mentioned in MAST's annual report for 2021 was the occurrence of nephrocalcinosis on one Arctic charr farm. This condition, which is characterized by the formation of calcium salt deposits in the kidney tissues, was likely due to elevated CO_2 levels, the report notes; when water is reused during production, CO_2 can accumulate in the system if not monitored appropriately (MAST 2021a). Gas bubble disease is also noted as a condition that has affected Arctic charr in some facilities over the years; this disease can occur if gases become supersaturated in the culture water. But, such occurrences are reportedly rare and are avoided by using powerful aeration and degasification to condition the incoming borehole water (MAST 2020).

In some of MAST's annual reports, Epitheliocystis is also noted to affect farmed Arctic charr at times; this is a skin and gill disease caused by pathogenic intracellular bacteria (*Candidatus Clavochlamydia salmonicola* and/or *Candidatus Pisci chlamydia salmonis*). Also mentioned is enteric redmouth disease, a systemic bacterial septicemia of salmonids, which is caused by the bacterium *Yersinia ruckeri* (MAST 2021a)(MAST 2020).

No instances of viral diseases affecting the Arctic charr sector were identified, and literature pertaining to the wider Icelandic aquaculture sector highlights its historical lack of viral concerns (Giang & Guðmundsdóttir 2016). MAST's Annual Veterinary Report of Fish Diseases discusses the routine viral screening that takes place across the sector each year and the methodology that is employed during this process. The 2021 report notes that the viral screening results for the year were favorable overall, but for the first time, the Icelandic Atlantic salmon sector suffered a serious viral outbreak: in November 2021, infectious salmon anemia (ISA) was detected in an open-net pen salmon farm in Reyðarfjörður fjord, in the east of Iceland.[143] Details of this event and its rapid containment are described in the MAST report (MAST 2021a). But, ISA is not a disease of concern to the Arctic charr sector (pers. comm., Dr. Bjarni K. Kristjánsson December 2021)(pers. comm., Dr. Bernhard Laxdal December 2021).

In summary, pathogenic bacteria are the primary cause of disease in the Icelandic Arctic charr sector. Although around 80% of mortalities are attributable to atypical furunculosis, the balance of mortalities is mostly attributed to winter ulcer disease, redmouth disease, and vibrio infections. Secondary infections can occur as a consequence of husbandry-related issues and suboptimal rearing conditions, which make fish more susceptible to health challenges arising from opportunistic pathogens. In the past, bacterial kidney disease has also presented the sector with health challenges, but the implementation of good biosecurity at the water inlet, in conjunction with the screening of eggs, has greatly reduced this threat. Ectoparasites and *Trichodina* spp. may also affect Arctic charr.

<u>Disease surveillance of wild and farmed fish and on-farm biosecurity</u>

As noted in the introduction to this criterion, since the 1980s, Iceland has implemented a surveillance program that monitors disease in both wild and farmed fish. Because the inception of this program aligns with the start of commercial fish farming in Iceland, these data are well placed to identify any intensification of disease in wild fish populations in the vicinity of farms, as opposed to populations elsewhere; however, no indication of this was identified in literature. No specific studies were identified that have involved the monitoring of the watersheds and species directly surrounding Arctic charr farms, to ascertain if any amplification in disease prevalence has occurred from the presence of these farms. But, such a study would be unlikely, given the relatively small scale of the Arctic charr sector.

Although the verification of disease transmission from farmed to wild fish is evidently challenging to confirm, it is relevant to note that the most recent sampling and analysis from the surveillance program found a 0% rate of bacterial kidney disease infection in farmed Arctic charr, even though this disease is endemic in Icelandic waters and commonly found in wild Arctic charr stocks. Farms also typically adhere to a Veterinary Health Biosecurity Plan, which is updated each year in cooperation with a veterinarian. Because the majority of Arctic charr

[143] https://www.icelandreview.com/business/first-ever-cases-of-infectious-salmon-anaemia-in-iceland/

farms in Iceland abstract water from fixed boreholes drilled through lava rock, and disease prevalence is demonstrably low on farms, it appears highly unlikely that effluents from these farms, which drain into the Atlantic Ocean, could conceivably be transporting a pathogen load that subsequently causes disease prevalence to become amplified in wild species. Thus, the risk of Arctic charr farms amplifying and retransmitting disease to wild populations is assessed to be minimal.

Conclusions and Final Score

This criterion does not assess the impacts that disease has upon the species being farmed; rather, it assesses the ecological risk that on-farm diseases may present to wild species in the surrounding environment. Although it is challenging to evidence the transmission of disease from farm stocks to wild fish, Iceland has been routinely sampling wild and farmed fish for disease since commercial aquaculture began there in the 1980s. Hence, this dataset is a valuable resource that could provide indicators of such disease transmission occurring. But, no such indications of disease transmission are noted in the literature that discusses these surveillance endeavors, and the risk of disease transmission from land-based Arctic charr farms to wild fish would appear to be low. A review of data pertaining to the Arctic charr sector in Iceland indicates that this species is robust, and that the occurrence of on-farm diseases is low, resulting in an average mortality rate of 5–8% for production in brackish water, whereas the small balance of production that takes place in freshwater has a mortality rate of 1–3%. Though disease transmission may occur via culture water discharged from farms, the data do not indicate that pathogens or parasite numbers on wild species are amplified above background levels by such aquaculture activities. Furthermore, robust fish health and biosecurity management measures are in place and are properly enforced, preventing the occurrence and spread of disease between farm sites, and from farm sites to wild species. As a result, the level of concern for this criterion is low, and the final numerical score for Criterion 7—Disease is 8 out of 10.

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

Impact, unit of sustainability and principle

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

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

Criterion 8X Summary

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	
C8X Source of Stock Final Score (0 to –10)		**0**
Critical?	No	**GREEN**

Brief Summary

Hólar University runs Iceland's only Arctic charr breeding program, which supplies about 90–95% of the eggs stocked by the sector; overseas egg sales are not permitted. When the breeding program commenced in 1992, a variety of Icelandic Arctic charr strains were interbred to optimize the traits of fast growth and delayed maturation in cultured fish. The breeding program is now working with fish that have been domesticated for about 10 generations; hence, there is no reliance on wild populations for broodstock. While all Arctic charr farms in Iceland utilize eggs from the Hólar breeding program, two of these farms also maintain broodstock at their own facilities. The broodstock kept at one of these farms also belong to the Hólar strain, and this serves as a back-up facility for the breeding program. The other farm maintains broodstock from a different local strain of Arctic charr, called the Litlaá strain; these were initially introduced to the farm around 15 years ago, and no further wild collection has occurred since—of note, eggs from these fish are only used on-site. Because 100% of the Icelandic Arctic charr sector maintains its production independent of wild stocks, there is no deduction applicable, and the score for Criterion 8X—Source of Stock is 0 out of –10.

Justification of Rating

For decades, Iceland's Arctic charr sector has been self-sustained through the supply of high-quality eggs from Hólar University's centralized, closed life-cycle breeding program (Leblanc et al. 2014)(Sæther et al. 2013), so it does not have any dependence on the active capture of juveniles or broodstock. Hólar's breeding program, which started in the autumn of 1992, is funded both through the sale of eggs to farmers as well as by a contract with the Ministry of Fisheries and Agriculture, which stipulates that sales cannot be made to parties outside of Iceland. Each generation spans around 3–4 years (Hólar 2022), so the breeding program is now working with fish that have been domesticated for around 10 generations (pers. comm., Dr. Bjarni K. Kristjánsson December 2021). Aquaculture studies have been taught at Hólar University since 1985, and a large part of the institution's research focuses on Arctic charr, both farmed and wild (Hólar 2022). Regarding the latter, a declining trend in the abundance of stocks has become apparent; this may be related to stress induced by warming waters, and anadromous stocks appear to be particularly vulnerable (pers. comm., Dr. Bjarni K. Kristjánsson December 2021)(Kristmundsson et al. 2010). Though Hólar University runs Iceland's only Arctic charr breeding program, which supplies 90–95% of the eggs stocked by the sector, two farms still maintain their own broodstock on-site—although both farms also purchase eggs from Hólar. One of these farms maintains a back-up broodstock facility for the Hólar breeding program; hence, the broodstock held on this site all belong to the Hólar stock, whereas the other farm's broodstock, which are solely for their use, belong to a different local strain of Arctic charr, called the Litlaá strain; these broodstock were introduced to the farm around 15 years ago, and no further wild collection has occurred since (pers. comm., Dr. Bernhard Laxdal May 2023).

Before the initiation of the breeding program, scientists at Hólar University conducted research to compare the growth and age of maturation between 13 different Icelandic Arctic charr populations that were selected from a variety of riverine and lacustrine environments, in addition to some existing aquaculture broodstock. These investigations confirmed that a great deal of diversity exists between families with regard to these study parameters; further research showed that growth rates and the age of maturation were highly heritable characteristics, which indicated that a selective breeding program could be beneficial to the developing Arctic charr aquaculture sector. The best performing fish from these studies were selected to initiate the breeding program (Hólar 2022). Anadromous stocks grow much faster than those that remain in freshwater (Freyhof & Kottelat 2008), so the selection process for aquaculture stocks has favored fish that demonstrate the highest tolerance to salinity (pers. comm., Dr. Bernhard Laxdal December 2021), although performance in both fresh and brackish water is examined within the breeding program (pers. comm., Dr. Bjarni K. Kristjánsson February 2023). Since the introduction of Hólar University's breeding program, there has been a steady increase in the volumes produced by the Icelandic Arctic charr sector (MAST 2021a).

In the early days of the breeding program, many different strains of Arctic charr were experimented with (pers. comm., Dr. Bernhard Laxdal December 2021). Later, in 1994, two breeding lines were established, based on market demand for different skin colors: light-skinned fish were predominantly bred from individuals originating in the Grenlæk River, whereas a dark-skinned variant was bred mainly with Arctic charr sourced from Lake Ölvesvatn.[144] But, as market demands changed, these two separate strains were merged into one (Hólar 2022).

[144] https://debeslab.com/the-arctic-charr-breeding-programme/

Figure 18: Placed side by side, these two adult Arctic charr morphs demonstrate the contrasting size, coloration, and head morphology that exist between different stocks. The Arctic charr on top is a limnetic morphotype from Hólar University's aquaculture stock, whereas the specimen below is a benthic morphotype from Lake Þingvallavatn (Kapralova et al. 2014).

Originally, the breeding program was designed to assist agricultural farmers in earning some additional income by raising a small number of fish on their premises. As the industry has intensified, the number of smaller production facilities has declined, and the goals of the breeding program have evolved to keep pace with the needs of the developing sector (pers. comm., Dr. Bjarni K. Kristjánsson December 2021). The main aims of the breeding program at present are to promote fast growth and to delay sexual maturation as much as possible, while also selecting for high fecundity in broodstock (Hólar 2022).

Research into optimal broodstock management, including photoperiod and thermal manipulation, has done much to improve the spawning outcomes and egg quality within the Arctic charr sector, and temperature control has been identified as a key aspect in successful cultivation (Olk et al. 2019). Temperature has a direct influence upon metabolism and growth, affecting both feeding activity and energy demands (Leblanc et al. 2019). Research has also been conducted to ascertain the relationship between the rearing temperature and the final flesh quality and sensory characteristics of cooked fish (Imsland et al. 2021). Recent studies, based on production data from one of Iceland's main Arctic charr farms, demonstrate that, though higher temperatures increase growth, elevated temperatures during early development can actually have a negative impact on this species' overall, long-term growth performance, and also give rise to early maturation (Árnason et al. 2022). Although research to optimize production is ongoing, early maturation has been resolved to a great extent, enabling farmers to reliably harvest Arctic charr at a larger size than was previously the case (pers. comm., Dr. Bjarni K. Kristjánsson December 2021).

Conclusions and Final Score

Almost all Icelandic Arctic charr production (about 90–95%) comes from eggs that are produced by Hólar University's closed life-cycle Arctic charr breeding program, the only such breeding program in the country. This breeding program, which has now been in operation for three decades, is currently working with fish that are the product of around 10 generations of domestication. Apart from the Hólar breeding program, two Arctic charr farms also maintain broodstock on-site. The broodstock kept at one of these farms also belong to the Hólar strain—and this serves as a back-up for the breeding program—whereas the other farm keeps broodstock from another local strain of Arctic charr, called the Litlaá strain. These broodfish were initially introduced to the farm around 15 years ago, and no further wild collection of broodstock has occurred since. It can be concluded that 100% of the Arctic charr farmed in Iceland is produced without any dependence on wild stocks. Because 100% of the Icelandic Arctic charr sector maintains its production independent of wild stocks, there is no deduction applicable, and the score for Criterion 8X—Source of Stock is 0 out of –10.

Criterion 9X: Wildlife and Predator Mortalities

Impact, unit of sustainability and principle

- Impact: mortality of predators or other wildlife caused or contributed to by farming operations
- Sustainability unit: wildlife or predator populations
- Principle: preventing population-level impacts to predators or other species of wildlife attracted to farm sites.

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

Criterion 9X Summary

Wildlife and mortality parameters		Score
C9X Wildlife and Mortality Final Score (0 to –10)		**–2**
Critical?	No	**GREEN**

Brief Summary

Wildlife interactions in the Icelandic Arctic charr sector appear to be minimal, and any mortalities that do occur are limited to exceptional cases that do not significantly affect wild populations in any way. Thus, the final score for Criterion 9X—Wildlife and Predator Mortalities is –2 out of –10.

Justification of Rating

Because the Criterion 1—Data score for wildlife and predator mortalities is 7.5 out of 10, the evidence-based assessment is used here.

Iceland’s Nature Conservation Act (No. 60/2013),[145] which aims to protect the future diversity of Icelandic nature, includes provisions for the protection of wild species and ecosystems. Also, Iceland’s Act on the Protection, Conservation and Hunting of Birds and Wild Mammals (No. 64/1994)[146] extends protection to all birds and land mammals, with a few exceptions, including feral mink and rats. The Icelandic Institute for Natural History (IINH) is responsible for researching and monitoring Icelandic biota.[147] Based on guidelines developed by the International Union for the Conservation of Nature (IUCN), IINH compiles and maintains Red

[145] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC199801
[146] https://www.althingi.is/lagas/nuna/1994064.html
[147] https://www.government.is/topics/environment-climate-and-nature-protection/biological-diversity/research-and-monitoring-/

Lists for the biota of Iceland. The most recent inventory of species was compiled in 2018: this assessment considers the status of 91 bird species and 18 mammals,[148] of which 41 bird species and 5 animal species are on the Red List, which indicates that these species are the most vulnerable to potential mortalities or disturbance from aquaculture farms.

In addition to the Nature Conservation Act, the farm siting process seeks to minimize disturbance or impacts to Iceland's biota. Farm development is prohibited in the vicinity of migratory bird nesting sites; birds such as terns, puffins, and seagulls typically return to the same nesting sites each year, and these sites are protected (pers. comm., Karl Steinar Óskarsson April 2023). Regarding the development of new farms or the expansion of existing ones, the potential for wildlife interactions is one of the aspects that is assessed during the environmental impact assessment (EIA) process. The potential impact of farm effluents upon wildlife is also considered. For example, the proposed expansion of an existing Arctic charr farm was recently the subject of an EIA, and a review of online documentation related to this process provides an overview of the deliberations pertaining to potential wildlife interactions.[149] This EIA reviewed bird species that were present in the vicinity, as well as their migratory patterns, and considered different drainage scenarios to determine how best to limit potential wastewater impacts on wildlife.

On-farm wildlife interactions are also discussed in the operating permits issued by the Environmental Agency (UST). Regarding pest control, permits stipulate that, if pests are encountered, operators must ensure that the pests do not take up residence in the farm area, and operators must endeavor to block access to wild birds and mammals. But, such measures must always be taken in accordance with the law on hunting and animal protection,[150] which, as noted, extends protection to all birds and land mammals with a few exceptions, including feral mink and rats. Any pest control activities on farms must be conducted by an authorized pest control professional (pers. comm., Karl Steinar Óskarsson April 2023). In light of this, it is evident that any pest control measures implemented on farms by farm operators must be nonlethal. Also, although individuals in Iceland are able to obtain a recreational gun permit and hunting license, which permits the hunting of certain birds at certain times of year,[151] hunting activities are only permitted in rural areas and must occur at least 500 m from the nearest property—hence, hunting in the vicinity of land-based fish farms is prohibited (pers. comm., Karl Steinar Óskarsson April 2023).

Overall, communications with stakeholders in the Icelandic Arctic charr sector indicate that there are minimal interactions with wildlife on farms and that the main predators encountered are seagulls. Farmers are required to keep nets in place over their outdoor tanks, a measure that is designed to limit interactions between birds and fish stocks (pers. comm., Dr. Bjarni K.

[148] https://www.ni.is/en/fauna/red-lists-and-protection
[149] https://ust.is/library/sida/atvinnulif/starfsleyfi-og-eftirlitsskyrslur/Álit%20Skipulagsstofnunar_Matorka%20fiskeldi%20-%20Copy%20(1).pdf
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[151] https://ust.is/veidi/veiditimabil/

Kristjánsson December 2021)(pers. comm., Heiðdís Smáradóttir November 2021). If a seagull becomes irredeemably trapped in an indoor facility or entangled in a top net to the extent that it must be dispatched, it is incumbent upon farmers to solicit a permit and a professional to facilitate this. In addition to seagulls, mice and mink may also be present on farm sites (pers. comm., Árni Páll Einarsson December 2021). A new law has recently been instigated that prohibits the killing of mice outdoors, although this is permitted if mice are encountered in indoor facilities (pers. comm., Karl Steinar Óskarsson April 2023). Regarding the potential killing of mice, mink, and seagulls, none of these is identified as a species of concern in the IINH's Red Lists for the biota of Iceland. And, although lethal take of these species would appear to be uncommon, such activities are not considered to have any population impacts upon the species concerned.

Conclusions and Final Score

In conclusion, wildlife interactions on land-based Arctic charr farms in Iceland appear to be limited, and any mortalities are limited to exceptional cases that do not significantly affect wild populations in any way. Thus, the final score for Criterion 9X—Wildlife and Predator Mortalities is –2 out of –10.

Criterion 10X: Introduction of Secondary Species

Impact, unit of sustainability and principle

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: 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

Introduction of secondary species parameters	Value	Score
F10Xa Percentage of production reliant on trans-waterbody movements (%)	0.0	10
F10Xb Biosecurity of source/destination		0.0
C10X Introduction of secondary species Final Score (0 to –10)		0.0
Critical?	No	GREEN

Brief Summary

The Icelandic Arctic charr sector does not require any international or trans-waterbody live animal shipments. Thus, no deduction is applicable, and the score for Criterion 10X—Introduction of Secondary Species is 0 out of –10.

Justification of Rating

Factor 10Xa—International or Trans-Waterbody Live Animal Shipments

As discussed in some detail in Criterion 8X—Source of Stock, around 90–95% of the eggs stocked by the Icelandic Arctic charr sector come from Hólar University's breeding program, which is located in northern Iceland. The breeding station, which has been in operation for over 30 years, uses a mix of spring water from wells that are buried in the springs and from deeper boreholes.

Observations do not indicate the presence of invertebrates in this water source, and the majority of farms that receive eggs from the breeding program are also using groundwater for their production (pers. comm., Dr. Bjarni K. Kristjánsson January 2023). Furthermore, all movements of roe or fry are required to be accompanied by a fish disease veterinarian's permit.[152] A small balance of production comes from eggs obtained from broodstock that a few

[152] https://www.skipulag.is/umhverfismat-framkvaemda/gagnagrunnur-umhverfismats/nr/939#alit

farms keep onsite at their facilities. Thus, no trans-waterbody or international live animal movements occur within the sector, and the score for Factor 10Xa is 10 out of 10.

Factor 10Xb—Biosecurity of Source/Destination

Because no trans-waterbody or international live animal movements occur, the default score for Factor 10Xb is 0 out of 10.

Conclusions and Final Score

Because the Icelandic Arctic charr sector does not rely on any trans-waterbody or international live animal movements, no deduction is warranted, and the score for Criterion 10X—Introduction of Secondary Species is 0 out of –10.

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Appendix 1: Data Points and all Scoring Calculations

Criterion 1: Data

Species: Arctic charr

C1 Data Category	Data Quality
Production	10.0
Management	10.0
Effluent	7.5
Habitat	7.5
Chemical Use	7.5
Feed	7.5
Escapes	7.5
Disease	5.0
Source of stock	10.0
Wildlife mortalities	7.5
Introduction of secondary species	10.0
C1 Data Final Score (0-10)	**8.182**

Criterion 2: Effluent

Species: Arctic charr

Effluent Risk-Based Assessment

C2 Effluent Final Score (0-10)	**8**	Green

Criterion 3: Habitat

All Species

C3 Habitat parameters	Value	Score
F3.1 Habitat conversion and function (0-10)		9
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)		4.800
C3 Habitat Final Score (0-10)		**7.600**
Critical?	No	Green

Criterion 4: Chemical Use

Select species or "All species": Arctic charr

C4 Chemical Use parameters	Score
C4 Chemical Use Score (0-10)	**8.000**

Critical?	No	Green

Criterion 5: Feed

Select species or "All species" — Arctic charr

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	**0.932**	
F5.1b Source fishery sustainability score (0-10)		**6**
F5.1: Wild fish use score (0-10)		**7**
F5.2a Protein INPUT (kg/100kg fish harvested)	**46.200**	
F5.2b Protein OUT (kg/100kg fish harvested)	**19.100**	
F5.2: Net Protein Gain or Loss (%)	**-58.658**	**4.000**
F5.3: Species-specific kg CO_2-eq kg^{-1} farmed seafood protein	**14.958**	**6.000**
C5 Feed Final Score (0-10)		**5.900**
Critical?	**No**	Yellow

Criterion 6: Escapes

Select species again — Arctic charr

C6 Escape parameters		Value	Score
F6.1 System escape risk (0-10)		6	
F6.1 Recapture adjustment (0-10)		0	
F6.1 Final escape risk score (0-10)			6
F6.2 Invasiveness score (0-10)			6
C6 Escape Final Score (0-10)			**6**
	Critical?	No	Yellow

Criterion 7: Disease

Arctic charr

C7 Disease parameters		Score
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0-10)		**8**
Critical	No	Green

Criterion 8X: Source of Stock

Arctic charr

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

Criterion 9X: Wildlife Mortalities

Arctic charr

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

Criterion 10X: Introduction of Secondary Species

Arctic charr

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on trans-waterbody movements (%)	0.0	10
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		0.000
Multi-species assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score		**0.000**
Critical?	No	Green

Appendix 2: Criterion 5 Calculations

The following section describes the equations and methodology used to calculate Factor 5.1—Wild Fish Use and Factor 5.3—Feed Footprint.

Factor 5.1—Wild Fish Use

Factor 5.1a—Feed Fish Efficiency Ratio (FFER)
The following equations, which are replicated here from Appendix 3 of the Seafood Watch Standard for Aquaculture, show how the data presented in Table 2 (also included in this appendix) of Criterion 5—Feed were calculated.

(Eq. 1)

$$FM_{inclusion} = \left(32\%_{feed\ manufacturer1} \times 75_{share\ 1}\%\right) + \left(34.8\%_{feed\ manufacturer2} \times 25\%\right)$$

$$FO_{inclusion} = \left(24\%_{feed\ manufacturer1} \times 75_{share\ 1}\%\right) + \left(9.5\%_{feed\ manufacturer2} \times 25\%\right)$$

Where:

$feed\ manufacturer_n.$ = average of lower and upper bound of FM and FO inclusion ranges reported by feed manufacturers and through personal communications with stakeholders.

$M_{share\ n}$ = estimated market share for each respective feed manufacturer within the Icelandic Arctic charr sector.

These calculations indicate that, as a percentage of total feed inputs, the average inclusion of fishmeal in Arctic charr diets in Iceland accounts for 32.7%, whereas fish oil inputs are 20.375%.

(Eq. 2)

$$FM_{bp\ inclusion} = \left(25.68\%_{f.manufacturer1} \times 75_{share\ 1}\%\right) + \left(34.8\%_{f.manufacturer2} \times 25\%\right)$$

$$FO_{bp\ inclusion} = \left(19.98\%_{feed\ manufacturer1} \times 75_{share\ 1}\%\right) + \left(9.5\%_{feed\ manufacturer2} \times 25\%\right)$$

Where:

$\%_{f.\ manufacturer\ n}$ = by-product inclusion level for FM and FO reported by feed manufacturers.

$M_{share\ n}$ = estimated market share for each feed manufacturer.

These calculations indicate that, as a percentage of total feed inputs, 27.96% contains fishmeal derived from by-products, whereas 17.36% is made of fish oil derived from by-products.

Whole fish inclusion levels are then determined by calculating the difference between the by-product percentages, as shown previously, and 100% of each respective input (Eq. 3).

(Eq. 3)

$$FM_{wf\ inclusion} = (32.7\% - FM_{bp\ inclusion})$$

$$FO_{wf\ inclusion} = (20.375\% - FO_{bp\ inclusion})$$

These calculations indicate that, as a percentage of total feed inputs, 4.74% contains fishmeal obtained from whole fish, whereas 3.015% is made of fish oil derived from whole fish.

Equation 4 is then used to calculate the FFER for FM and FO. The values calculated in the equations above are shown in Table 2, which also identifies the variables used in Equation 4.

(Eq. 4)

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

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

The FFER values for fishmeal and fish oil are estimated as 0.33 and 0.93, respectively.

Table 5: Parameters and their calculated values used to determine the use of wild fish in farmed Arctic charr diets in Iceland

Eq. variable	Parameter	Data
	Fishmeal inclusion level (total)	**32.7%**
a	Fishmeal inclusion level (whole fish)	4.74%
	Fishmeal inclusion level (by-product)	27.96%
b	Assessed fishmeal inclusion level (by-product)[153]	1.398%
e	Fishmeal yield	22.5%
	Fish oil inclusion level (total)	**20.38%**
c	Fish oil inclusion level (whole fish)	3.02%
	Fish oil inclusion level (by-product)	17.36%
d	Assessed fish oil inclusion level (by-product)	0.87%
f	Fish oil yield	5.0%
g	Economic Feed Conversion Ratio (eFCR)	1.2
Calculated values		
Fish meal feed fish efficiency ratio ($FFER_{FM}$)		0.33

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

Fish oil feed fish efficiency ratio ($FFER_{FO}$)	0.93
Assessed FFER	**0.9**

<u>Factor 5.1b—Sustainability of the Source of Wild Fish</u>

As described in Appendix 3 of the Seafood Watch Standard for Aquaculture, the following steps were completed to calculate a final 5.1b score:

1. Determine the sustainability score for each source fishery.
2. Calculate whole fish and by-product 5.1b Source Fishery Sustainability scores.
3. Determine the total sustainability scores by combining the whole fish and by-product sustainability scores for fishmeal and fish oil.
4. Calculate a final Factor 5.1b score by weighting the overall fishmeal and fish oil scores by the FFER of each, considering the actual biomass of fish required to produce the ingredients.

Step 1. Determine the sustainability score for each source fishery

See the criterion evaluation for this step; no equations were used.

Step 2. Calculate whole fish and by-product 5.1b Source Fishery Sustainability scores

To determine a single F5.1b Source Fishery Sustainability score for fishmeal and fish oil sourced from whole fish and byproducts across multiple separate feed types, the following equation is used, and the results are in Table 5:

(Eq. 5)

$$FM_{wf} = \left(\frac{\alpha_1 \times \beta_1 \times C_1}{W} + \frac{\alpha_2 \times \beta_2 \times C_2}{W} + \frac{\alpha_3 \times \beta_3 \times C_3}{W} \ldots\right)/100$$

$$FM_{bp} = \left(\frac{\alpha_1 \times \beta_1 \times C_1}{W} + \frac{\alpha_2 \times \beta_2 \times C_2}{W} + \frac{\alpha_3 \times \beta_3 \times C_3}{W} \ldots\right)/100$$

$$FO_{wf} = \left(\frac{\alpha_1 \times \beta_1 \times C_1}{W} + \frac{\alpha_2 \times \beta_2 \times C_2}{W} + \frac{\alpha_3 \times \beta_3 \times C_3}{W} \ldots\right)/100$$

$$FO_{bp} = \left(\frac{\alpha_1 \times \beta_1 \times C_1}{W} + \frac{\alpha_2 \times \beta_2 \times C_2}{W} + \frac{\alpha_3 \times \beta_3 \times C_3}{W} \ldots\right)/100$$

Where:

$\alpha_n =$ Total Fishmeal or Fish Oil inclusion from whole fish or byproduct for each feed type

$\beta_n =$ Feed weighting per feed type

$W = \sum {}^{(\alpha_n \times \beta_n)}/_{100}$

$C_n = \sum(K_n/\alpha_n) \times F_n$

Where:

K_n = Inclusion (%) of each type of marine ingredient

α_n = Total Fishmeal or Fish Oil inclusion from whole fish or byproduct for each feed type

F_n = SFW 5.1b sustainability score for each type of marine ingredient

The results indicate that the fishmeal sustainability scores from whole fish and by-products are 7.00 and 7.01, respectively, while the fish oil sustainability scores from whole fish and by-products are 6.00 and 7.59, respectively.

Table 5: Marine ingredients inclusion levels and sustainability scores

		Feed 1	Feed 2
Marine input	**Sustainability Score**	**Inclusion**	**Inclusion**
Total inclusion of fishmeal from whole fish as a percentage of the total feed		6.32	0
Capelin (*Mallotus villosus*)	8.00	3.17	
Atlantic herring (*Clupea harengus*)	8.00	1.05	
Mackerel (*Scomber scombrus*)	4.00	1.05	
Blue whiting (*Micromesistius poutassou*)	6.00	1.05	
Weighted whole fish FM Inclusion %	4.74		
Weighted whole fish sustainability score	7.00		
Total inclusion of fishmeal from by-products as a percentage of the total feed		25.68	34.8
Capelin (*Mallotus villosus*)	8.00	13.10	17.40
Atlantic herring (*Clupea harengus*)	8.00	2.48	5.80
Mackerel (*Scomber scombrus*)	4.00	2.48	5.80
Atlantic cod (*Gadus morhua*)	6.00	7.62	5.80
Weighted by-product FM Inclusion %	27.96		
Weighted by-product sustainability score	7.01		
Total inclusion of fish oil from whole fish as a percentage of the total feed		4.02	0
Blue whiting (*Micromesistius poutassou*)	6.00	4.02	
Weighted whole fish FO Inclusion %	3.02		
Weighted whole fish sustainability score	6.00		
Total inclusion of fish oil from by-products as a percentage of the total feed		19.98	9.5
Capelin (*Mallotus villosus*)	8.00	16.82	4.75
Atlantic herring (*Clupea harengus*)	8.00	1.58	2.38
Mackerel (*Scomber scombrus*)	4.00	1.58	2.38
Weighted by-product FO Inclusion %	17.36		
Weighted by-product sustainability score	7.59		

Step 3: Determine the total sustainability scores by combining the whole fish and by-product sustainability scores for fishmeal and fish oil.
Using the fishmeal and fish oil sustainability score values for whole fish and by-products calculated in Step 2, the following equation is then used to calculate the weighted overall sustainability scores for total fishmeal and fish oil (Eq. 6):

(Eq. 6)

$$S.Score_{FMtotal} = (S.Score_{FM-WF} \times 0.95) + (S.Score_{FM-BP} \times 0.05)$$

$$S.Score_{FOtotal} = (S.Score_{FO-WF} \times 0.95) + (S.Score_{FO-BP} \times 0.05)$$

Where:
$S.Score_{FM-WF}$ = weighted whole fish sustainability score for fishmeal
$S.Score_{FM-BP}$ = weighted by-product sustainability score for fishmeal, considering only 5%
$S.Score_{FO-WF}$ = weighted whole fish sustainability score for fish oil
$S.Score_{FO-BP}$ = weighted by-product sustainability score for fish oil, considering only 5%

Equation 6 results in weighted fishmeal and fish oil sustainability scores of 7.00 and 6.08, respectively, both of which include by-products at 5%—a value that is intended to capture the ecological cost of production associated with by-products.

Step 4: Calculate a final Factor 5.1b score by weighting the total fishmeal and fish oil scores by the FFER of each, considering the actual biomass of fish required to produce the ingredients.
The last step is to modify the weighted overall sustainability scores for fishmeal (7.00) and fish oil (6.08) by their respective FFER calculated in F5.1a ($FFER_{FM}$ = 0.327; $FFER_{FO}$ = 0.932). This is done to accurately attribute the sustainability of source fishery scores with the biomass utilized for feed, and the following equation is used (Eq. 7):

(Eq. 7)

$$\text{Final 5.1b score} = \frac{(FFER_{FM} \times S.Score_{FMtotal}) + (FFER_{FO} \times S.Score_{FOtotal})}{(FFER_{FM} + FFER_{FO})}$$

The application of Equation 7 results in a score of 6.32 out of 10 for Factor 5.1b—Source fishery sustainability score. When combined, the Factor 5.1a (0.93) and Factor 5.1b (6.8) scores result in a final Factor 5.1 score of 6.8 out of 10.

Factor 5.3—Feed Footprint: How to calculate the feed footprint for multiple feed types
Step 1: For each feed, calculate the total global warming potential (GWP) for each category (i.e., fishmeal and fish oil from whole fish and by-products, terrestrial crop ingredients, animal ingredients and other) by using the following equations:

(Eq. 9)

$$GWP_{FM\text{ - whole fish}} = \sum(K_n \times \mu_n \times 0.01)$$

$$GWP_{FM\text{ – by-products}} = \sum(K_n \times \mu_n \times 0.01)$$

$GWP_{FO\text{ -whole fish}} = \sum(K_n \times \mu_n \times 0.01)$

$GWP_{FO\text{ – by-products}} = \sum(K_n \times \mu_n \times 0.01)$

$GWP_{terrestrial\ crop\ ingredients} = \sum(K_n \times \mu_n \times 0.01)$

$GWP_{animal\ ingredients} = \sum(K_n \times \mu_n \times 0.01)$

$GWP_{other} = \sum(K_n \times \mu_n \times 0.01)$

Where:

K_n = Inclusion (%) of each ingredient
μ_n = GFLI Economic allocation—EF3.1, values from climate change (kg CO_2 eq/ton product) column; *note that these values are not published in SFW assessments due to licensing agreements.*

Step 2: For each feed, sum the total global warming potential (GWP) for all categories (i.e., fishmeal and fish oil from whole fish and by-products, terrestrial crop ingredients, animal ingredients and other).

(Eq. 10)

$$d = (GWP_{FM\text{ - whole fish}} + GWP_{FM\text{ – by-products}} + GWP_{FO\text{ -whole fish}} + GWP_{FO\text{ – by-products}} + GWP_{terrestrial\ crop\ ingredients} + GWP_{animal\ ingredients} + GWP_{other})$$

Where:

d = Total GWP/mt of feed for each feed

Step 3: For each feed, calculate the estimated total feed global warming potential (GWP) of each feed using the following equation:

(Eq. 11)

$$\rho = \frac{(a_n)}{(b_n)} \times \frac{(d_n) \times 10}{(c_n)}$$

Where:

a = the reported eFCR associated with each feed

b = the whole harvested fish protein content of the species under scope

c = the total ingredient inclusion for each feed, ideally is 100%

d = Total GWP/mt of feed for each feed, as calculated in Step 2

ρ = Est. kg CO_2-eq/kg of farmed seafood protein

Step 4: To determine a single feed footprint, a weighted average is calculated between the scores, using the following equation:

(Eq. 12)

$$\text{Weighted kg } CO_2\text{-eq per kg farmed seafood protein} = (\rho_1 \times \beta_1) + (\rho_2 \times \beta_2) + (\rho_3 \times \beta_3) \ldots/100$$

Where:

ρ_n = Est. kg CO_2-eq/kg of farmed seafood protein

$\beta_n = \text{Feed } w\text{eighting per feed type}$