Environmental legislation influencing Atlantic salmon farming in open net pen systems – A global perspective

BEST FISHES

Prepared by Fidra
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Fidra

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A Report by Fidra

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Cover image: Salmon farm at Drumbeg, Highlands, Scotland by phbcz from getty images, salmon on ice by shaunl from getty images.

Executive Summary

Introduction

Salmon aquaculture has formally been established in the marine industry for over 50 years. As the industry has expanded the environmental impact of the industry has also grown. Salmon aquaculture is now practiced across the world, though comparable environmental impacts associated with the industry can be seen across nations including organic and chemical waste, sea lice infection, disease and plastic waste as well as socio-economic impacts. Nations where salmon farming is undertaken have often sought to limit these impacts through regulation and legislation. However, the industry has often grown quickly, resulting in legislation and regulation, frequently implemented retrospectively.

The current state of global legislation

This study reviews current legislation and regulation, which varies between nations. There is a wide variety of legislative mechanisms in place across the different nations undertaking salmon aquaculture, much of which is with consideration to the environmental impacts of the industry. **Currently there is no global legislative requirement to monitor the environmental impacts of salmon aquaculture**, leading to a range in stringency and scope in regard to environmental monitoring practices and requirements by different countries. However, many environmental impacts associated with salmon aquaculture are common between nations, allowing a comparable analysis of different approaches to address these issues.

Effective licensing of sites for salmon farms is the first step in mitigating environmental impacts of aquaculture. It is essential that the cumulative environmental impacts of a proposed site are fully assessed. Canada can be highlighted for the strong consideration of cumulative environmental impacts of operation in a proposed location, while Norway tightly links a farm licence permitted production limits with environmental impacts. Scotland can be noted for the evolving use of computer modelling to assist in assessing locations of proposed farms. Meanwhile Norway has sought to invest in technology and research in recent years (e.g. closed cage systems) in efforts to continue to grow the industry while seeking to limit the impact of aquaculture to the wider environment as a result.

Transparency and publicly available data on aquaculture activities is vital to ensure regulatory compliance, effective monitoring and public trust is achieved. Norway and Australia have both implemented online dashboards where information and data is publicly available regarding salmon farms in these regions, with regularly updated monitoring reports and information. In Scotland a similar initiative has been proposed and hoped to launch in

2024. Such dashboards are an effective tool in increasing transparency and regulatory compliance while cultivating public trust.

Aquaculture activity waste is an area of serious environmental concern. Organic waste (e.g. feed and faeces) and chemical waste (e.g. pesticides) pass from salmon farm cages into the surrounding environment. The accumulation of the waste produced can greatly impact the benthic environment and water column surrounding farms and beyond. Monitoring of the benthic environment is a common method of assessing environmental impacts in many nations. Canada can be noted as implementing detailed monitoring and reporting of the benthic environment, while Chile have implemented monitoring of additional parameters in the water column (e.g. dissolved oxygen). However, despite these steps **pollutions as a result of aquaculture activities remains an ongoing issue which no nation has addressed sufficiently**. It is urgent that these issues are addressed before further expansion of the industry is permitted.

As with many marine activities, plastic pollution is an ongoing issue. Accountability through registration and colour coding system of plastic aquaculture equipment in Australia is an example of measures which can be undertaken to tackle the issue of plastic pollution. Each company's plastic equipment is colour coded and registered, allowing for clear identification of the source of plastic pollution. Such schemes could readily be implemented in other nations and effectively help identify polluters and hold them to account.

Sea lice are a persistent issue in almost all aquaculture nations. These small parasites spread between fish and multiply easily in the farmed environment, impacting the health of salmon and can pass from farmed stocks to wild populations in the surrounding area. Limits to the number of sea lice in farmed populations are in place across many nations. Norway represents the lowest regulation limits of any nation with regular monitoring and reporting in place. Compliance with these limits can influence a farm approved production limit. Scotland and Norway have introduced regulation to reduce limits further during periods of juvenile wild salmon migration in identified areas to limit transfer to vulnerable wild populations. Chemical treatments are widely utilised by many nations to address sea lice infections. However, the chemical waste from treatments passes into the surrounding environment with subsequent impacts to marine wildlife health. Efforts to treat sea lice infections in farmed populations and reduce environmental impacts have led to a number of non-chemical treatments being explored including in the Faroe Islands and Norway, such as the use of cleaner fish and mechanical cleaning.

The use of antibiotics in aquaculture has also been of concern, including the development of microbial antibiotic resistance and the transfer of antibiotics through the food chain. The

Faroe Islands are a prime example of where effective regulation implementation to address the issue has been effective, with zero uses of anti-biotics on salmon farms since 2004 as a result of stringent disease control regulation.

Interactions between farms and marine wildlife can result in damage to nets and loss of stocks while also resulting in harm to marine wildlife such as seals. The use of Acoustic Deterrent Devices (ADD) has been widely adopted across the sector as a means of non-lethal deterrent for marine wildlife. However, following increasing awareness of the wider impact of ADD use on marine wildlife and non-target species and import requirements from the USA has led to many nations taking steps to ban (e.g. Canada) or greatly limit the use of such devices by farms (e.g. Australia, Scotland). This is a commendable example of how a number of different regulatory mechanisms and influence from outside nations can be utilised to address environmental issue associated with aquaculture.

The future of aquaculture legislation and regulation

As multiple nations aim to grow their aquaculture industry in coming years it is vital that robust regulation and legislation is in place to address environmental impacts of aquaculture activities. Much of existing regulation across the sector is inadequate or out of date in the face of the industry expansion and the cost of this will be to the detriment of the environment A number of nations have acknowledged this and are in the process of reviewing existing regulation and legislation, however the final outcomes and impacts of these reviews remain to be seen.

This review shows that no single nation has sufficiently addressed the environmental impacts of salmon aquaculture. As many nations aim to expand the industry in their respective locations and undertake reviews of existing regulations it is urgent that such action is taken quickly to ensure the long-term protection and sustainability of the environment and communities. It is imperative that the expansion of the global salmon industry must come under moratorium until the following has been addressed across each salmon aquaculture nation:

1. Legislation and regulation must address the environmental impacts and where farms are repeatedly failing to meet environmental limits, they should cease operation. Long term monitoring of the environment should be a pre-requisite for all new salmon farm proposals/applications.
2. The introduction of a legal requirement for real time salmon aquaculture data to be publicly accessible to farm level, through an online dashboard or information portal.

3. Any decision-making process to approve the licence on a new farm location must account for the diverse range of environmental factors in the location which its operation is proposed and the potential cumulative impacts of the farming operations robustly assessed.
4. Detailed environmental assessments, ongoing monitoring and reporting, coupled with regular and robust enforcement of regulations, must take place where approval of new farms is granted.

Glossary

Acoustic Deterrent Device (ADD): A technology that emits a high-pitched frequency of sound to deter marine species (e.g. seals).

Allowable Zone of Effect (AZE): A defined area surrounding salmon farming operations. Beyond the zone boundary there must be no measurable impact to water or the sea bed as a result of the farming activity.

Benthic: Of, or relating to, or occurring at the bottom of a body of water

Benthos: Refers to the lowest ecological area in a body of water (e.g. sea bed, lake bed)

Biomass: Determined through the number of fish in a body of water, multiplied by the average weight of sampled fish from the population.

Carrying capacity: The capacity of a body of water to receive additional inputs, i.e. of organic matter, without causing a detrimental impact on its ecosystem.

Environmental Quality Standard (EQS): Environmental legislative and regulatory requirements.

Eutrophication: Excessive plant or algae growth, due to nutrient enrichment of a water body.

Genetic introgression: The introduction of escaped farmed salmon stocks genetic material in to wild salmon populations through interbreeding.

Global Salmon Initiative (GSI): International group of salmon aquaculture industry members, with a goal to improve sustainability of the industry.

Harmful algal bloom (HAB): Excessive toxin producing algae growth in a body of water with harmful effects to wildlife and humans

Maximum allowed biomass (MAB): the maximum volume of salmon a company can hold at sea at any given time.

Maximum sustainable yield (MSY): the largest number (yield) of fish that can be taken from a population over an indefinite period while sustaining the population, i.e. ensuring there are enough fish left to breed and maintain the population

Motile: Motile includes adult *L. salmonis* females (with or without egg strings) and other motile *L. salmonis* (including adult males and preadults). “Mobile” is considered a synonym of “motile.”

Non-governmental organisation (NGO): A non-profit organisation formed independent of or without affiliation with government.

Open net pen (ONP): The most commonly used form of salmon aquaculture pen. Open net pens are cages made of metal nets where adult salmon are grown until harvested.

Priority marine feature (PMF): Habitats and species in Scottish waters considered to be marine conservation priorities.

Recirculating Aquaculture Systems (RAS): A land based, enclosed system of salmon aquaculture. Often used for raising young salmon before transferring to open net pens.

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Introduction

The development of aquaculture is rooted in the desire to create a stable food source, with the additional potential to slow down ocean depletion[1]. However, over the last 20 years salmon farming has developed into a profitable business area. There has been a significant global expansion of farms with subsequent detrimental environmental impacts[2 3 4] (**Error! Reference source not found.**). To minimise the environmental costs of the industry, legislation and regulations have been developed and implemented to varying degrees around the world[5].

Table 1. Main environmental impacts of finfish aquaculture.

Issue	Impact
Diseases	Open net pens (ONPs) may contribute to infection of wild fish with disease and parasites[6 7], i.e. sea lice are naturally occurring parasitic crustaceans that affect adults and smolts in the marine phase
Chemical treatments	Pesticides and antibiotics used in ONPs to combat sea lice and other diseases may affect wild marine life[8].
Food waste and faeces	Waste from uneaten food and fish faeces under ONPs can create anoxic conditions and affect wild fish[9 10], marine habitats[11] and other organisms.
Predator interactions	(1) Acoustic deterrent devices (ADDs) and alternative devices, used to deter seals, may harm seals and other marine mammals[12 13 14] (2) Siting farms close to populations, i.e. seal haul out sites, can encourage interaction
Fish escapes	Damage to ONPs from predators (i.e. seals) and bad weather can result in escaped farmed fish interacting with wild populations[15].
Feed	Fishmeal and fish oil in feed is sourced from wild fish populations which may already be at maximum sustainable yield, i.e. catches are at the maximum limit which can be maintained by that population[16]

Environmental management of salmon farming

There are no global legislative requirements to monitor the impact of salmon farms on the surrounding environment, instead aquaculture legislation is created and implemented at a national or regional level[17]. This usually means salmon farms are subject to planning permission, including environmental impact assessments. Whilst consultation may be sought at a country level for planning approval, all governments explored in this report view aquaculture as an industry of economic importance. Most countries are striving for 'sustainable' aquaculture practices; however this is not always embedded in their aquaculture legislation.

There are no defined environmental quality standards (EQS) shared across countries and therefore EQS are driven at different spatial levels from husbandry through to location-specific legislative and regulatory requirements.

Some environmental metrics are well-established and adopted practices, such as regulation of the benthic (seabed) footprint of a salmon farm[18 19]. However, the level of monitoring or regulation of the movement of nutrients, medicines, chemicals and particulate organic wastes associated with salmon farming methodologies can vary greatly by country[20 21 22]. They are usually managed through site specific sampling locations or zones and often monitoring is not conducted outside these defined zones[23]. Therefore, it is much harder to manage and regulate input movements and the subsequent impact to the environment which are likely to be site-specific in many instances[24 25 26].

Socio-economic factors

Public support for aquaculture has often been taken for granted by policy makers due to the perceived economic advantages of the industry, especially in rural areas, however social challenges to the industry are increasingly apparent[27]. As well as environmental limitations on the siting and successful function of salmon aquaculture farms, growing public awareness of the environmental impacts of aquaculture has led to increasing consideration of the social acceptability or 'licence' of aquaculture[28].

Certification schemes have been increasingly used in salmon aquaculture, as a measure of apparent environmental performance in order to gain public trust and acceptance of the industry. The schemes are intended to provide independent assessment by a third party through regular monitoring and evaluation of a salmon farm and its practices[29]. The increasing awareness by industry of both the public perception of the environmental impacts of salmon farming, and the importance of that public perception, has led to greater consideration of both in certification schemes. This has been reflected in the most recent scheme to be developed, the Aquaculture Stewardship Council (ASC)[30]. However, the proliferation of schemes and their limitations has also led to mistrust of certification and by default the aquaculture industry[31].

While there is a myriad of certification bodies, there is no obligatory requirement for suppliers, farms or retailers to certify salmon products. The Global Salmon Initiative (GSI) is a leadership effort representing 40% of the global farmed salmon industry, with 15 member companies from 7 countries[32]. The GSI members have committed to aim for 100% ASC certification. The international NGO World Wide Fund for Nature (WWF) is a stakeholder for the ASC, which was established with the aim of linking strongly to environmental sustainability. In 2021 WWF-Australia introduced reforms of the certification to account for the cumulative impact of multiple farms in an area[33].

The development of aquaculture in some regions (e.g. Chile, Canada) has raised questions regarding the impacts upon the rights of communities and indigenous peoples in areas where fish farming is taking place. This can have multiple dimensions as well as impacting the local environment, including the exclusion of peoples from areas of cultural importance, disrupting livelihoods of communities, and impacting communities' cultural and spiritual relationship to traditional lands and waters[34]. However, views within a community can be varied, with both support and opposition of aquaculture often present. It is important that in these regions indigenous groups are included in discussions around aquaculture and the decision-making process, with the fundamental need to recognise and protect the rights of indigenous groups and communities[34, 35] .

Global scale of Atlantic salmon production

Salmon farming accounts for ~70% of the global salmon market[36] . The salmon aquaculture industry has substantially developed over the last 40 years, with global production nearing 2.9 million tonnes in 2021 [37] . The six countries of Norway, Chile, Scotland, Faroe Islands, Canada, and Australia share over 97% of all farmed salmon production worldwide (**Error! Reference source not found.**). The other Atlantic salmon farming nations that make up the remainder, less than 3%, of global production include Iceland, the Russian Federation (Russia) and The Republic of Ireland (Ireland).

Table 1. Global Atlantic salmon aquaculture summary table

Country	Number of marine open net farm sites	Estimated annual production (tonnes) - 2021[37]	Share of global production
Norway	~700 active sites in 2020[38]	1,562,415	54.11%
Chile	~300 sites[39]	724,835	25.11%
Scotland	213[40]	205,393	7.10%
Faroe Islands	30 sites[41]	115,650	4.00%
Canada	~75 in British Colombia[42], and ~62 in North Atlantic[43]	84,171	4.16%
Australia	49 farms[44]	84,045	2.91%

Iceland	102 licences[45]	46,458	1.61%
All other countries (including Ireland and Russia)	16 in Ireland[46] No data available for Russia	29,471	1.02%

Farmed salmon production is dominated by fifteen companies, with the five largest production volumes of 2022 from MOWI, Salmar, AquaChile, Leroy Seafood and Cermaq, in decreasing order[47]. The companies of Cooke and Bakkafrost, both with Scotland operations, were listed as 6th and 7th respectively.

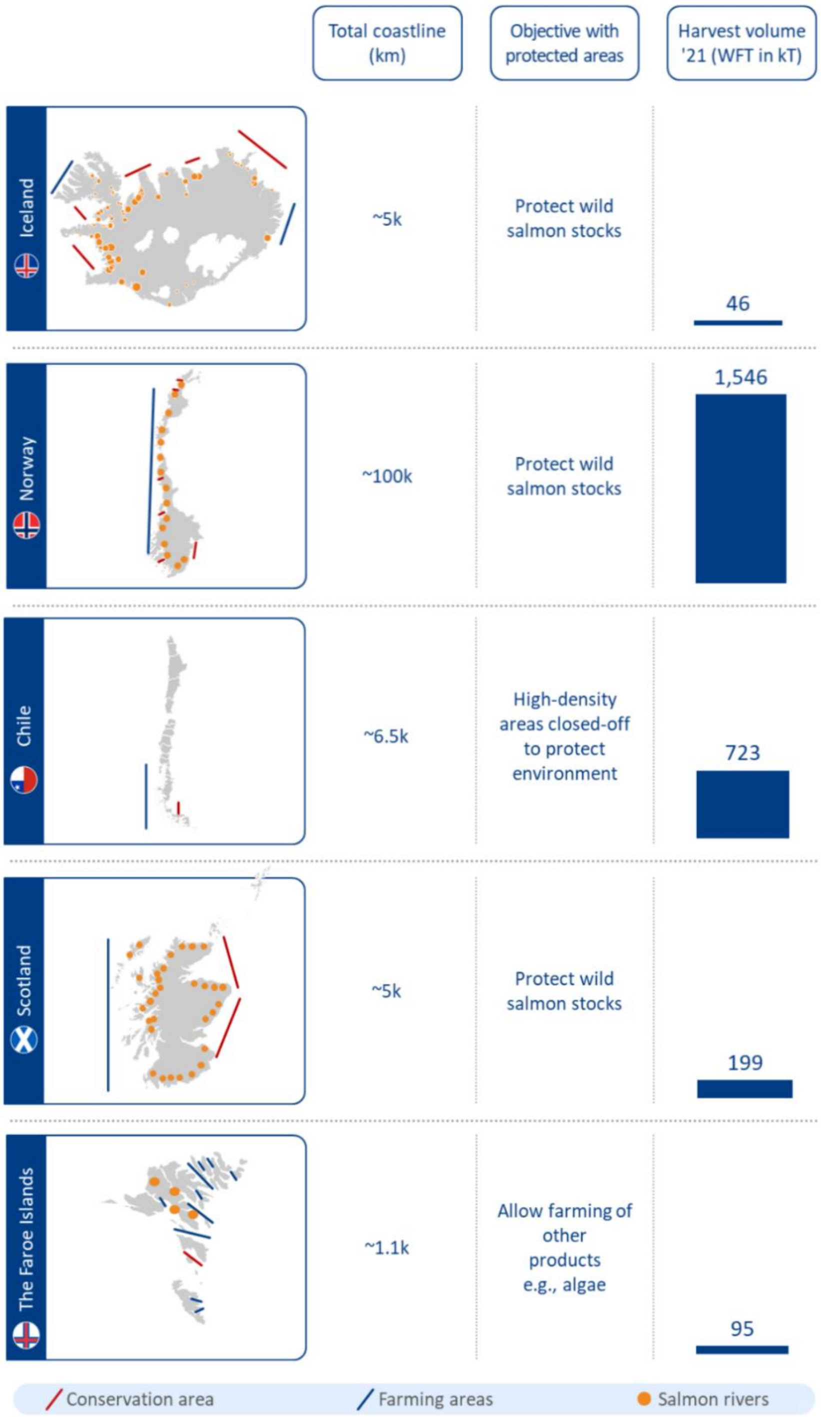

Figure 1. Principle salmon farming areas, conservation areas and salmon rivers of 5 salmon producing nations[45]

Study aim

This report explores the legislation and regulation of marine open net pen salmon fish farms and identifies the influences of these on protecting the environment.

The focus of this desk-based study is on the seven largest Atlantic salmon farming regions in the world, which are Norway, Chile, Scotland, Canada, Faroe Islands, Australia and Iceland, and the legislation each has in place.

The study provides an understanding of direct inputs/factors on the environment and the legislation and regulation associated with:

- Diseases, chemical treatments and antibiotic use;
- Waste:
  - Input to benthos and water column from feed and effluent,
  - Plastic use, reuse and recycling;
- Wildlife interactions (predators and wild salmon) and acoustic deterrent devices (ADDs)

Detailed discussion of socio-economic factors is beyond the scope of this report, however, some consideration is given to factors that could impact the legislation and regulation that is in place to protect the environment. These may include human and indigenous community rights, employment and local economy, third party certification, and social licence. For example, stakeholder perceptions and data availability can be vital to the salmon farming industry's social acceptability, or 'licence'.

Current legislation by country

Norway

Background

Norway is the largest producer of farmed salmon, accounting for ~54% of total global volume in 2022[45]. Including its islands and archipelagos, Norway has the second largest coastline in the world after Canada, with a length of ~100,000 kilometres. The Norwegian coast is divided into 13 geographical areas of production [38].

Almost all farmed salmon in Norway is produced in open net pens in coastal inshore environments, with the hatchery phase mostly in Recirculating Aquaculture Systems (RAS) on land. A very limited amount of production is in semi-closed pens and offshore operations, as these new technologies are being developed[48].

Salmon farming is licensed, with each license based on maximum biomass in a geographical area/fjord, and maximum biomass in a production area. Farmers bid for licenses in an auction, creating a source of revenue for the government, and if successful they own the license indefinitely with the right to sell it on the open market. License costs account for the highest share of Norwegian farmers' invested capital per kg harvested.

Current licensing regimes are reaching full utilisation rates due to biological and environmental boundaries[49] [50]. In addition, regulatory measures to mitigate environmental impacts have been implemented, where license utilisation is dependent on the sustainability of each farmers production[51]. Increased or new biomass is offered if production is compliant to environmental standards. **Commercial licences** account for ~83% of biomass. In different rounds these have been offered with different priorities, i.e. local ownership, female owners, small businesses. **Education licences** are owned by schools, where students have access to facilities to learn and experiment. **Research licences** provide facilities for research projects, on a range of areas from disease and feed to technological innovations. **Development licenses** were launched in 2015 and are intended to lead to technological innovations[52].

Legislative and regulatory frameworks

The regulatory system in Norway is complex, involving many public agencies with numerous old and new laws and regulations co-existing. In 2022 a new aquaculture strategy was published, called 'A Sea of Opportunities', designed to guide Norwegian aquaculture for the following 10-15 years[53]. A government appointed committee currently overseeing the regulatory system will provide proposals in September 2023, which are expected to propose a simpler and more streamlined system. The industry itself has a long-standing tradition of sharing information.

The Aquaculture Act (2005) regulates the management, control and development of aquaculture in both inland and marine waters[54]. The Act established a licencing system, which is administered by the Directorate of Fisheries, who sends licence applications to relevant bodies before a decision is made (Figure 2). The Norwegian Ministry of Trade, Industry and Fisheries awards the licenses. The production area must further be approved by the relevant county and municipality.

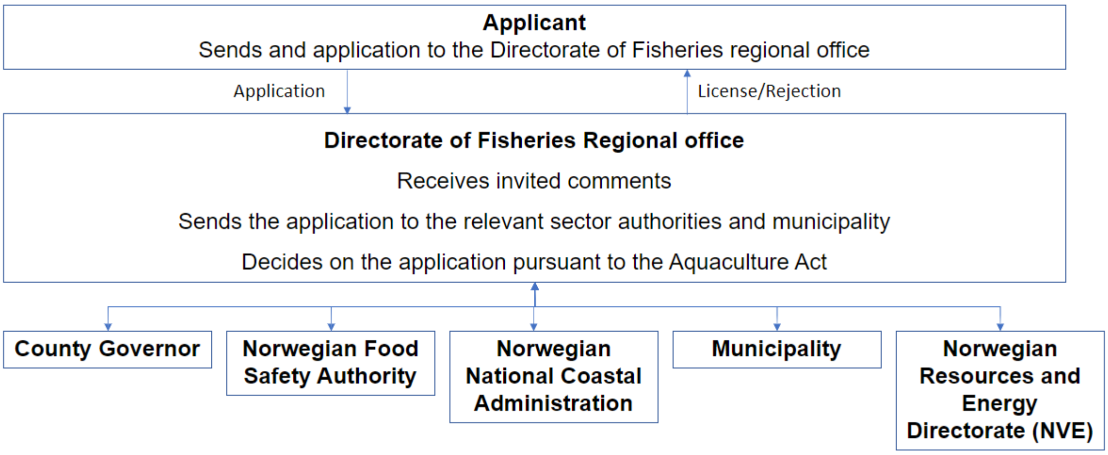

Figure 2. The application process and administrative bodies involved in Norway aquaculture licencing[45]

The Licencing Regulations (2004) established a maximum breeding biomass for each licence. Norway now uses a "traffic light system" to determine the Maximum Allowed Biomass (MAB) on existing and new licenses. The system is now widely accepted but was opposed by some of the industry initially[55]. The MAB is defined as the maximum volume of salmon a company can hold at sea at any given time. A green light allows for an increase in the MAB by 6%, while a yellow light allows for no change, and a red light leads to a requirement to decrease the MAB by 6% within the following two years. In 2021, there were eight green areas, two yellow areas and three red areas. The traffic light system has been used to indicate how many new licenses will be auctioned and the MAB per license.

Licenses are based on a maximum allowed biomass (MAB), with allowing a MAB of 780 metric tonnes on average. The MAB is higher in 2 of the 13 production area (Troms and Finnmark) at ~945 metric tonnes on average, where colder sea temperature results in slower growth.

Companies with more than one license hold the total sum of their licensed MABs, which can then be distributed across different production and geographical areas. However, each production area has a site-specific MAB based on the environmental assessment which cannot be exceeded. The flexibility of spreading their MAB allows farmers to optimize production areas to account for the fluctuations in volumes during production cycles. For example, when smolts are first stocked in pens, the total biomass within a production area is at its lowest and far from the maximum carrying capacity of the production area. The flexibility in Norway allows farmers, while smolts are maturing, to increase the biomass in another production area, as long as the combined biomass in all areas is within the licensed and production area MABs.

In 2013, the Norwegian government introduced 45 new salmon farming **green licenses** with ~780 metric tonnes on average MAB each, with strict environmental conditions for sea lice, escape risk and other environmental factors. The licenses were offered in three different groups (Table 3).

Table 2. Overview of green licenses with conditions and price offered by the Norwegian Government[45]

License	Number of Licenses offered	Required impact of new farming methods	Price
Group A and B	• **20 Licenses** offered to farmers operating in Troms and Finnmark (Group A) and 15 offered in closed auctions (Group B) • **MAB of green licenses to be redeemed** simultaneously with previous granted licenses	1. Reduce number of escapes 2. Fewer than **0.25 adult female** lice per salmon in a production area 3. Limit of three sea lice treatments per cycle	• **10m NOK per license** in Group A • **Auctioned** in Group B
Group C	• 10 licenses • An applicant **does not have to redeem** one of its previously granted licenses	1. Fewer than **0.1 adult** female lice per salmon in a production area 2. Limit of three sea lice treatments per cycle **3. Knowledge and experience with new solutions shared with industry**	• **10m NOK** per license in Group C equal to 1/5 of market price in 2013

Free development licenses were offered from 2015 to 2017 for farmers planning on developing new farming practices, to incentivise more investment in new technologies. These licenses could save the cost of auctioned licences of 100 to 200 million NOK, were for up to 25 years and could be changed to a commercial license if a concept was successful.

With the regulatory regime under review, other proposals are being considered, including imposing an end date on licences, and reducing the types of licences. New licenses were auctioned in Norway in October 2022 a few weeks after the Norwegian government proposed to introduce the new resource rent tax. Auction prices were significantly lower compared to those in 2020.

Environmental impacts and monitoring

Norway must implement and comply with applicable EEA regulations such as the Water Framework Directive (EU Water Framework Directive 2000/60) and regulations related to animal welfare and diseases (Regulation on Animal Welfare, Regulation (EU) 2016/429 on transmissible animal diseases).

Data availability in Norway is good and often at the site level, although many reports are only published in Norwegian. The Norwegian Institute of Marine Research (IMR) publishes an annual Risk Assessment for Norwegian fish farming with an accompanying comprehensive "knowledge status" review, which analyses the industry in each of the production areas along the coast[56]. Every second year, the government ranks each geographical area based on scientific modelling of currents, temperature and sea lice pressure by the IMR.

Policies on sea lice are the determining factor over a farmers' maximum allowed production. Farmers are offered additional biomass of 6% if the following conditions are met:

1. Over the past two years, female adult sea lice per fish have been always kept below 0.1 in the period between April 1 to September 30; and

2. There has been a maximum of one sea lice treatment during the last production cycle.

The sea environment is another, slightly lower rated factor, and limiting diseases and escapes are also factors, rated lower than sea lice or sea environment.

The model for sea lice pressure is based on mandatory weekly reporting by farmers. The IMR assesses two primary factors in each of the production areas which are combined to determine the risk of lice-induced mortality for juvenile salmon and sea trout. The first factor is the risk that wild fish will be infected by sea lice from farms, which is informed by the environmental conditions for lice, the emissions of lice from farms, and the overlap between wild fish and lice in time and space. The second factor is the wild fish's tolerance to sea lice infection, which mainly considers the fish size at the potential time of infection. Future growth is largely tied to salmon lice levels[48].

Most Norway salmon farmers are investing in larger smolts, from land-based recirculating aquaculture systems, with some projects aiming for sizes up to 1,000 grams. With larger smolt sizes, the fish needs less time to reach harvest size in sea pens. With licenses centred around the biomass in the sea, this can significantly increase the turnover at sea and, thus, overall production. An additional benefit may also be lower mortality, as releasing more resilient fish into seawater reduces the likelihood of disease and lice outbreaks.

Chemical inputs and treatments

Sea-lice treatments

By 2021 chemical pesticide use, mostly to treat sea lice, had declined by more than 90% over the previous five or six years [38]. This is mainly due to resistance developed by the lice making chemical treatments increasingly ineffective, and leading to them being largely replaced with non-chemical alternatives[57]. Non-chemical alternative treatments include includes mechanical delousing, freshwater bathing, thermal delousing and cleaner fish[58]. Pesticide use varies widely with production area, both in the total number of prescriptions and the number of treatments per site. Three regions had less than one treatment per site per year in 2020. The IMR's annual risk assessment concluded the risk of environmental effects on non-target species was moderate for the use of five of the main chemical treatments (emamectin benzoate, deltamethrin, diflubenzuron, teflubenzuron, and hydrogen peroxide) and low for azamethiphos [56].

Antibiotic use

In 2020 the lowest use of antibiotics was recorded by the Norwegian salmon industry with less than 1% of all salmon produced requiring the use of any antibiotic treatment[59]. Development of vaccines are continuing to significantly reduce the requirement for antibiotic use, and breeding activities have focused on diseases resistance[60,61].

Waste

Input to benthos (seabed) and water column from chemicals, feed and effluent

The IMR's 2020 risk assessment provides a comprehensive review of the industry's impact to the water column, and by combining modelling results and physical monitoring data, it determined with high confidence that there is a low risk of environmental impacts as a result of increased soluble nutrient supply from aquaculture in all production areas. Benthic monitoring of organic emissions at aquaculture facilities has been required since 2005 following a Norwegian standard (NS9410) last revised in 2016. Results are graded as unacceptable, at risk of future congestion, good, or very good. Locations are closely followed through monitoring to be able to intervene if results are rated 'unacceptable'.

Pens used in production areas are increasing in size to bring scale benefits to operations, such as better utilization of investments such as feed barges. This trend has been strong in Norway with pens growing from an average size of 40 to 120 meters in diameter. Benthic monitoring survey results have been relatively even from 2009 to 2020, suggesting no immediate effect from the increased pen sizes.

Plastic use, reuse and recycling

Some details of plastic use and decommissioning rates are available for Norway. A 2011 report estimated around 13,300 tonnes of plastic waste generated by Norwegian aquaculture that year, with 21% recycled, mainly nets[62]. The only regulations in place are technical standards for aquaculture installations, which requires plans to be in place for the maintenance, repair and replacement of materials in order to prevent fish escapes. With inspections required every 24 months, this standard will prevent some plastic waste but is not directly intended to.

Wildlife interactions

Harbour seals are the most likely marine mammals to interact with salmon pens in Norway, and killing seals near aquaculture facilities became prohibited in 2019[63]. Other than three companies reporting (zero mortalities) through GSI[64], there are no robust mortality (lethal control or entanglement) data. No data was found on the level of use of acoustic deterrent devices in Norway salmon farms, and there is no current legislation or regulation of their use[65].

Key migration zones in wild salmon rivers are protected (e.g., Atlafjord and Reisafjorden) to limit the risk of genetic mixing with farmed salmon. Conservation areas are defined close to the mouth of the wild salmon rivers. Norway gathers data on farmed salmon escapees and potential genetic mixing with wild salmon in ~200 rivers [56]. Data for each river is considered by an expert group, together with any other relevant information, and interpreted to give incidence levels as low to moderate (<10%), moderate (not possible to conclude whether its > or <10%), or high (>10%)[66]. In 2021 intrusion levels were above 10% in ~20 rivers, above the IMR's recommendation.

The 2021 IMR annual risk assessment concluded that escapees interbreeding with wild Atlantic salmon has led to reduced numbers of wild salmon, as well as changes in important biological properties in wild stocks such as age at sexual maturity and migration time for smolts. Genetic changes have also been observed in wild wrasse populations due to the escape of imported cleaner fish.

Socio-economic factors

Employment and local economy

Of the 279 Norway municipalities that have a coastline, 160 have aquaculture production. 10 companies are responsible for ~70% of the biomass[67]. Up to 70% of license costs are distributed to municipalities and counties in addition to taxes and fees. In addition to licence payments, farmers are also subject to a series of other taxes and payments to support local communities (Table 4). The tax payment is split evenly between the municipalities and the government and is expected to yield between 3.65 and 3.8bn NOK (~365-380m EUR) in annual revenue.

Table 3. Additional taxes and fees a Norwegian salmon farm is subject to (aside from lease/licence agreements)

Tax	Cost associated with tax	Additional information
Production fee	As of 2023 0.405 NOK per kilogram of salmon harvested	Annually amended: allocated directly to farming municipalities and counties

Municipal real estate tax (property tax)	0.2 to 0.7% of property value	Rate amended every 10 years: paid to municipalities for floating installations
Research fee	0.3%	Allocated to the Norwegian Seafood Research Fund (FHF),
Export fee	0.3%	Allocated to the Norwegian Seafood Council (NSC)
Annual registration fee	15,000 NOK	implemented by the Norwegian Seafood Council (NSC)
Resource rent tax	35% of annual profits of the fish farm, subject to parliament approval[68].	To safeguard smaller farmers from the impact of the resource rent tax, a tax-free allowance of between 4-5 kT is planned. Considering farmers' licensed biomass in 2021, it is estimated that 35-40% of farmers would be subject to the new resource rent tax

Social licence

Work has been undertaken since 2015 to improve the social licence of aquaculture in Norway, responding to concerns about its impacts. There is little apparent activity from NGOs in opposition to salmon farming, and recent research indicates that the general impression of the industry is quite positive[69]. However, despite a high level of acceptance of the industry, the research found that this did not indicate support for further expansion and suggested that the aquaculture industry's desire for expansion would lead to conflict in coastal areas. The research findings also indicated that improvements were needed in terms of industry impact on the environment, distribution of economic benefits, transparency and regulation, in order to achieve 'societal support'.

The social acceptance of the industry is strongly tied to its provision of jobs in rural and coastal areas, with the result that innovations and technological improvements which reduce jobs can be controversial[48].

Chile

Background

Salmon aquaculture has grown dramatically in Chile over the last 30 years, becoming the world's second largest salmon producer, with salmon exports of USD 4.8 billion in 2021[39]. As demand for salmon continues to grow, production is expected continue to expand [70].There were a total of 1,360 concessions as of 2022 across the regions of Los Lagos, Ayse and Magallanes, with a further 367 applications submitted[71],[72]. Not all concessions are active at the same time, with approximately ~300 operational in 2022.

In 2021 Chile produced 724,835 metric tonnes of salmon [37]. There are no regulations based on carrying capacity to determine the maximum allowed biomass per area of water body[22]. While there are limits set for the amount of Atlantic salmon in individual pens, with a maximum density of 17kg/m^3 in a pen[73], this will be more related to animal welfare than environmental impact.

Between 1990 and 2006 salmon production increased by 640%, to a peak of 700,000 tons/year in 2006[34]. In 2000 Chile overtook Scotland as the second largest global salmon producer, a position it still occupies, accounting for approximately 30% of the world's salmon production [34, 74, 75]

As demand for production continues to grow, aquaculture operations are expanding into new areas. These issues have drawn attention of NGOs and other organisations in Chile and internationally, demanding improved regulation in the industry[34, 76, 77, 78, 79, 80, 81, 82].

Legislation to improve environmental conditions surrounding aquaculture operations have been increasing since the late 2000s following viral outbreaks which significantly impacted the industry. These changes have been incremental, generally added as amendments to the General Fisheries and Aquaculture Law. However, a recent change in government indicates new legislation is on the horizon.

Following the election of President Boric in 2022 the salmon industry has been an area of focus for the new administration. Boric, himself from the Magallanes region, has been vocal over his desire for reform in Chile's aquaculture industry, with key priorities including:

- *"Conducting an evaluation of the environmental and economic impact of aquaculture in the southern macrozone, especially in terms of water quality, biological diversity, and sea floors.*
- *Increasing investment in SERNAPESCA,* [The National Fisheries and Aquaculture Service]*, allowing it to conduct additional, more thorough salmon-farming inspections, including the use of state-of-the-art technology, training of new inspectors, and the construction of new vessels.*
- *Increasing funding for SERNAPESCA to ensure salmon farms are complying with the country's environmental rules."* [83]

Legislative and regulatory frameworks

The framework for the licensing of aquaculture farming operations involves multiple governmental departments. Aquaculture licensing is regulated primarily under the General Fisheries and Aquaculture Law, which dictates the organisation of licences and the technical requirements of a project.[34] Conditions and environmental parameters are determined by the Undersecretariat for Fisheries and Aquaculture [84, 85]. The areas designated as suitable for aquaculture farm licences are determined and licences granted by the Ministry of Defence and Undersecretariat of the Armed Forces [86]. Areas deemed suitable for aquaculture are designated as Areas for Aquaculture Activity (A.A.A.).

Aquaculture projects are required to undertake an Environmental Impact Assessment (EIA) or produce an Environmental Impact Statement (EIS) prior to being licenced. The Superintendency of the Environment (SMA), under the Ministry General Secretariat of the Presidency, is responsible for the EIA system alongside general environmental legislation[84,85].

The National Fisheries and Aquaculture Service (SERNAPESCA) is responsible for ensuring compliance with legislation by aquaculture operations and enforcement, this includes monitoring conditions defined by regulations.

In 2007 Chilean Atlantic salmon farms experienced outbreaks of Infectious Salmon Anaemia virus (ISA) in 97% of production areas, the worst outbreak ever recorded, which can lead to significant mortality rates of farmed fish salmon[87, 88]. This led to a moratorium on new aquaculture concessions being granted since 2010 under Law 20.434 and renewed in Law 20.583 and 20.825 in 2012 and 2015 respectively[89]. This was recently extended in 2020 in the Los Lagos and Aysen regions[78,89].

However, concessions have been granted in the Magallanes region, as production demand continues to increase, and the colder southern water allow for reduced use of antibiotics and chemical treatments. There is significant focus on concessions within National Parks and protected areas in this region. Legislation forbids granting of concessions within national parks, however protected areas and reserves do not have the same level of protection [76, 77]. This has led to highly controversial concessions being granted in protected or reserve areas, with lawsuits filed by NGOs and indigenous groups. The new Chilean government has indicated that it intends to address this. It is anticipated that there will be a moratorium on concessions in these areas until impact assessments can be undertaken [83]. Subsequently, Aqualchile, an industry giant, announced its exit of operations from national parks following government negotiations, however other reports suggest renewed investment from industry in these regions [90,91]. There is potential that operations may relocate to areas adjacent to or not covered by the national park status, while concerns over the ability of the government to reform the industry, in the face of powerful corporate political influence also persist [76,77,92].

In 2022 the government announced plans to replace the current General Law on Fisheries and Aquaculture with a New General Law on Aquaculture (Nueva Ley General de Acuicultura), with the new version presented in 2023, with debate expected in 2024[78].

Environmental impacts and monitoring

Chemical inputs and treatments

Sea-lice treatments

Pesticides are commonly used in treating the sea lice *Caligus rogercresseyi*, administered via baths or feed. Sea lice infections have been a persistent issue in Chilean aquaculture, having the greatest biological and economic impact on salmon farming operations[93]. It is estimated that over one third of global costs associated with sea lice infections come from Chile[94].

In 2007 SERNAPESCA began a national surveillance program in an effort to address the issue, with updates to the program in 2012, known as Specific Sanitary Surveillance and Control Programme of Caligidosis (PSEVC-Caligidosis) [94]. This regulation most recently received further changes and updates in 2018[95, 96].

Current regulations require weekly monitoring of sea lice, with a limit of 3 female gravid per salmon [95,97]. A number of chemical treatments are used in treating sea lice in Chilean aquaculture, in 2021 7.72g of medical treatments were used per ton of harvested salmon, with 978,274 tonnes produced that year [93] . Azamethiphos and Hexalumuron accounted for 47% and 45.5% of chemical volume used respectively, as well as 5,532 tons of Hydrogen Peroxide [93] . Emamectin benzoate has been used in Chile throughout the 2000s where it was the only available authorised treatment. However, from 2005 evidence of resistance to the treatment lead to decreased use and authorisation of alternative chemotherapeutants on the market, though it is still used by some farms[98],[99].

Increasing resistance to treatments has driven the controversial high use of treatments in Chile. The use of chemical treatment is also highly contentious due to the impacts on non-target species in the wider marine environment, with varying impacts varying between species [100].

The push to reduce the use of chemical treatments has been one factor in increasing numbers of farming operations in the southern Magallanes region, where colder water temperatures and glacial run off aid in supressing sea lice numbers[101],[102] However, there is concern of sea lice introduction to wild species and the impact of chemical treatments in new regions ecosystems [103].

Antibiotic treatments

In contrast to many northern hemisphere salmon aquaculture operations, antibiotic treatments are used extensively in Chile. In 2019 the production of 989,546 tons of salmon used 334.1 tons of antibiotics (500g/ton), which is 2000 times greater than that used by Norway to produce 1.3 million tons of aquaculture produce in 2016 (0.01g/ton) (95% of which was salmon) [97,104] . This is due to the prevalence of bacterial infection in the region. The greatest bacterial threat is from *Piscirickettsia salmonis,* the bacterial cause of Salmonid Rickettsia Septicemia (SRS), and is responsible for 83.3% of Chilean Atlantic salmon deaths in 2019[22, 85, 104]

Antibiotics are predominantly administered through feed, and as much of the feed is not eaten the antibiotics enter the surrounding environment in high levels, along with other waste sources. It is estimated between 70-80% of administered antibiotics are entering the aquatic environment [22,104] . There are concerns surrounding the use of antibiotics in relation to increasing antibiotic resistance and the transfer of antibiotics into the food chain, as well as the use of antibiotics designated by the World Health Organisation (WHO) as important for human medicine [97,104, 105,].

Historical legislation surrounding the use of antibiotics has been relatively lenient [97]. In recent years laws have been tightened in response to public health and environmental concerns as well as export market demands (particularly in from US markets)[105 ,106]. Regulation relating to antibiotic use is the responsibility of SERNAPESCA, with the Agriculture and Livestock Service (Servicio de Agrícola y Ganadero) and Ministry of Agriculture (Ministerio de Agricultura) responsible for authorising pharmaceuticals for aquaculture use [86,105]. The main regulations relating to disease control are found in the General Fisheries and Aquaculture Law and its regulations, and the Regulation on High Risk Diseases of Living Aquatic Species[86]

When the total mortality rate of a cage reaches >0.05% for five consecutive days (excluding environmental and predatory causes of death), government regulations require a pre-prepared action plan to be implemented, which may include antibiotic treatments[104]. Antibiotics are prescribed by a vet following a laboratory confirmed diagnosis, with no limit to the number of treatments which can be administered per harvest cycle [97,104,105]. However, antibiotics cannot be applied as a preventative treatment, under Article 86[105]. Antibiotic use must be recorded and reported monthly to SERNAPESCA via the Aquaculture Inspection System, with annual reports published (SIFA)[105].

In 2016 SERNAPESCA initiated a program to certify salmon farms as antibiotic free[22]. Additionally, a program between the Monterey Bay Aquarium Seafood Watch and SalmonChile called the Chilean Salmon Antibiotic Reduction Program (CSARP) is aiming for 50% reduction in antibiotic use by 2025 (compared to 2017 levels)[107]. Amendments to the General Fisheries and Aquaculture Law from the 31st January 2023 under Law No. 21,532 included sections aimed at improving transparency surrounding antibiotic use in the industry, including the required reporting and publishing of amounts and types of antibiotics used on farm and company levels[108, 109, 110] .

Waste

Input to benthos (seabed) and water column from chemicals, feed and effluent

Regulations regarding waste, sanitation and related environmental monitoring parameters are predominantly regulated by the General Law on Fishing and Aquaculture and the Environmental Regulation for Aquaculture. New regulations implemented from 2010 following the 2007 ISA virus crisis[111] aim to reduce the density of farms as a response to the outbreak, with the goal to reduce concentrations of waste in aquaculture areas and address waste management and disposal[78, 111, 112].

Widespread 'Red Tide' harmful algal blooms (HABs) in 2016 raised strong concerns about eutrophication from salmon aquaculture[22]. Even with moratoriums aimed at addressing sanitation issues surrounding aquaculture, fish deaths resulting from environmental causes doubled from 13-26% between 2020-2021, with algae blooms a noted issue[78] .

From 2020, operations were mandated by the Superintendencia de Medioambiente (SMA) to continually monitor water in areas surrounding cages for dissolved oxygen, temperature and salinity levels in real-time, and send it directly to the relevant government agencies [113]. Monitoring of the benthic environment is conducted during the point of maximum biomass accumulation of the production cycle or year. If monitoring shows failure to meet environmental standards farming licenses can be revoked [97,114]. In 2022 the producer Nova Austral was sued by the Chilean government over waste dumping practices and damage to the seabed environment[115] .

Plastic use, reuse and recycling

Aquaculture has been noted as source of marine plastics, including buoys, lines and floatation aids[116]. In 2021 a Supreme Decree No. 64/2020 set out conditions for use of and disposal of aquaculture waste, including plastics[117]

Wildlife interactions

Currently there is no legislation inhibiting the use of acoustic deterrent devices (ADDs) in Chile, with aquaculture regulation recommending the use of ADDs to prevent damage to nets from marine life, while also as a means of protecting wildlife from harm from operations [97,118]. Marine mammals are protected species under Decree 225/1995 of Chilean law, with the use of lethal force illegal [97,118]. Most attacks are from sea lions, which are a protected species under Chilean law, preventing lethal force[97] . In 2019 SUBPESCA (Undersecretary of Fisheries and Aquaculture) required salmon farming operations to report any interaction with sea lions to SERNAPESCA. This also included the installation of anti-predator nets and mandatory contingency plans for marine mammal interaction and approved by SERNAPESCA. This seems to have been driven by demand from the USA export market, as imports can be banned if marine mammals were harmed in relation to production (under the USA Marine Mammal Protection Act, implemented in 2017)[119, 120,]

Much of the salmon produced in Chilean aquaculture operations is non-native Atlantic salmon[103]. Despite concern over the impact of escapes, limited studies or monitoring have taken place[121] . Escapes have been a chronic issue for producers, with 1.6 million salmon fish escaping between 2018 and 2022, and up to 16 escape events per year in the Patagonia region[122] .

Recapture has previously been the responsibility of producers, with escaped fish considered private property[123]. Producers are expected to have action plans in place in the event of escapes and must inform authorities within 24hrs of escapes and the numbers[133]. Producers are required to recapture at least 10% of escapes[124] .

New amendments to the General Fisheries and Aquaculture Law under Law No. 21,532 from the 31st January 2023 has established greater penalties for producers of escaped produce, with a fine equivalent to the value of the escaped produce, an operations suspension of up to 4 years and the financing of ocean monitoring assessing impact of escapes for two years[122,124,125]. This new amendment also aims to increase the recapture of escaped fish by de-privatizing escaped salmon, allowing third parties and artisanal fishers to capture escaped salmon, to aid increasing recapture rates for escaped fish stock [108,122,124].

Socio-economic factors

Employment and local economy

It is estimated that the aquaculture industry employed over 80,000 people nationally[34]. Research has found that aquaculture operations in a region can have a positive impact on a local community's income, with evidence of up to a two-thirds reduction in poverty within 13km of a farms[126]. Along with greater employment opportunities some areas have seen infrastructure improvement and investment[34]. However, the industry has been accused of poor labour conditions, health and safety, long working and low wages[34,127].

Reports indicate that between 2016-2019 a worker died every seven weeks, with divers being particularly dangerous jobs [34]. Furthermore the increasing reliance of some regions on aquaculture for employment has resulted in mass unemployment at various points (e.g. ISAV crisis)[34] . There are also concerns from local artisan fishing groups over the environmental impact that aquaculture activities can have on their livelihoods[128] Click or tap here to enter text..

Indigenous rights

Salmon aquaculture has become a highly controversial industry in Chile, with concerns over human rights surrounding aquaculture operations have been raised, particularly by indigenous communities [34,129]. A notable example of this is the Kawésqar communities in the Kawésqar National Reserve in southern Chile [76,129].

The Kawésqar argue that farming operations have infringed on their rights, occupying areas of traditional fishing grounds and reducing access to sacred sites, while polluting the environment in their territory. They argue that this results in degradation of their culture and damage to important cultural sites, while government and industry failed to consult indigenous groups on projects in the area [76,128]. However, industry has responded by noting many concessions were in place before the creation of the protected areas and requirement to consult indigenous groups, with farms only covering 0.06% of the reserve area[76].

Local groups have led campaigns against aquaculture operations in the Kawésqar National Park, assisted by NGOs, including Greenpeace Chile, AIDA and FIMA, predominantly aiding in legal advice [76]. However, there are also locals in the area who are in favour of aquaculture in the area and see it as an opportunity [130].

Social licence

Public opinion surrounding salmon aquaculture is mixed. According to results of the 2019 regional barometer survey, local opinion is that the industry provides jobs and economic benefits to regions, however there is demand for better regulation of operations and control of expansion, with demand for tighter environmental regulation[131].

Consumption of salmon in Chile has historically been relatively low, with much of production destined for export purposes. However, consumption has been increasing over recent years, potentially increasing public awareness of production practices and impacts[39] .

A number of NGOs have been involved in campaigning around the issues surrounding salmon aquaculture in Chile. The WWF have worked with the industry through their Seafood

Sustainability project to aid farms in gaining Aquaculture Stewardship Council (ASC) certification for a number of years[132] .The WWF-US also began a project in 2022 with the Walmart Foundation, aimed at creating development guidelines, developing blue financing and improved monitoring of operations and data collection[133],[134] .

Several NGOs have been active in regards to the Kawésqar National Park, and Patagonia region, with aims to include the sea as part of the park, halt new project approval within the park and stop further expansion of the aquaculture in the Chilean Patagonia region[76,82,135].

Scotland

Background

Most salmon farming nations use freshwater facilities on land for the juvenile stages of Atlantic salmon, however Scotland is unusual in that it utilises open net pens in freshwater lochs. As in the other salmon farming nations, salmon smolts are then transferred to open net pens to grow out in the open sea or in sea lochs. The Scottish Parliament held two inquiries into Scottish salmon farming in 2018, the first by the Environment, Climate Change and Land Reform (ECCLR) Committee and the second by the Rural Economy and Connectivity (REC) Committee[136], [137].

The REC Committee report had 65 recommendations, which were accepted in principle by the Scottish Government. Several of the recommendations addressed regulatory processes, leading to a review of the aquaculture regulatory processes in Scotland[138]. The review further recommended the development of a 10-year framework, for which the Scottish Government subsequently formed the Scottish Aquaculture Committee (SAC), consisting of stakeholders ranging from industry, statutory consultees and environmental NGOs. The SAC fed into and reviewed the Scottish Government's 'Vision for Sustainable Aquaculture' published in July 2023, which is intended to guide aquaculture in Scotland to 2045[139].

Legislative and regulatory frameworks

Aquaculture policy differs between individual countries within the UK, it is a devolved matter with each of the separate administrations of Wales, England, Northern Ireland, and Scotland being responsible for its collective oversight. In Scotland, farms are based in the West and Northwest coasts, as the Scottish Planning Policy restricts salmon farming in the North and East coasts[140]. These restrictions are mainly intended to limit the risk of genetic introgression with wild Atlantic salmon. The length of coastline available for farming is similar to that of Iceland's, but Scotland produces ~4x more.

Four different site approvals are required: a Planning Permission from the local Planning Authority (since 2007), a Marine License from Marine Directorate (formerly Marine Scotland), a Controlled Activities Regulations (CAR) License from the Scottish Environment Protection

Agency (SEPA) and an Aquaculture Production Business authorization from Marine Directorate. Additionally, as UK territorial waters are Crown Estate Scotland (CES) property, an operator must apply for a lease from the CES and pay rent to install and operate a farm on the seabed. Rent payment is per kilo of harvested fish. A CES lease is generally granted for a 25-year period and is dependent on securing planning permissions. The licenses are not auctioned as in Norway.

The application process is, where the local Planning Authority consults with other governmental bodies to decides whether a farm can operate the proposed area and whether an environmental impact assessment must be conducted.

Planning permissions for new sites are expected to take around 6 months and applications for environmental licenses around 4 months. An Environmental Impact Assessment (hereafter referred to as EIA) must also be conducted. That said, both processes can take considerably longer. To increase production, the most cost- and time-effective option is to expand already-existing facilities, provided the environment is suitable.

Licenses are based on MAB per production area, which is determined based on an assessment of environmental impact, capacity of the seabed and the local marine environment. The MABs are not uniform and vary depending on site characteristics and location. As the MAB is dependent on location, it cannot be moved between production areas as with the total MAB in Norway.

In the event of non-compliance with environmental standards, the MAB can be decreased and potentially revoked in cases of significant and long-term non-compliance.

A new regulatory framework came into effect in 2019. This involved using more precise modelling methods, setting new spatial restrictions on the size of the genetic introgression impact zone around farms, and improving environmental monitoring. The new criteria, a more accurate model, and improved monitoring have made it possible to approve larger farms than would previously have been possible.

Environmental Impacts and Monitoring

Beyond limits imposed by carrying capacity, Scotland sets additional restrictions with the objective of limiting the impact of escapes on wildlife and sea environments. Sanctions are applied in Scotland if production has a damaging impact on seabed and water conditions, such as an obligation to decrease biomass. Farms in Scotland must obtain an environmental license that can be revoked for non-compliance. Surveillance is governed by the Marine Directorate Fish Health Inspectorate.

There are multiple legislative acts applicable in Scotland with the aim to limit environmental impact, including the Aquaculture and Fisheries Act (2007) and associated secondary legislation, the Aquatic Animal Health Regulations (2009), and orders on Fish Farming Businesses regulating what farmers should record and report[141, 142]. The Scottish Government has further funded a computer model (DEPOMOD) developed by the Scottish Association for Marine Science[143]. The objective is to limit environmental impact by predicting the impact of farming on the seabed, considering e.g., feeding rate, configuration, and water currents. Certain EU regulations have further been implemented such as a regulation on animal health and welfare.

The Marine Directorate is responsible for governing farming operations in cooperation with SEPA and NatureScot. Surveillance is administered by the Marine Directorate Fish Health Inspectorate (FHI). The FHI carries out assessments for disease control, sea lice management and containment measures and SEPA oversees impact from organic load on seabed, including other pollutants from production areas.

A separate environmental license is required to operate a salmon farm. Farmers must obtain an environmental license from SEPA to produce salmon and assess the production plan impact on the environment. The maximum allowed biomass for sites in Scotland was changed in 2019 and is dictated by the environmental and fish-health performance of each site instead of a standard unit per production area overseen by the DEPOMOD computer model. The environmental license can be reviewed, and MAB reduced in the event of non-compliance with environmental standards and revoked in cases of significant and long-term non-compliance.

Sea lice and Infectious Salmon Anaemia virus (ISA) are the largest biological challenge in Scotland, followed by Pancreas Disease (PD) and Cardio-myopathy syndrome (CMS).

Chemical inputs and treatments

Sea-lice treatments

In Scotland, farmers are required to report the weekly average adult female sea lice numbers per fish on farm sites to the FHI. The FHI can carry out inspections and assess measures in place to control and reduce parasites on farms.

If the sea lice count reaches or exceeds an average of 2.0 adult female sea lice per fish, the FHI will increase monitoring of site until levels are below 2.0. If levels reach or exceed 6.0, the farmer must intervene with treatments or harvesting until levels are below 2.0 again[141].

Scotland had a sea lice outbreak in 2014-2016, where average number of adult female sea lice per fish went above 1.0[144]. Between 2018 and 2022, the adult female sea lice levels were around 0.5, which is low in comparison to the previous 4 years.

A range of treatments are used in Scotland to combat sea lice, with the in-feed treatment emamectin benzoate used most frequently and the bath treatment azamethiphos used in the greatest quantities by weight. Hydrogen peroxide is also used in large quantities with 5.3 million litres used in 2018. The total number of pesticide treatments per year has generally declined over the ten years prior to 2021, but the industry still uses over three treatments per site on average each year, or over five treatments per 18-month grow-out cycle. On a regional basis, the Orkney Isles have a much lower reliance on pesticides, with only seven treatments in 2020 plus additional hydrogen peroxide treatments (six in 2018) equating to slightly less than one treatment per site per year[145].

The spread of sea lice from farmed salmon populations to wild populations has also been of concern in and the impact on wild salmon populations. SEPA has aimed to address this issue through implementation of a risk-based framework for managing interaction between sea lice from marine finfish farm developments and wild Atlantic salmon (commonly referred to as the 'Sea Lice framework')[146]. This framework aims to mitigate the transmission of sea lice from farm sites to migrating juvenile wild salmon during migratory periods. Farms identified as at risk of high sea lice numbers along migration routes (known as Wild Salmond Protection Zones – WSPZ) during the migratory period will be required to implement measures to reduce sea lice numbers among the farmed salmon population. This limit is calculated for each farm based on licence agreements.

Antibiotic use

The UK Veterinary Medicines Directorate has published an annual report since 2017 with sales figures of antibiotic active ingredients for veterinary use. Use of antibiotics in salmon farming decreased significantly between 2006 and 2015, from over 5,000 kg used for a production of approximately 130,000 mt to less than 200 kg being used for a production of approximately 170,000 mt. This is equivalent to a reduction by a factor of almost 40 times, from approximately 40 mg/kg to approximately 1 mg/kg (antibiotic active ingredient/salmon produced)[145]. Levels of antibiotic use has increased since 2015, reaching approximately 40 mg/kg again in 2021, with a decrease to approximately 18 mg/kg in 2022, with a total of 3.1 tonnes of antibiotic active ingredient used[147]. The antibiotic classes used have been predominantly oxytetracycline and florfenicol, both of which are listed by the World Health Organization as highly important for human medicine[148]. The use of antibiotics varies considerably by area, with use particularly low in Orkney[145].

Waste

Input to benthos (seabed) and water column from chemicals, feed and effluent

Waste effluent emission data is published annually for each aquaculture site and reported quarterly by operators. This includes emissions of nitrogen, phosphorus, zinc, copper and total organic carbon. Benthic monitoring methods and results are also available dating back over 10 years. SEPA provide a mapping database, which presents data on site biomass, benthic monitoring and use of chemical treatments per site [145, 149]. A new Depositional Zone Regulation was introduced in 2019 in response to the growth of the industry[150].

In Scotland a 'Maximum Mixing Zone' of 100m is designated surrounding a farm (100m measured form the edge of pens)[151]. Operators must ensure that no negative impacts to biodiversity or sea life occur beyond this limit due to waste from farm operations. Computer modelling is then used to determine Observed Mixing Zone, which maybe off set from a maximum mixing zone as the "framework provides for mixing zones that are not symmetrical. Mixing zones may extend more than 100 metres from the pens in some directions provided their maximum area does not exceed the area that a symmetrical, 100 metre mixing zone would have"[152] and is dependent on the location's environmental characteristics. Permits require two standards to be met in regard to the biological of the sea bed/loch bed, one for observed mixing zone and one for maximum mixing zone. On going environmental monitoring within the mixing zones is used to ensure that conditions within these areas meet environmental parameters set out in permits.

Plastic use, reuse and recycling

The Marine Litter Strategy for Scotland was first published in 2014 and updated in 2022[153]. The updated Strategy addresses aquaculture gear with commitment to develop waste management options to improve recycling routes for end-of-life gear. This includes the development of a European Committee for Standardisation (CEN) standard with the British Standards Institute, for circular design of fishing and aquaculture gear, including specifications to address gear loss.

Wildlife interactions

Until 2021 farms could use lethal methods of control under licence for predators if non-lethal methods had been tried and were not effective. However due to the amendment of the Animals and Wildlife (Penalties, Protections and Powers)(Scotland) Act 2020, from 1 February 2021 licences are no longer granted to shoot seals in order protect fish farms[154].

Marine Scotland produced a Code of Practice in relation to marine mammal interactions, following a review of using Acoustic Deterrent Device (ADD) to protect salmon farms from

Predators. As a result of this, since 2022 ADD use has been essentially banned due to strict licence criteria[155,156].

Socio-economic factors

The Scottish Government's framework published in 2023, the 'Vision for Sustainable Aquaculture', aims for outcomes where 'communities are supported through the provision of highly skilled employment opportunities, access to healthy local foods and other lasting benefits'[139]. To realise the Vision for Sustainable Aquaculture, the Scottish Government intends to deliver across all six of the outcomes identified within its Blue Economy Vision, including[157]:

- 'Thriving, resilient, regenerated, healthy communities have more equal access to the benefits that ocean resources provide.
- Scotland is an ocean literate and aware nation'.

Employment and local economy

Scotland's corporate income tax rate increased to 25% from April 1, 2023, resulting in Chile and Scotland having the highest corporate income tax rates of all markets.

Scotland has implemented a fee specifically applied to farmers, often referred to as a rental fee. The Crown Estate Scotland manages public property in Scotland, and companies with permission to produce salmon in public locations must pay a fee/rental cost reflecting the level and value of the production[139, 158]. The size of the fee is normally revised every five years and was set to 2.25 pence/kg (~0.03 EUR/kg) on January 1, 2017 for all harvested fish. The Crown Estate is currently reviewing proposals to align rental payments to company turnovers, and rental costs are therefore forecasted to increase. The fee is not distributed to local authorities but used for marketing and research purposes related to aquaculture. Farmers must also pay an annual fee for an environmental license, which can cost more than 15k GBP (~17k EUR). If a production area is not used for 4 consecutive years, farmers must pay an additional 1k GBP (1.1k EUR) and a further 2k GBP (2.3k EUR) if an area is dormant for 2 more years.

Social licence

The Scottish Government's 2023 Vision for Sustainable Aquaculture has the intended outcome that 'Communities which host aquaculture are engaged in the sector's development, share in its success and are supported through a range of lasting benefits including the provision of employment opportunities' which it intends to achieve by

> 'protecting and improving the ability of, and opportunity for communities to meaningfully contribute to aquaculture planning and consenting embedding

consideration of the protection and development of social licence across all operations and management decisions'[139]

Salmon aquaculture however remains a highly charged issue within Scotland, with a range of views and opinions on how the industry should operate, be regulated and what the future of salmon aquaculture in Scotland should look like.

Faroe Islands

Background

Aquaculture operations began in the Faroe Island in the 1960s, with open net farming growing from the 1980s [41,159]. In 2003 legislation regarding operation of salmon aquaculture was overhauled following devastating outbreaks of Infectious Salmon Anaemia (ISA) in the salmon populations, with current legislation aiming to increase productivity, while sustaining a healthy environment [160] [161]. Salmon aquaculture accounts for approximately 50% of Faroe Island export value, with 89,081tonnes whole salmon produced in 2022, and salmon aquaculture accounting for 8% gross national product, employing 5% of the labour force [162, 163]. The Faroe Islands are currently the world's 5th largest producer of salmon, consisting of 4% of global exported salmon [37, 41, 159,]. Since the 1980s salmon farming has seen consolidation into three companies: Bakkafrost, Hiddenfjord and Mowi, constituting 70%, 18% and 11% of salmon production respectively as of 2021[41].

Legislative and regulatory frameworks

Following the outbreaks of disease in the early 2000s, new regulations surrounding aquaculture were implemented in 2003, known as the Faroese Veterinarian Act on Aquaculture (FVAA)[164]. This act aimed to increase productivity, fish welfare and increase the environmental sustainability of aquaculture operations[159]. Details of the act include:

- *"Mandatory vaccinations against infectious salmon anaemia (ISA)*
- *Single generation single fjord strategy with mandatory fallowing for a minimum of two months between generations (all-in, all-out strategy)*
- *Protocols and equipment which have to be in place on plants in order to avoid the spread of any potential disease*
- *All boats and trucks used for aquaculture have to be specifically designed for aquaculture transport and approved by the Food and Veterinary Agency*
- *Minimum distances between any aquaculture facilities*"[159].

The regulatory framework set out by the FVAA have been further expanded on in subsequent years, with key legislation also including:

- The Aquaculture Act (2009)
- The Animal Welfare Act (2018)

- The Animal Disease Act (2001)
- Environmental Protection Act (1988)
- The Food Act (2010)
- Biosecurity Regulation (2019)
- Sea Lice Regulation (2016)[165]

Regulation and monitoring of aquaculture is conducted by the Faroese Food and Veterinary Authority (FFVA) (under the Ministry of Foreign Affairs and Trade) and the Environment Agency[159, 160]. Current aquaculture policy is mainly based on the Aquaculture Act of 2009 and subsequent amendments in 2018 [159].

Aquaculture licenses are issues by the FFVA[41]. For a license to be granted applications must meet requirements set out in the Environmental Protection Act, Animal Disease Act and Food Act [41, 164]. Under the Parliament Act on Environment Protection (No. 134 of 1988, amended by No. 128 of 2008) environmental permits must also be obtained from the Environment Agency prior to issuing of a license, environmental permits can contain one or more operation sites, applying to a fjord. As of 2022 there are 22 environmental permits issued, with a total of 35 aquaculture production sites, of which 32 are salmon [41, 159, 165]. It is noted that not all sites are active at the same time, e.g. between 2019-2021 between 21-25 were active on average[165]. It has also been noted that environmental permission is not an EIA [41].

The Environment Agency is also responsible for guidelines which specify sites which are suitable for aquaculture operations [41]. Once issued, a license is valid for 12 years and is transferable, with no company able to hold more than 50% of licenses, although this seems to be the contradicted by current permits[159, 165]. Of the 32 salmon farming sites, Bakkafrost holds 20 permits, Hiddenfjord 6 and Mowi the remainder[159] . Currently most locations suitable for aquaculture are occupied by fish farm operations, limiting future expansion of operations and new licenses being issued [159, 160]. As a result expansion into previously unsuitable locations (e.g. areas with stronger currents and offshore) is being considered as an option but requires innovation to do so, which has resulted in increased investment in the area from industry**Error! Bookmark not defined.**. Areas of aquaculture operations and specifically salmon aquaculture can be found on the Foroyakort dashboard[166]: https://kort.foroyakort.fo/kort/. (Note: this information is only available in Faroese at the time of accessing)

Environmental Impacts and Monitoring

Chemical inputs and treatments

Sea-lice treatments

Sea lice are a persistent issue in aquaculture in the region and seen as the largest issue currently, with both the salmon louse *Lepeophtheirus salmonis* and common sea louse *Caligus elongatus* present, but the former most abundant[165]. As of 2021 new regulation relating to sea lice levels was published under Regulation No. 93, specifying sea lice levels as 0.5 adult female lice/fish from the 1st May- 31st July, with a limit of 1.0 for the rest of year[41]. Sea lice monitoring is conducted by an independent 3rd party and reported to the FFVA on a biweekly basis [165]. Results of sea lice monitoring correspond to a points system, which is a factor in determining the production limits allowed in the next production cycle of a site. Managing of sea lice is a condition of licensing[167].

The use of sea lice treatments are limited, with 1.31 treatments/production cycle between 2019 and 2021, approximately 1 per/year[41]. Emamectin Benzoate was the most commonly used (85% treatments), while Diflubenzuron was the largest volume used (75% total pesticide volume). Azamethiphos is also used to a limited extent, however there is evidence of increasing sea lice resistance to all treatments[41].

The use of chemical treatments published by FFVA are updated weekly under Executive Order 80 June 2019 [41]. This includes information on treatment type, applications method (e.g. bath, feed), quantity, site location and date of application [41]. Trends show increasing use of non-chemical treatments, such as cleaner fish (specifically Lumpfish), mechanical and thermal treatments and overall decrease in the use of chemical treatments, however some recent increase in chemical use has been observed in response to the ongoing issue of sea lice infections and resistance [41, 165]. Regulation focuses on the impact on farmed salmon as opposed to wild salmon, as there are no natural salmon spawning in the Faroe Islands region, and limited evidence of impacts of sea lice on wild trout populations[165].

Antibiotic use

Following the implementation of strict veterinary regulation in 2003 under the FVAA, the use of antibiotics has been 0 since 2004 [41]. This has been attributed to strict fish welfare regulations and monitoring.

Waste

Input to benthos (seabed) and water column from chemicals, feed and effluent

Waste and associated effluent from aquaculture operations are a significant source of nutrients entering the aquatic environment in the Faroe Islands region, with fish aquaculture categorised as a “highly polluting activity” by the Faroese Environment Agency [41]. The

Environment Agency is responsible for the monitoring of the benthic environment surrounding operations, while the Faroe Marine Research Institute monitors the surrounding water column [41].

Surveys of the benthic environment are carried out at peak fish biomass of a production cycle by a 3rd party, with results reported to the Environment Agency. A plan for the next production cycle is also submitted for approval, with environment results a factor potentially impacting the production numbers permitted at the site in the following cycle. In addition to this, monitoring frequency can be increased as a result of the previous cycle's peak biomass result, i.e. poor results cause an increased frequency in the next cycle. Pollution thresholds are detailed in Guidance, 19/2018[165].

Between 2018-2021 benthic surveys resulted in 47% of all sites deemed as polluted or highly polluted [41]. Should benthic surveys not comply with thresholds, companies will be required to take action (e.g. fallow the site), if issues persist the Environment Agency can implement restrictions to the site [165]. Monitoring focusses on levels of heavy metals and organic waste built up below pens [41, 168,]. To try to control waste from food sources, feed distribution is monitored closely, including the use of cameras and sensors to try to prevent excess feed [159]. However total feed use has doubled between 2008 and 2021. Benthic fauna are not monitored as part of regulations, however some surveys are conducted as part of 3rd party certification programme requirements [165Error! Bookmark not defined.].

Plastic use, reuse and recycling

The Marine Environmental Act sets out regulation in relation to marine pollution and is enforced by the Environment Agency[169]. This does not seem to be specific to aquaculture but encompasses all marine activities.

Wildlife interactions

No information regarding the use of ADDs was found in relation to Faroe Islands aquaculture in accessible documents, language barriers maybe an issue for accessing further information.

The use of lethal measures to control marine mammals in relation to aquaculture has been banned from 2020, any accidental deaths to marine mammals at aquaculture sites must be reported (e.g. entanglement in nets) [41,165]. Prior to 2015, 550-2000 seals were culled annually. Bird deaths have also been recorded but have been noted to have decreased[165].

Operations are legally required to report escapes, detailing numbers escaped, cause, the actions in response and steps to prevent it in the future to the FFVA. All farms must have actions in place in the case of escapes, which must be approved by the FFVA and adhere to protocols set out by the department [41, 159]. Escapes are an ongoing issue, with the largest being 370,000 escaped fish in 2020 [41]. Companies are required to attempt to recapture escaped fish, however limited information regarding this is available. Escapes are deemed to be a low environmental risk issue, due to the absence of a native salmon population and limited evidence of escaped salmon colonising the surrounding environment.

Socio-economic factors

Employment and local economy

Salmon aquaculture is economically important to the Faroe Islands. Recent investment has aimed to expand production and also develop enclosed or land based operations as a means to address issues such as sea lice[165]. Aquaculture has increased as a share of employment over time, as of 2021 employing 1,350 people (5% labour population), while employment in wild fisheries has decreased[165].

Social licence

Aquaculture is generally supported by the public, with stricter environmental regulations also supported. There appear to be no NGOs in the islands campaigning against aquaculture operations. As of May 2023 there were 20 salmon farms in the Faroe Islands that were ASC certified (1 Mowi, 19 Bakkafrost)[170]. This is equal to approximately two thirds of total farms.

Canada

Background

Canada has the largest coastline of the farming nations being considered in detail in this report, and all of Canada's salmon production is through coastal open net pen farms. Salmon farming represents ~70% of aquaculture by value, with Atlantic salmon the main species alongside Chinook and Coho salmon[171]. The country has ambitions to remain technology neutral (i.e. refrain from prescribing specific technologies usage), and is exploring the possible industry-led transition to alternative closed containment systems which would reduce the potential impact aquaculture has on surrounding aquatic environments whilst promoting sustainable resource development[172]. Initial studies suggested the main two technologies that would be financially viable to be open net pens and recirculating aquaculture systems (RAS)[173]. Subsequent research also considered floating closed-containment systems and offshore open production systems to be several years from being viable[174].

Canada's Atlantic salmon aquaculture is divided into two main regions, British Columbia (BC) and the Northern Atlantic region (covering New Brunswick (NB), Nova Scotia (NS), Newfoundland and Labrador (NL). Approximately two thirds of salmon production occurs in BC[175]. The way in which the industry is regulated and managed varies between the regions. Across the Northern Atlantic region farm lease approval and monitoring is managed by the provincial governments[176]. In BC farm lease approval is shared between the provincial and federal administration, and monitoring of farms is managed by the federal government. The responsibility for aquaculture was transferred from the province level to the federal government in 2010, after a federal court case challenged the authority of the provincial government to be the lead regulator of salmon aquaculture in 2008[176].

Legislative and regulatory frameworks

Across Canada as a whole, fish farming is managed under the Fisheries Act 1985[177], with Fisheries and Oceans Canada (DFO) acting as the federal lead, including where the provincial government has a lead leasing or licensing role. The DFO's involvement in aquaculture is carried out by a team of regional aquaculture management offices located across the country.

Regulations made under the Fisheries Act include the Aquaculture Activities Regulations, which specify the conditions under which aquaculture operators in Canada may install, operate, maintain or remove an aquaculture facility, or undertake measures to treat their fish for disease and parasites, as well as deposit organic matter. These regulations require farms to report usage of chemicals annually, the data for which has been publicly available via the National Aquaculture Public Reporting Data website since 2017[178].

Other regulations under the Fisheries Act include the Fish Toxicant Regulations, and in BC the Pacific Aquaculture Regulations which cover pollution control, including marine plastic debris[179].

Additional legislation is in place under the Species at Risk Act 2002[180] which focuses on the protection of wild species and their habitats. Also relevant to aquaculture is the Canadian Navigable Waters Protection Act 1985[181] which is associated with maritime safety regulations.

In 2012 a review of the Fisheries Act considered the 'large scale' effects of salmon farming on the marine environment. The review led to the updated Canadian Environment Assessment Act 2012[182], which includes a decision support system alongside an environmental assessment to score suitability of new farm lease proposals based on cumulative impacts to the area, particularly protected marine features. Once approved it is the provincial government's responsibility to ensure a farm complies with regulations. Each farm is given an individual maximum allowed biomass (MAB) based on site characteristics, which is specified in individual farm licence documentation[183].

While at the federal level, Canada has never enacted an Aquaculture Act or similar legislation specific to aquaculture, the provinces of NB and NL have both passed Aquaculture Acts to regulate salmon farming and issue licenses to operate[176]. NS relies primarily on a Fisheries and Coastal Resources Act to do the same.

Environmental Impacts and Monitoring

The monitoring and sampling requirements of the Aquaculture Activities Regulations under the Fisheries Act are supported by the Aquaculture Monitoring Standard, which is implemented across all aquaculture regions and incorporated into provincial regulations[184] [185].

In NL, changes proposed to the Aquaculture Act, 2023, would require aquaculture operators to undertake or implement: increased licensing and operating requirements; formalized aquatic animal health practices; prescribed mitigation and monitoring requirements; and stringent public reporting requirements[186].

Chemical inputs and treatments

Usage of antibiotics and pest control products across licensed marine salmon farms is regulated by the Canadian Aquaculture Activities Regulations and must be reported. The information related to the chemical use in aquaculture is collected by the Canadian Aquaculture Integrated Information System (AQUIIS) with a first full year of data collection in 2016[179]. The data associated with chemical treatments is publicly available but not in real time (**Error! Reference source not found.**).

Table 4. Aquaculture Activities Regulations reported chemical use in 2021, by region. Where active ingredient quantities are in kilograms[179]

Region	Farm number	Azamethiphos	Emamectin benzoate	Florfenicol	Formalin	Hydrogen peroxide	Ivermectin	Oxytetracycline
BC	57	-	21	4427	-	99982	-	1656
NB	20	166	5	57	-	12607	0.1	91
NS	3	-	1	14	-	-	-	-
NL	12	193	5	91	2422	21735	-	-

Sea-lice treatments

The federal government in Canada is responsible for the protection of wild salmonids as well as managing salmon aquaculture. It has set on-farm sea-lice thresholds for farms in BC, which require sea lice abundance counts on farmed salmon to be reported. Public information on counts in the Northern Atlantic Region of Canada has not been accessible until recently. In NL, sea lice abundance numbers have been reported since 2021 as monthly average values of sea lice per fish across all the sites belonging to one company but not as site specific data[187].

Sea lice are abundant in the coastal waters and concerns over farm sea lice outbreaks and the impact on wild populations of salmon has led to the issue being heavily studied[188]. The Canadian Government's most recent report into understanding the association between sea lice and the production of salmon farms concluded that sea lice presence on farmed fish does not have a statistically relevant association with sea lice levels on wild juvenile salmon across BC[189].

A precautionary approach has been taken, with licensing conditions in BC requiring farmers to manage sea lice according to the timing of wild juvenile Pacific salmon migration, using a non-migration window (July 1 to January 31), pre-migration window (February 1 to February 29), and out-migration window (March 1 to June 30). During the pre-migration and out-migration window, current licence conditions require that farms conduct bi-weekly sampling to report to DFO the average level of motile, chalimus-stage, and adult female *L. salmonis*, as well as the average level of adult and preadult *Caligus clemensi* per fish. Average counts of more than 3 motiles *L. salmonis* per fish (equals about 0.64-1.65 adult females[190]) require licence holders to reduce sea lice levels below this threshold within 42 days[191]. They must also notify the DFO about planned delousing measures in the pre-migration window, to ensure that counts will be under the threshold by the first day of out-migration. The threshold is applied regardless of farm inventory. British Columbia's coastal waters are broadly divided into 5 Fish Health Surveillance Zones (FHSZ) based loosely on watershed boundaries. The DFO publishes an Industry Sea Lice Abundance Counts report (per farm), updated on a monthly basis, however there can be a significant time-lag of up to several months in data publication[191].

Delousing therapeutants use in fish farms have continually been used by the industry. In BC the use of Ivermectin was discontinued in 2000, the year emamectin benzoate was introduced as an in-feed drug to manage sea lice presence within the farm[192]. In BC emamectin benzoate reached peak use in 2020 where 0.4 grams per tonne of salmon produced was distributed through feed. Another treatment, hydrogen peroxide has been used since 2014 in BC farms. Across NB ivermectin is still used despite the introduction of emamectin benzoate[179].

Antibiotic use

Across BC the use of antibacterial agents has substantially dropped since 2005, though there has been an overall decline in use since 1997[193]. However, when comparing antibiotic use across regions there is still a high level of use in the BC area (**Error! Reference source not found.**).

Waste

Input to benthos (seabed) and water column from chemicals, feed and effluent

There has been a longstanding call in Canada by First Nations from coastal areas across BC for industry to improve farm practices, including waste management[194]. A BC review into land-based closed system options, which would provide a solution to waste management from salmon farming, deemed them viable but only on a small scale and not in isolation from the current sector[195].

The DFO initiated the Aquaculture Monitoring Program (AMP) in 2017 to monitor marine aquaculture inputs into the sediment[179]. Benthic sediment is sampled around aquaculture cages at selected farms (sites), ranging from the cage edge to 1500 m away. A series of chemical, geochemical, and physical parameters are assessed while considering the different stages of production, bathymetry, and some oceanographic conditions. Recently, AMP data sets have been analysed to study organic matter enrichment surrounding farms by considering trace metal signatures[196].

Plastic use, reuse and recycling

Management of marine debris from aquaculture in Canada is through the sector's licences. In BC pollution control has always been a component of the Pacific Aquaculture Regulations under the Fisheries Act [180]. In the rest of Canada it is regulated at a provincial level and overall the marine finfish sector has a high level of compliance. In addition to this, there have been several programs introduced to tackle plastic waste including the Plastics Challenge: Sustainable Fishing and Aquaculture Gear through the Department of Fisheries and Oceans Canada (DFO), which sought out technically viable innovations to reduce and eliminate aquatic plastic pollution from Canadian fisheries and aquaculture[197]. In NS the issue of abandoned fishing gear and the associated impact this has on wildlife and the environment led to the announcement of a new gear retrieval contribution program to help retrieve and dispose of 'ghost gear' responsibly[198]. There is also a Sustainable Fisheries Solutions and Retrieval Support Contribution Program[199].

Wildlife interactions

Fish farms were permitted to kill seals that interacted with salmon farms, until 2018[200]. The change in practice was voluntarily agreed by fish farmers to continue access to the United States (US) seafood market which does not allow protected species to be killed. Approximately 80% of farmed salmon is exported to the US seafood market[201]. Further to this, whilst trials of acoustic deterrent devices (ADDs) took place between 1993-1996 to deter predators from fish farms, the negative environmental impact on porpoises alongside the ineffectiveness to stop seal attacks on farms has led to the phasing out of ADDs and the prohibition of their use[202].

Socio-economic factors

Federal and provincial Canadian governments have both actively supported aquaculture development since the early 1980s, with the industry seen as important for rural development while employment in fisheries and coastal forestry has declined[161]. Public perception of the salmon industry has also had an influence on salmon farming operations in Canada[203] and there is opposition to the Atlantic salmon industry in particular[204]. These opinions vary by territory, the vast geographical distribution of Canada means communities have different relationships with the industry linked to regional specific conditions of the environment[205]. For example, in December 2020 the Fisheries minister, Bernadette Jordan, made the decision to close 19 salmon farms[206], despite salmon farming's significant economic impact and reports of minimal risk to wild pacific salmon populations[207]. The decision was overturned in 2022[208], however, several of those farms have not had their licences reinstated due to the government's decision to take a cautionary approach to salmon farming in BC because of the uncertainty of the impact of cumulative effects on protected species[209].

Indigenous rights

Salmon farming has been actively opposed by local First Nations[210], yet ASC certified farms lie in many indigenous territories where farms do not have consent from indigenous communities and therefore the certification scheme is not 'socially responsible'[211]. Some indigenous territories farm fish in BC. These communities represent 30% of the labour force of the four largest farming companies who operate the majority of farms in BC versus 5% of the population of BC[212]. The most notable First nation impacted are the Laich-kwil-tach as farms are within their core territories[213].

Employment and local economy

In 2021 across BC ~ 5,270 labourers were employed across aquaculture and marine harvest sector[214]. Across the Atlantic region nearly 2,200 labourers were employed, and although these figures do not distinguish how many of these worked directly in the Atlantic salmon farming sector, aquaculture is an important component of seafood production that currently represents 20% of the seafood sector across Canada[215].

Social licence

The lack of a publicly available portal containing accessible information on salmon farming practices in Canada may have led to starkly opposing views on the salmon farming. Information that is publicly available is not provided in real-time.

Australia

Background

Atlantic salmon is a non-native species farmed in Tasmania. The industry established itself in Tasmania in the 1980's and now farms companies operate across seven coastal regions. Across the Tasmania territory there are 16 freshwater farms and 48 licensed salmon marine farming leases[216] making Australia the sixth largest producer of Atlantic salmon. In March 2022 the Department of Agriculture, Water and the Environment announced Australia's aquaculture industry overtook wild caught fish[217]. Marine farm leases across Tasmania are found within coastal waters. Only three companies operate in Tasmania (Tassal, Huon and Petuna)[44].

Legislative and regulatory frameworks

All Tasmania operating finfish farms are required to hold an environmental licence by the Environmental Protection Authority (EPA) in line with the Environmental Management and Pollution Control Act 1994[218]. Monitoring is a stipulation of the act, as outlined in the Marine Farming Planning Act 1995[219] and the Living Marine Resources Management Act 1995[220]:

- Marine farming planning act 1995 – This act and the associated regulations provide zoning areas of state waters and create an opportunity to amend and review marine farming development plans. Proposed as an adaptive management approach it encompasses environmental monitoring.
- Living marine resources management act 1995 – This act ensures each licence includes specific environmental provisions to mitigate 'unacceptable impact on the marine environment'.

Additional key legislation that impacts salmon farming is the Inland Fisheries Act 1995 and Biosecurity Act 2019.

A 2022 parliamentary inquiry into finfish farming resulted in the recognition of the need for more uniform practices for lease holders to conduct extensive environmental monitoring[217], however these are still in a draft process (the consultation period closed in March 2023). The

Tasmanian Salmon Industry Plan 2023 came into effect on 1st May 2023 and outlines 21 strategic pathways to guide the Tasmanian Government's long-term priorities for the salmon industry over the next 10 years[221].

Environmental Impacts and Monitoring

Despite the industry establishing itself in the 1980's across Tasmania. Formalised environmental monitoring requirements were introduced ~15 years later and remained unchanged until 2004 when the Australian government commissioned a review on the Environmental regulatory arrangements for Aquaculture[222]. This decision was driven by a build-up of evidence of the environmental issues associated with salmon farming[223] [224] [225] [226]. Tasmania, like Scotland, has adopted a zone approach to management of the environmental effects fish farms have on the immediate and surrounding environment [227] However, there are no formally established lease management zones across Tasmania where environmental monitoring takes place, instead every farm licence contains lease specific environmental standards and monitoring requirements. The operational 'Farm zone' and 35m from the lease boundary within the 'Allowable Zone of Effect (AZE)' are subject to environmental monitoring.

There are Broadscale Environmental Monitoring Programs (BEMPs) to document broadscale trends of key environmental parameters including monthly water quality sampling, annual/biannual surveys of sea floor fauna and chemistry as well as annual BEMP reports. Though fish farm BEMPs requirements vary across Tasmanian regions. Two region reviews of BEMPs for (1) Macquarie Harbour and (2) D'Entrecasteaux Channel and Huon River) recommended an expansion of monitoring methods to include physio chemical and biological parameters of soft sediments habitats[228], modernisation of key aspects of monitoring (e.g. DNA analysis) [, 229] and increasing statistical analysis to show relationships between environmental parameters.

Following the 2022 parliamentary inquiry it is anticipated that for compliance, reference sites will also be monitored (compliance points) to determine if changes to the condition of the marine environment could be as a direct result of the fish farm. The chosen compliant points will be monitored over time alongside the monitoring conducted as part of the baseline assessment report and the environmental monitoring associated with the fish farm lease[230].

Chemical inputs and treatments

Since 2019 information on chemical inputs and treatments is publicly available through the Tasmanian Government dashboard for salmon farming data[Error! Bookmark not defined.]. This information is split by area, then company, which means if the company has more than one farm lease in the area it is unclear of the chemical use at a farm level. Data pre-2019 is not available via this portal. Within the Macquarie Harbour area there are nutrient indicator limits for ammonia, nitrate and oxygen outputs from fish farms. There are also metal threshold levels for copper and zinc in the water column and sediment across fish farms[44].

Sea-lice treatments

Sea lice is a significant issue for salmon aquaculture in the northern hemisphere however despite research indicating sea lice presence in mariculture of salmonids in Tasmania[231], there is no current known risk to farmed salmon populations in Tasmania.

Antibiotic use

The salmon industry can only use antibiotics in line with the Department of Natural Resources and Environment's Code of Practice for the supply and use of veterinary chemical products under the Primary Produce Safety Act 2011[232]. Within the Code of Practice reasonable residue testing when stock is treated is also part of the agreement. However, in February 2023 media brought to light that the TEPA experienced pushback from industry to share monitoring reports associated with antibiotic use from a 2022 outbreak of Vibrio at two fish farms[233]. Vaccination of farmed salmon would reduce the overuse of antibiotics, though it is unclear of companies' commitments to vaccination, with current levels of vaccination relatively low. Further to this whilst antibiotic use is reported and available to the public, the public is not informed when an antibiotic is approved[234]

Waste

Input to benthos (seabed) and water column from chemicals, feed and effluent

There is significant research across Tasmania identifying the impact of organic enrichment to sediment beds associated with fish farms[234] [235] [236]. For example, the Macquarie Harbour has seen significantly modified infauna communities, with evidence of impacts to abundance, richness and their structure[237] due to the impact of a series of fish farms in the Harbour. The consequences of poor management of waste inputs to the environment has led to the move away from using Maximum Allowed Biomass (MAB). The environmental watchdog responded to the high mortality rate within Macquarie Harbour initially by cutting the MAB to 9,500 tonnes for two years (a 21% drop in MAB) in the region[238]. Since the Environmental Protection Agency has shifted to setting region specific Total Permissible Dissolved Nitrogen Output (TPDNO), which controls the amount of nitrogen any company is allowed to release into the environment annually in regions where their environmental concerns linked to farming practices introducing nutrients into the environment. Despite the move away from MAB, not all regions have maximum TPDNO levels (**Error! Reference source not found.**)[44 **Error! Bookmark not defined.**].

Table 5. Total Permissible Dissolved Nitrogen Output limits by region, dates effective and company (Tonnes of nitrogen per year)[44]

Region	Dates effective	Tassal	Huon	Petuna
Macquarie Harbour	01/09/22-31/08/27	151.2	124.2	224.7
D'Entrecasteaux Channel and Huon River	02/12/22-01/12/32	1246.03	1094.52	
Storm Bay Off Trumpeter Bay	N/A		Operates in the region	
Storm Bay North	Lease not yet operational			
Tasman Peninsula and Norfolk Bay	N/A	Operates in this region		
Great Oyster Bay and Mercury Passage	N/A	Operates in this region		
Tamar Estuary	From 01/07/23			309.3

Plastic use, reuse and recycling

In 2015 additional regulation came into effect which focused on the impact of fin-fish aquaculture on waterway health, to tackle increasing marine debris from the industry. A committee report noted that marine debris associated with fish farm operations was increasing, with plastic rope waste being noted as one of the largest contributors of marine debris[239]. Three recommendations were made:

- *'Fin-fish farming licensees have identifiable rope so that sources of waste can be clearly identified and monitored.*
- *Fin-fish farming licensees are required to report on the amount of marine debris collected, including that which is attributable to their operations.*
- *The federal government's threat abatement plan for the impacts of marine debris on vertebrate marine life should be updated to include the impacts from fin-fish aquaculture'.*

As a result of these recommendations quarterly reporting of marine debris clean ups are required and a marine farming equipment register was created. Marine debris clean ups are conducted across all areas where fish farming is practiced. The length of coastline surveyed, time, volume of marine debris collected, and the proportion of waste associated with fish farming (%) is recorded yearly on the Tasmanian salmon farming portal[44]. The marine farming register requires all fin-fish equipment to be traceable through marking or colour coding.

Wildlife interactions

The use of acoustic deterrent devices (ADDs) is widely adopted in marine farming operations and permitted within the Seal Management Framework[240]. Deterrents can be used where there is a risk to the marine farm staff or if seals are interfering with the infrastructure and operations of the farm[241] There are several marine species within The Environmental Protection and Biodiversity Conservation Act 1999 including Australian and New Zealand fur-seals[242], which are listed as endangered (since 2016). Despite acknowledgement of the required and necessary protection of these marine animals, the industry has been reported to have continued to use acoustic deterrents, with 2,400 anti-seal explosives used in a three-month period in 2022[243]. In addition to this, an 18-month reporting period identified 25 interactions with seals which led to seal mortality[243]. The Department of Natural Resources and Environment data defined seal deaths as 'mortality caused by an interaction with marine farming activities, operations and infrastructure including but not limited to: entanglement, vessel strike, other infrastructure interaction, deterrent use, sedation, and humane destruction'[244].

Socio-economic factors

Australia aquaculture, particularly in the Tasmanian region, has come under scrutiny in recent years, in relation to salmon farming incidents at Rowella and Macquarie Harbour[245][246]. Tasmania's most recent inquiry into finfish farming in Tasmania identified the main areas of focus for regulations should be to improve public confidence and build the social licence of fin fish farming[217]. Large concerns associated with the evident environmental impact of the industry, proposed expansion of the industry and the adequacy of the current regulatory framework are at the centre of discussions.

Community and indigenous rights

Atlantic salmon are not native to Tasmania, and there are large concerns that the large expansion of the industry is not considering the stocks of wild fish and how they are affected by salmon aquaculture[247]. Aboriginal communities have managed to establish a permanent voice within parliament and because of this the first commercial fishing rights were given to the community, who previously had limited rights to fish[248].

Employment and local economy

Figures on employment, at a company level are available on a quarterly period and is state-wide, the employment data is split and includes permanent and casual staff [44].

Social licence

In 2014 Tassal shared in their Sustainability report that through stakeholder engagement they identified that marine debris was seen as one of the most important issues within the industry[249]. Alongside reporting requirements by government, the industry has taken steps to improve this issue and a large array of data is now publicly available[250]**Error! Bookmark not defined.**. However, transparency prior to 2019 was poorer and the level of trust amongst stakeholder groups has been limited due to gaps in information, and misinformation[251].

Certification concerns have been identified in two areas across Tasmanian salmon farming, due to incidents at Rowella and Macquire Harbour[252]**Error! Bookmark not defined.**. The continued certification of farms in this area failed to prevent 'adverse ecological outcomes' **Error! Bookmark not defined.**.

Iceland

Background

Salmon aquaculture first began in Iceland in the 1950s, with a number of attempts including on land operations[253], [254]. However, the successful sustained production of salmon did not occur until within the last 15 years, with current operations taking hold within the last 10 years[256]. Salmon production has grown significantly, with 44,934 tonnes (ungutted) produced in 2022, increasing from 3,965 tonnes in 2014[255]. As of 2023 salmon aquaculture in Iceland has been consolidated into 3 companies, Arctic Fish (27% market share), Arnarleax (26% market share) and a recent merger between Icefish Farm and Laxar Fiskeldi (41% market)[45]. In 2021 Iceland represented 1.6% of the global salmon market share[45]. It should be noted that these companies are majority or fully Norwegian owned, rather than Icelandic [256]. The industry directly employs approximately 980 people as of 2021[45]. The Icelandic government aims to encourage expansion and develop salmon aquaculture operations over the coming decade, with the industry projected to represent 6% GDP by 2032 under current plans[45].

Legislation and Regulatory frameworks

Aquaculture is governed by the Ministry of Fisheries and Aquaculture and the Ministry of Environmental and Natural Resources[256]. The Icelandic Food and Veterinary Authority (FVA) is responsible for fish health and issuing operation licenses, while the Environment Agency is responsible for monitoring and issuing environmental licenses [256]. Both licenses are required. Salmon aquaculture operations are predominantly governed by the Act on Fish Farming no.71/2008 (with updates in related regulations on fish farming no. 1170/2015) and

Act on Health and Pollution Control no. 7/1998 (with additional regulation in related regulation no. 941/2002)[256]. There are areas where aquaculture cannot take place, which is covered in Advertisement no. 460/2004.

The rapid growth of aquaculture in Iceland has meant that the legislative and monitoring frameworks surrounding aquaculture are being developed simultaneously alongside industry growth[161, 256]. In 2023 the Icelandic government published the State and Future of Aquaculture report which outlined ambitions for growth of the industry over the coming decades[45]. Calls for improved legislation and regulation have also been increasing as the industry grows quickly [45,161,256].

Operations require two licences to start production, an environmental licence and an operating licence. Applications are submitted to the National Planning Agency (NPA), it is then determined if an environmental impact study is required, which is submitted to the NPA for approvall[176, 256]. Following acceptance of the report, applications are forwarded to the Food and Veterinary Authority (FVA), the FVA will process the operating licence, while the environmental licence is processed by the Environment Agency[176].

As of 2023, the 3 main producers hold 94% of licences, with Arctic fish, Arnarlax and IcefishFarm/Laxar Fiskeldi holding 27, 24 and 44 granted licenses respectively[45]. A minimum distance of 5km is required between production sites[176]. All currently issued licences were issued pre-2019, with each licence being 16 years long [45]. Licences specify the MAB and carrying capacity allowed for all species in the fjord where the licences applies[45].

As a result of environmental concerns relating to salmon aquaculture, only two geographical areas of Iceland are authorised for open net-pen salmon aquaculture operations. These are the Eastfjords and Westfjords, which are estimated to have a MAB of 42,000 and 64,000 tons respectively as of 2020[176, 255]. A total of 10 individual fjords currently have farming operations and are therefore production areas, with 4 more potential areas remaining. The Marine and Freshwater Research Institute (MFRI) determines the MAB based on the carrying capacity of the licence area, considering the seabed surveys, water oxygen levels and impacts of escapes[45]. The large area of Icelandic coastline designated as protected has limited expansion of aquaculture in many areas of the coastline[45] . The south coast was deemed unsuitable for aquaculture, while north and west coasts contain salmon rivers[176] This has resulted in companies looking to alternative areas to expand production e.g. on land and off shore[45, 257].

Environmental impacts and monitoring

Chemical inputs and treatments

Sea-lice treatments

Sea lice are a growing issue in Icelandic aquaculture, with average numbers per fish increasing over recent years (0.16 in 2020, 0.21 in 2021, 0.47 in 2022)[45,258]. The first chemical treatments were approved in 2017, with 5-7 production areas treated each year between 2018 to 2022[45]. This is predominantly through either feed in the form of emamectin benzoate, or through bath treatments using deltamethrin[45].

Currently regulations state a limit of 0.5 adult sea lice per fish, beyond this limit action plans are to be actioned[45]. Sea lice numbers are reported monthly if sea temperatures are 4°C or higher, below 4°C no reporting is required[45]. Between 1st July to 1st October reporting is required on a bi weekly basis. It's been suggested that the sea lice threshold be lowered to 0.2 (in line with Norway's low level periods), with monitoring frequency increased to weekly all year round[45]. Lump fish are also proposed as a means to mitigate sea lice numbers following research in Norway[259] while it is also suggested that the cold water temperatures will limit sea lice infections[45,260]. As aquaculture operations expand, concerns of the impact of sea lice on wild populations and impacts of chemical treatments have grown [161].

Antibiotic use

The use of antibiotics must be approved for use by the FVA, with laboratory tests required before treatment[45,176]. Between 2011-2021 no antibiotics have been used, with the level of 0.5g/tonne harvested fish used in 2021 much lower than the 1990 level of 150g/tonne harvested fish [45]**Error! Bookmark not defined.**. New guidelines relating to the handling of disease outbreaks is expected to be published in 2023.

Waste

Input to benthos (seabed) and water column from chemicals, feed and effluent

Environmental monitoring is the responsibility of the Environment Agency, however further details of this was not found.

Plastic use, reuse and recycling

No specific information is available directly related to aquaculture. The general monitoring of plastic pollution in the marine environment has started recently, and compared to other regions it is not considered a significant pressure in the Icelandic Waters region. The main source of plastic recorded in monitoring programmes originates from fishing (synthetic nets, lines, etc.)[261].

Wildlife interactions

No information found on interactions with predators or the use of acoustic deterrent devices.

The Icelandic Marine Fisheries Research Institute (MFRI) monitors salmon rivers for escaped farmed salmon, using a combination of cameras, sampling, and reports from anglers[262]. Farms must report fish escapes immediately and action their preprepared contingency plan[176]. The issue of salmon escapes and interaction (particularly genetic) with wild populations is one of concern particularly to river owners, who operate recreational fishing operations on many of the rivers as well as from anglers and environmental groups[45, 161].

As farmed salmon are imported from Norway there is concern of impacts to local salmon populations[161], which has been a factor in limiting expansion in some coastal areas[45]. The MFRI uses monitoring and escape information to assess the risk of the farmed salmon breeding and therefore mixing genetically with wild salmon. The risk of genetic mixing is rated as the 'intrusion level', and if the intrusion level is greater than 4% the maximum allowed biomass (MAB) for a production area cannot be increased.

The risk of escapes was highlighted in 2022 with the escape of 80,000 fish from a Arnarlax owned farm, (while the wild population is estimated at 50,000), with fines imposed as a result [258, 263]. A further large scale escape in 2023 from an Arctic Fish owned farm (subsidiary of Mowi) brought further attention to the risk of farmed salmon escapes and impacts to the local wild populations.[264]

Socio-economic factors

Employment and local economy

Though a growing industry, from an economic standpoint aquaculture is relatively small in Iceland, and in very localised regions. However in rural areas near operations there is suggestion that it has benefited some communities, providing job opportunities and appearing to reduce shrinking populations of some communities as people stay for work rather than move to the capital region[176].

Social licence

Though the government expect the industry to continue to expand, resistance from environmental groups, river owners and sport fisherpeople is expected to persist, with calls to ban open net fishing now before it expands further[161, 176]. Additionally, all operations are foreign owned, which has been raised as an issue by some, who suggest that Iceland's image as a pristine natural environment could be damaged by foreign owned companies activities and associated environmental impacts as a result[45, 161]. Public opinion polls from 2022 showed 43.2% were against open pen farming with 20.7% for, while land based operations received greater support with 49.4% for and 17.1% against[45]. Currently 9 salmon farms in Iceland are ASC certified: 4 Arnarlax, 5 Arctic Sea Farm[265].

Discussion and recommendations

Aquaculture is seen to have a pivotal role in global food production systems, with the amount of farmed Atlantic salmon produced in the North Atlantic now almost 2,000 times greater than the reported catch of wild salmon in the same area[266]. The practice of farming of Atlantic salmon in open net pens in the marine environment can have a significant impact on the surrounding waters and wildlife, which has led to the development of legislation and regulation aimed at mitigating this. However many of the impacts are still not fully understood, therefore legislation and regulation needs to be regularly reviewed and amended as knowledge around the industry increases. Global aquatic food production also faces risks from environmental change, with the US and major producers in Asia most likely to be affected, which also needs to be taken into consideration by both aquaculture producers and the bodies that regulate them[267].

Comparison of regional legislation

Legislation and regulatory framework –

Effective legislation and regulatory frameworks are essential to ensure that salmon aquaculture operations are licensed, managed and monitored effectively and meet legislative and regulatory requirements. This report has detailed the diverse legislative and regulatory processes which have evolved in each of the major Atlantic salmon producing nations.

The process of licensing approval in Canada can be highlighted for strong consideration of the cumulative environmental impacts of a proposed farm location, with environmental assessments score informing the suitability of proposed farm lease sites, based on cumulative environmental impacts to the area. This enables informed consideration of environmental impact during the application processes. In Norway, regulation directly links a farm's permitted biomass and production limits with environmental impact results. Through a traffic light system, farms maybe permitted annually to increase production as a result of compliance with environmental assessment criteria, incentivising compliance from operators, maintain their current production levels or decrease production due to failure to meet environmental standards.

The Faroe Islands are notable as an example of effectively implementing fish health and disease control measures, with strict regulation in place to protect farmed fish health. These measures have been largely successful, resulting in no incidents of antibiotic use in Faroe Island aquaculture operations since 2004.

Norway and Australia aquaculture are examples of good publicly available aquaculture data, with both publishing data reported from farms on a number of parameters to central 'dashboard' websites, bringing together a range of information relating to aquaculture in these regions. This transparency is beneficial to build public trust in the industry and oversight. Scotland's environmental protection agency (SEPA) has announced plans to launch an online dashboard in 2024.

It is notable as of 2023, that there appears to be attempts across multiple nations (e.g. Norway, Scotland, Chile, Iceland), to reform regulatory and legislative frameworks, in order to improve or streamline processes going forward. This suggests an awareness that current frameworks are out of date and there is a significant opportunity for nations to address issues and deficiencies within aquaculture regulation and legislation, and in turn ensure an environmentally sustainable industry in the future. This is of particular importance where a salmon-producing nation supports growth of the industry, which should only occur if it is clearly sustainable in environmental terms. Where existing salmon-producing sites are shown to be unsustainable in environmental terms, regulatory frameworks must be structured in such a way that these sites can be addressed, for example through corrective actions or site-closure.

It is also worth noting the use of taxation as a mechanism in regulating salmon aquaculture. As of 2023 Norway has introduced additional taxation on the highly profitable industry is used to gather funds which are then allocated to a number of recipients including national and municipal government, with allocations used to support local communities and fund research into seafood production for example. This may also have benefits for the industry, as potentially enabling smaller producers to grow while redistributing profits of larger producers back into communities[268], [269]. The Faroe Islands have also similarly approved increasing taxation on salmon producers[270]. Though these measures may not be of direct environmental benefit they, ensure that investment in communities and research into sustainable practices can take place, leading to potential long-term benefits to sustainability of communities and the industry and reduction in environmental impacts through improved production methods.

The influence of non-salmon producing nations should not be overlooked. The USA animal protection act bans the import of produce if marine mammals were harmed in relation to production. For example, as the USA is a major market for international salmon exports, this has influenced salmon producing nations (e.g. Chile, Canada, Scotland) to take steps to adopt non-lethal methods to address marine mammal interactions around farm to comply with these requirements.

Environmental impacts and monitoring

Monitoring environmental impacts associated with salmon aquaculture is vital to ensure regulatory compliance while also assessing and monitoring impacts to the surrounding environment. Extensive environmental monitoring regimes can be identified in both Norway and Canada.

Norway undertakes detailed monitoring at site level, with good availability of collected data across the country. Annual reports also provide environmental assessments of each designated aquaculture area along the Norwegian coast. Sea Lice monitoring in Norway is also stringent, implementing the lowest permissible sea lice limits of any salmon producing nation, with weekly reports of numbers from farms. This data is used to inform modelling of sea lice numbers and transmission. Sea lice risk, environmental impacts, disease risk and escape risks combine to inform the maximum production limits of farms. In recent years Norway has begun to invest in alternative systems of aquaculture (e.g. closed containment and land based) as a route to mitigate environmental impacts, though these systems are yet to be widely implemented[48].

Many of Canada's provinces require detailed environmental monitoring, often cumulative environmental impacts are accounted for, and in Nova scotia monitoring via video is mandatory. These examples demonstrate how comprehensive monitoring of multiple environmental parameters can be implemented and could enable informed decision-making based on the impact of aquaculture on a region's environment.

Licenses and environmental standards applied to fish farms in Scotland are specific to each site (taking into account farm size and location)[271] [272]. Failure to comply with the license can result in a license being revoked[273]. This system of environmental monitoring is comparable with those implemented in Australia, where each farm is issued with specific environmental monitoring conditions, though the AZE used in Australia does not cover as wide as area surrounding the farms (35m from the farm boundary) as regulations implemented in Scotland (100m Maximum mixing zone) [150, 274] .

Chemical inputs and treatments

Sea-lice treatments

Sea lice outbreaks continue to be a significant and persistent issue for many aquaculture regions. Norway represents the most stringent limits to sea lice numbers in salmon stocks, with a limit of 0.5 (lowered to 0.2 during migration periods)/adult fish. The use of pesticide treatments, including those used for sea lice mitigation, has decreased over recent years. This in part, has been in response to growing resistance of sea lice to chemical treatments and consequential to this the use of non-chemical alternatives have become increasingly prevalent. This trend has also been seen in the Faroe Islands, where non-chemical treatments for sea lice such as cleaner fish and mechanical or thermal treatments have grown in use.

In the Faroe Islands, reported sea lice limits are closely linked to licensing conditions, with reported sea lice numbers informing allowed production limits during the next production cycle of a farm.

Mitigating the impacts of sea lice on wild salmon populations has resulted in some nations implementing frameworks to mitigate sea lice transmission to wild salmon during specific migratory periods. In Norway permissible sea lice limits are reduced from 0.5 to 0.2 for periods of juvenile wild salmon migration to reduce sea lice transmission from farms to the migrating juveniles. These limits are implemented in all farms in southern Norway, followed by all farms in northern Norway during identified migratory timeframes[191]. The BC province of Canada has also implemented measures to limit sea lice spread to wild juvenile Pacific salmon during migratory periods. This is applied to all licence holders in the region and requires reduced sea lice limits to be implemented (<3 Molile sea lice/fish between March – June [275]. Scotland has committed to implementing a similar framework to that seen in Norway from 2024. However, unlike Norway region wide approach Scotland will utilise farm level modelling and reporting assessments to determine which farm operations will need to implement reduced sea lice limits during the migratory periods. In Canada concern of the impact of aquaculture on wild salmon has contributed to a number of farm sites closing, under the rational of protecting wild salmon migratory routes. However, this has been controversial, resulting appeals to the closures[276].

Table 6. Sea lice regulation limits of each nation

Country	Monitoring	Limit (adult ♀/fish)	Time period	Additional information
Norway General	Weekly if sea temperature ≥4*C Biweekly if sea temperatures <4*C	<0.2 + Maximum of 1 treatment in last production cycle	April 1 – Sept 30 (weeks 16-21 in southern Norway; weeks 22-26 in northern Norway)	If both conditions (limit + maximum treatments) met, get extra +6% biomass
Norway General	Weekly if sea temperature ≥4*C Biweekly if sea temperatures <4*C	<0.5	October 1 – March 31	

Norway Green licence Group A & B	Weekly if sea temperature ≥4*C Biweekly if sea temperatures <4*C	<0.25 + Maximum of 3 treatment/cycle		
Norway Green licence Group C	Weekly if sea temperature ≥4*C Biweekly if sea temperatures <4*C	<0.1 + Maximum of 3 treatment/cycle		
Chile	Weekly	<3.0		
Faroe Islands	Biweekly (3rd party)	<1.0	August – April	
		<0.5	May – July	
Iceland	Biweekly	<0.5	July 1 – October 1	
	Monthly if sea temperature >4*C		October 2 – June 30	
	No reporting if sea temperature <4*C		October 2 – June 30	
Australia	-	-	-	-
Canada BC	Biweekly in pre-migration and out-migration windows; Monthly at other times	<3.0	March 1 – June 30 – Juvenile out migration period	
Scotland	Weekly	<2.0	Farms in designated Wild Samon Protection Zones adhere to lower sea lice limits during juvenile migration periods. Determined on site-by-site basis	

Antibiotic use

The use of antibiotics in aquaculture has been a topic of increasing prominence across world aquaculture. Through strict regulation, the Faroe Island have been able to ensure no antibiotic treatments have been used in the country's farms since 2004. This concerted effort to ensure fish health throughout the life cycle is the foremost example of preventing the need for antibiotic treatments. The use of antibiotics have also been very low in Norway (1% of salmon in 2020 were treated with antibiotics), as a result of vaccination and breeding programs increasing resistance to disease in farmed populations. In Scotland antimicrobial use declined to a very low level of use in 2015, but there has been an increase since 2017.

The number of sites also increased about 10-fold between 2015 and 2019. Although current use is less than one treatment per site per year, this is a concerning trend.

Waste

Input to benthos (seabed) and water column from chemicals, feed and effluent

Monitoring of waste effluent is commonly assessed via benthic environment surveys in areas beneath and surrounding farms and is conducted by all major salmon producing nations.

Scotland's waste effluent regulatory systems are well established, with all farms required to obtain a Water environment (controlled activities) (Scotland) Regulations 2011 (CAR) license before any discharge is permitted[277]. Limits to waste are dependent on each sites maximum biomass limit as described in a farm's permit. This level is estimated based on modelling of the areas around the farm. Once implemented, benthic sampling is conducted to monitor compliance with specified limits [145]. As of 2019, 40% of farms in Scotland had benthic impacts that were deemed borderline or unsatisfactory [145]. The volume of nutrient waste discharged from aquaculture operations in Scotland has been noted as increasing as the industry has expanded, however this is not thought to be of wider environmental impact [145].

In Australia, the monitoring of waste now includes the monitoring of the Total Dissolved Nitrogen Output of farms as a means to monitor organic waste release in the water and not only the seabed. In Chile following significant issues surrounding algae blooms farms are required to measure and report dissolved oxygen levels, temperature and salinity of the areas surrounding farms in real time.

In Canada, analysis of benthic data from the Aquaculture Monitoring Program showed that most samples had at least two drugs present: 75.2% (BC), 91.4 % (NL), and 54.8 % (NB /NS) highlighting the potential for cumulative effects[278]. Emamectin benzoate and oxytetracycline were detected four and three years respectively after last known treatments, demonstrating the need for research on overall persistence of compounds.

Plastic use, reuse and recycling

Many nations have aquaculture-specific regulation in relation to plastics. An effective example of this is in Australia, where plastic equipment used in aquaculture must be registered and traceable through markings and colour coding of plastic equipment. This allows for a source of plastic pollution to be identified. In Chile, regulation specific to addressing aquaculture operations as a source of plastic pollution have also been implemented since 2021. In the Faroe Islands the Marine Protection Act sets out regulation addressing all marine pollution, including plastic pollution, however this is not specific to aquaculture. In Scotland one of the statutory consultees, Crown Estate Scotland (CES) has developed guidelines to manage and report on plastics use[279]. However plastic management and plastic pollution prevention are still areas of improvement.

Wildlife interactions

Acoustic Deterrent Devices (ADDs) are commonly used in many regions as a means of non-lethal predator deterrent for marine mammals. However, the use of ADDs has become increasingly controversial due to impacts on non-target marine wildlife. Of the reviewed salmon-producing nations, only Canada has prohibited the use of ADDs in the aquaculture industry. Australia requires a permit to be obtained for use of ADDs, to do so sites must show that the ADD will not impact non-target wildlife and that all other alternatives to deter wildlife have been sought.

In Scotland, recent legislation essentially banned the use of ADDs in 2022[280]. The Conservation (Natural Habitats &c.) Regulations 1994[281] states that licences are required in order to use ADDs due to the potential harm these could cause marine animals. Licences are only permitted if there is evidence ADDs would not have an impact on wildlife and there are no alternative solutions to deter wildlife from salmon pens[282]. To install an ADD, a fish farm must obtain an EPS (European Protected Species) license, demonstrating that the implementation of the ADD will not harm cetaceans and that there is no suitable alternatives available, this is then enforced by Scotland's Marine Directorate (formerly known as Marine Scotland)[283], [284].

Regulation prohibiting the killing of marine animals is present in both the Faroe Islands and Chile, while a voluntary agreement among aquaculture operators in Canada to prevent killing of protected species has been in place since 2018 to comply with United States seafood market demands for imported produce. In Scotland, the killing of seals to protect aquaculture fish stocks has been banned since 2021, partially in order to comply with US import regulations[285].

Concluding remarks

Norway

Norway leads the world in global Atlantic salmon production, with aquaculture a well-established sector and significant component of the national economy. Norway has developed a complex regulatory and licensing framework to address the industry and has invested significantly in technology to enable continued growth and limit environmental impacts, though currently only implemented at a small scale. A good level of transparency around the industry though a central dashboard aids ensuring standards are upheld, while production limits are closely linked to environmental performance. However environmental impacts of the industry remain an issue in areas of operations, with sea lice a particular ongoing concern. A review of current regulation is underway with outcomes to be determined.

Chile

Salmon aquaculture in Chile has been a commercial success, growing to be a highly profitable export for the nation. However increasing scrutiny over what have historically been relaxed laws surrounding salmon farming in Chile has increased following a series of environmental crisis, health concerns and international market pressures. The recent change in administration offers potential for much needed reforms to how the industry operates and address legislative short comings. How successful these reforms will be remains to be seen.

Scotland

Scotland aims to grow its salmon aquaculture industry further in the coming years, with the long term aims set out in the 'Vision for Sustainable Aquaculture'. As the industry grows regulatory and legislative frameworks must be in place to protect the marine environment in areas where farms are located from negative impacts of farming operations. Examples of positive steps such as the creation of centralised information dashboard (to be launched in 2024) and increased use of computer modelling to assist in assessing environmental impacts of farms are being undertaken which will improve transparency in the sector. However, the environmental impacts of the industry remain prominent issues. Furthermore, no timeline has been provided for regulatory reform following the publishing of the 'Vision for sustainable aquaculture' meaning that a clear path to achieve its aims is needed to ensure timely and effective implementation.

Faroe Islands

Salmon aquaculture is an important area of the Faroese economy. Following legislation implemented in 2003 there's seems to have been success in addressing disease among salmon stocks, however sea lice are an ongoing concern. Environmental impacts are seen to be relatively limited, though this may be due to monitoring practices, with fish aquaculture categorised as a highly polluting activity. Information available is limited and often not available in English, although there seems to be a general lack of transparency and information publicly available.

Australia

Australia's aquaculture industry is set to continue grow with ambitious economic targets, despite concerns over the adequacy of current legislation. There has been an inquiry into environmental monitoring of salmon farm leases and acknowledgment this needs to be more uniform, yet it is unclear when the improvements to environmental monitoring will be decided and acted upon. The country has faced multiple failings to protect the environment from the negative impacts of salmon farming including the event at Macquarie Harbour, but the publicly accessible portal helps both consumers and communities understand more about the finfish farming occurring across Tasmania.

Canada

Unlike other nations Canada has overarching marine industry Acts that are then incorporated into provincial legislation. The country is proud to be pushing technological neutrality which may benefit smaller aquaculture operations but with this comes a reliance on industry-led transitions. Without legislation forcing progress and relying on industry experts for progression the country could see a delay in more sustainable resource development. However, the Northern Atlantic salmon region has some of the most thorough environmental monitoring, with video monitoring mandatory in one province. Canada provincial approach means there is no uniformity to data and therefore it is unsurprising that the level of transparency varies across the aquaculture sector.

Iceland

The rapid growth of the aquaculture industry in Iceland over the last 10 years has resulted in legislation, regulation and monitoring catching-up with the new industry as it grows and develops. As the Icelandic government hopes to continue to grow production and increase the share of GDP, improved frameworks to regulate and monitor the industry are needed, a fact that seems to be generally acknowledged by all parties and actors. The form that legislation and regulation takes remains to be seen. Issues of the impact of aquaculture on wild salmon stocks particularly seems to be a recurring point of discourse, while sea lice may become an increasing issue. Iceland appears to propose a mix of land, coastal and offshore aquaculture as part of its plan for growing the industry.

Conclusion

This report aimed to assess and compare the legislative and regulatory frameworks in place across five major salmon producing nations in relation to environmental management and protection. Globally the salmon aquaculture industry continues to grow, with many producing nations aiming to increase production in coming years. Salmon aquaculture has the potential to bring multiple environmental impacts to the areas in which farms are located, however, there remains no global requirements to monitor or regulate the environmental impacts of salmon aquaculture.

The review demonstrates that no single nation has sufficiently addressed the environmental impacts of salmon aquaculture. As many nations aim to expand the industry in differing locations and undertake reviews of regulation it is imperative that urgent action is taken to ensure the long-term protection and sustainability of the environment and communities.

Until this is resolved the expansion of the global salmon industry should come under a moratorium.

As this report shows regulatory and legislative frameworks vary across salmon farming nations, leading to no common environmental standards. In recent years several salmon producing nations have recognised that existing regulation and legislation are outdated, leading to multiple nations undertaking reviews of existing regulation and legislation. This is an opportunity and potentially positive step in developing robust environmental regulation and monitoring of the sector in these regions in the future.

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