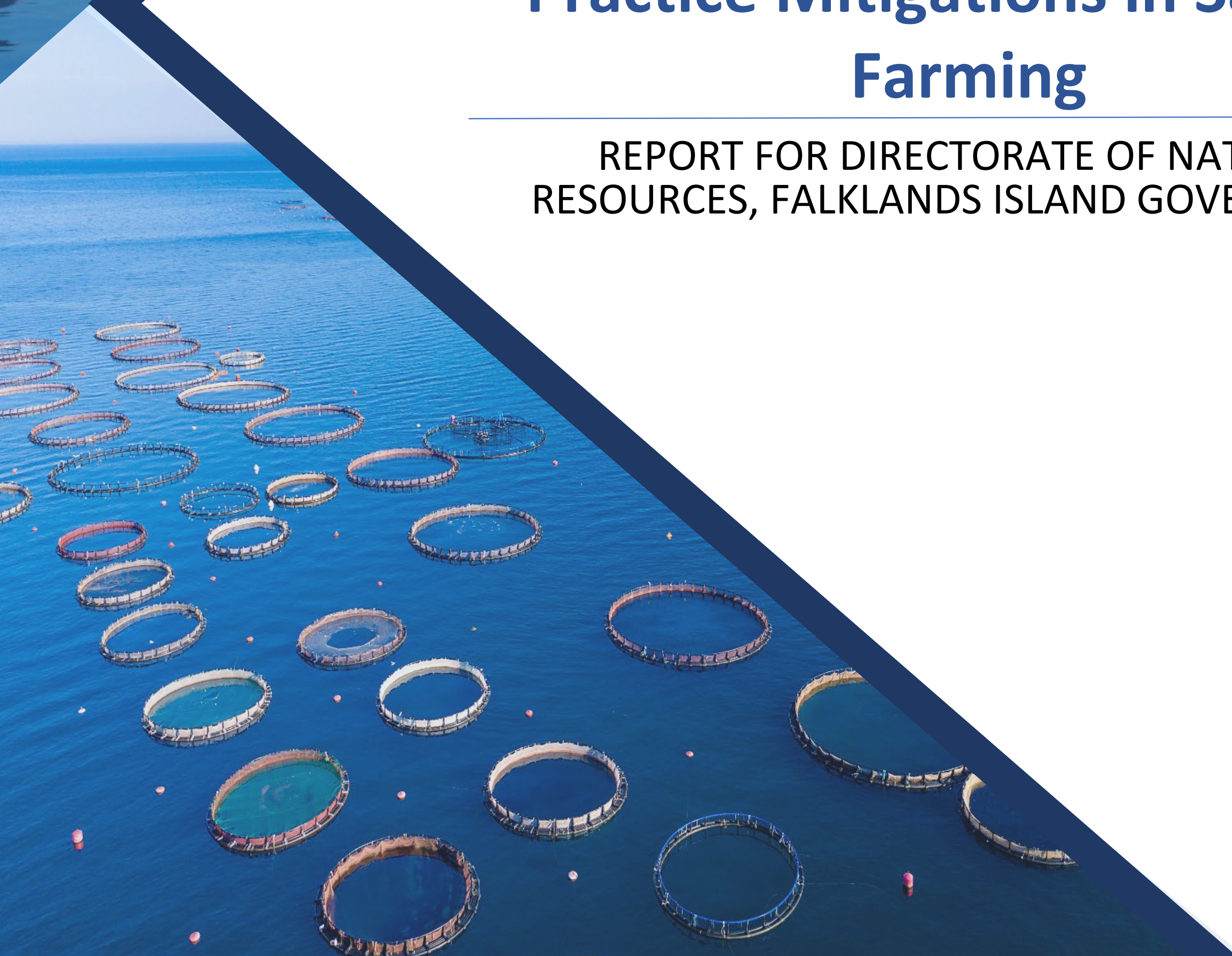

Environmental Impacts and Best Practice Mitigations in Salmon Farming

REPORT FOR DIRECTORATE OF NATURAL RESOURCES, FALKLANDS ISLAND GOVERNMENT

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Abbreviations and Acronyms

ABM	Area-Based Management
ADDs	Acoustic Deterrent Device(s)
AGD	Amoebic Gill Disease
AHDs	Acoustic Harassment Device(S)
AMR	Antimicrobial Resistance
ASC	Aquaculture Stewardship Council
ASI	Accreditation Services International
AZE	Allowable Zone of Effect
BAP	Best Aquaculture Practices
BEMPs	Broadscale Environmental Monitoring Programs
BKD	Bacterial Kidney Disease
CAB	Conformity Assessment Body
Cd	Cadmium
CEN	European Committee for Standardisation
CIEP	Centre for Research in Ecosystems of Patagonia
CMS	Cardiomyopathy Syndrome
Cu	Copper
DIC	Dissolved inorganic carbon
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
DOC	Dissolved organic C
DON	Dissolved organic N
DOP	Dissolved organic P
EU	European Union
FCR	Feed Conversion Ratio
FFDRm	Fishmeal Forage Dependency Ratio
FFDRo	Fish Oil Forage Dependency Ratio
FFVA	The Faroese Food and Veterinary Authority
FHI	Fish Health Inspectorate
FIG	Falkland Islands Government
FoS	Friends of the Sea
FT	Full Time
GAA	Global Aquaculture Alliance (now GSA)

GDP	Gross Domestic Product
GLFA	General Law of Fisheries and Aquaculture
GSA	Global Seafood Alliance (formerly GAA)
HAB	harmful algae bloom
HCVA	High Conservation Value Area
HSMI	Heart and Skeletal Muscle Inflammation
IFOP	Fisheries Development Institute
IHN	Infectious Haematopoietic Necrosis
IHVN	Infectious Haematopoietic Necrosis Virus
EIAs	Environmental Impact Assessments
INCAR	Interdisciplinary Centre for Aquaculture Research
IPN	Pancreatic Necrosis
ISA	Infectious Salmon Anaemia
ISAV	Infectious Salmon Anaemia Virus
m	Metre(s)
MAB	Maximum Allowable Biomass
MEP	MacAlister Elliott and Partners
MMAs	Marine Managed Areas
MT	Metric tonnes
NH3 +	Ammonia
NFSA	Norwegian Food Safety Authority
NMNRs	National Marine Nature Reserves
N	Nitrogen
NGO	Non-Governmental Organisation
OECD	The Organisation for Economic Cooperation and Development
P	Phosphorus
PD	Pancreas disease
PMCV	Piscine myocarditis virus
POC	Particulate organic carbon
POM	Particulate organic matter
PON	Particulate organic nitrogen
POP	Particulate organic phosphorus
PRV	Piscine reovirus
PD	Pancreas disease

PO4 3−	Phosphate
PT	Part Time
RAS	Recirculating Aquaculture Systems
RTRS	Roundtable for Responsible Soy
SAV	Salmonid alphavirus
SMZs	Sustainable Multi-Use Zones
SRS	Salmon rickettsial syndrome
U	Uranium
UK	United Kingdom
VHS	Viral Haemorrhagic Septicaemia
Zn	Zinc
WHO	World Health Organization
WSPZs	Wild Salmon Protection Zones

Executive Summary

Aquaculture production has seen a remarkable growth in production over the past three decades, partly in response to wild capture resources reaching capacity and the need to feed an ever-growing global population. Since 2013, salmonids have consistently been the highest-value traded aquatic species, representing 20% of the total export value of aquatic animal products in 2022. The global trade of salmon and trout has expanded significantly, with an average annual value growth of 10.4% since 1976. In 2022, exports surged to USD 38 billion, reflecting a 15% increase from 2021, driven by rising demand, premium pricing, and advancements in value-added processing. Atlantic salmon remains the leading farmed species, contributing to the 4.24 million MT of salmonid aquaculture production, which accounted for 6.9% of global finfish aquaculture. Norway is the world's top producer. Chile, along with the United Kingdom and Canada, also plays a significant role in the industry.

This rapid growth in production has come with a host of challenges, both environmental and social which have raised concerns as to the sustainability of production. These concerns include the pollution of the surrounding water column (with increased nutrient loading, creation of anoxic benthos and high levels of chemical release), the escape of farmed salmon (and potential to degrade wild genetic stocks or create new non-native stocks), interaction with wildlife (including the lethal control of seals), the development of increased antibiotic resistance and the proliferation of high sea lice levels in wild stocks (as a result of outbreaks in farmed populations). Since the farming of salmon has started, reports of widespread disease outbreaks and mortality events (Chile), changes in wild genetic characteristics of natural stocks (Norway) and reduced returns of wild salmon to spawn in European rivers have been reported. The blame in many of these cases and others has been laid at the door of salmon farming, sometimes fairly and sometimes with little evidence.

It is also true that the location of these cage farms are often in areas of outstanding beauty which are widely regarded as tourism and wildlife hot spots and so do not sit well with intensive farming methods.

All the above has led to a recent groundswell in criticism of the industry by many NGOs and commentators. Currently, this does not seem to affect sales of the species in its dominant markets, but the general public are starting to ask more and more questions about salmon farming.

However, it is also true that the salmon industry has brought significant employment opportunities and revenue generation to many of the major producing nations. For example, in Scotland the total turnover of the Scottish salmon farming sector was £1.23 billion, an increase from £1.06 billion in 2021, despite a decrease in production. During the same year, the sector employed 1,508 staff, an increase of 13 compared to 2021.

Currently, the Falklands Island Government (FIG) are considering the option of commencing commercial salmon farming operations in the Islands. Previous interest in the idea has been received from some commercial outfits who see the country as suitable for production While some NGOs and segments of the local community have expressed concerns—often referencing the environmental and social challenges observed in Chile— it is important to note that community perspectives are varied, and recent stakeholder engagement exercises, such as those documented in a recent socio-economic impact assessment (SEIA) report produced by MEP and Hatch, indicate a mix of views across the population. What's clear is that any salmon farming which is completed will need to be done in line with the best environmental and social practices to ensure it is as sustainable as possible. Ensuring this will be the job of the countries regulatory policies and framework and so it is important that the FIG draws on the current best practices employed in other countries.

In general, the strength of a countries regulatory system is based on a strong licensing system and maintained with regular monitoring and assessment. Most licensing systems are based on standard planning permission systems and require the completion of detailed Environmental Impact

Assessments (EIAs) and stakeholder engagements. Backing up this regulatory system, most countries have developed a range of environmental parameters which planning decisions can be based on. These create trigger points at which development is or is not considered acceptable. In Norway, it is generally accepted that nearshore farming has reached the capacity limit, and so no new licences are currently issued. Instead, they are now refining the current system to provide monitoring parameters which allow for the reduction or increase of biomass production in specific areas depending on outcomes (for example the traffic light system for sea lice numbers).

For major producing countries, a move to local management areas are also being seen, with, for example, a single loch system being treated under one set of determining rules. This reflects the idea of cumulative capacity (i.e. they may be individual farms, but they are all based in the same area and have a cumulative effect which should be treated as such).

However, the strength of the salmon sector is invariably driven by the performance of the individual farms with some naturally showing greater stewardship than others. The regulatory system though is designed to ensure a minimum standard which no operator can fall below (whether for managing escapes, controlling environmental waste or the health management of the fish). The level at which this minimum standard is set is the role of the regulator and requires a balance between promoting an industry and ensuring sustainable production.

A recent development in the sector has been the proliferation of sustainable certification or eco-labelling. This has been led by the Aquaculture Stewardship Council (ASC) and Global Aquaculture Alliance’s (GAA) (known as the Global Seafood Alliance (GSA) since 2021) Best Aquaculture Practice (BAP). Both provide a standard against which operators can be audited to show they are meeting best international practices. However, these schemes are voluntary and should be viewed as such (i.e. the regulatory system should help operators achieve certification and not demand it as a condition of licensing). That said, a commitment to work toward certification within a reasonable timeframe may offer benefits to both operators and regulators. Certified farms are subject to independent audits, which can enhance transparency, reduce regulatory burden, and demonstrate adherence to high environmental standards. This approach allows flexibility for producers to choose the most appropriate scheme (e.g. ASC, BAP), while still encouraging best practice and accountability.

An alternative option of organic farming is also considered in this report as a sustainable method of production for the Falkland Islands (i.e. the potential of making the Falklands an ‘organic only’ production zone). This though appears unfeasible as organic certification is generally not permitted for non-native species (as would be the case here).

The FIG has a strategic decision to make in the first place about what level of farming it wishes to see in its shores (none, some but below carrying capacity, or as much as carrying capacity will allow). All have disadvantages and advantages which need careful consideration. It is also true that should any salmon farming be permitted in the Islands; some negative environmental consequences will need to be accepted even if the best management practices are implemented (although these could be very small). A robust regulatory system will need to be implemented to ensure that the highest standards can be achieved. Furthermore, this report does not consider the economic and financial viability of operators setting up farms in the Falklands. This is clearly an area which will require further consideration as without an understanding of the interest and what is possible for the sector in the country it is hard to know what the vision for the industry might be capable of looking like.

1. Introduction

This report has been compiled by Macalister Elliott and Partners Ltd (MEP) on behalf of the Falklands Government (FIG). MEP is a UK based fisheries and aquaculture consultancy which has been operating since 1977.

The Falkland Islands are considering the potential for commercial scale salmon farming operations in the future. The waters of the Falklands are considered well suited to salmon farming and approaches have been made to the authorities by interested parties previously.

The potential for commencing commercial salmon farming would create additional revenue for the government and create jobs for islanders. However, the negative impacts that may exist because of these operations on both the natural environment and the social fabric of the community need careful consideration prior to any further steps being taken.

At the same time, global demand for sustainable protein sources is rising, and salmon aquaculture is increasingly recognised for its relatively low carbon footprint, efficient feed conversion, and minimal land and freshwater use compared to terrestrial livestock. These attributes position salmon farming as a potentially valuable contributor to sustainable food systems—if managed responsibly.

This report is an update of the 2021 report and represents an initial assessment of the impacts of salmon farming. The report aims to provide a detailed overview of what the negative impacts of salmon farming are and how these have been experienced by other countries in the development of the sector. It also provides a consideration of what current best practices have been or are being introduced to mitigate these impacts. The report also considers the current status of both sustainability and organic certification schemes with the salmon sector and the impacts these may have.

This report draws on a wide range of peer-reviewed literature, including both recent studies and foundational research. While some references pre-date 2015, they are included to illustrate historical context, worst-case scenarios, or long-term trends that remain relevant to understanding the evolution of salmon aquaculture impacts and for precautionary planning—particularly in a region like the Falklands where aquaculture is not yet established. The intention is not to overemphasise outdated practices, but to provide a balanced view that includes both legacy challenges and contemporary best practices. Where appropriate, more recent literature has been incorporated to reflect current technologies, regulatory frameworks, and mitigation strategies.

The overriding aim of the report is to present the current best practices globally and make initial recommendations on how the FIG might move forward with development within the sector. In making these initial recommendations and following initial discussions with the FIG, MEP has put ‘best practice’ at the forefront of its considerations. In doing this we have aimed to create a position in which any future salmon aquaculture industry in the Falklands could be considered the ‘global benchmark’. This is considered vital in ensuring that the Falklands maintains a pristine environment for now and future generation but with the potential for sustainable salmon farming within its shores.

2. Salmon Farming – Brief History and Current Status

The history of salmon farming is relatively short; until the early 1960s, salmon was only a wild capture industry, but due to the exponential growth of the aquaculture sector during the last 50 years, it has transformed into a global industry.

Farmed salmonids, or species of fish in the family Salmonidae, include the Pacific salmon coho (*Oncorhynchus kisutch*) and chinook (*O. tshawytscha*), the Atlantic salmon (*Salmo salar*) and the rainbow trout (*O. mykiss*), also known in seawater facilities as the steelhead (Figure 1). Production of salmonids is mainly based around the production of eggs and juveniles in freshwater facilities on land and grow-out of adult fish in floating cages or pens in semi-sheltered coastal bays, sea lochs or fjords.

The mid-19th century saw the establishment of freshwater salmonid hatcheries in UK and North America producing parr to enhance natural populations, however, it was in the 20th century that the concept of fish farming developed. Initially the culture of salmonids started on an experimental level during the 1950s, with the first farms established in Scotland and Norway in the 1960s. By the end of the 1980s, commercial salmon farming was well established in many temperate countries globally, *i.e.* Scotland, Ireland, the Faroe Islands, Canada, the Northeastern Seaboard of the US, Chile and Tasmania (Australia), with minor production in New Zealand, France, Spain and Japan.

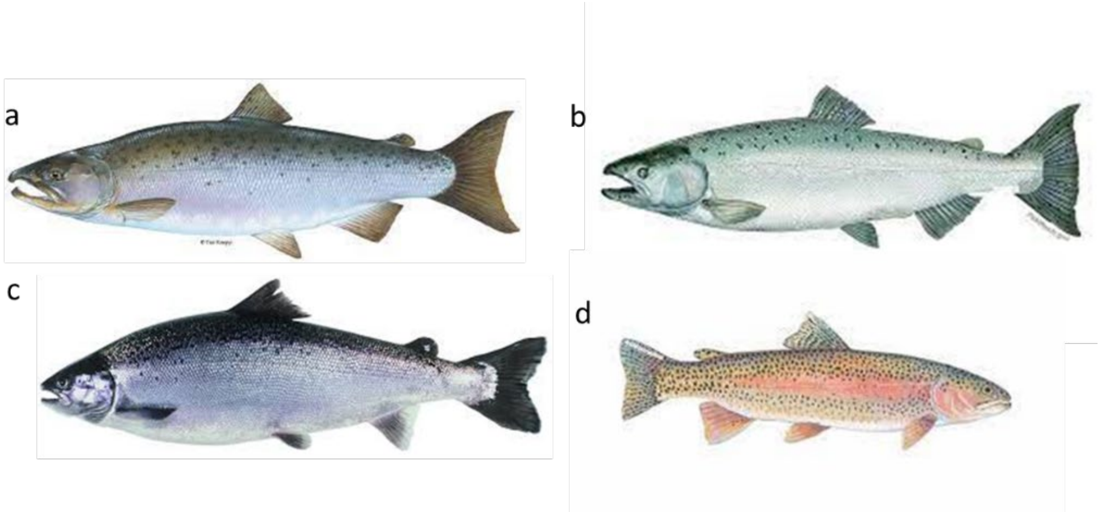

Figure 1: Common Species of farmed salmon

a) coho (Oncorhynchus kisutch) and b) chinook salmon (O. tshawytscha), the Atlantic salmon c) (Salmo salar) and d) rainbow or steelhead trout (O. mykiss).

The Food and Agriculture Organisation of the United Nation's (FAO) 'State of World Fisheries and Aquaculture' (FAO, 2024) report that global food fish consumption has increased at an average annual rate of 3.0% between 1961 to 2021. This growth was higher than that of all terrestrial meats combined (2.7% per year) except for poultry (4.7% per year). Per capita fish consumption grew from 9.1 kg (live weight equivalent) in 1961 to 20.6 kg in 2021, with projections estimating it to reach 21.3 kg by 2032 (FAO, 2024).

In 2022, total global capture fisheries production reached 92.3 million metric tonnes (MT), comprising 91.0 million MT (live weight equivalent) of aquatic animals and 1.3 million MT (wet weight) of algae. This represents a 0.2% decrease compared to the average of the previous three years. The decrease follows a peak of 96.5 million MT in 2018, driven by exceptionally high anchoveta catches in Peru and Chile. Marine capture fisheries remain dominant, but their sustainability continues to decline; the proportion of fish stocks within biologically sustainable levels decreased from 90% in 1974 to 62.3% in 2021, a 2.3% drop from 2019 (FAO, 2024).

Global fish production, including fish, crustaceans, molluscs and other aquatic animals (excluding seaweeds and other aquatic plants), reached 185.4 million MT in 2022, with a total first-sale value estimated at USD 472 billion. Of this, 94.4 million MT (51%), valued at USD 312.8 billion, came from aquaculture production (Figure 2). World aquaculture production of farmed aquatic animals continues to grow but at a slower pace, with an average annual growth rate of 1.6% projected for 2022-2032, compared to 4.0% from 2012 to 2022. Despite this slowdown, aquaculture remains the fastest-growing sector among animal food production systems (FAO, 2024).

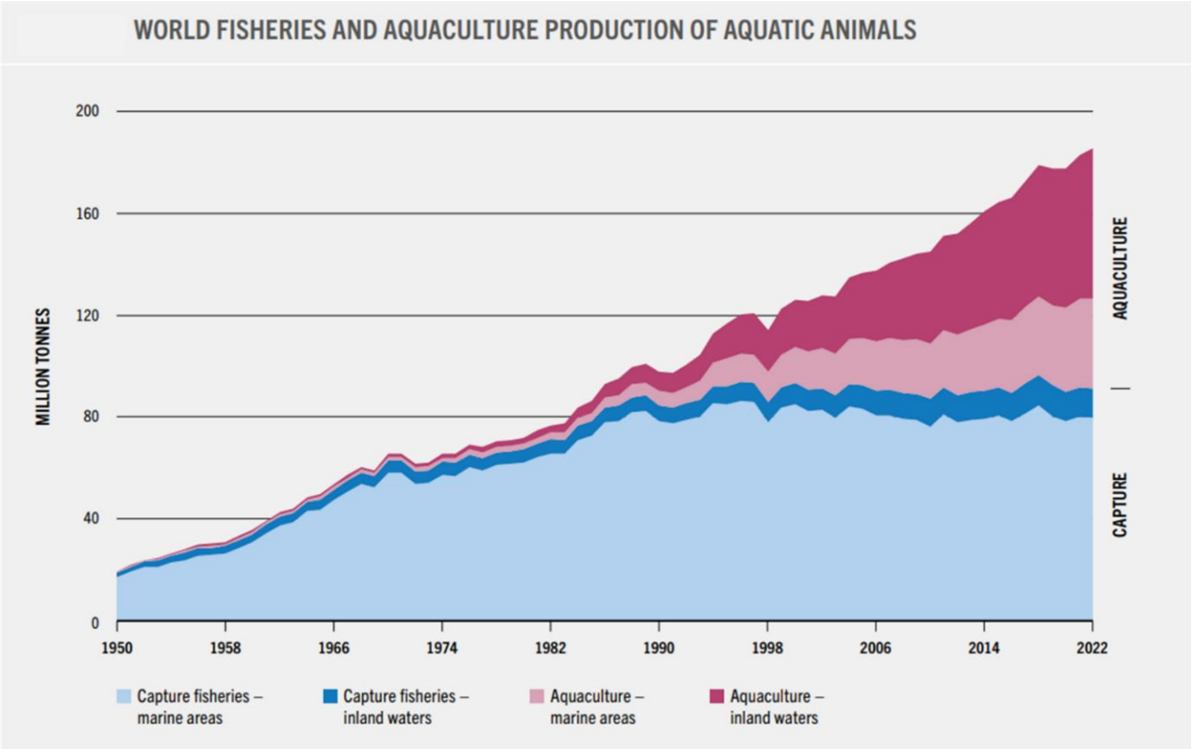

Figure 2: World capture fisheries and aquaculture production (1950 - 2022)

Source: FAO, 2024 The State of World Fisheries and Aquaculture

Aquaculture production continues to be dominated by finfish, which accounted for 61.6 million MT in 2022. This production is divided into 53.0 million MT from inland aquaculture and 8.6 million MT from marine and coastal aquaculture. Marine aquaculture or mariculture is conducted in a marine environment and includes the culture of anadromous fish species, *i.e.* species that rely on seed production from hatchery and nursery facilities in freshwater with mariculture representing the 'grow-out' or 'on-growing' phase of the production cycle, such as salmonids. There is clearly a great diversity of aquaculture species raised, both in the freshwater and marine environment; climatic and environmental conditions will determine the species choice, however global marine aquaculture production by volume is dominated by a small number of 'staple' species or species groups (FAO, 2024). The Organisation for Economic Cooperation and Development (OECD) member countries, *e.g.* Norway, Chile, Japan, the United Kingdom of Great Britain and Ireland, Canada and Greece dominate the production of these 'staple' mariculture finfish species.

Atlantic salmon (*S. salar*) continues to be one of the most valuable seafood commodities globally, driven by a strong customer demand (FAO, 2024). It remains the largest single fish commodity by value, surpassing other farmed salmonid species such as coho (*O. kisutch*), chinook (*O. tshawytscha*) and rainbow trout (*O. mykiss*).

Since 2013, salmonids have consistently been the most valuable traded aquatic species group, accounting for 20% of the total export value of aquatic animal products in 2022. The global trade in salmon and trout has experienced remarkable growth, with an average annual increase of 10.4% in value since 1976, outpacing the broader aquatic animal product trade. In 2022, global salmon and trout exports soared to USD 38 billion, marking a 15% rise from 2021, fuelled by increasing demand, premium pricing, and innovations in value-added processing. As a leading farmed species, Atlantic salmon continues to dominate mariculture, contributing significantly to the 4.24 million MT of salmonid aquaculture production in 2022, which represented 6.9% of total global finfish aquaculture (FAO, 2024) (Table 1). Norway remains the top global producer. Chile follows closely as the second-largest producer, maintaining a strong presence in Atlantic salmon, coho, and rainbow trout exports, while the United Kingdom and Canada also play pivotal roles in the industry (FAO, 2024) (Figure 3).

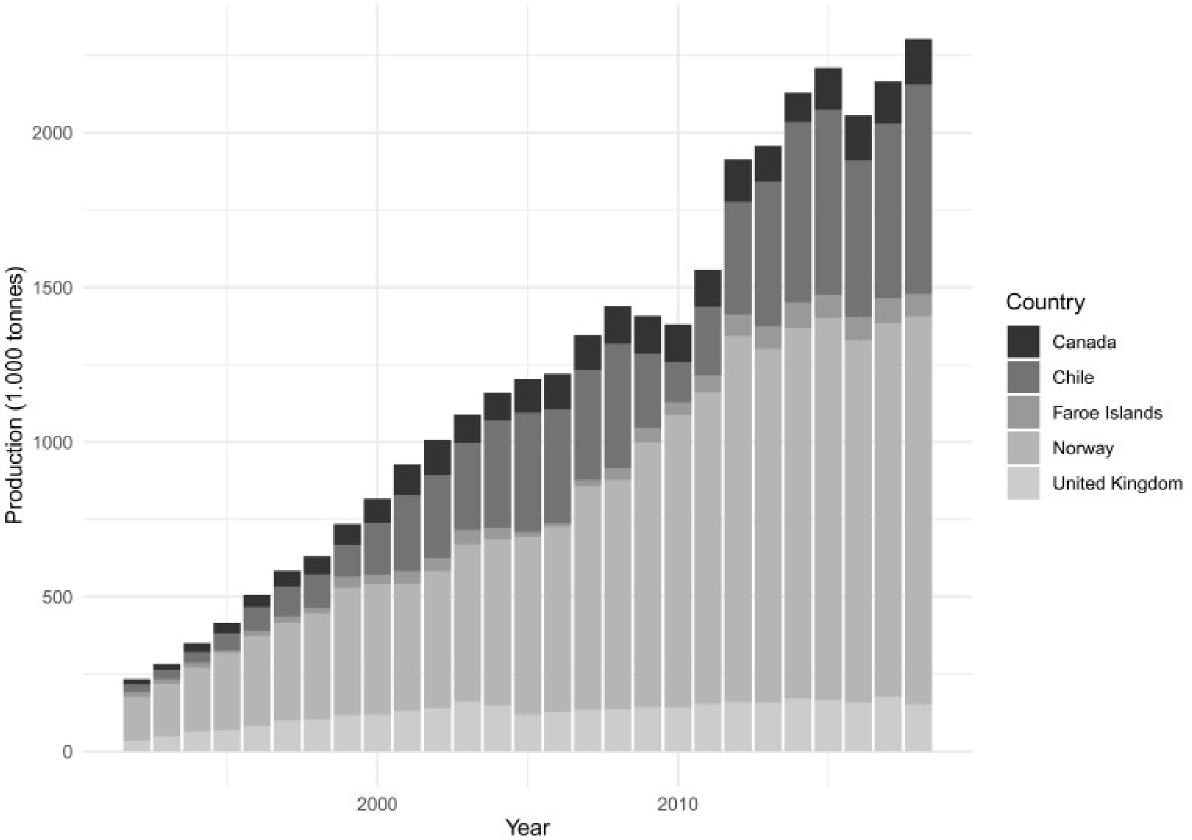

Figure 3: Atlantic salmon production in the five largest producer countries

Source: Kontali Analyse AS; taken from Iversen et al., 2020. Production costs and competitiveness in major salmon farming countries 2003-2018. Aquaculture, 522: 735089).

Table 1: Major finfish groups (freshwater and marine) produced in Global Aquaculture

Species or species group	2018	2019	2020	2021	2022	Share of species in species group, 2022 (%)
	(thousands tonnes, live weight equivalent)					
Finfish	54 564	56 354	57681	59 602	61 567	100
Carps	29 015	29 426	30 208	30 901	31 788	51.6
Catfishes	5 782	6 286	6 092	6 199	6 628	10.8
Cichlids	6 043	6 407	6 066	6 293	6 549	10.6
Salmonids	3 517	3 812	3 996	4 205	4 243	6.9
Milkfish	1 327	1 297	1 284	1 278	1 196	1.9
Largemouth black bass	434	480	521	704	804	1.3
Snakeheads	554	583	649	687	690	1.1
Sea breams and porgies	391	436	485	533	564	0.9
Other finfish	7 500	7 628	8 280	8 803	9 105	14.8

Source; FAO, 2024 The State of World Fisheries and Aquaculture

In addition to its economic value, Atlantic salmon aquaculture has evolved into one of the most resource-efficient animal protein systems. Through decades of genetic improvement, feed innovation, and technological advancement, feed conversion ratios have declined from over 5:1 in the 1970s to approximately 1.2:1 today, while protein content in feed has dropped from 55% to 35% (Torrissen et al., 2011).

These improvements have contributed to a significantly lower environmental footprint compared to terrestrial livestock. Farmed salmon now has a carbon footprint of approximately 5–6 kg CO_2e per kg of edible product—substantially lower than beef (30 kg CO_2e) and lamb (12 kg CO_2e) (Poore & Nemeck, 2018). These efficiencies, combined with the absence of land and freshwater requirements, make salmon aquaculture a compelling option for sustainable protein production, particularly in regions with limited agricultural capacity.

3. Environmental Impacts of Salmon Farming

Over the last 50 years, scientific developments have led to a greater understanding of the functioning of aquatic ecosystems and a global awareness of the need for sustainable management of these precious resources. The worldwide increase in reliance on aquaculture production, due to depletion of wild fish stocks and a growing population, has understandably triggered concerns. Aquaculture, by its very nature, has an impact on the aquatic environment; fish are in direct contact with their environment over which there is less control.

The intensive production of salmon, especially in their marine phase, results in the release of solid wastes into the environment, either as unused inputs, *i.e.* residual feed, or by-products such as faeces, dissolved wastes, *i.e*. by-products of feed metabolism containing major components such as nitrogen (N) and phosphorus (P) (Boyd and Massaut, 1999) and chemical inputs, *i.e.* chemotherapeutants, disinfectants and antifoulants. However, it would be true to say that there is a restricted ability to manage waste products in the same way as in terrestrial farming systems. Of particular concern is the release of pathogens originating from cultured salmonids, many of which are able to survive long-term without a host and which spread at faster rates than in terrestrial systems, with their dispersal aided by a lack of barriers in a highly connected aquatic system (McCallum, Harvell and Dobson, 2003).

Environmental interactions of aquaculture operations vary in their nature and extent depending on species farmed, farming system, as well as the level of intensification, however such rapid growth of the salmonid aquaculture sector, whose production system is one of the most profitable and technically advanced in the world, has resulted in several environmental challenges. Ecosystems have a remarkable capacity for resilience, however, if environmental impacts are not effectively managed, degradation of the benthic environment can occur. While such impacts are typically reversible through fallowing and adaptive management, recovery rates vary depending on site-specific conditions such as depth, current velocity, and production intensity.

Recent large-scale analyses, such as Wang and Olsen (2024), which reviewed over 3,400 benthic monitoring reports from Norwegian salmon farms, confirm that most benthic impacts are recoverable. However, they also highlight that recovery is more rapid and complete when degradation is detected early and managed proactively. This underscores the importance of robust environmental monitoring and timely intervention to prevent long-term or cumulative degradation, particularly in sensitive or low-flushing environments.

Below will be discussed, in an historical context, the main environmental sustainability concerns and constraints to the development of the global salmonid production, including both the production of eggs and juveniles in freshwater facilities on land and the on-growing phase in open cages in the sea.

3.1. Use of Freshwater

Salmonids are diadromous species (*i.e.* they migrate between freshwater and seawater) and more specifically anadromous species *(i.e*. they are born in freshwater, spend most of their lives in seawater and return to freshwater to spawn). Wild Atlantic salmon (*S. salar*) usually spend around four years in deep-sea feeding grounds, feeding on pelagic fish species, and, at the onset of maturation, cease feeding and return to their rivers of origin to spawn (October to January). Following spawning, fertilised eggs settle in riverine gravel beds or ‘redds’ to incubate for approx. 500 degree days (i.e., the cumulative temperature exposure a salmon egg experiences) before hatching. The larvae or alevins live off their large yolk-sac reserves for a further 300 degree days, and then actively begin to feed as they pass through the fry and parr stages for approx. two years, until physiological changes known as the smoltification or seawater adaptation process takes place, and they migrate downstream (normally in May and June) and enter the sea to on-grow.

Production of smolts for on-growing in sea cages is carried out in land-based hatcheries (smolt farms). Broodstock are selected from sea site production stocks and moved to freshwater facilities a few months prior to stripping. Eggs are manually stripped dry, fertilised with stripped milt, and laid down in trays to incubate, usually at around 10 ºC. Following hatching and yolk-sac absorption, fry are on-grown in tanks fed with artificial feed until they are moved to larger tanks or lake-cage systems to mature into smolts, usually in the spring of the year following hatching and are known as S1 smolts, prior to stocking at sea.

There are three principal hatchery systems–smolt farms, based on the level of technology and water management (Fivelstad *et al.,* 2004);

A) Single-pass flow-through systems with oxygenation: According to regulations for licensing of Norwegian hatcheries (Norwegian Department of Fisheries), the lowest allowable flow limit in single-pass flow-through farms is 0.3 L/kg min.
B) Partial reuse systems, *e.g.* aeration, oxygenation and particle removal, partial recirculation, lowest allowable flow limit 0.15 L/kg/min.
C) Recirculating aquaculture systems (RAS), *e.g.* biofiltration, fully recirculated water, with lowest allowable flow of 0.02-0.04 L/kg/min (Fivelstad *et al.,* 2003) (Figure 4).

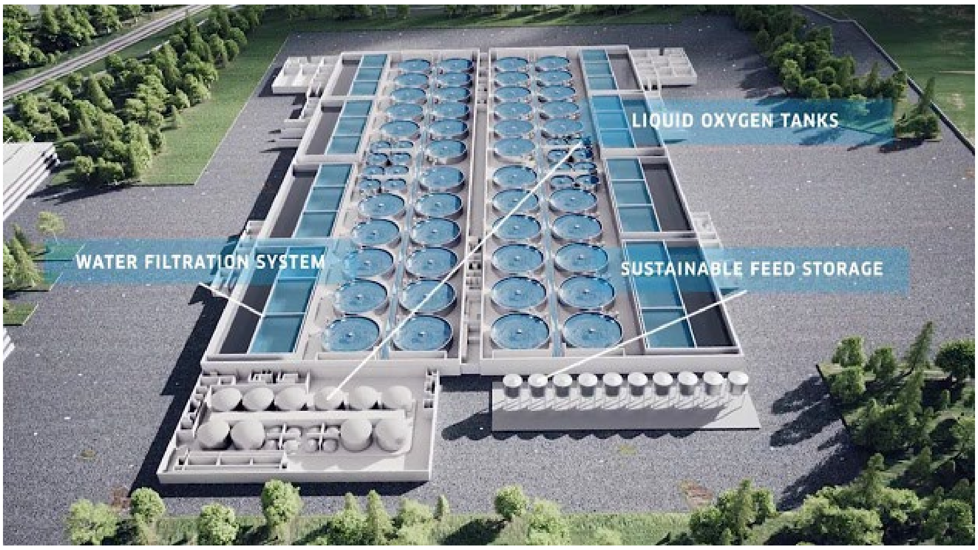

Figure 4: A model of a large RAS system

The traditional single-pass flow-through systems or partial reuse systems have a number of constraints which include:

i) limitations in available freshwater resources, especially during dry periods of the growing season,
ii) poor water quality of inlet water, *i.e.* low alkalinity,
iii) threat of ingress of disease-causing pathogens and the requirement for disinfection, *i.e.* UV irradiation or ozone,
iv) high CO_2 levels in groundwater that requires stripping, and
v) the need to regulated inlet water temperature (Kristensen *et al.,* 2009).

There is therefore considerable interest in the growth potential of land-based, intensive recirculating aquaculture systems (RAS) as a means to mitigate these problems. Not only do intensive RAS systems decrease water consumption, but they also allow essential water quality parameters *e.g.* temperature, dissolved oxygen, carbon dioxide, ammonia, nitrite, nitrate, pH, salinity and suspended solids to be continuously monitored, hence optimising rearing conditions in terms of fish health and welfare, food conversion ratios *etc*. In addition, smolts raised under controlled conditions can be ready for moving to sea sites throughout the year. There is also currently interest in the production of larger more robust smolts, *i.e.* 250-1000 g, as this reduces the overall production time at sea mitigating the problems such as risk of exposure to sea lice infestation (Bergheim *et al.,* 2009).

Freshwater Requirements

The hatchery production process for salmon is completed in freshwater in land-based systems. Traditional flow-through hatcheries can require large volumes of freshwater, which may raise concerns in regions where water is scarce or where competing demands exist.

However, many modern hatcheries now use RAS based systems which allow for the recirculation of freshwater and hence reduce the quantities required and help reduce potential harmful outputs. In some countries (Norway) the use of RAS is being incentivised to encourage use (for example, licensing costs are reduced, and pollution permits made easier to achieve for these systems).

While freshwater availability is not a universal constraint, it remains a critical consideration in site selection and system design. For example, in the Faroe Islands, some operators have required subsea pipelines to be constructed to secure adequate freshwater supply for smolt production. This highlights the importance of proactive planning to ensure sustainable water use in aquaculture development.

3.2. Infectious diseases

'Aquatic animal disease is one of the most serious constraints to the expansion and development of sustainable aquaculture.' (FAO, 2020).

Infectious diseases, *i.e*. bacterial, viral and parasitic, have historically, and indeed still do, represent a major and concerning limiting factor for the expansion of the aquaculture industry; it is certainly true to say that the aquatic environment imposes '*a constant and omnipresent risk of pathogen exposure to resident hosts'* (Stentiford *et al.,* 2017). With the intensification of aquaculture there has been a concomitant proliferation and spread of pathogens resulting in direct costs that includes not just that of lost production from mortalities, but also a reduced growth and feed conversion ratio (FCR), associated expenditures for therapeutic treatment and disinfection of associated facilities and equipment (Pillay and Kutty, 2005), as well as temporary or permanent closure of aquaculture facilities.

It has been estimated that 10% of all cultured aquatic animals are lost because of infectious diseases, amounting to > 10 billion USD in losses annually on a global scale (Evensen, 2016). Regarding infectious disease in salmon aquaculture, there is a wealth of literature regarding disease epidemiology, transmission, impact and treatment options *etc*., clearly indicating that disease is a top priority for the industry and a potential impediment to its growth (Lafferty *et al*., 2015; Stentiford *et al.,* 2017).

The diseases affecting farmed salmonids tend to vary by country and production area over time and seasonal patterns have emerged for different disease challenges. It is revealing that The World Organisation for Animal Health's (OIE*) 'Diseases, infections and infestations in force in 2021'* (OIE, 2021) lists 10 notifiable finfish diseases, four of which affect farmed salmonids, *i.e.* Infectious Haematopoietic Necrosis (IHN) a viral disease caused by the Infectious Haematopoietic Necrosis Virus (IHVN), Pancreas disease (PD) (caused by a salmonid alphavirus (SAV), infestation by *G. salaris* (an ectoparasitic monogenean fluke) and Viral Haemorrhagic Septicaemia Virus (VHS).

While this section outlines a range of infectious diseases that have impacted salmon aquaculture globally, it is important to clarify their relevance to the Falkland Islands. Some of the pathogens and parasites discussed—such as those affecting wild salmonid populations—are not currently present in the region, nor are salmonid species native to the Falklands.

However, the inclusion of these risks is not intended to overstate the threat, but rather to provide a precautionary framework for biosecurity planning. The experience of other Southern Hemisphere producers, particularly Chile, demonstrates how rapidly diseases and parasites can spread in aquaculture systems, especially when facilitated by shared host species or regional connectivity. This report therefore takes a forward-looking approach, identifying both current and potential risks to support the development of a robust, preventative biosecurity strategy tailored to the Falklands' unique ecological context. A summary of commonly occurring diseases in salmonid aquaculture are listed below;

Viral diseases: Viral diseases currently represent a significant problem in salmonid aquaculture; the most frequently reported viral diseases include Infectious Pancreatic Necrosis (IPN), PD, Heart and Skeletal Muscle Inflammation (HSMI), Cardiomyopathy Syndrome (CMS), IHN and VHS. The main reason for the continued challenge posed by viral diseases is that, while vaccines do exist for some viral pathogens, their effectiveness can vary, and in many cases, they do not provide full protection or long-term immunity. This contrasts with bacterial diseases, for which vaccination has proven more consistently effective in reducing disease incidence and antibiotic use.

Bacterial diseases: These may include Furunculosis (*Aeromonas salmonicida*), Vibriosis (*Vibrio* spp.), salmon rickettsial syndrome (SRS) or Piscirickettsiosis (*Piscirickettsia salmonis*) and bacterial kidney disease (*Renibacterium salmoninarumon).* In recent years, there have been fewer outbreaks of bacterial diseases, reflecting the efficacy of currently available bacterial vaccines (Austin and Austin, 2007).

Parasites: The main parasitic threats to salmonids include parvicapsulosis, due to the myxosporean *Parvicapsula pseudobranchicola* and the microsporidian *Paranucleospora theridion*. The free-living amoeba *Paramoeba perurans,* the causative agent of Amoebic Gill Disease (AGD), is now a significant problem in worldwide salmonid producing areas. Sea lice, considered the greatest disease challenge in salmonid aquaculture, will be considered separately below.

Transmission from infected to potential susceptible hosts is strongly dependant on environment, therefore, in a highly intensive aquatic (fluid) environment, transmission patterns vary considerably to those in terrestrial systems (McCallum *et al*., 2004); not only does transmission occur between individuals due to close proximity, but also water currents will allow the spread of free pathogens, impacting populations located some distance from the source. Infectious diseases also pose disease risks for wild fish (discussed in more detail later in this report).

While the Falkland Islands' cooler sea surface temperatures and relatively low salinity may reduce the likelihood of some parasitic outbreaks—such as AGD, which is more commonly associated with warmer, higher-salinity waters—this does not eliminate the risk entirely. AGD has been reported in temperate regions such as southern Chile and Tasmania, and recent evidence suggests *that P. perurans* is highly adaptable, with outbreaks recorded in waters as cold as 5–6°C in Norway. Given the ubiquity of this pathogen in marine environments and its demonstrated ability to survive in low-salinity conditions, its inclusion here is precautionary and reflects the potential for emergence under intensive farming conditions, even if current environmental parameters in the Falklands suggest a lower baseline risk.

Chemotherapeutants or chemical treatments are used both prophylactically (to prevent) and therapeutically (to treat) within the global salmonid industry, however there is a clear trend towards treating outbreaks using a 'best practice' approach, that includes such measures as improved biosecurity, sanitation and disinfection, alternative non-chemical treatments, *e.g.* freshwater treatments for AGD, using heated water to remove sea lice, better husbandry practices, site fallowing, vaccines, functional aquafeeds and immune modulators (pre- and probiotics) and phytochemicals or botanical products.

Infectious Diseases

Salmon farming has had significant issues with infectious diseases which have led to a variety of direct consequences including mass mortality and lower FCRs (additionally there are indirect effects which are discussed separately).

The production of any species in confined areas at increase densities is likely to result in a higher risk from infectious disease. To combat these diseases a range of treatments (prophylactic and therapeutic) have been created. However, current best practices are focusing on reduced the use of these and improving preventative measures through better vaccination, increased biosecurity and non-chemical treatments. This area is driven more by industry requirements than government regulation, although limits on chemical and treatment uses do exist. As an example, Norway is reported to of reduced its antibiotic use (for example) by 99% since the late eighties (mainly as a result of successful vaccination regimes).

3.3. Sea lice

Infestation of farmed Atlantic salmon by sea lice is considered such a significant barrier to the expansion of the industry that it will be dealt with here separately.

Sea lice is the generic name given to a group of ectoparasitic copepods from the family Caligidae, (Burka *et al.,* 2012; Torrissen *et al.,* 2013) that attach to and live on the skin of marine and anadromous fish species. They affect farmed and wild salmonids in their marine phase causing severe skin damage and are currently considered to be the most economically significant parasites to worldwide salmonid industry (Gallardo-Escarate *et al.,* 2019).

The sea lice species affecting farmed Atlantic salmon (*S. salar*) and rainbow trout (*O. mykiss*) in northern hemisphere salmon farming countries, *e.g.* Norway, Canada, Maine (USA), Ireland, Scotland, Ireland and the Faroe Islands, is the native species *Lepeophtheirus salmonis* (Costello, 2006; Burka *et al.,* 2012; Torrissen *et al.,* 2013) (Figure 5) , and, to a lesser degree, *Caligus elongatus* (Costello, 2006). However, these species are not present in the Southern Hemisphere and are therefore not directly relevant to the Falkland Islands context. In contrast, the species of concern in Chile—and potentially more relevant to the Falklands—is the native Southern Hemisphere species *C. rogercresseyi* (Gonzalez *et al.,* 2000; Gonzalez and Carvajal, 2003) (Figure 5). Transmission of sea lice to fish hosts occurs during the copepodid, free-living or planktonic life stages when the larvae are dispersed by water currents (Figure 5Figure 5) (McKibben and Hay, 2004; Brooks, 2005; Costello, 2006; Penston *et al.,* 2008; Amundrud and Murray, 2009; Krkosek *et al.,* 2010; Molinet *et al.,* 2011).

A high susceptibility to infection by the sea lice *C. rogercresseyi* (Figure 5) has been reported for farmed non-native or introduced salmonids in Chile, *e.g.* Atlantic salmon (*S. salar*) and rainbow trout (*O. mykiss*), however the Coho salmon (*O. kisutch*) is considered to be a resistant species (Zagmutt-Vergara *et al.,* 2005). Historically, *C. rogercresseyi* infestation had been reported in the coastal waters of northern Patagonia (40°15’S to 49°16’S) (Regions X and XI), where close to 90% of salmon farms are located, however, in 2017, this species was detected for the first time in farmed Atlantic salmon (*S. salar*) in the Magallanes region (Region XII) (south of 49°16’S) (Figure 6) and is currently considered the most economically important parasitic disease for the Chilean salmon industry (Arriagada *et al*., 2019). This spread was attributed to the migratory behaviour of the native rock cod *Eliginops maclovinus,* a natural host for *C. rogercresseyi* (Carvajal *et al.,* 1998; González *et al.,* 2000; Boxshall and Bravo, 2000; Bravo, Boxshall and Conroy, 2011). Indeed *C. rogercresseyi* has a broad fish host range and is known to infest a number of other native South American marine fishes, *e.g.* the Patagonian blenny (*Eleginops maclovinus*), the Peruvian silverside smelt (*Odontesthes regia*), the small-eye flounder (*Paralichthys microps*) (Carvajal *et al*., 1998; Boxshall and Bravo, 2000). Of concern is that the rock cod *Eliginops maclovinus* is endemic to southern Chile, southern Argentina and the Falkland Islands and although reports of infestation have not yet been reported on the eastern coast of South America this fish could potentially act as a vector for the rapid dispersal and geographic spread of this parasite.

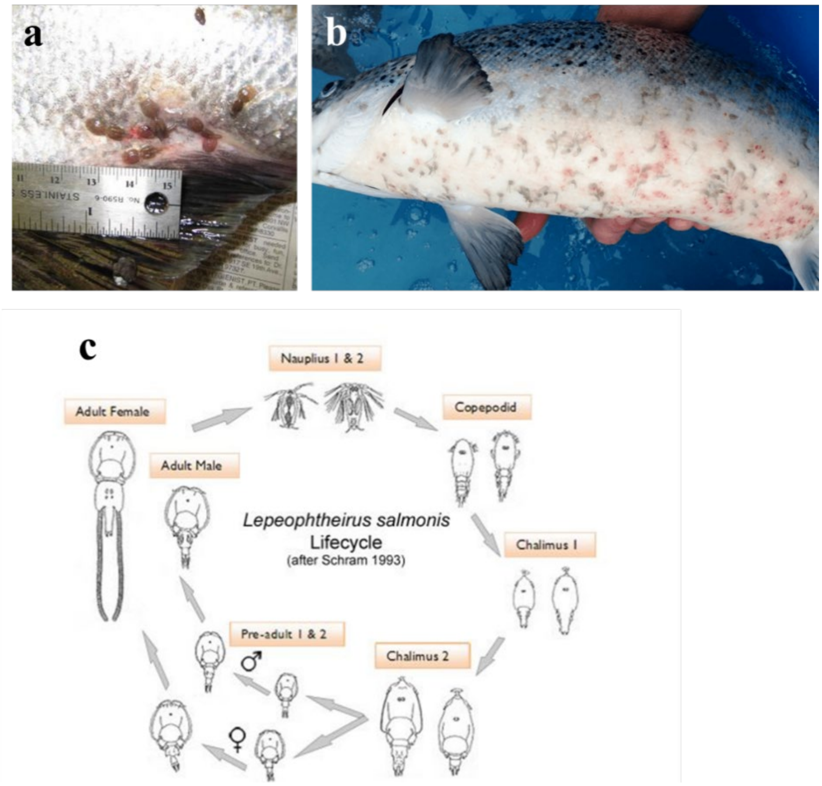

Figure 5: a) *Lepeophtheirus salmonis* infestation on farmed Atlantic salmon; b) *Caligus rogercresseyi* infestation on farmed Atlantic salmon in Chile; c) life-cycle of *L. salmonis*.

A high susceptibility to infection by the sea lice *C. rogercresseyi* (Figure 5) has been reported for farmed non-native or introduced salmonids in Chile, *e.g.* Atlantic salmon (*S. salar*) and rainbow trout (*O. mykiss*), however the Coho salmon (*O. kisutch*) is considered to be a resistant species (Zagmutt-Vergara *et al.,* 2005). Historically, *C. rogercresseyi* infestation had been reported in the coastal waters of northern Patagonia (40°15'S to 49°16'S) (Regions X and XI), where close to 90% of salmon farms are located, however, in 2017, this species was detected for the first time in farmed Atlantic salmon (*S. salar*) in the Magallanes region (Region XII) (south of 49°16'S) (Figure 6Figure 6) and is currently considered the most economically important parasitic disease for the Chilean salmon industry (Arriagada *et al*., 2019). This spread was attributed to the migratory behaviour of the native rock cod *Eliginops maclovinus,* a natural host for *C. rogercresseyi* (Carvajal *et al.,* 1998; González *et al.,* 2000; Boxshall and Bravo, 2000; Bravo, Boxshall and Conroy, 2011). Indeed *C. rogercresseyi* has a broad fish host range and is known to infest a number of other native South American marine fishes, *e.g.* the Patagonian blenny (*Eleginops maclovinus*), the Peruvian silverside smelt (*Odontesthes regia*), the small-eye flounder (*Paralichthys microps*) (Carvajal *et al*., 1998; Boxshall and Bravo, 2000). Of concern is that the rock cod *Eliginops maclovinus* is endemic to southern Chile, southern Argentina and the Falkland Islands and although reports of infestation have not yet been reported on the eastern coast of South America this fish could potentially act as a vector for the rapid dispersal and geographic spread of this parasite.

Figure 6: Incidence of reported *Caligus rogercresseyi* infestations in South America (dotted Lines)

NOTE: *Regions X, XI and XII are important salmonid producing areas (Taken from Bravo, Boxshall and Conroy, 2011).*

Heavy sea lice infestation causes severe skin damage, resulting in chronic osmoregulatory stress, reduced growth and feed-conversion efficiency (González and Carvajal, 2003; Johnson *et al*., 2004; Rozas and Asencio, 2007; Revie *et al*., 2009; Gonzalez *et al*., 2015). The economic burden of this disease is not only due to mortality and reduced marketability from unsightly skin lesions (Costello, 2009; Liu and Bjelland, 2014), but also the high associated costs of therapeutic treatments. Data from Norway estimate that lice parasitism caused losses of US$ 480 million in 2011 (Abolofia *et al.,* 2017).

In addition, the impact of sea lice from salmon farms is well recognised as a hazard to wild anadromous salmonids (Serra-Llinares *et al.,* 2014). Intensively farmed salmon produce huge amounts of planktonic larval stages of lice that spread via water currents; hydrodynamic modelling combined with biological data show that salmon lice can be transported up to 200 km over a 10-d period, although most dispersed 20 –30 km (Asplin *et al.,* 2011; Serra-Llinares *et al.,* 2014). These can infect migrating wild Atlantic salmon post smolts and other susceptible fish species, *i.e*. sea trout (*S. trutta*) and Arctic char (*Salvelinus alpinus*) (Jones and Beamish, 2011). With the expansion of the industry, the risk of wild salmonid population being exposed and infected by salmon lice larvae is greatly increased; it has been estimated in Norway, the largest producer of farmed Atlantic salmon, in 2014 that the worst case releases of larval lice originating from the farmed stocks in Norwegian farms are more than one billion larvae a day (Taranger *et al.,* 2014).

While the Falkland Islands do not have native wild salmonid populations, the potential for lice to affect farmed stock and interact with native marine species remains a valid concern. Given the presence of a known host species and the documented spread of *C. rogercresseyi* into southern Chile, the inclusion of sea lice as a potential risk in the Falklands is justified under a precautionary approach.

Over the years, a range of treatment and preventative measures have been employed to manage sea lice in salmon aquaculture. Historically, chemical treatments were the most widely used—and often the most controversial—approach. In Chile, for example, pharmacological treatments remain the dominant control method, with 7.72 g of medicine prescribed per tonne of harvested salmon in 2021 (Bravo & Treasurer, 2023). These are typically administered via tarpaulins which are placed in-side the cage to form an enclosed water body around the fish. The chemical is then added to the water (usually Hydrogen Peroxide, although many others also exist) and left for a set period. The effect of this is the removal of sea lice but subsequently if the water is not properly oxygenated, high mortalities can be seen in the fish as well. Once finished, the water is then released into the environment (which creates another host of environmental concerns).

A more recent chemical approach involves medicated feed treatments, using compounds such as emamectin benzoate and various flubenzurons (e.g. teflubenzuron, diflubenzuron). These compounds act systemically or interfere with the lice's moulting process.

In response, the industry has increasingly adopted a range of non-chemical sea lice control methods, many of which are now widely used in major salmon-producing countries. Freshwater baths have proven highly effective, particularly in Chile, where a 2023 review reported that this method reduced lice infestation by more than 80% without adverse effects on fish health (Bravo & Treasurer, 2023). These treatments exploit the osmotic stress experienced by sea lice in low-salinity environments, causing them to detach from the host.

Thermal and mechanical delousing systems are also increasingly common (Barrett et al. 2020). Thermal treatments involve briefly exposing fish to warm water (typically 28–34°C), which causes lice to release. Mechanical systems use gentle water jets or brushes to physically remove lice. While effective, these methods must be carefully managed to avoid stress or injury to the fish.

A more recent innovation is the use of laser-based systems, such as the Stingray laser node, which autonomously detects and targets lice on fish in real time. These systems are now widely deployed in Norway as a prophylactic measure, reducing the need for reactive treatments and contributing to long-term lice suppression.

In addition to these active treatments, preventative strategies are also employed. These include the use of physical barriers, such as impermeable skirts around cages, which limit lice exposure by excluding the upper water column where lice larvae are most concentrated. Another increasingly popular method is the use of cleaner fish, such as lumpfish and wrasse, which feed on lice attached to salmon. These biological controls are often integrated into broader lice management strategies.

Collectively, these non-chemical approaches are favoured for their reduced environmental impact and their role in mitigating chemical resistance. However, their effectiveness can vary depending on site conditions, fish size, and lice life stage. As such, they are typically used in combination as part of an integrated pest management strategy tailored to local conditions (Barrett et al., 2020).

A secondary method for the treatment in sea lice is much more recent and uses the addition of chemicals to the feed. These chemicals can vary but include avermectin; emamectin, flubenzurons; teflubenzuron and diflubenzurons and all work in different ways.

All of the above methods are discussed in more detail in the country specific analysis sections further down in this report.

Sea lice

Sea lice is currently one of the main threats to salmon farming with significant environmental and economic concerns resulting from infections. The problem has been experienced in all nations farming salmon and is not limited to specific locations.

The treatment of sea lice has developed greatly in recent years. It commenced with the use of bath style immersions in chemicals but has recently moved more to the use of additives in feed (which is more targeted and less risky for the fish). A growing number of natural treatments are also forming part of best practice guidelines with the use of physical barriers and cleaner fish growing in popularity.

The control of sea lice represents a significant focus point for regulatory systems in key producing nations. In Norway, for example, a traffic light system is being employed which requires the reduction of biomass in areas of high sea lice numbers. Similarly, lower areas can increase biomass accordingly. These, and other best practice approaches are discussed in more detail further down in this report.

3.4. Climate change on disease emergence and spread

In the current times, it is particularly relevant to discuss the impact of global climate change on the salmonid industry.

It is well established that the potential for disease outbreaks within aquaculture production systems can be mediated by changes in global climate patterns (Leung and Bates, 2013). Karvonen *et al.,* (2010) noted that epidemiological issues associated with aquaculture would be exacerbated by climate change and, indeed, extreme weather events have become more frequent since that time and an upsurge in pathogen outbreaks and severe environmental challenges has been reported; increases in sea temperatures and precipitation have favoured the extension of seasonal windows of existing pathogens (Altizier *et al.,* 2006), as well as the introduction of pathogens to new geographical regions by producing environmental conditions that favour certain pathogen growth and transmission (Harvell *et al.,* 2002). A severe Harmful Algal Bloom (HAB) event in the Los Lagos region in Chile in 2016 raised awareness that climate change related sustained elevated sea temperatures and rainfall deficits were affecting salmon productivity and threatening the security of the Chilean salmon sector (Soto *et al.,* 2019).

3.5. Pathogen transfer from farmed salmon to wild fish

For most aquatic animal pathogens, any clear evidence for transmission from farmed to wild fish is limited (Raynard *et al.,* 2007). Most of the diseases currently reported in salmonid aquaculture are enzootic, *i.e.* regularly affecting wild populations in a particular district or at a particular season, suggesting that these infections occur or occurred in the past in wild stocks at undiscernible levels and were transmitted to the farmed population (Taranger *et al.,* 2015). An example is the southern hemisphere sea lice *C. rogercresseyi* who, due to its low host specificity (Carvajal *et al*., 1998), readily infected the first introduced salmonids in Chile by probable transmission from naturally infected native fish species (Carvajal *et al*., 1998). Since then, it has rapidly spread and *C. rogercresseyi* can be found along the southern Pacific coast of Chile (41°S) and was recently reported in the far south (51°S) (Arriagada *et al.,* 2018).

There are, however, two serious and highly impactful cases documented in which exotic pathogens have been introduced due to farming activities, that have impacted wild Atlantic salmon populations in Norway;

1) The ectoparasite *Gyrodactylus salaris* (Monogenea) was first detected in Norway in 1975 (Johnsen *et al.,* 1999) and, by 2005, had been detected in 45 rivers and 39 freshwater farms (Mørk and Hellberg, 2005). A high mortality of Atlantic salmon parr in rivers was reported, with a reduction in numbers 50–99% (Johnsen *et al.,* 1999).

2) *Aeromonas salmonicida*, the causative agent of Furunculosis, was first reported in a single farm in Norway in 1964 that received rainbow trout from Denmark and spread to neighbouring farms and wild fish stocks. Following a second introduction in 1985, connected to an import of Atlantic salmon smolts from Scotland, the disease spread rapidly and in 1992 a total of 550 salmon farms and 74 river systems were affected (Johnsen and Jensen, 1994). Mortality in farmed fish was high, reaching 50%, but the disease was first controlled by antibiotics and subsequently effectively with oil-based vaccines (Sommerset *et al.,* 2005; Johansen, 2013).

Pathogen transfer from farmed to wild salmon

Current scientific evidence suggests that most pathogens reported in farmed salmon actually move from wild populations to farmed populations, rather than the other way around (although a few examples do exist which have been seen from the introduction of farmed species).

Maybe of greater concern, however, is the propensity for farms to act as areas of increased infections which can then promote higher levels in wild populations. It is this effect rather than the risk of introduced diseases being spread directly which provides probably the greatest concern.

3.6. Transboundary aquatic animal diseases

In recent years, reports of previously unreported pathogens causing the introduction of exotic aquatic diseases that have spread rapidly both within countries and across national borders and major aquaculture production losses have emerged (FAO, 2019). This is due to the increase in global trade and movement of live aquatic animals and their products; live aquatic organisms, *e.g.* eggs larvae fry and adults, have become food commodities and, when adequate national biosecurity is missing, pathogens may be transferred simultaneously. These transboundary aquatic animal diseases are usually caused by viruses, however occasionally the causative agent may be a bacterium or a parasite.

The concept of 'biosecurity' is therefore key in the prevention of these disease emergences within the aquaculture industry. A lack of knowledge of pathogens, *i.e.* pathogenicity and transmission routes and their potential susceptible hosts, *i.e.* species, life stages *etc*. is often lacking, as are appropriate diagnostic testing methods for identification. A lack of aquatic animal health management also limits the application of effective biosecurity measures. Risks lie in weak regulatory frameworks, enforcement and implementation of standards at farm, sector and national levels and also insufficient capacity for response to disease emergencies.

3.7. Escaped farmed Atlantic salmon

Fish escapees from farms have historically been a challenge and the salmonid industry was certainly no exception. Unintentional escapement of farmed Atlantic salmon, either through regular, low-level 'leakage' or through major escape events, can occur as a result of mechanical damage to containment units, *e.g.* tears in cages or nets pens due to harsh weather conditions, *e.g.* storms, surges *etc*., predatory marine mammals, *e.g.* seals or otters or simple daily wear and tear. Escapes can also occur during routine husbandry activities or disease treatment procedures, *i.e.* transferring between fish between cages, grading, towing of cages, movement to well boats *etc.* Whilst a decrease in the number of escapees has been observed since the mid-1990s, due to the development of more secure and robust sea pen and cage systems, improved predator control measures and vigilance in husbandry methods, escapes of domesticated Atlantic salmon still represent a threat to the sustainability of the industry and a number of large-scale escape events have been reported in recent years (see **Figs. 7 & 8**).

Country	Company	Year	No. Fish	Cause
Chile	AquaChile	2013	787,929	Damaged cages due to bad weather
Chile	Marine Harvest (MOWI)	2018	680,000	Wind
Norway	Marine Harvest (MOWI)	2005	496,000	Strong wind and electricity
United States	Cypress Island Inc.	1997	369,000	Unknown
Scotland	Meridian Salmon Farms	2011	336,470	High tides
Norway	Sjolaks	2008	307,356	Unknown
Scotland	Scottish Sea Farm	2000	258,000	Weather
Scotland (Shetlands)	Grieg Seafood	2002	238,420	Unknown
Chile	Australis	2016	173,156	Displacement of modules due to strong underwater currents
Norway	SalMar	2011	173,156	Unknown

Figure 7: Largest reported Atlantic salmon escapes worldwide

Source; IntraFish, Feb. 2019; accessed 12/02/2025: https://www.intrafish.com/aquaculture/here-are-the-largest-recorded-farmed-atlantic-salmon-escapes-in-history/2-1-388082

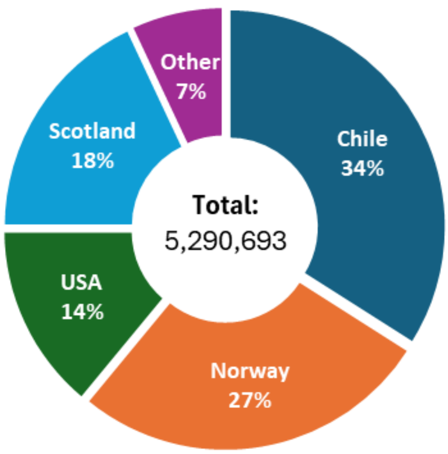

Figure 8: Escape events of over 100,000 farmed salmonids

NOTE: *Chile and Norway account for > 60% of the largest escape events*

Source; IntraFish, Feb. 2019; accessed 12/02/2025: https://www.intrafish.com/aquaculture/here-are-the-largest-recorded-farmed-atlantic-salmon-escapes-in-history/2-1-388082).

From a global perspective, the Atlantic salmon (*S. salar*) is now farmed not only within its native range, *e.g.* northern Europe and eastern North America, but also beyond, *e.g.* western North

America, Chile and Tasmania. There have been documented escapes both in South America (Soto *et al.*, 2001)

Country	Company	Year	No. Fish	Cause
Chile	AquaChile	2013	787,929	Damaged cages due to bad weather
Chile	Marine Harvest (MOWI)	2018	680,000	Wind
Norway	Marine Harvest (MOWI)	2005	496,000	Strong wind and electricity
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Chile	Australis	2016	173,156	Displacement of modules due to strong underwater currents
Norway	SalMar	2011	173,156	Unknown

Figure 7 and on the west coast of North America where, worryingly, Atlantic salmon have been documented in more than 80 rivers in British Columbia and are reproducing in some areas (Volpe *et al.,* 2000).

While these cases have raised concerns, it is important to note that many countries now operate formal monitoring and reporting systems to track and respond to escape events. For example, Norway's Directorate of Fisheries maintains a national escape register[1], requiring mandatory reporting and investigation of all incidents. Scotland publishes escape data through Marine Scotland's aquaculture portal[2], and Chile's Sernapesca enforces reporting and recovery protocols for escapees. These systems support transparency, inform regulatory oversight, and help reduce the frequency and impact of escape events.

Interaction of escapees with native species raises a number of concerns that include competition for habitat and food resources, predation and the introduction and spreading of diseases and parasites (Forseth *et al.,* 2017). Another area for concern is 'biological contamination' or the introduction of exotic or non-native indigenous species into the marine environment, which can displace native species through competition for space and food and introduce new and potentially fatal diseases to endemic populations (Shelton and Rothbard, 2006).

3.7.1 Competition and Genetic Impact

The hybridisation or breeding of escaped farmed stock with indigenous populations of Atlantic salmon is currently of the greatest concern and has been outlined as the most important contemporary challenge to wild salmon populations (Forseth *et al.,* 2017). In Norway it has been

[1] Norwegian Directorate of Fisheries data and statistics on aquaculture: escape incidents
[2] Refer to Aquaculture Scotland for up-to-date escape data

recently documented that 51 of 109 Norwegian Atlantic salmon populations showed significant genetic introgression (the movement of genes from one species to another) from farmed salmon (Karlsson *et al.,* 2016).

Breeding programmes for the domestication of Atlantic salmon was initiated in Norway in the early 1970s and has now approached 15 generations or more for several strains (Gjedrem, 2010). Currently there exists a range of worldwide breeding programmes that expedite improvements of key production traits in Atlantic salmon (Glover *et al.,* 2013; Wringe *et al.,* 2018; Naval-Sanchez *et al.,* 2020). As a consequence, domesticated salmon now display a wide range of phenotype and behavioural differences to wild salmon (Glover *et al.,* 2017) that include disease resistance (Gjedrem *et al*., 2012; Gutierrez *et al.,* 2014, 2016), improved growth rate (Thodesen *et al.,* 1999; Glover *et al.,* 2006, 2009; Solberg *et al.,* 2013a, b), stress tolerance (Solberg *et al.,* 2013a) and behavioural and life history traits, *e.g.* reproductive seasonality (Einum and Fleming, 1997). Results from modelling have indicated that where genetic introgression is high enough, life-history and demographic changes are expected in recipient wild populations (Castellani *et al.,* 2018). Empirical findings from Bolstad *et al.,* (2021) confirm that introgression from farmed salmon significantly affects the full life cycle of wild Atlantic salmon, leading to increased growth, younger age at seaward migration, and earlier maturation. Notably, farmed ancestry was associated with a reduction in smolt age by approximately 0.34 years and an increase in growth at sea by 6%, but these effects varied among populations.

Most concerning is that interbreeding of escapees with wild populations can result in a less genetically variable hybrid population which is maladaptive for life in their natural environment (Ferguson *et al.,* 2007). Bolstad *et al.,* (2021) further demonstrate that farmed introgression accelerates life-history transitions in wild salmon, pushing them toward a "faster pace of life" with earlier reproduction but potentially lower fitness. Despite these significant phenotypic changes, the allele frequencies at key loci controlling age at maturity (vgll3 and six6) showed little response to introgression, indicating that other genetic or environmental factors drive these changes. These impacts of long-term and widespread escapes from aquaculture facilities seen in wild salmon include a lowering of reproduction rates, which cascades into a reduced smolt production and adult returns to the sea (Fleming *et al.,* 2000) as well as reduced sea survival (McGinnity *et al.,* 2003).

While the Falkland Islands currently have no known native populations of Atlantic salmon or other salmonids (noting the presence of the introduced European brown trout), and thus the specific risk of genetic introgression into wild conspecifics is not directly applicable, this does not render the issue irrelevant. Escape events can still pose ecological risks through other mechanisms, including competition with native fish species, predation, habitat disruption, and the potential for disease transmission. Moreover, the introduction of a non-native species—even if not genetically interacting with local fauna—can have cascading effects on food webs and ecosystem dynamics. These broader concerns justify the inclusion of genetic and ecological impact discussions within a precautionary framework.

On the other hand, due to domesticated breeding programs, farmed salmon exhibit significant genetic differences from their wild counterparts, and these differences may impact their survivability in the wild following an escape. Domesticated salmon have been selectively bred for traits that are advantageous in controlled aquaculture environments, such as rapid growth, disease resistance, and stress tolerance. However, these traits may not be beneficial, and can even be detrimental, in the wild (Ford & Myers, 2008). For instance, the rapid growth rate of farmed salmon can lead to increased metabolic demands that are difficult to meet in a natural environment where food resources may not be as abundant or predictable as in a farm setting. Due to continuing reliance and conditioning to consume processed feeds, it is also possible that the ability of farmed salmon to recognise and forage for wild feed sources is reduced compared to their wild counterparts.

Moreover, the reduced genetic variability in farmed salmon populations, resulting from selective breeding, can lead to a lack of adaptability to the diverse and changing conditions of the wild. This reduced genetic diversity can make farmed salmon more susceptible to diseases and environmental stressors that wild salmon are better equipped to handle. Additionally, the behavioural traits of farmed salmon, such as altered reproductive seasonality and reduced predator avoidance (House *et al*., 2010), can further decrease their chances of survival in the wild.

These factors suggest that while farmed salmon may survive following escape, their long-term establishment in the wild is questionable—particularly in regions outside their native range. For example, there are studies that suggest no evidence of self-sustaining Atlantic salmon populations in Chile despite large-scale escapes (Thorstad et al. 2008, Soto et al. 2023). Nonetheless, the ecological implications of escapees—such as competition with native species, trophic disruption, or disease transmission—remain valid concerns in the Falklands context and should be considered in any future risk assessments.

3.7.2 Disease Transmission

A study by Madhun *et al.,* (2015) highlights an increasingly pressing issue in aquaculture: the transmission of disease from escaped farmed salmon to wild populations. While much attention has been given to the genetic consequences of interbreeding between wild and farmed fish, the potential for farmed escapees to act as disease vectors remains underexplored. Research conducted in Norway's Hardangerfjord region found that nearly all examined escapees carried two significant viruses—salmon alphavirus (SAV) and piscine reovirus (PRV). These viruses, associated with serious diseases such as pancreas disease (PD) and heart and skeletal muscle inflammation (HSMI), are widespread in fish farms and could be inadvertently introduced into wild salmon populations through escapees. The detection of infected fish in both fjord and river systems underscores the risks of transmission, raising concerns about the long-term implications for wild salmon health and population stability.

Recent studies have reinforced these concerns. Madhun *et al.,* (2024) examined 567 escaped farmed salmon captured in a Norwegian river over five years, revealing that over 90% were infected with one or more viruses. PRV-1 was the most prevalent, detected in 75.7% of individuals, while SAV and piscine myocarditis virus (PMCV) were also widespread. Notably, fish that had recently escaped showed significantly higher viral loads than those that had spent longer in the wild, suggesting that infected escapees may either succumb to disease or clear infections over time. Additionally, immature escapees had a higher prevalence of PMCV than mature individuals, hinting at a possible link between viral infection and delayed maturation. These findings confirm that farmed escapees represent an ongoing source of infectious agents, posing a continuous risk of disease transmission to wild salmonids and potentially other marine species.

Although the Falkland Islands do not currently host wild Atlantic salmon populations, the risk of disease transmission remains relevant. Escapees may interact with other native or migratory species, and the introduction of novel pathogens into a relatively pristine marine environment could have unpredictable ecological consequences. Furthermore, while the specific pathogens discussed above are most commonly documented in the Northern Hemisphere, their inclusion here serves to illustrate the broader risks associated with intensive aquaculture. In the Southern Hemisphere, Chile provides a more regionally relevant analogue, where similar viral and parasitic challenges have been documented in farmed salmon populations.

One of the greatest challenges in assessing the full impact of farmed escapees on disease transmission is the lack of baseline data on pathogen prevalence in wild fish populations. The presence of virus-infected escapees in rivers, where juvenile wild salmon reside, increases the likelihood of viral shedding into freshwater habitats, potentially compromising wild salmon recruitment and survival. Furthermore, disease transmission is not necessarily confined to interactions between wild and farmed salmon. Research indicates that PRV-infected farmed salmon have been consumed by wild Atlantic cod, highlighting the potential for cross-species transmission. The persistence of these viruses in escapees suggests that, once introduced into wild populations, they could contribute to long-term disease outbreaks, further complicating conservation and management efforts.

The evidence from both past and recent studies underscores the urgent need for stricter biosecurity measures in aquaculture to prevent large-scale escapes and mitigate disease risks. The high prevalence of viral infections in farmed escapees suggests that routine health monitoring should extend beyond farmed populations to include escaped individuals. Additionally, enhanced containment strategies—such as closed-containment systems or improved escape-prevention technologies—could significantly reduce the risk of disease spillover into wild ecosystems. In the Falklands context, where marine ecosystems are relatively undisturbed, the introduction of novel pathogens could have disproportionate impacts. As such, while the specific pathogens discussed may not all be present or likely under current conditions, the broader principle of disease risk from escapees remains valid and should be addressed through precautionary planning, robust monitoring, and adaptive management. Ultimately, addressing the disease risks posed by aquaculture escapees is a crucial component of sustainable fisheries management, requiring continued research, robust regulation, and proactive mitigation strategies to safeguard wild fish populations.

3.7.2 Mitigation Measures

The above discussion is clearly of vital importance to FIG since the introduction of salmon farming to the islands would represent the introduction of a non-native species. As reported, this has been practised in a variety of other countries/regions including Chile and Alaska (to name a few) and the evidence now shows that wild Atlantic salmon populations are present in the environment as the result of escapes. This position has changes somewhat with previous scientific opinion suggesting that Atlantic salmon were unable to survive outside their natural range. It must also be mentioned here that a difference exists between a species being present and breeding freely. Although evidence exists that breeding can occur, it remains the general scientific consensus that although escapees may be able to survive in the wild to some degree, but that active breeding is much less common (although it is acknowledged to occur).

For FIG to agree to the commencement of salmon farming in the Falklands requires the following key points to be fully understood;

1. That they will be introducing a new non-native species to the waters of the Falklands and that despite best efforts, escapes will occur at some point.
2. That the effects of these escapes on the Falklands environment may result in Atlantic salmon populations become established around the islands (either through breeding or simply through survival) and that this may have some direct or in-direct detrimental effects on the environment.

Other than the use of good management practices at the farm level (regular maintenance, etc.) one further option does exist for reducing the risks of escapes in the form of farming sterile fish. While several different sterilisation techniques exist (Güralp et al. 2020), the only commercially available method of producing sterile salmon is to “triploidise” newly fertilised eggs (Golpour et al. 2016).

A triploid fish is one which has three sets of chromosomes rather than the normal two. This is completed by exposing salmon eggs to high pressure. This process prevents early sexual maturation and results in a sterile fish. This sterility is clearly a positive from the perspective of ensuring that salmon escapes do not reproduce. Unfortunately, some evidence of physical deformations have also been linked to the use of triploids (jaw deformities, heart deformities etc.) (Sadler *et al* 2001, Amoroso *et al*. 2016) and they are known to be more sensitive to temperature changes. Moreover, triploid salmon have been found to be more reactive to stimuli, which leads to a higher frequency of injuries such as winter ulcers, particularly when transferred to sea in the autumn[3].

The use of triploid fish is, or has been, a requirement in several countries including Iceland, Scotland, Ireland, Tasmania, Norway and in parts of Newfoundland and Labrador (Kolavani & Nather et al., 2025). In Norway, the Food Safety Authority grants special licences for growth of triploid salmon. These require farm sites to meet temperature and oxygen benchmarks to accommodate for triploids increased sensitivity to high sea temperatures and low oxygen levels. However, despite these regulations, it has been observed that triploid salmon generally exhibit higher rates of mortality, especially during handling and transportation, compared to diploids. They also show increased susceptibility to bacterial infections such as winter-ulcer disease, tenacibaculosis, and infectious salmon anemia (ISA), particularly when exposed to handling stress during colder months[1].

It must also be pointed out that the triploid process is not absolutely 100% successful and so does result in the occasional breeding fish (although numbers are very low).

Very few hatcheries currently produce triploid fish globally and insisting on its use in the Falklands would clearly reduce the chance of escapees forming new populations to very low levels. However, it would also raise welfare concerns about the fish themselves plus the consideration of genetic modification which can be very unpopular with public opinion. Economic evaluations indicate that triploid salmon are economically inferior compared to diploid salmon due to higher mortality rates, lower product quality at harvest, and higher cumulative feed conversion ratios, which increase production costs[1].

Another mitigation strategy used in some aquaculture systems is the cultivation of all-female stocks. All-female salmon populations are used in aquaculture, but they are not universally standard across the industry. All-female populations are typically produced through hormonal feminisation of genetic males, followed by breeding with normal females. Their use is more common in certain contexts, particularly where early maturation in males is a concern (as it can reduce growth rates and product quality), reproductive containment is desired, especially in freshwater or closed systems, and/or where triploidy is being applied, since triploid females tend to perform better than triploid males. Their use is more prevalent in freshwater hatcheries and less common in marine grow-out phases, unless combined with sterility measures. The technique is well-established but not ubiquitous, and its adoption varies by country, company, and production system. This approach reduces the likelihood of successful reproduction in the wild. While not a guarantee of sterility, all-female stocks can further reduce the ecological risk posed by escapees, especially in environments where the establishment of a breeding population is a concern.

In addition to biological controls, technical standards play a critical role in reducing escape risk. For example, Norway's NS 9415:2021 standard sets out detailed requirements for the design, installation, and operation of floating aquaculture facilities. It includes specifications for mooring systems, net strength, and site-specific environmental assessments. The implementation of this standard has been associated with a measurable reduction in escape incidents in Norwegian aquaculture and is widely regarded as a best-practice benchmark internationally.

Farmed Salmon Escapes

All farms at some point will experience escape events, and for the FIG this is a vital consideration given that Atlantic salmon is not native to the Falkland Islands. Evidence from other countries shows that escaped Atlantic salmon can survive in the wild (and in some cases breed) but there is

[3] https://www.hi.no/templates/reporteditor/report-pdf?id=69769&72467649

limited evidence of escapes establishing self-sustaining populations outside their native range. That said, the ecological implications of escapees—such as competition with native species, habitat disruption, or disease transmission—remain valid concerns.

The likelihood of colonisation appears to be low, as supported by studies in Chile and elsewhere, but the potential consequences of even low-probability events in a relatively pristine ecosystem warrant careful consideration. One option to mitigate this risk is the use of triploid (sterile) fish, though this approach has trade-offs in terms of sourcing and performance. Additionally, while containment technologies have improved, escape events still occur in all major producing countries. This highlights the importance of robust containment systems, monitoring, and contingency planning.

It is our opinion that this represents one of the main areas for further discussion by the FIG and a significant point of concern for future salmon farming operations in the islands. However, the decision on how to manage the risk of escapes—and whether to permit farming of a non-native species—ultimately rests with FIG. A detailed risk assessment is recommended as part of any future regulatory framework, in line with the precautionary principle.

3.8. Wildlife Interactions

The rapid expansion of the marine finfish aquaculture industry over the past 30 years has led to increasing interactions and conflicts with marine mammals, birds, and fish. Predatory species, particularly pinnipeds (seals), often damage aquaculture infrastructure by tearing nets, which can result in large-scale fish escapes, and directly prey on fish within enclosures (seal strikes) (Northridge *et al*., 2013; Quick *et al*., 2004). More broadly, aquaculture alters the behaviour and distribution of marine wildlife—while some species benefit from increased food availability and habitat structures, others face risks such as entanglement, displacement, and disrupted feeding patterns. As the industry continues to grow, understanding and mitigating these interactions is essential for balancing economic interests with environmental sustainability.

3.8.1 Effects on marine mammals

Fish farming has both positive and negative impacts on mammals, particularly marine mammals such as dolphins, seals, and sea lions (see Callier *et al.,* 2017 and references therein). One of the primary positive effects is the increased availability of food, as waste feed and attracted fish species around aquaculture structures become an easy source of nutrition. For example, bottlenose dolphins in Italy have been observed to adapt their foraging strategies to exploit dense prey aggregations near fish farms. Similarly, seals and sea lions are frequently seen around aquaculture sites, exploiting both the farmed fish and waste as food. This increase in food availability can sometimes lead to changes in mammalian behaviour and social structures, as seen with dolphins modifying their hunting techniques to suit the new feeding opportunities.

However, fish farming operations do also pose documented risks to mammals. Noise from farm operations, including feeding, boating, and the use of Acoustic Harassment Devices (AHDs), can disrupt natural behaviours and displace non-target species, such as porpoises and killer whales, from their natural habitats. Similarly, light pollution and broader habitat disturbances associated with aquaculture infrastructure can alter migration patterns and impact the overall health and fitness of mammal populations (see Callier *et al.,* 2017 and references therein).

Anti-predator netting, designed to keep seals and other marine predators away from fish cages, can pose a serious entanglement hazard for marine mammals, particularly when netting is not properly tensioned (i.e., kept taut). Entanglements can lead to injuries or fatalities, highlighting the need for effective management practices. Although these incidents are relatively rare, entanglement events have been documented in aquaculture regions such as British Columbia, Chile, and Tasmania

(Storlund et al., 2024; Espinosa-Miranda et al., 2020; Groom & Coughran, 2012). Documented cases include entanglements of sea lions in Chile (Espinosa-Miranda et al., 2020), fur seals in Tasmania (Groom & Coughran, 2012), and humpback whales in British Columbia (Storlund et al., 2024). Furthermore, light pollution and habitat disruption caused by fish farms can alter migration patterns and impact the overall health and fitness of mammal populations (see Callier *et al.,* 2017 and references therein).

Fish farms in British Columbia have had a limited but notable impact on humpback whales, primarily through entanglement in aquaculture gear. Between 2008 and 2021, eight incidents involving young humpbacks—mostly subadults—were recorded, with three resulting in fatalities and five requiring human intervention for release. Whales were typically caught in predator nets or anchor support lines, often at fallowed farms and during off-peak seasons like late autumn and winter. These interactions likely stem from overlapping habitats and seasonal shifts in whale foraging behaviour, particularly when prey like herring move closer to shore. While overall numbers are low, improved farm design and rapid response protocols are key to minimising future risks (Storlund et al. 2024).

Mitigation Measures and Their Effectiveness

In order to mitigate these problem interactions, different predator control measures have been used that include lethal methods such as shooting individuals, *i.e.* sea lions in Chile (Gaitán-Espitia *et al.,* 2017) or culling programmes, as well as the use of non-lethal deterrence devices such as physical barriers (secondary nets placed around the cages) and Acoustic deterrent devices (ADDs, also known as AHDs)) (Quick *et al.,* 2004).

Whilst non-lethal approaches are preferred, they can also have an impact on local wildlife; additional nets can cause unintentional death by entrapment (Tecklin, 2016). ADDs are used to mitigate seal depredation on aquaculture sites, a particular problem in the cage based Atlantic salmon industry, through the emission of loud and pervasive noise within the hearing range of the target species (pinniped underwater hearing range 50 Hz to 86 kHz; National Marine Fisheries Service, 2016), with the aim of deterring them from approaching and damaging the pens or the fish themselves (Coram *et al.,* 2014; Götz and Janik, 2013; Jacobs and Terhune, 2002; Quick *et al.,* 2004). In Scotland, they were first introduced in the mid-1980s (Coram *et al.,* 2014) and a widespread uptake of ADDS was seen in the 1990s; they were reported to be used at 52% of 195 aquaculture sites in 2001 (Quick *et al.,* 2004). They are deployed underwater, attached to the cages, and can run continuously or only at times when seals are observed close to the nets (Northridge *et al.,* 2013), however data suggests that ADDs are a chronic and widespread source of underwater noise pollution as their frequency ranges have the potential to cause physical harm and behavioural effects on foraging, resting and reproductive behaviour on both target and non –target species (Brandt *et al.,* 2013; Coram *et al.,* 2014; Harris *et al.,* 2014; Morton and Symonds, 2002; Findlay *et al.,* 2018).

Negative Predator Impacts

Seals, penguins and dolphins are all naturally attracted to salmon farming cages as it offers a source of available food. This can result in damage to cages and resulting escapes. To control this, a variety of methods have been used including lethal control, additional netting and acoustic deterrents.

Current best practices have greatly reduced the need for large scale lethal control, but it is still often required in most farms at some point (and is allowed in all regulatory systems in the world albeit with strict controls and licensing).

Predator interaction and control is likely to be a similar concern in the Falklands and so will need careful consideration.

3.8.2 Effects on birds

Seabirds interact with aquaculture in a variety of ways, with some species benefiting while others are negatively impacted. Birds are often attracted to salmon farms due to the increased availability of food sources, including uneaten feed, farmed fish, and wild fish that aggregate around the cages. This attraction is particularly evident in omnivorous diving birds and carrion feeders, whose populations can be significantly higher around farm sites compared to non-farm areas. For instance, studies conducted in Chile have shown that the abundance of such birds can be two to five times greater in areas with salmon farms. Additionally, the physical structures of the farms, such as net cages and protective coverings, provide novel roosting and perching opportunities, making these sites attractive resting and hunting grounds for predatory birds like bald eagles and ospreys. Night-time lighting used in farming operations can further increase bird presence, particularly attracting nocturnal species to the illuminated areas (see Callier *et al.,* 2017 and references therein).

However, salmon farms can also pose significant risks to bird populations. Some seabird colonies or feeding areas may be displaced or disrupted due to changes in benthic conditions or increased human activity around farm sites. Furthermore, anti-predator measures, such as netting designed to protect farmed fish from avian predation, can inadvertently cause harm to birds. Instances of birds becoming entangled and dying in these protective nets have been reported, raising concerns about the conservation impact of such practices. Noise and human disturbances from routine farm operations may also deter some bird species from using these areas for roosting or feeding. Consequently, while salmon farms may enhance local bird abundance by offering food and habitat, they can also lead to mortality and displacement, highlighting the need for careful management to mitigate negative impacts (see Callier *et al.,* 2017 and references therein).

3.8.3 Effects on commercially fished species

Fish farms dramatically alter the local marine environment, often attracting a wide variety of wild fish species. The main reason for this attraction is the availability of food. Uneaten fish feed, faeces, and biofouling organisms on aquaculture structures provide an easy meal for opportunistic species, leading to an increase in fish abundance around farms. Numerous studies have documented how wild fish biomass is significantly higher in the vicinity of aquaculture sites compared to surrounding waters. Some researchers have even suggested that fish farms could be managed similarly to marine protected areas, as they serve as de facto refuges where fish populations can grow due to the trophic subsidy provided by waste feed (see Callier *et al.,* 2017 and references therein).

While fish farms provide a temporary feeding ground, they may also alter fish behaviour and migration patterns. Many species develop a dependence on farm waste, meaning their movements are no longer dictated by natural feeding cycles. Some studies indicate that fish aggregating around farms may experience improved growth rates due to the high-calorie feed, but their nutritional quality can change. For instance, fish that consume aquaculture waste often develop different fatty acid compositions compared to their wild counterparts, which could have implications for their health and reproductive success. In cod, for example, changes in fatty acid intake can influence gamete quality, potentially reducing fertilisation success and larval viability. Furthermore, cod that spend prolonged periods around farms may develop enlarged livers due to lipid accumulation, which, while providing an energy reserve, could also interfere with metabolic regulation and overall health (Bøhn *et al.,* 2024). Additionally, the seasonal nature of fish farming means that these aggregations can suddenly disappear when feeding stops, potentially leaving dependent fish without an immediate food source (see Callier *et al.,* 2017 and references therein). This abrupt loss of trophic support may be particularly concerning for resident species like Norwegian coastal cod, which are already experiencing population declines (Bøhn *et al.,* 2024).

Fish farms also influence predator-prey dynamics. By attracting large numbers of wild fish, they, in turn, draw in predators such as tuna, sharks, and larger gadoid fish. In some cases, this secondary attraction can lead to changes in local fisheries, as fish populations become more concentrated in areas around farms, making them more vulnerable to commercial and recreational fishing. Some studies suggest that fish caught near farms show clear dietary shifts, with their stomach contents reflecting a diet rich in aquaculture waste rather than natural prey. This raises concerns that farm-associated fish may become less adept at foraging in the wild, making them more vulnerable to environmental changes or reductions in aquaculture activity. Cod populations, for instance, could see declines in recruitment if juveniles fail to transition back to natural feeding habits after prolonged exposure to farm waste. Additionally, by altering the distribution of prey species, salmon farms may unintentionally disrupt broader food web dynamics, affecting the availability of natural forage for other commercially important species (Bøhn *et al.,* 2024).

This raises questions about whether aquaculture creates ecological traps. The concept of ecological traps—where wild fish are attracted to aquaculture sites due to food availability but may become more vulnerable to predation or fishing—is a recognised hypothesis in ecological literature (Callier et al., 2017). While this remains a debated and context-specific concept, it is not without empirical support. In the case of the Falkland Islands, we acknowledge that the current species composition, ecological setting, and fishing practices suggest a low probability that aquaculture would create ecological traps for commercially important wild fish. However, given the novelty of aquaculture in the region and the potential for future changes in scale or practice, we consider it appropriate to include this concept as a theoretical consideration. Its relevance should be assessed through targeted monitoring and adaptive management, in line with precautionary principles.

3.8.4 Potential impact on the Falkland Islands

The Falkland Islands support a rich and diverse array of wildlife[4], both on land and in the surrounding waters. The islands are home to an impressive variety of marine mammals, including southern elephant seals, South American sea lions, fur seals, and dolphins such as Peale's and Commerson's dolphins. Orcas are frequently seen during the elephant seal breeding season, while sei whales and other large whale species migrate through offshore waters in late summer and autumn. Pinnipeds follow distinct breeding cycles, hauling out seasonally, with elephant seals and sea lions occupying key coastal areas.

It is important to acknowledge that the fisheries sector is a key contributor to the Gross Domestic Product (GDP) of the Falklands and represents a significant source of income/employment for local people. The primary targets of the Falkland fishery include the Patagonian toothfish (*Dissostichus eleginoides*) and squid (*Doryteuthis gahi*, formerly recognised as *Loligo dahi*), as well as several other finfish species). While direct interactions between salmonids and squid – or indeed their eggs – are not well documented, it can be said that salmon are opportunistic feeders, preying on a variety of smaller animals, including small fish, crustaceans, and squid (NOAA, n.d.). For example, Chinook and Coho salmon reportedly consume large volumes of *L. opalescens* off the coast of North America when they are available (Fields, 1965; Morejohn, 1978). It is therefore plausible that farmed Atlantic salmon may consume squid and/or their eggs if they encounter them during their oceanic phase (i.e., those being raised in cage nets). This is more likely to occur in areas where squid spawn in large aggregations, as seen in the waters of the Falkland Islands.

It must be stated that the likelihood of significant predation on squid eggs by escaped salmon is currently unknown, and may be low, particularly given the limited survival of escapees in the wild (see Section 3.7.1). Nevertheless, due to the ecological and economic importance of *D. gahi*, it is again appropriate to consider this as a theoretical interaction under the precautionary principle. The potential for such interactions, while speculative, warrants consideration in future monitoring and research. At present, the extent and ecological implications of any such interactions are unclear (see

[4] Birds of the Falklands – Falklands Nature

Callier *et al.,* 2017 and references therein). However, current knowledge on this particular topic can be presented as follows:

- The egg capsules of *D. gahi* consist of two gelatinous layers, with the outer layer acting as a protective measure against predation. Although there is no documented evidence of salmon preying on squid eggs, the patchy distribution of egg masses, identified by Arkhipkin et al. (2000), suggests an adaptive strategy to increase the survival chances of these eggs in the variable environment of the Falklands. This patchy distribution could limit the damage caused by escaped salmon, as even if they predate on some eggs, it is unlikely to wipe out an entire fishing season. However, as escaped salmon can cover more ground than native inshore species, this potentially increases their chances of encountering egg masses. On the contrary, escapees may also have a genetic predisposition that hinders their ability to recognise and predate on naturally occurring feed sources such as squid, as discussed in Section 3.7.1.
- It is worth noting that there is a lack of egg masses found in certain areas of the Falklands, such as the central part of Falkland Sound, where salmon pen development has been identified as a suitable location for development, further diminishing the likelihood of escapees encountering egg masses. However, the spatial and interannual variability of egg mass distribution means that the absence of eggs in Falkland Sound does not guarantee they do not spawn there. For example, whilst a survey conducted in 1999 found no evidence of egg masses in the central part of Falkland Sound (Arkhipkin et al., 2000), more recent surveys have found egg masses in nearby Berkley Sound (van de Grient et al., 2023). This appears to indicate variability in spawning locations, suggesting that salmon escapees could impact squid populations if they encounter egg masses.

- The role of *D. gahi* in the Falkland Shelf ecosystem is crucial, as it occupies a central position in the food web, being both a predator and prey. Potential salmon escapees, classified under the "pelagic fish" functional group, could negatively affect *D. gahi* populations, in much the same manner as other pelagic fish.

- Outwith the interactions of squid and salmon directly, studies to evaluate the interactions of squid with fish farms are similarly limited. However, it is possible that the use of artificial lighting in aquaculture may play a significant role in influencing squid behaviour. Squid are known to be attracted to light, a method exploited in commercial fisheries, and similar responses may occur around illuminated fish farms. This raises questions about whether fish farm lighting unintentionally alters the distribution of squid, their feeding patterns, or their visibility to other predators.

For anglers, the European brown trout (*Salmo trutta*) offers recreational opportunities and economic benefits. Brown trout were introduced in the mid-20th century for recreational fishing and have since spread extensively, exerting their own impacts on native species like zebra trout (*Aplochiton zebra*) and Falklands minnow (*Galaxias maculatus*). Due to their ability to navigate both freshwater and marine environments, the containment of this non-native species has been difficult and resulted in the naturalisation of the species in rivers of the Falkland Islands. This has led to a significant decline in native fish populations, reducing the likelihood of finding native galaxiids in these streams (Minett 2022). Nonetheless, brown trout are now highly prized by anglers in the Falklands and are an important part of the national economy. To this end, the potential development of fish farms in the Falkland Islands adds another layer of complexity and the impacts of farmed salmon on 'local' brown trout merit discussion.

Fish farming can exacerbate the spread of invasive species through escapes and untreated waste discharge, impacting local habitats. Additionally, salmon farms can introduce diseases and parasites, such as salmon lice, which can affect wild brown trout populations. For example, the Norwegian

Institute for Nature Research highlighted that salmon farming significantly increases the abundance of salmon lice, which attach to wild fish like brown trout, causing stress, reduced growth, and increased mortality (Thorstad & Finstad, 2018). While the specific species of sea lice and salmonids referenced in this literature are not native to the Southern Hemisphere, the underlying mechanisms of parasite amplification and transmission remain ecologically relevant. In Chile, for example, *C. rogercresseyi* is a major concern in salmon aquaculture, and its presence demonstrates that lice-related risks are not limited to the Northern Hemisphere.

In the Falklands context, the presence of naturalised brown trout suggests that parasite transmission from farmed salmon to wild salmonids could be a potential concern, though the likelihood and severity of such impacts remain uncertain and would depend on local environmental conditions, the parasite species involved, and farm management practices. Evidence from regions with intensive salmon farming shows that higher lice loads in wild fish can lead to ecological and economic consequences, such as reduced fish stocks and fewer opportunities for fisheries. That said, a variety of mitigation measures are available and increasingly used, including improved farm management, physical barriers, and selective breeding of lice-resistant salmon (Thorstad and Finstad 2018) (see also Section 3.3).

Alongside its marine life, the Falklands are a haven for bird species, with around 213 recorded, including 55 resident breeders, summer visitors, and numerous transient and vagrant species. The islands host two endemic species—the flightless Falkland Steamer Duck and Cobb's Wren, which survives only on predator-free islands. Additionally, 14 endemic subspecies, such as the Upland Goose and Black-throated Finch, contribute to the region's unique biodiversity. The Falklands are a crucial breeding ground for five species of penguins—Gentoo, Rockhopper, Magellanic, King, and Macaroni—while the Black-browed Albatross, with over 80% of its global population nesting here, is another iconic resident. Despite this abundance, some species face conservation challenges, with 14 classified as globally threatened by the IUCN.

However, as human activities expand, including the potential development of aquaculture, concerns are growing over its impact on both marine and bird species. Increased coastal activity, underwater noise pollution, and entanglement risks in nets and mooring systems could disrupt marine mammals such as dolphins and seals, while fish farms may attract predatory seabirds, increasing the risk of entrapment or disturbance. As the industry develops, careful management will be essential to balance economic growth with the protection of the Falklands' unique and fragile ecosystems.

3.9. Use of Fishmeal and Fish oil

Global non-fed aquaculture production has shown a clear downward trend over the last 20 years and now fed aquaculture production has outpaced the non-fed subsector in world aquaculture; (FAO, 2020). Intensively farmed salmonids rely entirely on industrially compounded aquafeeds, in the form of pellets at the marine on-growing phase, for their provision and supply of nutrients.

Energy, protein, and lipids in aquafeeds can be derived from crops and crop by-products, wild fisheries, *i.e.* forage fish, and fish and livestock processing by-products from the processing of fishery products for human consumption (Naylor *et al*., 2009). Atlantic salmon are carnivores and have a dependency and a high requirement for fish meal and fish oil in their diet. It is this reliance on fish meal and fish oil and the consequences for wild fish stocks that has received the most attention in recent years (Ytrestoyl, Aas and Asgard, 2015) and is often used as an argument against the sustainability of salmon production, *e.g.* Duetch *et al.,* 2007; Naylor *et al.,* 2000; Tacon and Metian, 2008.

As the global salmon industry has grown, the demand for fish meal and fish oil has increased concomitantly. The availability of small pelagic fish for aquafeeds, at prices that allow the feed industry to remain economically viable, has declined as many stocks are still overexploited and as more fish are consumed directly by humans for nutrition and pharmaceutical purposes (Ytrestoyl *et al.,* 2015). As a result, the use of fish processing wastes as a prime ingredient in aquafeeds is becoming more prevalent and will be a critical factor in augmenting net food supplies from aquaculture (Klinger and Naylor, 2012; Troell *et al.,* 2014; Ytrestoyl *et al.,* 2015). In addition, in order to reduce the components of marine origin (fish meal and fish oil) in salmonid aquafeeds, significant progress has been made in recent years identifying alternatives, *i.e*. products of plant origin and/or by-products of insect origin (Rumpold and Schluter, 2013; Shephard *et al.,* 2017).

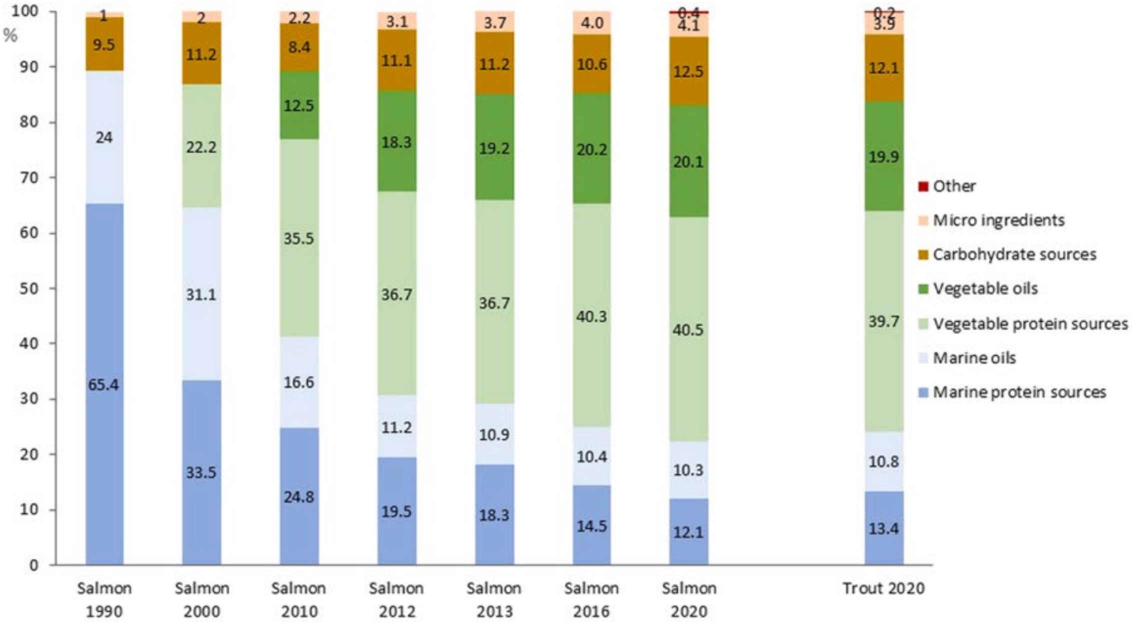

Figure 9: Sources of feed ingredients (% of feed) in Norwegian salmon farming compared to Norwegian trout from 1990 to 2020.

Source: *Ytrestoyl, Aas and Asgard, 2015, Aas et al., 2022.*

As the global salmon industry has grown, the demand for fish meal and fish oil has increased concomitantly. The availability of small pelagic fish for aquafeeds, at prices that allow the feed industry to remain economically viable, has declined as many stocks are still overexploited and as more fish are consumed directly by humans for nutrition and pharmaceutical purposes (Ytrestoyl *et al.,* 2015). As a result, the use of fish processing wastes as a prime ingredient in aquafeeds is becoming more prevalent and will be a critical factor in augmenting net food supplies from aquaculture (Klinger and Naylor, 2012; Troell *et al.,* 2014; Ytrestoyl *et al.,* 2015). In addition, in order to reduce the components of marine origin (fish meal and fish oil) in salmonid aquafeeds, significant progress has been made in recent years identifying alternatives, *i.e*. products of plant origin and/or by-products of insect origin (Rumpold and Schluter, 2013; Shephard *et al.,* 2017).

It is clear that salmon feed composition has changed considerably during the relatively short history of intensive salmon farming; in 1990 around 65% of Norwegian salmon aquafeed was composed of ingredients of marine origin, whereas in 2020 it had reduced to *c*. 12% (Figure 9). However, there are a number of caveats; not only may worldwide supplies of crop based feeds be threatened in the future due to changing climactic conditions (Troel *et al.,* 2014) but also the use of vegetable alternatives to replace marine based-protein sources could alternatively be used as high-grade food for human consumption (Troell *et al.,* 2014; Troell *et al.,* 2015; Cashion *et al.,* 2017; Fry *et al*., 2018). A further concern is the fact that, by replacing the marine components of the salmon feed with terrestrial products, the content of omega-3 fatty acids, notably eicosapentaenoic acid [EPA; 20:5n-3] and docosahexaenoic acid [DHA; 22:6n-3] in salmon may be reduced (Sprague *et al.,* 2016). This could have an important negative impact as neither humans nor salmon can synthesize omega-3 fatty acids and therefore must obtain them from their diet (Cadillo-Benalcazar *et al.,* 2020).

One promising approach to address these challenges is the exploration of alternative feed resources that do not compete directly with human food sources while maintaining the nutritional quality of salmon. Low-trophic marine species, such as mesopelagic fish, krill and marine copepods, offer substantial potential as sustainable feed ingredients, given their high protein and omega-3 fatty acid content. Additionally, microbial ingredients like yeast, bacteria and microalgae are emerging as viable options due to their rapid growth rates, low carbon footprints and ability to utilise waste streams as feedstocks. Insects and animal by-products, including poultry and hydrolysed feather meals, are also being investigated for their nutritional profiles and cost-effectiveness. However, the successful incorporation of these novel ingredients into salmon diets requires overcoming technical challenges related to nutrient digestibility, anti-nutritional factors and consumer acceptance. To ensure that the nutritional profile of farmed salmon remains optimal, it is crucial to focus on refining processing methods, enhancing digestibility and integrating a variety of feed sources to balance the essential omega-3 content (Albrektsen et al. 2022).

Sustainable Fish feeds

The salmon farming sector has made great strides in reducing its reliance on fishmeal and fish oil over the past two decades, but concerns do exist over its sourcing and indeed the sourcing of its substitutes (from a sustainability perspective).

The issue of feed is not readily one that is addressed through regulation and is more the responsibility of sustainable certification initiatives which are discussed further on in this report.

3.10. Effects of Associated Wastes on the Marine Environment

As has already been discussed, salmonid farming is an intensive monoculture system and farmed salmonids are wholly dependent on the input of external feed (Folke, Kautsky and Troell, 1994) which, in open sea cages, will result in the release of organic and inorganic effluents, in the form of waste feed, faeces and metabolic by-products, directly into the surrounding aquatic marine environment without any form of treatment or recycling. (Carroll *et al.,* 2003; Holmer *et al.,* 2005; Strain and Hargrave, 2005). With the historical, exponential growth of the salmonid industry, there has been an increased awareness of the risks associated with increased discharges of wastes originating from salmon farms and a higher scrutiny of their environmental impacts (Taranger *et al*., 2021a).

The extent of nutrient enrichment and eutrophication is dependent on a number of factors, *i.e.* the size of the farm and fish biomass, the ambient environmental conditions, *i.e*. existing hydrodynamics (current velocities), water depth, wave exposure, topography and substrate type, as well as husbandry and management practices of the individual site (Holmer *et al.,* 2005; Carvajalino-Fernandez *et al.,* 2020).

3.10.1 Inorganic Waste

Salmonids are carnivorous fish and are fed a protein-rich diet hence they excrete large amounts of dissolved metabolic by products mainly from their gills into the environment, in the form of dissolved inorganic nitrogen (DIN), i.e. NH_3^{+} (ammonia) and dissolved inorganic phosphorus (DIP), i.e. PO_4^{3-} (phosphate) and dissolved inorganic carbon (DIC) as CO_2 through respiration (Wang *et al*., 2012) (Figure 10). These different nutrient components have the potential to influence different parts of the marine ecosystem, however the potential impact of inorganic or dissolved waste generated by fish farms is difficult to determine because of dilution and uptake by microorganisms in the water column (Quinones *et al*., 2019).

Excess dissolved nitrogen and phosphorus can disrupt natural nutrient balances and contribute to eutrophication, promoting excessive algal growth and reducing oxygen levels in the water. The N:P ratio, which is crucial for maintaining ecological stability, can become skewed due to fish farming inputs, potentially favouring harmful algal species over those that support higher levels of marine biodiversity. Elevated levels of DIC from fish respiration may also contribute to shifts in ocean acidification, particularly in enclosed or poorly flushed environments where CO_2 accumulates rather than dispersing into the atmosphere (see Elvines *et al.,* 2023 and references therein).

In addition to dissolved nutrients, trace metals originating from fish feed and antifouling treatments on nets pose another environmental risk. Copper (Cu) and zinc (Zn), used in antifouling coatings, accumulate in sediments beneath fish farms. While these metals are essential in small amounts, their excessive concentrations can be toxic to benthic organisms, altering community structures and affecting sediment biogeochemistry. Furthermore, cadmium (Cd) and uranium (U), sometimes present in fish feed, have been found to bioaccumulate in marine food webs, posing potential risks to higher trophic levels, including commercially important fish species and human consumers (see Elvines *et al.,* 2023 and references therein).

The extent to which inorganic waste spreads is largely influenced by hydrodynamic conditions. In high-energy coastal environments, dissolved nutrients and trace metals are dispersed more effectively, reducing the risk of localised accumulation. However, in more enclosed areas, these substances can build up over time, leading to long-term contamination of sediments. Scientists use stable isotopes (δ15N, δ13C) and elemental tracers (Zn, Cu, P) to monitor these changes, allowing for a clearer understanding of how fish farm waste interacts with the marine environment. Research suggests that traditional monitoring methods often underestimate the true dispersal footprint of fish farm waste, with some elements detectable well beyond farm boundaries (see Elvines *et al.,* 2023 and references therein).

3.10.2 Organic Waste

The particulate fraction of the waste generated from salmon cages or Particulate Organic Matter (POM) is considered the largest source of negative impact upon the neighbouring benthic (the lowest level of a body of water such as the sea bed) communities at aquaculture sites, with up to 70–80% in the form of faecal material (Cubillo *et al*., 2016; Riera *et al*., 2017). Sedimentation of waste products can result in increased sediment organic matter (OM), i.e. particulate organic carbon (POC), particulate organic nitrogen (PON), particulate organic phosphorus (POP) (Wang *et al*., 2012). Dissolved organic C, N and P (DOC, DON and DOP, respectively) are generated through dissolution of particulate organic fractions (Olsen & Olsen 2008; Wang *et al*., 2012) (Figure 10). In addition, dissolved 'free' pore water sulphides (Σ S2–, HS^- and H_2S) (S), particulate acid-volatile sulphides (AVS) and bottom coverage by white sulphur bacterial (Beggiatoa spp.) mats (Hargrave, 2010) will result in the generation of hypoxic (a deficiency of oxygen), anoxic (an absence of oxygen) or, potentially, azoic (devoid of life) conditions in areas that are in close proximity to the farm (Brooks *et al*., 2002; Hall-Spencer and Bamber, 2007; Keeley *et al*., 2012) in which macrofauna cannot survive (Haya *et al*., 2001).

In recent years there has seen a movement of salmon fish farms to more dispersive locations which results in a greater horizontal transport of POM thus widening the potential zone of impact (Broch *et al*., 2017). However, while this approach mitigates some immediate seabed effects, it widens the overall footprint of fish farm waste, potentially affecting marine ecosystems at greater distances. Research using biochemical tracers, including fatty acids and stable isotopes (δ13C, δ15N), has demonstrated that fish farm-derived waste can be detected hundreds of metres beyond farm boundaries. These tools have also revealed how waste enters local food webs, providing energy subsidies to filter feeders, scavengers, and detritivores. While some organisms benefit from this additional food source, excessive organic inputs can disrupt natural ecological balances, favouring opportunistic species at the expense of more sensitive marine life (see Elvines *et al.,* 2023 and references therein).

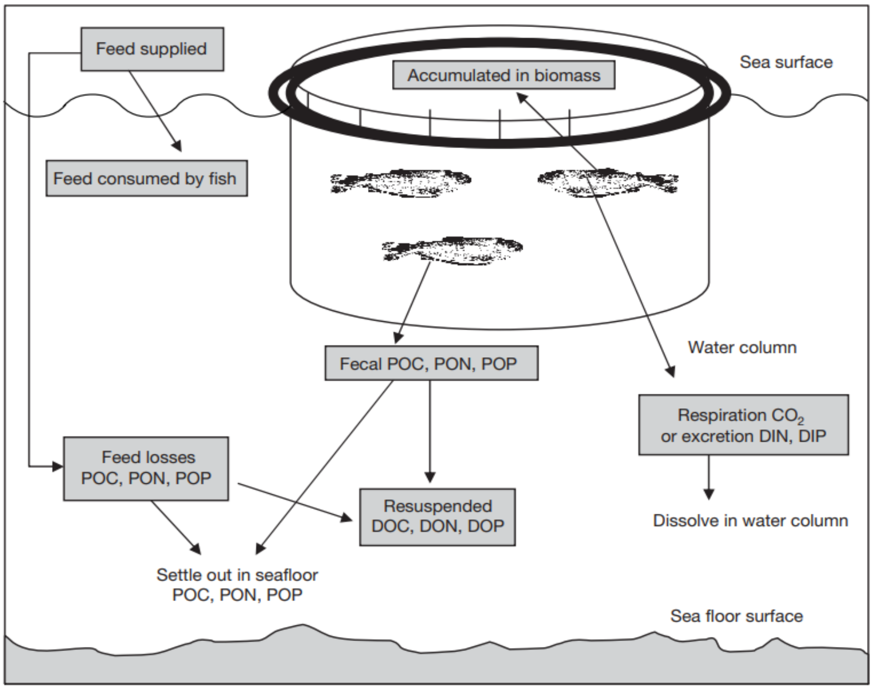

Figure 10: The flow and fate of nutrient components from a salmon cage system

3.10.2 Effects of chemical discharge from salmon farms

Infections by bacteria, parasites, fungi and viruses are frequent causes of morbidity and mortality in salmon aquaculture with important negative effects on production and profit (Dresdner *et al*., 2019). (See Section 3.1.1. Infectious Diseases). As is the case in any intensive animal food production system, it is often necessary to treat farmed salmon against diseases.

It would be true to say that aquaculture management practices have evolved over the past 20 years, and fish husbandry has greatly improved, resulting in a reduction in the use of some chemicals, particularly the use of antibiotics in most jurisdictions (See Section 3.1.5.2. Antibiotics), however, the industry still relies on the use of chemo-therapeutants to combat bacterial infections and infestations of ectoparasites as well as disinfectants to manage the spread of diseases (Haya *et al*., 2005).

Disease management of salmonid production systems will result in the release of chemical inputs to the surrounding aquatic marine environment and those issues of most concern will be discussed below.

3.10.3 Parasiticides

Parasitic diseases have been a serious problem for salmon aquaculture industries for a number of years, especially infestation by sea lice.

Compounds used to treat infestations of sea lice are applied under veterinary prescription and are, as discussed above, ultimately released to the aquatic environment. These chemical parasiticides have historically been identified as a major environmental concern (Nash, 2003). The classes of therapeutants currently used to combat sea lice infestations include avermectins, pyrethroids, hydrogen peroxide and organophosphates (Haya *et al*., 2005; Bravo *et al*., 2005; Lees *et al*., 2008). These compounds may be classified into two groups based on their route of administration, bath treatments, i.e. pyrethroids, hydrogen peroxide and organophosphates and in-feed additives, i.e. avermectins (Burridge *et al*., 2010).

In general, anti-lice treatments lack specificity and have the potential to negatively impact sensitive non-target organisms, specifically crustaceans, by altering the population structure within the immediate surroundings (Johnson *et al*., 2004). Of further concern is that historically sea lice have shown a remarkable adaptability to develop resistance to chemical treatments; it can take only a few years for evidence of resistance to appear following a new treatment with a new chemical. One solution has been to switch between different treatments methods, but the problem of resistance seems to be hard to overcome, and multi-resistance has emerged rendering them useless. The treatment of the sea lice problems also involves costs to the industry; Abolofia *et al.,* (2017) estimated that the cost of sea lice treatment constituted production costs ranging from 0.12 to 0.67 US$/kg, or in the range of 2.27 to 13.10% of yearly revenues.

However, due to the development of resistance, the way in which parasitic infections, including sea lice and amoebic gill disease (AGD) has changed and there has been a significant decrease in the use of chemical parasiticides in the salmon industry. Although the development of vaccines against commonly occurring parasites is proving challenging, an integrated pest management strategy using a combination of both preventative and therapeutic approaches is becoming established in the salmon industry (see Section 3.3 above for more details; and Section 5.1.4 below for Norway-specific and Section 5.2.3 for Chile-specific examples).

3.10.4 Antibiotics

Antibiotics have been used in veterinary medicine since the 1940s (Lozano *et al*., 2018) and in aquaculture for more than 50 years (Shamsuzzaman and Kumar, 2012). Indeed, they are currently amongst the most applied chemicals in the aquaculture industry (Sapkota *et al*., 2008). They are used as therapeutic agents in the treatment of bacterial infections (Alderman and Hastings, 1998; Angulo, 2000; Sørum, 2000, 2006; Pillay, 2004; Silbergeld *et al*., 2008) and work by either killing (displaying bactericidal activity) or inhibiting the growth of (displaying bacteriostatic activity) pathogenic bacteria and are usually administered to farmed fish through medicated feed (Smith *et al*., 2009; Rico *et al*., 2013; Wang *et al*., 2015). Antibiotics can also be applied to promote growth (Chowdhury *et al*., 2009),

A number of antibiotics have historically been used to treat bacterial infections in salmon aquaculture;

- Amoxicillin: a broad-spectrum antibiotic effective against gram positive and gram-negative bacteria and used to treat fish with Furunculosis (causative agent: *Furunculosis salmonicida*).
- Florfenicol: a broad-spectrum antibiotic used also to treat Furunculosis.
- Tribrissen (sulfadiazine: trimethoprim (5:1): a broad-spectrum antibiotic used to treat gram negative bacteria causing Furunculosis and Vibriosis (*Vibrio anguillarum*)
- Oxolinic acid and flumequin: quinolone antibiotics used to treat gram negative bacteria causing Furunculosis, Vibriosis and *Piscirickttsia salmonis*
- Oxytetracycline: a broad spectrum antibiotic effective against Furunculosis and Vibriosis (Powell, 2000).
- Erythromycin: effective against gram positive and non-enteric gram-negative bacteria causing Bacterial Kidney Disease (BKD) (Powell, 2000).

Antibiotics are stable chemical compounds that are not broken down by the host (Capone *et al*., 1996; Hektoen *et al*., 1995; Boxall *et al*., 2004; Aarestrup, 2006; Sørum, 2006) and a significant percentage are released into the environment through unconsumed feed, or excreted in urine and faeces (Cabello *et al*., 2013; Miranda *et al*., 2018). Therefore, these antibiotics and their metabolites end up in the surrounding environment (Boxall *et al*., 2004; Sørum 2006). Residues can accumulate in sediments, causing changes in microbial species composition and biogeochemical function of the benthic community (Contanzo *et al*., 2005; Tamminen *et al*., 2011) as well as in the culturing or adjacent waters affecting wild fish and shellfish which can be collected for human consumption, therefore potentially affecting capture fishery product safety and human health (Chen *et al*., 2015, 2018b; Lulijwa, Rupia and Alfaro, 2020). The consequences of human consumption of antibiotic residues include adverse drug reactions (ADR) and development of antibiotic resistance (AMR) for clinically important bacterial pathogens (Liu *et al*., 2017) (see Section 3.5.3. Antibiotic resistance).

Antibiotic usage in some major salmon producing countries has reduced in recent years due to vaccination against many economically important bacterial infections While vaccines also exist for certain viral diseases—such as infectious haematopoietic necrosis (IHN) and infectious salmon anaemia virus (ISAV)—they are not a substitute for antibiotics, which are used exclusively to treat bacterial infections. The reduction in antibiotic use is therefore primarily attributed to improved control of bacterial pathogens through vaccination, alongside better husbandry, biosecurity, and site management practices, including site fallowing between production cycles (Lillehaug *et al.,* 2003; Burridge *et al*., 2010; Chuah *et al*., 2016). However, therapeutic antibacterial therapy still remain a necessary last resort in managing bacterial infections in aquaculture (OSPAR, 2009; Lulijwa, Rupia and Alfaro, 2020).

Schar et al. (2020) suggest almost 6% of global total antibiotic usage is estimated to be applied in aquaculture, with per-biomass quantities in some species exceeding usage in human and terrestrial food-animals. For example, antimicrobial consumption in aquaculture (164.8 mg/kg) is 18% higher than that in terrestrial food-producing animals (140 mg/kg) and 79% higher than human consumption (92.2 mg/kg). However, in countries like Norway and Scotland, regulatory oversight and responsible medicine use have contributed to relatively low antibiotic inputs. For example, data from the Responsible Use of Medicines in Agriculture (RUMA) Alliance and the UK Veterinary Medicines Directorate (VMD) show that antibiotic use in Scottish salmon farming is now comparable to, or slightly lower than, that in terrestrial meat and poultry production—and significantly lower than in pig and turkey farming (RUMA, 2024).

Despite growing awareness, many countries still lack robust systems for tracking antibiotic use and resistance in aquaculture. This is particularly true in low- and middle-income countries, where data collection is often fragmented or absent. Without reliable information, it becomes difficult to assess risks, monitor trends, or implement effective policies. Strengthening surveillance systems and harmonising data collection methods is essential for managing AMR in aquaculture globally.

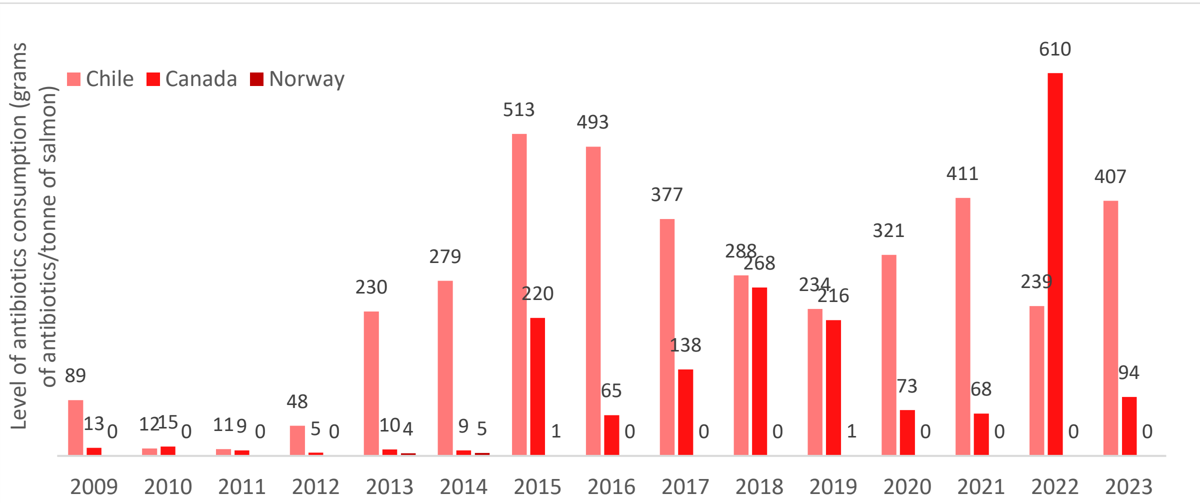

Figure 11: The amount of antibiotics used by Cermaq in Chile, Canada and Norway for one tone of production (2009-2023)

Source: *Data Deep Dive by the Global Salmon Initiative (2024). Based on Cemaq's annual sustainability reports in 2015-2024*

This comparative context highlights that, when well-managed, salmon aquaculture can operate with minimal reliance on antibiotics. However, this is not universally the case (Figure 11). In Chile, antibiotic use remains high due to persistent challenges with *Piscirickettsia salmonis*, the causative agent of Piscirickettsiosis, against which vaccines have proven largely ineffective (Miranda et al., 2018; Figueroa et al., 2019). In 2017, 94.7% of antibiotics used during the marine grow-out phase in Chile were for treating Piscirickettsiosis, with 4.5% used for Bacterial Kidney Disease (BKD) and 0.73% for other conditions (SERNAPESCA, 2017).

3.10.5 Antimicrobial resistance (AMR)

While antibiotics have historically been an effective tool, their widespread use—particularly in regions with persistent disease challenges—has contributed to the emergence of antibiotic or antimicrobial resistance (AMR), posing significant risks to both aquaculture sustainability and public health. AMR is considered by the World Health Organisation to be one of the greatest threats to global health, food security and development (WHO, 2021) and will be dealt with here separately.

AMR results from the selection of spontaneous mutants and horizontal gene transfer between different species and genera (Alonso *et al*., 2001; Hastings *et al*., 2004; Sørum, 2006; Aarestrup, 2006; Welch *et al*., 2007; Baquero *et al*., 2008; Silbergeld *et al*., 2008; Martinez, 2009) causing the development of a disease-causing microbe to subsequently survive exposure to an anti-microbial agent, i.e. an antibiotic, and is well documented in the aquatic environment. In an aquaculture context, AMR can result from both short-term, low dose administration of antibiotic compounds, and, more so, from prolonged, high dose administration (Rezk *et al*., 2015; Chuah *et al*., 2016; Monteiro *et al*., 2016); in other words, the more antibiotics that are used in the aquaculture industry, the greater the risk of emergence and spread of AMR, with the result that the drug becomes increasingly useless against its target.

The first reports of AMR against fish bacterial diseases came from farmed aquaculture species in Thailand (Reungprach and Kesomchandra, 1983), however the problem soon became global; from 1990 to 2007 a total of 29 studies on AMR in aquaculture reported 100 incidences across 13 of the 15 top aquaculture producers (Lulijwa, Rupia and Alfaro, 2020). Although, unsurprisingly China - as the world's largest producer of aquaculture products - is currently leading globally in reports of AMR in farmed fish (Liang *et al*., 2013; Su *et al*., 2017; Chen *et al*., 2018a; Marti *et al*., 2018) there is also cause for concern within the salmonid industry. Chile is the second-largest global producer of salmonids after Norway and, as has been seen above, Chile currently leads in antibiotic usage amongst salmon producers (Fig. 11); in 2016, Norway used a total of 201 kg (EMA, 2016) of antibiotics to produce 1.3 million tons of salmon (0.01 g/ton) (Luthman, Jonell and Troell, 2019) however in the same year, Chile used 382,500 kg of antibiotics to produce 727,812 tons of salmon, and 334,100 kg of antibiotics were reported for 2019 (500 g/ton) (SERNAPESCA, 2020), indicating the continuous excessive antibiotic use in Chilean salmon farming, which threatens to cause environmental and health issues.

The excessive use of antibiotics not only selects for resistant bacterial strains but also results in antibiotic residues in farmed fish, which can lead to trade restrictions when detected by importing countries like the European Union (EU), the United States, and Japan.

Regulators have got better at determining the risks of associated wastes in aquaculture over the past decade and most now require some form of 'plume modelling' to be completed as part of the licensing processing. In Scotland, a modelling platform called DEPOMOD is used for this purpose and allows regulators to determine the movement of nutrients and other residues from a specific site. Using this, regulators can then perform regular monitoring to ensure that farms are maintaining levels in line with those predicted (and regulated).

Associated Wastes

Salmon farms produce an array of both solid and dissolved associated waste products during operation. This includes uneaten fish feed, and fish waste (both solid faecal matter and dissolved nutrients). In significant quantities these can lead eutrophication of the water body of the build-up of anoxic seabed conditions. Furthermore, other chemicals including antibiotics and pesticides can form high levels around cage farms if not carefully managed.

The control of these associated wastes has improved dramatically through better regulation and licensing. Most farms require modelling of associated waste at the planning phase and these must show levels which are in line with accepted regulatory requirements. Once approved farms are also often required to complete seabed and water column monitoring to ensure that levels are maintained as predicted (and this is often backed up by direct testing and sampling by the authorities).

To address the growing challenge of AMR, the aquaculture industry is actively exploring alternative disease management strategies (see Bondad-Reantaso *et al.,* 2023 and references therein). One of the most effective solutions has been the introduction of vaccination programmes. Norway, for instance, drastically reduced its antibiotic use from approximately 50,000 kg per year in the late 1980s to less than 2,000 kg by 1997 following the widespread adoption of vaccines. Vaccines for salmonids are now commercially available against several key bacterial pathogens, including those responsible for furunculosis, vibriosis (*Vibrio anguillarum*), and yersiniosis (*Yersinia ruckeri*). These vaccines, administered via injection, immersion, or oral routes, provide long-term protection, reducing the need for antibiotic treatments (see Bondad-Reantaso *et al.,* 2023 and references therein).

Beyond vaccination, other innovative approaches are being developed to control bacterial infections in salmonids. Probiotics and prebiotics are gaining traction as a means of promoting gut health and enhancing the immune response of fish. These beneficial microorganisms help maintain a balanced microbiome, preventing the overgrowth of harmful bacteria. Similarly, quorum quenching is being explored as a method to disrupt bacterial communication systems, known as quorum sensing. By interfering with the ability of bacteria to coordinate their virulence and biofilm formation, quorum quenching can reduce the severity of infections without directly killing the bacteria, thereby lowering the selective pressure for resistance.

Another promising alternative is the use of bacteriophages—viruses that specifically target and kill bacterial pathogens. Bacteriophage therapy is highly specific, meaning it does not affect beneficial bacteria, unlike broad-spectrum antibiotics. Research has demonstrated the effectiveness of phages against common salmonid pathogens such as *Aeromonas* and *Vibrio* species. However, challenges remain in ensuring the consistent efficacy of phage treatments, as bacteria can evolve resistance to phages just as they do to antibiotics (see Bondad-Reantaso *et al.,* 2023 and references therein).

It is important to note that no single solution will be universally applicable across all aquaculture systems. The diversity of farmed species, environmental conditions, and production methods means that disease management strategies must be tailored to specific contexts. What works for salmon in Norway may not be suitable for trout in Chile or carp in Asia.

Plant-based compounds and other natural substances are also being investigated for their antimicrobial properties. Certain medicinal plant extracts have shown antibacterial activity against fish pathogens, while others act as immunostimulants, enhancing the fish's natural ability to fight infections. The use of these plant-derived compounds in salmonid diets could offer a sustainable and environmentally friendly alternative to antibiotics.

Another crucial strategy in reducing antibiotic reliance is the use of specific pathogen-free (SPF) seed stock. By ensuring that farmed fish are free from major diseases at the hatchery stage, the risk of outbreaks later in the production cycle is significantly reduced. This proactive approach, combined with improved biosecurity measures, can limit the introduction and spread of pathogens in salmon farms (see Bondad-Reantaso *et al.,* 2023 and references therein).

The future of salmonid aquaculture lies in a multifaceted approach to disease management. While antibiotics will likely remain a last-resort treatment for severe outbreaks, the industry is moving towards a more sustainable model that prioritises preventive measures. Vaccination, probiotics, bacteriophage therapy, and improved biosecurity practices will play a critical role in maintaining fish health while mitigating the risks associated with AMR. Moreover, stricter regulations and consumer demand for antibiotic-free seafood are pushing producers to adopt these alternative strategies.

Ultimately, the transition away from antibiotics in salmonid farming is not just about protecting aquaculture production—it is also about safeguarding public health and ensuring the long-term viability of the industry.

3.11. Operational Impacts

Aquaculture, particularly salmon farming, has become an increasingly visible presence in coastal and offshore waters. While the industry plays a vital role in global seafood production, its expansion has raised concerns beyond environmental pollution and resource use. The physical presence of salmon farms, as well as their use of artificial lighting, contributes to changes in the visual landscape and light pollution levels, impacting both marine ecosystems and coastal communities.

3.11.1 Energy and Fuel Equipment

Salmon farming is highly reliant on energy and fuel, particularly for vessels, feed barges, and land-based operations. As the world's largest producer of farmed salmon, Norway contributed over half of the global supply in 2022, with advanced aquaculture practices such as open net pens and land-based Recirculating Aquaculture Systems (RAS) (Ziegler et al., 2024). Globally, aquaculture produces about 245 million tons of carbon dioxide (CO_2) per year, accounting for 0.49% of global greenhouse gas (GHG) emissions. In contrast, terrestrial agriculture emits between 400 and 660 million tons of CO_2 (Macleod et al., 2020). Nevertheless, the sector's environmental footprint is noteworthy, primarily due to GHG emissions associated with feed production and airfreight.

According to Ziegler et al. (2024), the salmon farming value chain, including breeding, farming, processing, packaging, and distribution, generates approximately 5.2 million tonnes of CO_2 equivalent (CO_2e) annually, with feed production and airfreight contributing 45% and 35% respectively. In Norway, airfreight to overseas markets like Asia and the US accounts for 68–82% of emissions in transcontinental supply chains. Recent assessments indicate a 10% reduction in GHG emissions since 2017, largely due to decreased use of Brazilian soy in feed (from 21% to 17%). The same study identified five key measures that could collectively reduce sector emissions by 60%: improving feed efficiency, increasing utilisation of side streams, transitioning from road and air to sea freight, enhancing energy efficiency, and altering feed composition to incorporate more sustainable ingredients like algae oil and fish processing side streams.

While these emissions are significant within the aquaculture sector, it is important to note that the carbon footprint of farmed salmon remains considerably lower than that of most terrestrial livestock. As discussed in Section 3.13.5, farmed salmon typically emits 5–6 kg CO_2e per kg of edible product, compared to 12–15 kg for pork and lamb, and up to 30–60 kg for beef (Poore & Nemeck, 2018). This positions salmon aquaculture as a relatively low-emission source of animal protein, particularly when best practices in feed sourcing and logistics are applied.

In Scotland, fish farms are generally smaller and more dispersed, resulting in higher emissions per unit of fish produced compared to larger, consolidated operations in other countries. For example, Scotland’s aquaculture sector is dominated by firms with a strong focus on sustainable practices but faces challenges with higher Scope 1 emissions due to smaller farm sizes and more intensive vessel use (Hammer et al., 2022). Smaller support vessels and service boats significantly contribute to carbon emissions, especially in remote areas with limited infrastructure. In Scotland, open-net pens require relatively little electricity, whereas closed containment systems are more energy-intensive due to water circulation and oxygenation requirements (Hammer et al., 2022).

Norway remains at the forefront of innovation and emission reduction strategies. Electrification of feed barges and hybrid generator installations have reduced emissions in sites such as Rogaland by 4% from 2017 to 2018, highlighting the potential for emission cuts through electrification and energy management (Johansen et al., 2022). In addition, initiatives like switching from marine fuel oil to ammonia or hydrogen for wellboats can reduce emissions by up to 65% when using renewable energy sources (Ziegler et al., 2024). Furthermore, Norway's adoption of renewable energy sources for land-based operations, combined with advanced monitoring and energy management systems, demonstrates significant potential for emission reductions.

GHG emissions in aquaculture are typically categorised into Scope 1, 2, and 3 emissions. Scope 1 emissions are directly released from fuel combustion on-site or from company-controlled sources. Scope 2 emissions arise from purchased electricity generation, while Scope 3 emissions, the largest contributor, come from upstream and downstream activities within the value chain (Hammer et al., 2022). The Scottish aquaculture sector has particularly high Scope 3 emissions, mostly linked to feed production and transportation.

Mitigation strategies need to address the carbon intensity of the feed supply chain, which is the most significant emission source, accounting for over 75% of emissions in many cases (Winther et al., 2020). Strategies to reduce emissions include minimising fishmeal dependency, incorporating novel ingredients such as insect protein or algal oil, and improving fish health to lower mortality rates, thus enhancing resource efficiency (Newton and Little, 2018). Implementing these measures, however, requires substantial investment, research, and regulatory support. The industry must also navigate trade-offs, such as potential land-use changes linked to plant-based feed alternatives. For instance, replacing fishmeal with soy protein can reduce marine impacts but may increase land use and agricultural emissions.

Despite these efforts, achieving long-term emission reduction targets—such as a 55% decrease by 2030 and a 90% reduction by 2050—will necessitate more ambitious strategies and innovations beyond current best practices (Ziegler et al., 2024). Addressing both carbon efficiency and sustainability comprehensively remains essential for the industry's future viability, balancing emission reduction with environmental, economic, and social impacts.

3.11.2 Noise Pollution

The increasing presence of anthropogenic noise in marine environments has become a pressing ecological concern, particularly in areas with high levels of industrial activity. A study conducted in a Northern Patagonian fjord, home to active salmon farms, found that human-made noise dominated the underwater soundscape for 97% of the time (Avilés-Sanhueza and Hinojosa, 2023). The primary source of this noise was likely electric generators used in salmon net pens, producing sound with a peak frequency of approximately 80 Hz—about 40 dB higher than natural ambient noises. This substantial alteration in the acoustic environment raises concerns about its impact on marine life, particularly species that rely on sound for essential functions such as communication, navigation, and predator detection.

While human activities such as aquaculture contribute significantly to economic growth, they may also have unintended ecological consequences. The persistence of artificial noise in marine environments can mask natural sound cues, leading to potential disruptions in the behaviours of marine organisms. Many marine species, including fish and invertebrates, rely on sound for orientation, mate selection, and predator avoidance. Thus, a shift in the underwater acoustic landscape could have far-reaching implications.

A comprehensive review[5] highlights that most fish and invertebrates use sound for critical life functions, including communication, reproduction, and survival. Prolonged exposure to elevated noise levels has been linked to developmental delays, anatomical injuries, and heightened stress responses in marine organisms. Moreover, behavioural modifications—such as changes in foraging patterns, migration routes, and predator-prey interactions—can disrupt ecosystem stability.

The cascading effects of noise pollution extend beyond individual species, potentially altering entire marine communities. For example, disruptions in predator-prey dynamics could lead to imbalances in population structures, affecting biodiversity and ecosystem resilience. Additionally, chronic noise exposure may contribute to habitat degradation, reducing the overall suitability of certain regions for marine life.

3.11.3 Light Pollution

Recent research highlights growing concerns about the impact of artificial light at night on salmon, both in the wild and in aquaculture. A 2022 study by the U.S. Geological Survey found that excessive nighttime lighting alters key behaviours in juvenile salmon, making them more vulnerable to predators by extending hunting hours and increasing their exposure in illuminated waters. In aquaculture, artificial lighting is widely used to manipulate growth and reproduction cycles, but a recent review warns that while these practices may boost production, they can also disrupt the fish's natural rhythms and physiology (Bassi *et al*., 2021)**.**

For farmed salmon, lighting is a double-edged sword—helping to increase yield but potentially affecting welfare and long-term sustainability. A growing body of evidence suggests that excessive or poorly managed artificial lighting near waterways can also interfere with the migration patterns of wild salmon, delaying their journey to the sea and increasing predation risks. A study on Atlantic salmon smolts found that streetlights near rivers disrupt their nocturnal migrations, leading to higher mortality rates (Riley *et al*., 2012).

3.11.4 Visual Impacts

Salmon farming, like many forms of aquaculture, has a profound impact on the visual landscape of coastal environments, often leading to conflicts with local communities and tourism industries[6]. The presence of large-scale sea-cage farms, floating feed barges, and land-based processing facilities can alter the aesthetic appeal of coastlines, particularly in areas valued for their natural beauty and recreational opportunities. In regions such as Norway, Scotland, and the Mediterranean, where both tourism and aquaculture are significant economic activities, balancing the visual footprint of fish farms with public perception and economic interests has proven to be a complex issue (see Dempster and Sanchez-Jerez, 2007 and references therein).

The visual impact of salmon farms is most noticeable in sheltered coastal areas such as fjords, bays, and archipelagos, where floating structures are often highly visible from the shore. Sea-cages are large and can cover several hectares, with supporting infrastructure such as buoys, nets, and feeding systems further contributing to their presence. Additionally, maintenance vessels and floating storage units add to the industrial appearance of these sites. While these structures are essential for the efficient production of farmed salmon**,** their visual impact is highly subjective and depends on

[5] Underwater-Noise-Pollution_Impact-on-fish-and-invertebrates_Report_OceanCare_EN_36p_2018.pdf
[6] Microsoft Word - 6_Aquaculture_Tourism_final_kg.docx

location, viewer values, and the number of visitors. In areas with high scenic value or tourism activity, they may be seen as intrusive, especially in locations with high scenic value (see Dempster and Sanchez-Jerez, 2007 and references therein). On the other hand, in communities where aquaculture provides stable, year-round employment and underpins the local economy, fish farms may be viewed more positively and as symbols of economic resilience.

In many cases, the visual impact of aquaculture has led to resistance from local communities, particularly in areas where tourism is a primary economic driver. Tourists often seek unspoiled coastal landscapes, and the presence of industrial fish farming facilities can disrupt their experience. As a result, some countries have implemented stricter regulations on farm placement. In the Mediterranean, for example, fish farms have been moved further offshore or restricted from certain coastal zones to protect tourism interests. Similarly, in Norway, where salmon farming is a dominant industry, there has been a noticeable shift in farm placement from inner fjords to more exposed coastal areas. This relocation reduces visibility from populated areas and popular tourist sites but introduces new challenges, such as increased exposure to rough seas and higher operational costs (see Dempster and Sanchez-Jerez 2007, and references therein).

Beyond aesthetics, the presence of fish farms can also influence public perception of coastal water quality. The accumulation of organic waste, the potential for algal blooms, and concerns about farmed fish escaping into the wild can further reinforce negative perceptions. This is particularly relevant in regions where recreational activities such as sailing, diving, and fishing depend on the quality of the marine environment. The sight of fish cages, sometimes with noticeable debris or net fouling, can create an impression of pollution, even if environmental management practices are in place (see Dempster and Sanchez-Jerez, 2007 and references therein).

Ultimately, the assessment of visual impacts is context-dependent and should be informed by local consultation processes. Public engagement will be essential in determining how different stakeholder values—economic, environmental, and aesthetic—are weighed in future aquaculture planning.

3.12 Impacts on Protected Land and Coastal Areas

The impact of salmon farming on protected lands and coastal areas is increasingly recognised as a significant environmental concern. Industrial salmon farming, while economically beneficial, has the potential to lead to habitat degradation and ecological disruption, particularly when conducted within protected marine areas. The most critical issues arise from nutrient runoff, chemical contamination, and physical disturbances linked to the operation of salmon farms. Waste products, antibiotics, and excess feed released into the water contribute to eutrophication, promoting algal blooms that reduce oxygen levels and threaten marine biodiversity. This process significantly impacts native flora and fauna, disrupting the ecological balance and diminishing the resilience of coastal ecosystems.

Moreover, salmon farming introduces physical disturbances through heightened vessel traffic, which poses additional threats to sensitive habitats. In shallow or ecologically fragile environments—such as seagrass beds, kelp forests, or intertidal zones—the movement of aquaculture-related vessels may contribute to physical disturbance, including from anchoring, propeller wash, or repeated transits. The extent of these impacts depends on site-specific conditions and should be assessed on a case-by-case basis. Although most aquaculture vessels do not typically use ballast water systems, the broader maritime activity associated with aquaculture operations—including international shipping of feed, equipment, or harvested fish—may intersect with international shipping routes. Ballast water discharge from larger vessels remains a recognised vector for the introduction of invasive species, which could have ecological consequences and potential implications for aquaculture operations, particularly through the introduction of novel pathogens or competitors. These combined effects can compromise the ecological integrity of protected areas, leading to long-term degradation that undermines conservation efforts. The presence of aquaculture operations in regions designated for environmental protection raises critical questions about the compatibility of economic activities with conservation priorities.

These issues are particularly pronounced in Chilean Patagonia, where the rapid expansion of salmon farming has posed severe risks to protected areas such as the Guaitecas National Reserve, Magdalena Island National Park, and Kawésqar National Reserve (Harms at al. 2024). Despite being designated for conservation, these areas have been subject to intensive aquaculture activities that significantly alter water quality and threaten vital marine habitats like giant kelp forests. The nutrient and chemical runoff from salmon farms have led to eutrophication and habitat loss, undermining the ecological functions that these forests provide, including coastal protection and carbon sequestration.

The impacts of salmon farming in these protected areas are further exacerbated by climate change, which independently threatens kelp forests through rising sea temperatures and altered nutrient dynamics. As climate change continues to intensify, these stressors combine to make marine ecosystems increasingly vulnerable. For instance, in the Kawésqar National Reserve, despite its vast protected coastal space, medium and high-risk zones persist, particularly where salmon farming intersects with climate change impacts.

Socially, the presence of salmon farming within these protected areas has also sparked widespread controversy and opposition from environmental groups and local communities. The contradiction between industrial aquaculture and conservation objectives is stark, prompting calls for more stringent legal frameworks and enhanced enforcement. Efforts to mitigate the environmental risks posed by salmon farming must take into account the complex interplay of industrial practices, climate change, and the conservation of vulnerable ecosystems. Addressing this challenge requires integrated management approaches that prioritise ecological health while balancing economic interests (Harms at al. 2024).

3.13 Indirect environmental impacts through use of feed/operational materials with high production-related environmental impacts

Indirect environmental impacts associated with salmon farming primarily arise from feed production, operational energy use, and transportation logistics. As global demand for salmon continues to grow, the environmental burden of aquaculture systems also increases, particularly due to the carbon footprint associated with producing and transporting feed ingredients. Addressing these impacts requires a comprehensive understanding of the lifecycle of salmon production, from feed sourcing to export logistics, as well as the adoption of innovative practices and technologies to mitigate emissions.

3.13.1 Feed Production: The Dominant Source of Indirect Environmental Impacts

The most significant indirect environmental impact in salmon farming is linked to feed production. Historically, salmon feed was primarily composed of marine-based ingredients, such as fish meal and fish oil. However, as marine resources became increasingly scarce and concerns about overfishing grew, the industry shifted towards plant-based proteins. This shift, while reducing pressure on marine ecosystems, has brought about a substantial increase in carbon emissions, particularly due to the use of soy protein concentrate (Ziegler et al. 2024).

Soy protein, predominantly sourced from Brazil, has a substantial carbon footprint due to the associated land-use change and deforestation. The conversion of forests to agricultural land results in the release of stored carbon, significantly increasing greenhouse gas emissions. Studies have shown that replacing marine ingredients with Brazilian soy protein can substantially increase the carbon footprint of salmon feed, as the emissions from land-use change and intensive agricultural practices are considerable.

Efforts to reduce the reliance on soy have led to the exploration of alternative protein sources, including insect meal, algae oil, and fish processing side streams. Insect meal, particularly from black soldier fly larvae, has demonstrated potential due to its relatively low carbon footprint, ranging from 0.1 to 49 kg CO_2 equivalent per kg of protein, depending on substrate and processing methods (Cantillo and Deshpande 2025). Likewise, algae oil is increasingly being considered as a sustainable alternative to fish oil, though its production remains limited and costly (Ziegler et al. 2024).

The utilisation of fish processing side streams also represents a promising mitigation strategy. By using by-products from fish processing, such as fish trimmings and offcuts, the industry can reduce dependence on high-impact agricultural ingredients like soy and improve overall resource efficiency. This shift contributes to circular economy principles and helps reduce pressure on wild fish stocks by making better use of existing marine biomass. However, the scalability of this approach remains a challenge, particularly in regions where the infrastructure for side stream processing is underdeveloped (Ziegler et al. 2024).

Public and stakeholder perceptions of by-product use in aquafeeds are varied and continue to evolve. While some environmental organisations have raised concerns about transparency and traceability in feed sourcing, others have endorsed certified sustainable aquaculture practices that include the responsible use of by-products. At the same time, global demand for farmed salmon has continued to rise, suggesting that consumer acceptance of such practices is not a limiting factor at present. As feed innovation progresses, clear communication and robust certification will remain important tools for maintaining public trust and supporting sustainable growth in the sector.

3.13.2 Energy Use and Operational Efficiency: Addressing Carbon Emissions

Beyond feed production, the operational phase of salmon farming also contributes significantly to indirect environmental impacts, primarily through the use of energy in various farming activities. Wellboats and feed barges are traditionally powered by diesel, which significantly contributes to greenhouse gas emissions. Transitioning to renewable energy sources, such as hydrogen or ammonia fuel cells, could reduce emissions from wellboats by up to 65%. Additionally, energy efficiency improvements in land-based processing facilities and feed mills could lower energy consumption by up to 30% (Ziegler et al. 2024).

However, transitioning to renewable energy in aquaculture is not without challenges. While the Falkland Islands have experience with decentralised renewable energy systems, the availability of site-specific infrastructure in remote coastal areas—where salmon farms are typically located—may be limited. In such contexts, developers are likely to bear responsibility for establishing dedicated power systems, which introduces logistical and financial considerations. Retrofitting existing vessels and equipment to accommodate new energy carriers requires significant investment and technological adaptation. Despite these obstacles, integrating renewable energy into salmon farming operations represents one of the most impactful measures to reduce indirect emissions.

To contextualise these emissions, it is useful to compare them with other protein production systems currently active in the Falkland Islands. While precise local data are limited, global benchmarks suggest that wild capture fisheries using trawling or longlining emit between 2–10 kg CO_2e per kg of catch, depending on gear type and species (Gephart et al. 2021). Sheep farming, which is a major land-based protein source in the Falklands, is associated with significantly higher emissions—typically 20–25 kg CO_2e per kg of meat—largely due to methane emissions from enteric fermentation and land use. In contrast, salmon aquaculture emits approximately 5–6 kg CO_2e per kg of edible product (Poore & Nemeck, 2018) (discussed further in Section 3.13.5, below). These comparisons suggest that, from a climate perspective, salmon farming—if implemented with best practices in energy use and logistics—could offer a lower-emission alternative to existing protein production systems in the Falklands.

3.13.3 Transportation Logistics: Mitigating Emissions from Export Operations

Transportation of salmon from farms to global markets also contributes significantly to the carbon footprint of the sector. Airfreighting fresh salmon to distant markets, such as Asia and North America, accounts for a substantial share of emissions due to the energy intensity of air transport. For instance, exporting fresh gutted salmon from Norway to Asian markets by air generates notably high emissions compared to sea freight (Ziegler et al. 2024).

To mitigate these emissions, innovative approaches such as supercooling have been proposed. Supercooling involves rapidly reducing the temperature of the product to just above freezing, significantly extending its shelf life. This technique allows for slower but far more carbon-efficient sea transportation rather than airfreight. Nevertheless, consumer preferences for fresh over frozen products pose a significant barrier, as many markets still equate quality with freshness.

An additional strategy is to combine transportation with onboard processing, allowing salmon to be processed during transit. This approach not only preserves product quality but also reduces the need for rapid airfreight. However, the success of this strategy depends on optimising the cold chain and maintaining stringent quality controls throughout the transportation process (Ziegler et al. 2024).

3.13.4 Interactions Between Feed Production and Transportation

The indirect environmental impacts of feed production and transportation are often interconnected. As salmon farming increasingly relies on terrestrial ingredients like soy and cereals, the emissions related to transporting these feed components from distant production sites add to the carbon footprint. For instance, the transport of Brazilian soy to Norwegian feed mills contributes significantly to the overall impact (Ziegler et al. 2024). Addressing this requires not only optimising feed composition but also sourcing ingredients locally wherever possible.

Alternative protein sources, such as single-cell proteins and insect meals, also face challenges related to transport emissions. While their production may have a lower carbon footprint, the distance between production sites and aquaculture facilities can offset potential emission reductions. Consequently, regional production hubs and local sourcing strategies need to be integrated into emission reduction plans.

3.13.5 Integrated Mitigation Strategies and Industry Challenges

Reducing the indirect environmental impacts of salmon farming requires a comprehensive approach that optimises feed efficiency, incorporates sustainable ingredients, transitions to renewable energy, and enhances logistics. Lowering the feed conversion ratio (FCR) from 1.3 to 1.2 kg per kg of salmon could significantly cut emissions, while replacing soy with insect meal and algae oil reduces carbon footprint despite scalability challenges.

Since the 1970s, Atlantic salmon production has undergone substantial improvements through selective breeding, feed formulation, and on-site technological innovation. These advances have reduced feed conversion ratios (FCRs) from over 5:1 to current lows of approximately 1.2-1.3:1 (and indeed, lower in some cases), and decreased protein content in feed from 55% to 35% (Torrissen et al., 2011). This means that just over one kilogram of feed is now required to produce one kilogram of edible salmon, making it one of the most efficient animal protein systems in terms of both protein and calorie retention.

In contrast, FCRs for terrestrial livestock remain significantly higher—6 to 10:1 for cattle and 4 to 6:1 for sheep (Fry et al., 2018). This efficiency translates into lower demand for feed inputs per unit of protein produced, reducing the environmental burden associated with feed cultivation, processing, and transport. It also contributes to a lower overall carbon footprint for salmon farming, estimated at 5–6 kg CO_2e per kg of edible product, compared to 30 kg CO_2e for beef and 12 kg CO_2e for lamb (Poore & Nemeck, 2018).

However, it is important to acknowledge that FCR alone may not fully capture the sustainability of feed use. Tlusty et al. (2018) argue that FCR oversimplifies interspecies comparisons and fails to account for differences in feed quality, edible yield, and broader life cycle impacts. As a farm-level metric, FCR does not reflect upstream or downstream emissions, nor does it incorporate social or ecological trade-offs. More comprehensive indicators—such as protein retention efficiency, calorie conversion, and life cycle assessments (LCAs)—are increasingly recommended to evaluate the true sustainability of aquaculture systems.

Nonetheless, the comparative advantages of salmon aquaculture in feed efficiency and emissions intensity underscore its potential role in supporting more sustainable global food systems. These benefits are further amplified when combined with innovations across the production chain — from feed sourcing to energy use and transportation logistics — that collectively reduce the environmental footprint of farmed salmon.

For example, adopting renewable energy in wellboats and processing facilities can significantly decrease operational emissions, while shifting from airfreight to supercooled sea freight offers a lower-carbon alternative for product distribution. However, these improvements are not without challenges. Economic barriers, regulatory constraints, and consumer preferences for fresh products can limit the feasibility of such transitions, particularly in remote or infrastructure-limited regions.

Addressing these challenges requires holistic strategies that integrate environmental, economic, and social considerations. These strategies must be supported by robust data monitoring, transparent reporting, and collaboration across industry stakeholders to ensure long-term sustainability as global salmon demand continues to rise.

In parallel, industry standards are evolving to support more responsible practices. The ASC Feed Standard[7], for example, represents a significant step forward in addressing the challenges associated with feed production, particularly in terms of sustainability and social responsibility. The primary aim is to ensure that feed ingredients are sourced responsibly, thereby minimising environmental impacts and safeguarding ecosystems. Furthermore, the standard sets out clear expectations regarding social responsibility throughout the supply chain, which is vital for maintaining ethical practices. However, some may contend that implementing such standards could pose challenges for producers, especially smaller operations, who may find compliance both costly and complex. Nonetheless, the ASC Feed Standard undeniably represents a positive stride towards more transparent and accountable feed production within the aquaculture sector.

3.15 Understudied Impacts

Areas of salmon farming impacts where limited research can be identified include microplastic and contaminant accumulation, climate change interactions and cumulative and synergistic effects. These areas represent significant gaps in scientific knowledge, making it challenging to comprehensively assess the full environmental consequences of salmon farming.

[7] See the ASC Feed Standard v1.1 (May 2025)

Firstly, there is limited evidence regarding the accumulation of microplastics and contaminants from salmon farms within marine food webs. While microplastic pollution is a growing environmental concern globally, few studies have specifically addressed how salmon farming contributes to microplastic dispersal or how contaminants from feeds and treatments persist in the surrounding ecosystem (e.g. Abihssira-García et al. 2022; Fred-Ahmadu et al. 2024). Limited data makes it difficult to evaluate the long-term health risks to both farmed and wild marine organisms, as well as the potential human health implications through seafood consumption.

Another critical gap lies in understanding the interactions between climate change and salmon farming. Climate change is altering marine environments in unprecedented ways, including increasing sea temperatures and changing current patterns. However, limited research has been undertaken to examine how these changes might exacerbate or mitigate the environmental impacts of salmon farms. For example, warmer waters may heighten disease transmission or alter waste dispersion patterns, but systematic studies to quantify such effects are scarce.

Lastly, cumulative and synergistic impacts from multiple salmon farms within a single water body are poorly understood. While individual farms are often assessed for environmental compliance, the combined effects of several farms in close proximity are rarely investigated. This oversight could mask broader ecosystem changes that only become apparent when considering the cumulative load of waste, chemicals, and biological interactions.

4. Holistic impacts on Falkland Islands environment and other sectors

The potential introduction of salmon farming in the Falkland Islands raises important environmental, economic, and social considerations[8]. While it could provide economic opportunities, concerns exist regarding its long-term sustainability and impact on the islands' unique marine ecosystem. Understanding these factors is essential for making an informed decision on whether large-scale salmon farming would be beneficial or detrimental to the Falklands.

A key issue associated with salmon farming is its potential impact on the marine environment. The release of organic waste, including uneaten fish feed and faeces, can increase nutrient levels in coastal waters, potentially leading to seabed degradation and changes in local biodiversity. The extent of this impact depends on factors such as water circulation and farm location, but experience from other regions suggests that poorly flushed areas are particularly vulnerable. Given that the Falklands' marine environment is largely unstudied, it is difficult to predict how it might respond to such nutrient inputs.

The risk of escaped salmon is another concern, as farmed fish have been known to compete with native species and introduce new diseases and parasites. In other farming regions, sea lice infestations have been linked to declines in wild fish populations, raising questions about whether similar issues could arise in the Falklands. Additionally, the need to import live fish or eggs could increase the risk of introducing non-native pathogens, further complicating the ecological balance.

Chemical use is another important factor. Salmon farms often rely on antibiotics and pesticides to manage disease and parasite outbreaks, and while these chemicals are used under strict regulations in some countries, their accumulation in marine environments can have unintended consequences. Seabirds, marine mammals, and other non-target species may be affected, making this a significant consideration for the Falklands, where wildlife plays a crucial role in both biodiversity and tourism.

[8] Microsoft Word - Falklands Salmon - Bridson - September 12th 2018.docx

On the economic side, salmon farming has the potential to create jobs and stimulate investment. In southern Chile, a 30,000-metric-ton operation supports over 800 full-time jobs across farming and processing, suggesting that a similar industry in the Falklands could generate significant employment.However, given the small local workforce, there is a question of whether the industry would need to rely on imported labour, which could bring social changes.

There is also the issue of how salmon farming might interact with existing industries. The Falklands currently depend on fishing and tourism, both of which rely on a healthy marine environment. If salmon farming were to impact fish stocks or disrupt marine ecosystems, it could have knock-on effects on fisheries and tourism operators. Additionally, increased boat traffic and infrastructure development associated with large-scale salmon farming could change the character of the islands' coastal areas, which may not be universally welcomed by the local community.

One of the biggest challenges in introducing salmon farming to the Falklands is the current lack of specific baseline data required for aquaculture development and environmental impact assessments (EIAs). Unlike regions with long-established industries, the Falklands do not yet have high-resolution datasets for key parameters such as hydrodynamic modelling, benthic habitat mapping, water quality and nutrient cycling, and carrying capacity assessments. This lack of information makes it difficult to assess potential risks and benefits, and increases the uncertainty surrounding long-term impacts. Ultimately, while institutions such as Falklands Conservation, SAERI, and the Shallow Marine Survey Group have made valuable contributions to understanding the broader marine environment, the spatial and temporal resolution of existing data may not meet the regulatory requirements for salmon farming site approval. This situation is not unique to the Falklands—it is a common challenge in any new aquaculture region. The cost and responsibility for generating these datasets typically fall to the developer, and should be factored into early-stage planning and feasibility assessments.

Regulation is another critical factor. In Scotland, where the salmon farming industry is well-established, the process of obtaining farm site approval takes over two years, involving multiple regulatory bodies. If the Falklands were to introduce salmon farming, a strong regulatory framework would be needed to ensure environmental protection, biosecurity, and sustainable management.

Overall, the potential for salmon farming in the Falklands presents both opportunities and risks. While it could provide economic benefits, there are significant environmental and regulatory challenges to address. The limited understanding of the Falklands' marine environment makes it difficult to predict how the industry might impact local ecosystems, and concerns over fish escapes, chemical use, and habitat changes remain key issues. Additionally, the social and economic consequences of introducing a new large-scale industry require careful consideration.

Before any decision is made, further research and a thorough environmental assessment would be essential to ensure that any development aligns with the long-term sustainability of the Falkland Islands.

4.1 Impacts on proposed MMAs

The Falkland Islands Government (FIG) is working to protect its marine environment while supporting sustainable economic activities (FIG internal report). The plan proposes a network of Marine Managed Areas (MMAs), covering around 15% of the Falklands' waters—approximately 67,000 km². These areas are designed to safeguard key ecosystems, such as kelp forests, seabird nesting sites, and feeding grounds for marine mammals, while allowing for responsible resource use.

Two types of MMAs have been put forward:

1. **National Marine Nature Reserves (NMNRs)** – These are strictly protected areas where conservation takes precedence. Activities such as commercial fishing, mining, large-scale tourism, and practices that impact shipping will be prohibited. However, small-scale tourism and scientific research will be permitted under strict guidelines to minimise disruption.
2. **Sustainable Multi-Use Zones (SMZs)** – These zones allow for both conservation and sustainable economic activities. Low-impact fishing methods, small-scale tourism, and research will be permitted, but damaging practices like trawling, dredging, and oil and gas extraction will be banned.

The proposed MMAs cover ecologically significant areas, each with its own conservation focus. Offshore sites like Burdwood Bank support vital deep-sea habitats, while coastal locations such as the Jason Islands, Bird Island, and Kidney and Cochon Islands are crucial for seabirds, marine mammals, and seabed ecosystems. Beauchene Island, a largely untouched wildlife sanctuary, highlights the government's commitment to marine biodiversity. However, balancing conservation with economic interests—particularly in relation to aquaculture—remains a challenge.

Aquaculture has been suggested as a way to diversify the Falklands' economy, but it raises concerns. Finfish farming in sea cages, for instance, can lead to pollution, habitat degradation, and disease transmission to wild fish populations. Many MMAs aim to protect sensitive environments, such as kelp forests, meaning that fish farming in or near these areas could undermine conservation goals. Waste from sea cages—such as uneaten feed and fish waste—could affect water quality, while disease transmission from farmed fish could threaten wild stocks of commercially valuable species like toothfish and squid.

5. The Salmon Industry: Lessons learnt and mitigation strategies

In 1995, the Food and Agriculture Organisation of the United Nations' (FAO) 'Code of Conduct for Responsible Fisheries (the Code)' - whose aim was to set international standards of behaviour for responsible practices for both fisheries and aquaculture with a view to ensuring the effective conservation, management and development of living aquatic resources - was adopted by all FAO members. It set out globally agreed principals and standards for the use of fisheries and aquaculture resources with the overreaching aim of ensuring the 'sustainable use of aquatic-living resources in harmony with the environment' (FAO, 1995)

Therefore, it can be seen that the sustainability of the aquaculture industry, that is to say its long-term viability, has historically been a key factor of consideration. Considerable focus has been turned towards the development of best management practices, codes of conduct and aquaculture certification programmes etc. in order to promote more environmentally and socially responsible sustainable aquaculture farming practices (Quinones *et al*., 2019). This is certainly the case for the economically valuable and intensively farmed salmon industry.

As has already been seen, the scale of the impacts of salmon farming can vary depending on the geographical location and hosting ecosystem, the scale of production, management practices etc. The way that historical issues, that have been discussed above may vary, and mitigation measures that have been taken to address these issues reflect these differences. These will be explored below in the context of the two main global salmon producing countries, i.e. Norway and Chile.

5.1 Norway

5.1.1 A brief history of the Norwegian salmon industry

Norwegian salmon farming has grown exponentially over the last 50 years and is continuing to grow. It has historically and continues to rank first amongst the major global salmonid producers, though recent policy changes, such as the resource rent tax on salmon and trout farming introduced in 2023, may impact future growth. In 2022, Norway's salmonid production remained strong, with exports reaching USD 15.5 billion, despite a 6.7% drop in live weight equivalent exports. Salmon and trout accounted for over 74% of Norway's total aquatic animal export revenue, far surpassing traditional fisheries (Hersoug, Mikkelsen and Osmundsen, 2021). However, projections suggest that if the resource rent tax remains, Norwegian aquaculture output could decline by 9% by 2032 (FAO, 2024).

Salmon production began in Norway in the late 1960s as a diversification of small-scale farmers supported by the government, with little or no regulation (Olaussen, 2018). It was in 1973 that the first law on concessions in salmon aquaculture was introduced with permissions required to set up a fish farm (Aarseth and Jakobsen, 2009), and, in 1985, the first specific aquaculture related law was issued. However, this did not cover concessions to set up a hatchery, with the result that overproduction of smolts reduced salmon prices and the industry faced allegations of dumping in the US market. It was only in 2005 that key environmental issues were addressed, with a new law focussing on the sustainable production and growth of an already significant and environmentally impactful industry, which will be explored below.

5.1.2 Key constraints to the growth of the Norwegian salmon industry

It seemed clear that the rapid expansion of the industry meant that management guidelines and targets to address potential negative effects had generally not developed in pace with growth. Therefore, there was a need for more coordinated efforts to identify hazards related to open sea cage farming and evaluate environmental risks. In 2009, the Norwegian government identified 5 key Goals or areas of environmental concern that threatened the sustainability of the Aquaculture industry that required to be addressed in the 'Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry' (Anon, 2009b) and which are set out in Table 2.

Table 2: The five primary goals for the future development and sustainability of the Norwegian aquaculture industry (Norwegian government, 2009)

Goals	Threat	Process of concern	Endpoint concern	Management goal
Goal 1: Disease	Salmon lice	Salmon lice from fish farming affects wild fish	Salmon lice from fish farming significantly increase the mortality of wild salmonids	Disease in fish farming will not have a regulating effect on stocks of wild fish, and as many farmed fish as possible will grow to slaughter age with minimal use of medicines.
	Viral diseases i.e. PD, IPN, HSMI, CMS	Disease transmission from fish farming affects wild fish	Viral transmission from fish farming significantly increase the mortality of wild salmonids	Disease in fish farming will not have a regulating effect on stocks of wild fish, and as many farmed fish as possible will grow to slaughter age with minimal use of medicines.

Goal 2: Genetic interaction	Escapes of farmed salmon	Farmed escaped salmon successfully interbreed with wild salmon populations	Changes observed in the genetic characteristics of wild salmon populations	Aquaculture will not contribute to permanent changes in the genetic characteristics of wild fish populations
Goal 3: Pollution and discharges	Discharges of organic material: local effects (ii) regional effects	Emissions of organic materials to the surrounding environment	(i) Unacceptable change in sediment chemistry and faunal communities in the production zone; (ii) Significant change in bottom communities beyond the production zone—regional impact	All fish farming locations in use will maintain an acceptable environmental state and will not have higher emissions of nutrient salts and organic materials than the receiving waters can tolerate.
	Discharges of nutrients: local effects regional effects	Emissions of nutrients to the surrounding environment	(i) Nutrients from fish farms results in local eutrophication; (ii) Nutrients from fish farms results in regional eutrophication	All fish farming locations in use will maintain an acceptable environmental state and will not have higher emissions of nutrient salts and organic materials than the receiving waters can tolerate.
Goal 4: Zoning				The aquaculture industry will have a location structure and zoning which reduces impact on the environment and the risk of infection.
Goal 5: Feed and feed resources				The aquaculture industry's needs for raw materials for feed will be met without overexploitation of wild marine resources.

5.1.3 Pollution and discharges

During the marine phase of intensive salmonid culture, the cage or net pen rearing systems are situated in a large body of water and solid organic wastes, i.e. waste feed and faeces, passes through the bottom of the cage and settle in the surrounding area. The most severe impact has been associated with poor currents and water circulation, where general conditions and benthic fauna are negatively impacted mainly because of the lack of oxygen in the sediment after high bacterial respiration (Soto and Norambuena, 2004). In an optimal situation, the farm should be located at a site with high water currents, which aid organic matter dispersal and prevent accumulation below the cages. In addition, moving the cages and the fallowing of sites between production cycles avoids the build-up of solid wastes (See Table 2; Goal 3).

Requirements before new farms can become operational that include an Environmental impact assessment of new farms (Table 3). In general terms, an EIA requires an operator to set out what it intends to do, determine a baseline for the site (for example what the current environment looks like) and then determine what potential impacts that these activities will have on this baseline. Once this is done, the operator will tend to suggest mitigation measures when possible to reduce the impacts to as 'low as practically possible'. The results of this EIA are then opened up to public and regulatory consultation and approval so that improvements can be suggested and/or issues raised. A finalised EIA is then usually attached to planning consent and further informs the final decision making process (basically asking regulators to agree if the potential impacts are acceptable). Finally, the EIA process usually requires the operator to put forward a monitoring program to allow for the continuous assessment of the impacts of the operation over time.

Table 3: Regional requirements before farms can become operational

Region	Requirements before receiving a license to farm salmon
Norway	Each farm must provide either the shire or Fiskeridirektoratet with an Environmental Impact Assessment (including size of the farm, biomass, potential effects on wildlife and environment), as well as management plans for escaped salmon, jelly fish invasions, algae blooms and predatory attacks. Furthermore, the farmer must provide a retention plan for escapes and a diploma or certificate that they are allowed to farm salmon (Aquaculture course level-II).
Chile	A license will not be issued unless an Environmental Impact Assessment is accepted by the Undersecretary or Sub-Secretariat for Fisheries or the Undersecretary or Sub-Secretariat for Marine Affairs. The assessment should include information about; potential risks for human health from effluents or discharges, significant alterations on renewable resources such as soil, water or air, if communities would have to resettle, if the environment would be seriously altered or if other resources or settlements would be affected, if tourist attractions, scenic areas or culturally important monuments or locations would change.

5.1.4 Sea lice

The levels of sea lice infestation on farmed salmonids, a historical problem in Norway, has been closely regulated on farms since 1997 in order to reduce the harmful effects on wild and farmed fish (Heuch *et al*., 2005). Indeed, effective methods of controlling the impact appeared to be critical for sustainable expansion of Atlantic salmon production (Jevne *et al*., 2021).

From 2000 to 2013, the legal lice infection thresholds, enforced by the Norwegian Food Safety Authority (NFSA), were set to 0.5 adult female lice per fish, or 3 lice per fish of other mobile stages, i.e. adult males or pre-adult mobiles, during the period spanning Jan 1st –Aug 31st, and 1 adult female or 5 other motile stage per fish during the wild smolt migration period. However, in 2013, the threshold for taking action were significantly reduced to 0.2 lice per salmon on average in week 16–22 (wild smolt migration period), and less than 0.5 lice per salmon in remaining season. If thresholds are exceeded, it is mandatory for the farmer to treat or slaughter their fish within two weeks. The

NFSA also requires farmers to count sea lice in their pens weekly if water temperatures are > 4 °C, bi-weekly if < 4 °C (Table 2; Goal 1).

In October 2017 The Norwegian Department of Fisheries and Aquaculture introduced the new and somewhat controversial 'Traffic light system' (Vollset *et al*., 2017; Myksvoll *et al*., 2018); the Norwegian coastline was divided into 13 production zones, each with an environmental indicator to determine whether the sea lice threat is low (green), medium (yellow) or high (red) based on regularly monitored sea lice counts of wild sampled salmon, thus allowing the salmon industry to grow (green), freeze production (yellow) or reduce production (red). This gauge is used as an indication of production status, i.e. growth of farmed stock within the respective production zone (Myksvoll *et al*., 2018). This system that relies on the principal that sea lice pressure on wild fish is key to growth has attracted criticism as it does not take account of other external factors, e.g. nutritional status, health status and immune competency, etc.

With the emergence of chemical resistance by sea lice and the associated reduction in the use of chemical-based treatments, there has been considerable research and development carried out in Norway to explore alternative delousing methods, with varying degrees of success. Based on the premise that sea lice are more prevalent in the surface layers of the water, snorkel cages (a fine mesh net ceiling preventing fish from swimming in the surface waters of the cage) (Fig. 13 a), and skirts (fine mesh nets around the upper parts of cages) (Fig. 13 b) are being trialled to prevent sea lice attaching to farmed salmon (Stien *et al*., 2016, 2018; Grøntvedt *et al*., 2018). Mechanical and thermal delousing methods, i.e. flushing salmon with clean sea water at ambient temperature or elevated temperatures (28-34 ºC) have also been recently introduced and, although they are stressful and potentially lead to elevated salmon mortality rates post-treatment (Gismervik *et al*., 2019; Nilsson *et al*., 2019; Overton *et al*., 2019), they are, at present, the most common whole cage lice removal method currently applied in Norway.

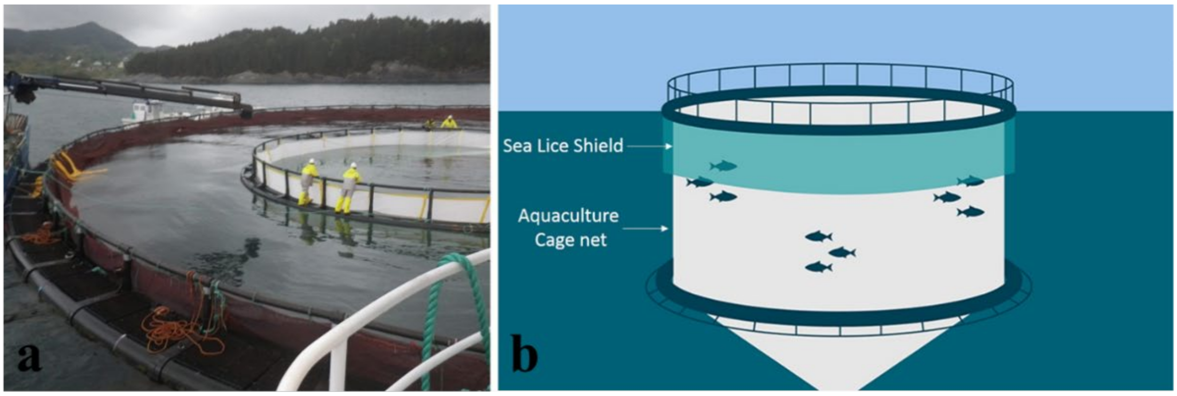

Figure 12: a) Photo of a large circular salmon cage with centre 'snorkel', i.e. tube in the net ceiling allowing fish to access the surface to fill swim-bladders; b) representation of a lice skirt or shield around a marine cage

Over the last ten years or so concern has prompted investment in biological control methods that have minimal welfare impacts upon salmon, specifically the use of 'cleaner fishes', i.e. lumpfish (*Symphodus melops*) (Fig. 8), ballan wrasse (*Labrus bergylta*), goldsinny wrasse (*Ctenolabrus rupestris*) and cuckoo wrasse (*Labrus mixtus*) that eat attached pre-adult and adult lice stages directly off salmon (Imsland *et al*., 2015, Powell *et al*., 2018). The use of cleaner fishes as biological control agents of salmon lice began in the late 1980s (Bjordal, 1991, Torrissen *et al*., 2013) and in Norway increased rapidly from 2012, (Overton *et al*., 2019); by 2018, 49 million cleaner fish were stocked in Norway, with 65% of farms using them (wrasse: 18 million; lumpfish: 31 million; Norwegian Directorate of Fisheries, 2019). Recent research has shown that efficacy is minimal and high losses of cleaner fish and incidence of disease do not fulfil fish welfare requirements (Overton *et al*., 2020).

Figure 13: Lumpfish or lumpsucker (*Cyclopterus lumpus*)

5.1.5 Infectious diseases

Vaccines are recognised as critical tools for the prevention and control of fish diseases especially for Atlantic salmon, for which they are used routinely and recognised as an essential route to the reduction in use of antibiotics within the aquaculture industry and have been seen to significantly reduce antibiotic usage in salmonid aquaculture in Norway (Fig. 14).

Vaccination is a process by which protective immune response is induced in animals through the administration of preparations of antigens derived from pathogens and made non-pathogenic by means of heat or other ways and stimulate fishes' immune response and increase protection against diseases. The fish vaccination programme was initiated in 1942 with the first commercially available vaccine against *Aeromonas salmonicida* (Roar and Van Muiswinkel, 2013; Ayalew and Abunna, 2018); Ingunn *et al*., 2005) and since that time advances in biotechnology and immunology has led to development and commercialization of many other fish vaccines like DNA vaccines, Nano vaccines, subunit vaccines, genetically modified vaccines and polyvalent or multivalent vaccines (Dadar *et al*., 2017); Plant and La Patra, 2011). There are currently 24 licenced fish vaccines for some economically important fish species for treating bacterial and viral diseases and 18 for salmonids (Shefat, 2018; Adams and Subasinghe, 2019; Adams, 2019) (Table 4).

The following table (Table 4) lists commercially available vaccines for salmonids, including those targeting both bacterial and viral pathogens. While vaccines for bacterial diseases have been widely adopted and are generally effective, viral vaccines vary in efficacy and are often used as part of broader disease management strategies.

Table 4: Commercially available vaccines against major bacterial and viral infections for salmonids

Name of vaccine	Species vaccinated	Targeted disease
Arthrobacter Vaccine	Salmonids	Columnaris disease
Vibrio anguillarum-Ordalii	Salmonids, Rainbow trout	Vibriosis
Aeromonas salmonicida Bacterin	Salmonids	Furunculosis
Yersinia ruckeri Bacterin	Salmonids	Yersiniosis
Listonella anguillarum Vaccine	Salmonids seabass, yellowtail	Vibriosis
Vibrio salmonicida Bacterin	Salmonids	Coldwater Vibriosis
Vibrio anguillarum-salmonicida Bacterin	Salmonids	Vibriosis
Moritella viscosa Vaccine	Salmonids	Winter ulcer or Wound Disease
Enteric Red Mouth (ERM) Vaccine	Salmonids	Enteric red mouth disease

Pasteurella Vaccine	Salmonids	Pasteurellosis
Aeromonas hydrophila Vaccine	Salmonids	Motile Aeromonas Septicaemia
Piscirickettsia salmonis Vaccine	Salmonids	Piscirickettsiosis
Flavobacterium psychrophilum Vaccine	Salmonids, FW species	Flavobacteriosis
Renibacterium salmoninarum Vaccine	Salmonids	Bacterial Kidney Disease
Infectious Hematopoietic Necrosis Virus Vaccine	Salmonids	Infectious hematopoietic necrosis
Infectious Pancreatic Necrosis Virus Vaccine	Salmonids	Infectious pancreatic necrosis
Infectious Salmon Anaemia Vaccine	Salmonids	Infectious Salmon Anaemia
Pancreas disease Virus Vaccine	Salmonids	Pancreas Disease

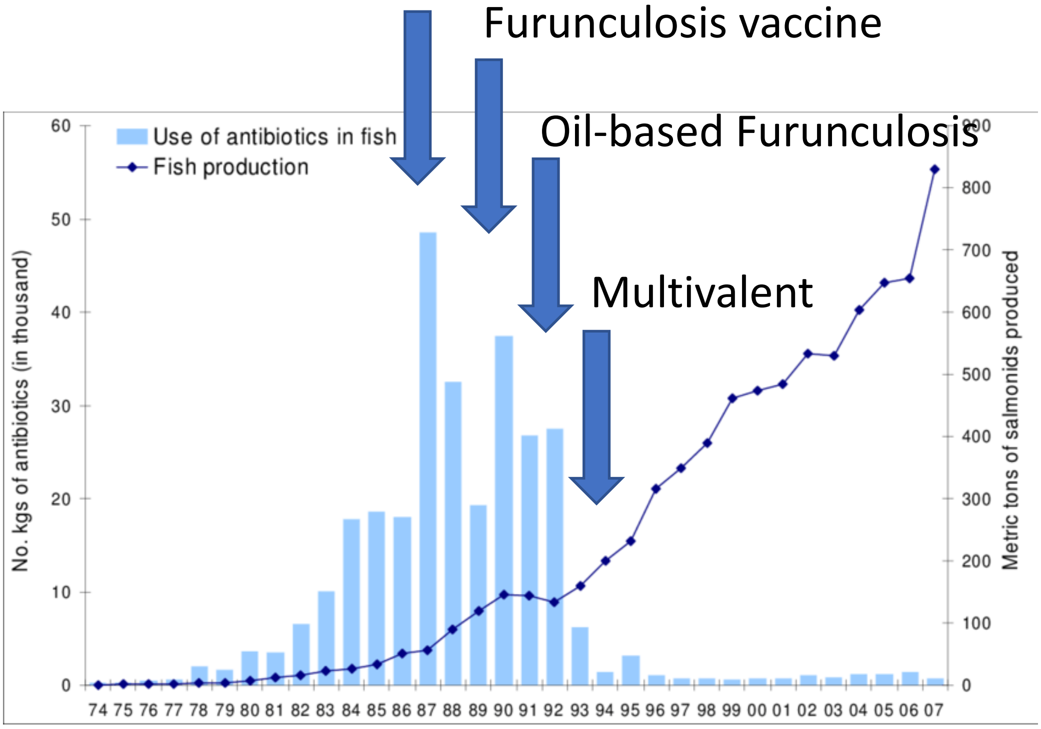

Figure 14: Yearly use of antibiotics used for the treatment of farmed salmon in Norway against MT salmon produced from 1974-2007 showing impact of vaccines

5.1.6 Escapees

Fish escapees from farms has historically been a challenge in Norway and raises a number of concerns. The proportion of escapees from fish farm facilities against the average total wild adult Atlantic salmon returning to spawn in rivers in Norway between the years 1993-2016 is shown in Figure 15. Worryingly, the accuracy of this data has been called into question; the analysis of catch statistics and tagging studies suggests that the numbers of escapees in Norway was 2-4 times higher in the years between 2005-2011 (Skilbrei, Heino and Svasand, 2015). Of further concern is the fact that 90% of the global wild stocks of Atlantic salmon live in the north-eastern Atlantic Ocean, i.e. Norway, Iceland, Scotland and Ireland, and 85% of these stocks are listed as vulnerable, endangered or critical (Aquaculture and Fisheries (Scotland) Act, 2007).

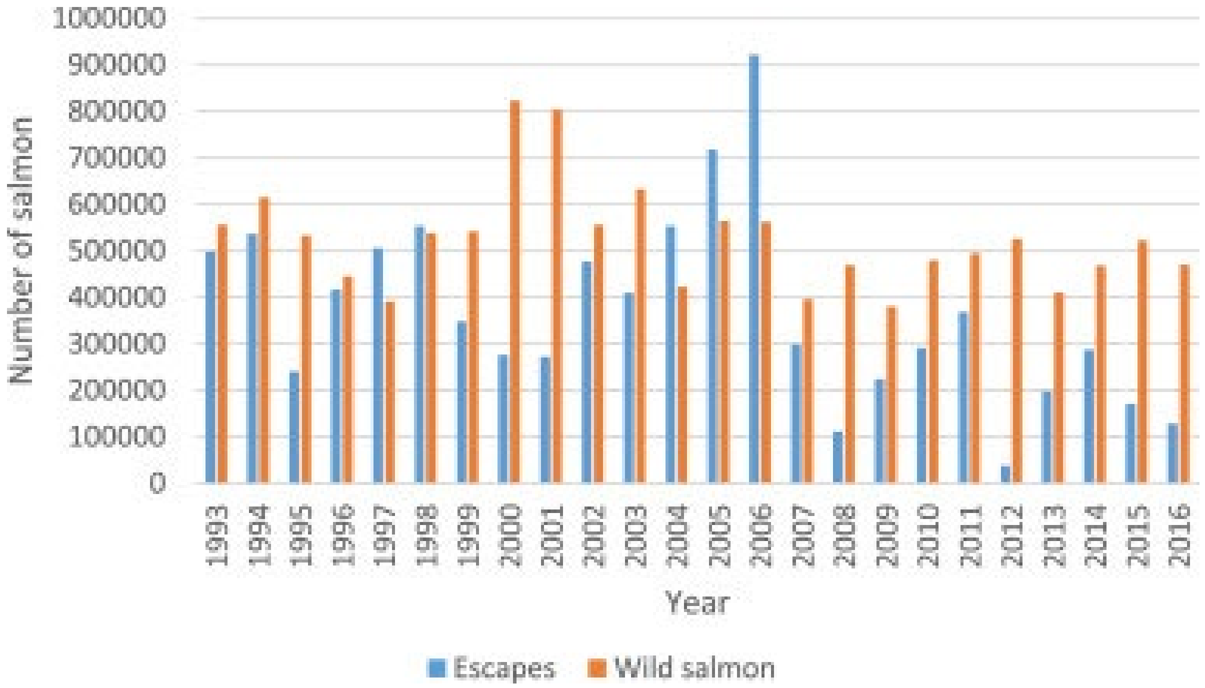

Figure 15: Yearly escape of salmon from fish farms and inflow of wild salmon to Norwegian rivers.

***Source:** Fiskeridirektoratet, 2016; Anon, 2017). Taken from Olaussen, 2018.*

Norway aims to have zero escapes from salmon farm sites and requires that farms have trained personnel and a retention plan in place (European Commission, 2012), not just because potentially negative impacts on wild stocks, but also because of the economic loss that escapees implies (Luthmann, Jonel and Troel, 2019) however there is currently no escape cap in Norwegian legislation (Table 2). In 2019, a new approach to the risk assessment of Norwegian aquaculture was established (Grefsrud *et al*., 2019), specifically to address the challenge of escapees and genetic interactions of domesticated escapees in wild populations in the future. However, as many wild populations in Norway are already introgressed with domesticated escapees (Glover *et al*., 2013; Karlsson *et al*., 2016), the assessment of risk of introgression was defined as the assessment of risk of further introgression of domesticated escapees in wild populations.

In addition to regulatory oversight and risk assessment frameworks, Norway has implemented technical standards to reduce escape incidents. The NS 9415:2021 standard sets out detailed requirements for the design, installation, and operation of floating aquaculture facilities, including specifications for mooring systems, net strength, and site-specific environmental assessments. This standard has contributed to a measurable reduction in escape events and is widely regarded as a best-practice model internationally.

Biological containment strategies, such as the use of triploid or all-female salmon, have also been explored in Norway to reduce the risk of escapees establishing breeding populations in the wild. While these approaches are not universally applied, they are used in specific contexts where reproductive containment is a priority, particularly in sensitive or high-risk environments.

5.1.7 Feed and feed resources

As has already been seen that salmon feed composition has changed considerably during the relatively short history of intensive salmon farming; in 1990 around 65% of Norwegian salmon aquafeed was composed of ingredients of marine origin, whereas in 2013 it had reduced to c. 20% (Fig. 9). However, this does not form part of Norwegian legislation requirements but is driven by the market (farmers do not want to spend money on expensive fishmeal if it can be avoided).

5.1.8 Norway Conclusions

Norway currently ranks first amongst the major global salmonid producers, accounting for 1.4 million MT live weight in 2018 (FAO, 2020); it was only in 2005 that key environmental issues were addressed, with a new law focussing on the sustainable production and growth resulting in the development of a valuable industry. It is not fair to say though that the Norwegian regulatory environment is the strongest in the world with a significant change in focus towards sustainable development. Indeed, new licenses are now extremely limited and often only to RAS based systems. Norway's approach to managing escapees combines regulatory, technical, and biological strategies. The adoption of NS 9415:2021 and the targeted use of sterile or all-female stocks in certain regions reflect a multi-layered strategy to minimise ecological risks while supporting continued industry development. Companies wishing to expand current production are currently only able to do this through auctioning of existing biomass permits.

5.2 Chile

5.2.1 Specific issues in the Chilean salmon industry

The history of the salmon farming industry in Chile is a very interesting case study on resilience. Chile currently ranks 2nd amongst the major global salmonid producers, with 1.1 million MT live weight of farmed salmonids produced in 2022 (FAO, 2024). The main farmed species is the Atlantic salmon (*S. salar*) but also rainbow trout (*O. mykiss*) and coho salmon (*O. kisutch*) are farmed, with the marine, on-growing phase carried out in the austral or southern regions of the country, i.e. in the Patagonian fjords and channels of Los Lagos, Aysen and Magallanes (Regions X, XI and XII, respectively) (Quinones *et al*., 2019). The Chilean salmon industry began in the mid-1970s and, by 2007, was viewed to be amongst the most competitive in the world (Asche *et al*., 2009). This success can be seen to be due to a number of factors, i.e. rich natural and environmental resources, a supply of domestic fishmeal, as well as a business and political environment that clearly favoured the development of export-oriented industries (Barton 1998; Bjørndal & Aarland 1999; Bjørndal 2002; Barton & Murray 2009; Asche & Bjørndal 2011). Key also were the low costs of labour and hence lower production costs; by the end of the 1990s, Chilean-produced salmon was around 50 cents per dollar per kilogram cheaper than the salmon produced in Norway (Bjørndal & Aarland 1999; Bjørndal 2002).

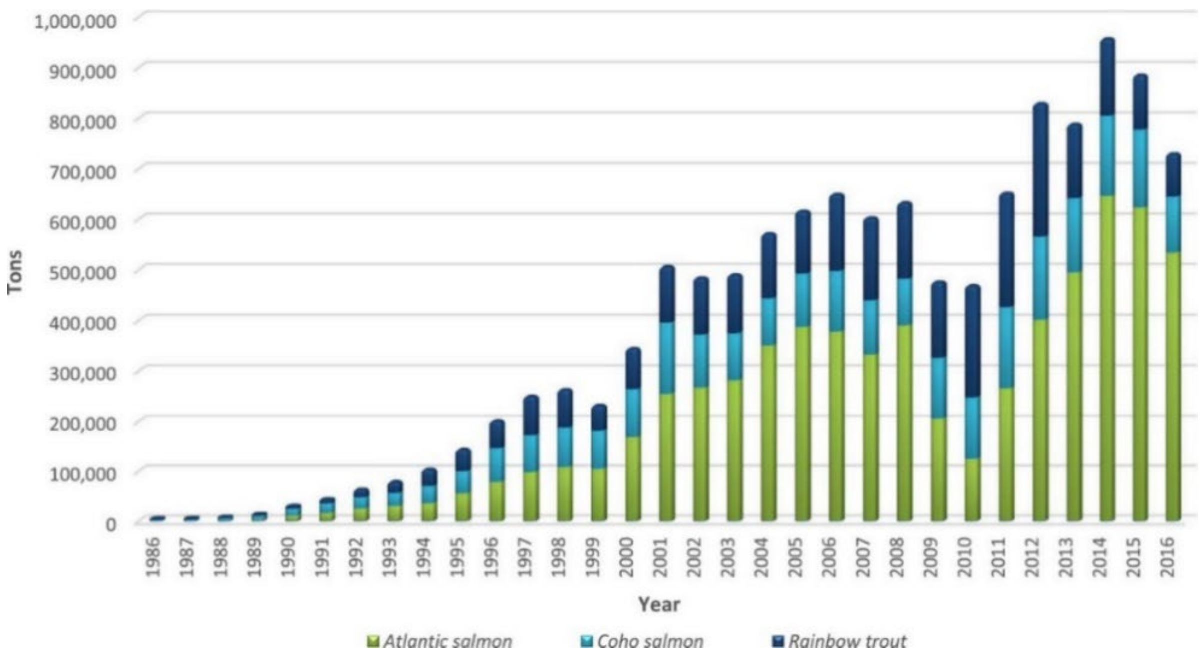

Figure 16: Evolution of Chilean salmon industry production between 1986 and 2016

Source: Lhorente *et al*., 2019.

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As the industry grew and production intensified, epizootics or disease outbreaks occurred, however it was the 'ISA Crisis' in 2007 that dealt a devastating blow to the Chilean salmon industry. Infectious Salmon Anaemia (ISA) is a serious and highly contagious viral disease affecting farmed Atlantic salmon, caused by the Infectious Salmon Anaemia virus (ISAV), with reported mortality rates of up to 100% in the worst cases (Asche *et al*., 2009; Fischer, Guttormsen, and Smith, 2017; Quezada and Dresdner, 2017). Compounded by the appearance of the sea lice (*C. rogercresseyi*) and the bacterial disease Piscirietsiosis, Chile's aquaculture production, which had reached c. 700, 000 MT in 2007, was seen to dramatically drop in 2009, reaching an all-time low in 2010 (Asche *et al*., 2018) (Figure 16). The disease not only had devastating effects on productivity but also caused a social crisis due to job losses (c. 20,000), particularly in the Los Lagos and Aysen Regions (Iizuka and Katz 2011; Iizuka and Zanlungo, 2016).

It may well be that 'the fast growth and lack of control of the Chilean salmon industry' (The Norwegian Veterinary Institute, 2016) was responsible for the ISA catastrophe in 2007. What is clear, however, is that the Chilean salmon industry, as susceptible as it was to environmental and disease events, showed remarkable resilience and has shown a rapid rebound since then. It is important to note that, due to the importance of salmon farming to the Chilean economy, the Government was particularly responsive (Alvial *et al*., 2012). The rapid response to this crisis resulted in significant changes to the Chilean production model of salmon farming (Iizuka and Jorge Katz 2015; Hosono *et al*., 2016; Chavez *et al*., 2019), which now appears to have evolved to include many of the international recommended best practices (Fuentes and Engler, 2016; Alvial, 2017).

5.2.2 Changes to the existing regulatory framework

Following the crisis, dramatic modifications, both short term and more long term, were made and reforms were refined and incorporated into the General Law of Fisheries and Aquaculture (GLFA) (Chavez *et al*., 2019). (See Annex 1).

The strengthening of the legal regulatory framework for aquaculture production was achieved by addressing such key issues such as marine spatial planning, environmental protection and sanitary measures (biosecurity) and the current framework now includes;

- Requirements before new farms can become operational that include an Environmental impact assessment of new farms (Table 3);
- Renewal of existing aquaculture leases subject to strict compliance with environmental regulations (see above);
- Defining of geographical areas for monitoring and surveillance;
- Protocols to prevent escape and to recover escaped fish; there is no maximum escape cap (as in Norway) – note Atlantic salmon, Coho and rainbow trout salmonids are potentially invasive species in Chile (as they would be in Falklands).
- New, more stringent production standards, e.g. a mandatory fallow period between production cycles, reduction in stocking densities (cage biomass) and reducing the concentration of farms within a given area and moving farms to new production areas especially Aysen and Magallanes regions (Iizuka and Zanlungo, 2016). (Note farms had been concentrated around Puerto Monte and Chiloe Island in the Puerto Monte area);

- Regular monitoring of the environmental conditions of the water column and the benthos and the development of tools to measure sediment aerobic conditions as an indicator compatible with the potential carrying capacity of the water body;
- The initiation of the 'barrio' (neighbourhood) or 'group of concessions' system for farms located within a similar geographical, oceanographic and epidemiological area, requiring that all farms must follow synchronised production cycles and collectively monitor and manage their health and disease status resulting in better control of disease transmission and reduction in disease outbreaks;
- Most critically, strengthening existing sanitary regulations with the introduction of a new self-reporting system for both health status and environmental information, with most importantly the implementation of sanctions if breached (Iizuka and Katz, 2015).

5.2.3 Sea lice management practices

The management of sea lice (*Caligus rogercresseyi*) in Chile offers a valuable case study for the Falklands, particularly given the potential for this parasite to emerge in new regions where suitable hosts and farming conditions exist. Since its first detection in Chilean salmon farms in the late 1990s, *C. rogercresseyi* has become the most economically significant parasitic threat to the industry, prompting the development of a wide range of control strategies (Bravo & Treasurer, 2023).

Initially, Chile relied heavily on pharmacological treatments, including emamectin benzoate, pyrethroids (e.g. deltamethrin, cypermethrin), organophosphates (e.g. azamethiphos), and benzoylureas (e.g. lufenuron, hexaflumuron). However, widespread and repeated use led to the rapid development of resistance in *C. rogercresseyi*, necessitating a shift toward integrated pest management (IPM) approaches. By 2019, the volume of antiparasitic medicines used reached 20.52 g per tonne of harvested salmon, before declining to 7.72 g/tonne in 2021 following the introduction of newer compounds and non-chemical methods.

Among non-pharmacological treatments, freshwater baths have proven particularly effective, with reported reductions in adult lice exceeding 80% when applied for 90–120 minutes. Chilean farms have also trialled mechanical delousing systems (e.g. thermal and flusher systems), though adoption has been limited due to concerns over fish welfare and increased susceptibility to secondary infections. Biological control using native cleaner fish species has not been successful to date, with trials showing limited efficacy and potential for these species to act as lice reservoirs rather than removers.

Preventative strategies have also been explored. These include:

- **Functional feeds** that modulate the host's immune response and reduce lice attachment.
- **Selective breeding** for lice resistance, which is now integrated into commercial breeding programmes.
- **Vaccines**, though still in early development, with limited field efficacy.
- **Physical barriers** such as cage skirts, which have shown mixed results due to hydrodynamic and oxygenation challenges.

Chile's regulatory framework has evolved to support these strategies. The introduction of the "Aggrupation of Salmon Concessions" (ACS) system has enabled coordinated treatments and fallowing across farms within defined epidemiological zones. Treatment thresholds are now set at ≥3 gravid females per fish, with mandatory harvests triggered by repeated exceedances. Monitoring is mandatory and must be conducted weekly by certified personnel.

For the Falklands, the Chilean experience underscores the importance of:

- Avoiding over-reliance on chemical treatments.

- Investing early in infrastructure to support non-chemical and preventative methods.
- Establishing robust monitoring and reporting systems.
- Coordinating treatments across farms to reduce reinfestation pressure.
- Maintaining a precautionary approach, particularly given the presence of *E. maclovinus*, a known host of *C. rogercresseyi*, in Falklands waters.

5.2.4 Harmful algal blooms (HABs)

In recent years an increase in the occurrence of harmful algal blooms (HABs) and jelly fish swarms, triggered by warming waters and nutrient rich environments, has led to mass mortality events and related economic losses for the salmon industry. Complex gill disease (CGD), a multifactorial condition affecting the gills of farmed Atlantic salmon, is caused by mechanical damage of the gills due to these environmental stressors such as harmful algae and jellyfish, subsequently compounded by infectious agents, such as bacteria, viruses and parasites, causing secondary diseases. It presents as gill inflammation, mucous and epithelial cell proliferation and osmoregulatory and respiratory distress, leading to reduced growth, increased mortality and compromised welfare. Because no single pathogen is responsible, CGD is difficult to diagnose and manage, making it one of the most persistent and costly emerging health challenges in salmon aquaculture. Indeed, the frequency and intensity of HABs have become a permanent threat to the aquaculture industry in southern Chile (Diaz-Tapia et al., 2019; Barria et al., 2022; Carias et al., 2024; Ceballos-Concha et al., 2025). Chile is attempting to tackle this problem using real-time monitoring and predictive modelling to anticipate outbreaks, giving an early warming to aquaculture operations. Careful planning of aquaculture zones can further mitigate the risks.

5.2.5 Knowledge gaps of the Chilean ecosystem

It is important to note that the huge geographical area and heterogenous nature of Chilean Patagonia, where the farms are located, impose a major challenge in terms of the generation of scientific knowledge and understanding of the marine ecosystem and environment, including biodiversity, trophic interactions, populations and community connectivity, biogeochemical cycling and circulation patterns etc. (Quinones *et al*., 2019). This knowledge is important in understanding the impact that farming activities have and how best to mitigate these issues.

However, in the last 10 years, there has been an increase in research efforts focused on Chilean Patagonian ecosystems, with new centres of research funded by the State, i.e. Center for Research in Ecosystems of Patagonia, CIEP; Center of Oceanographic Research COPAS Sur-Austral; Interdisciplinary Center for Aquaculture Research, INCAR; Center for the Study of Multiple Drivers on Marine Sociological Systems, MUSSELS; Millennium Nucleus of Invasive Salmonids, INVASAL; Research Center Dynamics of High Latitude Marine Ecosystems, IDEAL), either located in universities or linked to Regional Governments, e.g. CIEP (Quinones *et al*., 2019). In addition, the government has allocated funding for specific programmes to strengthen the institutional capacity of the Fisheries Development Institute (IFOP) in monitoring and research in areas such as HABS and oceanographic modelling and environmental modelling and pathogen interaction through the Fund for Strategic Investment, administered by SERNAPESCA.

5.2.6 Chilean Conclusion

In the years following the crisis, the Chilean salmon market has remained competitive, taking advantage of the northern hemispheres off-season salmon production for export (Asche *et al*., 2018), diversifying and adding value to salmon products as well as opening up ‘new’ markets, e.g. Latin America and Europe (Banco Central de Chile 2017). In spite of a new drop in production in 2016 due to a severe harmful algae bloom (HAB) outbreak (Montes *et al*., 2018) and the fact that Chile is still facing the usual problems, e.g. escapees, disease outbreaks, precarious infrastructure in remote locations in southern regions of country and higher related transport costs, lower levels of Research and Development, Chile still ranks 2nd amongst the major global salmonid producers (FAO, 2020).

In summary, it is fair to say that Chile went through an extremely dark period of salmon farming which it now has emerged from. However, the issues it has experienced appear to have been learnt from to some degree and legislation and regulation have dramatically improved in recent years. This said, some people would still question the sense of having the second largest production of a species in a country for which it is not even native to its waters.

5.3 Faroes Islands

Salmon farming in the Faroe Islands started in the 1960s, with open-net aquaculture expanding from the 1980s (Bjørndal and Mrdalo, 2023). After severe outbreaks of Infectious Salmon Anaemia (ISA), regulations were overhauled in 2003 to improve productivity while protecting the environment. Today, salmon farming is a major industry, making up half of the country's export value and contributing 8% to its GDP. In 2024, the Faroe Islands produced 87,678 tonnes of salmon, employing around 5% of the workforce[9][10]. As the world's fifth-largest salmon producer, it accounts for 4% of global exports. The industry is now dominated by three companies: Bakkafrost (70%), Hiddenfjord (18%), and Mowi (11%) as of 2021[11].

5.3.1 Regulatory overview

Following disease outbreaks in the early 2000s, the Faroese Veterinarian Act on Aquaculture (FVAA) was introduced in 2003 to improve fish welfare, productivity, and environmental sustainability. Key regulations include mandatory ISA vaccinations, a single-generation fjord strategy with fallowing periods, disease prevention protocols, and specific transport and facility requirements.

Since then, additional legislation[12] has been enacted, including the Aquaculture Act (2009), Animal Welfare Act (2018), Environmental Protection Act (1988), and Biosecurity and Sea Lice Regulations. The Faroese Food and Veterinary Authority (FFVA) and the Environment Agency oversee aquaculture regulation, issuing licenses and environmental permits.

As of 2022[13], there are 35 aquaculture sites, with 32 dedicated to salmon farming. Licenses last 12 years and are transferable, though no company should hold more than 50%, a rule seemingly contradicted by current allocations—Bakkafrost (20 permits), Hiddenfjord (6), and Mowi (remaining sites). Most suitable sites are already in use, prompting interest in expanding into offshore locations, requiring technological advancements and industry investment.

5.3.2 Environmental Impacts and Monitoring

Chemical Inputs and Treatments in Faroe Islands Aquaculture

Sea-Lice Treatments

Sea lice, particularly *Lepeophtheirus salmonis*, remain a major challenge in the region's aquaculture. Regulation No. 93 (2021) enforces sea lice limits of 0.5 adult female lice per fish from May to July and 1.0 for the rest of the year. Monitoring, conducted biweekly by an independent third party, impacts production limits in subsequent cycles. Managing sea lice is a licensing requirement[14].

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[9] Stats - Seafood from the Faroe Islands
[10] Aquaculture Overview for Faroes ecoregion
[11] Seafood Watch
[12] Faroes ecoregion – Aquaculture Overview
[13] Seafood Watch
[14] Atlantic salmon Salmon seafood recommendation | Seafood Watch

Treatment use has been minimal, averaging 1.31 treatments per production cycle (2019-2021). Emamectin Benzoate was the most used (85% of treatments), while Diflubenzuron accounted for the highest volume (75% of total pesticide use). Azamethiphos is also applied, though increasing resistance is a concern. The Faroese Food and Veterinary Authority (FFVA) publishes weekly updates on chemical treatments, including method, quantity, location, and application date.

There is a growing shift toward non-chemical solutions such as cleaner fish (Lumpfish), mechanical, and thermal treatments. However, chemical treatments have seen occasional increases due to persistent lice issues and resistance. Regulatory focus remains on farmed salmon, as there are no wild salmon populations in the Faroe Islands, with limited evidence of impact on wild trout[15].

Antibiotic Use

Since the implementation of strict veterinary regulations in 2003, antibiotic use has been zero since 2004, attributed to rigorous fish welfare policies and monitoring[16].

Waste

Aquaculture waste[17], including chemicals, feed, and effluent, significantly impacts the marine environment, leading the Faroese Environment Agency to classify fish farming as a “highly polluting activity.” The Environment Agency oversees benthic monitoring, while the Faroe Marine Research Institute monitors water quality.

Third-party benthic surveys occur at peak biomass and influence future production limits. Sites exceeding pollution thresholds must take corrective action, such as fallowing, and may face restrictions. Between 2018-2021, 47% of sites were classified as polluted or highly polluted.

Monitoring primarily assesses heavy metals and organic waste beneath pens. Feed use doubled between 2008 and 2021, despite efforts to minimize excess through cameras and sensors. While benthic fauna are not formally regulated, some surveys occur under third-party certification requirements.

Plastic Use and Marine Wildlife Interactions

The Marine Environmental Act[18] regulates marine pollution but is not specific to aquaculture.

Since 2020, lethal control of marine mammals at aquaculture sites has been banned, and accidental deaths (e.g., entanglements) must be reported. Previously, 550-2,000 seals were culled annually before a reduction in bird deaths and stricter protections[19].

Escapes

Aquaculture operators must report fish escapes, including numbers, cause, response actions, and prevention measures. Contingency plans must be FFVA-approved. The largest escape occurred in 2020, with 370,000 fish released. While companies must attempt recapture, little information exists on effectiveness. Escapes pose a low environmental risk due to the absence of native salmon populations and limited evidence of escaped fish establishing in the wild[20].

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[15] Faroes ecoregion – Aquaculture Overview
[16] Atlantic salmon Salmon seafood recommendation | Seafood Watch
[17] Atlantic salmon Salmon seafood recommendation | Seafood Watch
[18] Environmental Protection - Seafood from the Faroe Islands
[19] Faroes ecoregion – Aquaculture Overview
[20] Atlantic salmon Salmon seafood recommendation | Seafood Watch

In general, aquaculture is supported by the public and there appear to be no NGOs in the islands campaigning against aquaculture operations.

5.4 Scotland

In Scotland, Atlantic salmon farming is the dominating aquaculture activity which significantly contributes to the national economy through exports. Farms are primarily located on the West and Northwest coasts, as dictated by Scottish Planning Policy. However, the industry faces ongoing environmental challenges, particularly concerning salmon lice and their impact on wild fish populations.

5.4.1 Regulatory Overview

Following parliamentary inquiries in 2018, the Scottish Government launched a review of aquaculture regulations, leading to the creation of the Scottish Aquaculture Committee and the publication of the *Vision for Sustainable Aquaculture* (July 2023). This strategy outlines a long-term framework (until 2045) focused on sustainable growth, environmental protection, and balancing industry interests with community and conservation concerns.

Scottish salmon farming is regulated by multiple agencies requiring approvals for Planning Permission, Marine Licenses, and Environmental Licenses. A key regulatory measure is the Maximum Allowable Biomass (MAB), which sets production limits based on environmental impact assessments. Since 2019, stricter environmental modelling has enabled larger farms while ensuring better control over pollution, genetic introgression with wild salmon, and sea lice management.

Scotland enforces several laws to mitigate aquaculture's environmental impact, including the Aquaculture and Fisheries Act (2007) and the Aquatic Animal Health Regulations (2009), which mandate strict reporting and record-keeping[21]. Additionally, the DEPOMOD computer model[22], developed by the Scottish Association for Marine Science, helps predict the seabed impact of fish farming based on feeding rates and water currents. Some EU regulations on animal health and welfare remain in place, ensuring adherence to high environmental and ethical standards.

5.4.2 Environmental Impacts

Sea-Lice Treatments

Scottish fish farms must report weekly sea lice counts to the Fish Health Inspectorate (FHI), which inspects sites and enforces control measures. If lice levels reach 2.0 adult female lice per fish, monitoring is increased, and if they exceed 6.0 per fish, farmers must treat or harvest fish until levels drop. A severe outbreak between 2014 and 2016 saw lice numbers rise above 1.0 per fish, but from 2018 to 2022, levels remained lower at around 0.5 per fish[23]. Treatments include emamectin benzoate (the most common in-feed treatment), azamethiphos (used in the largest amounts as a bath treatment), and hydrogen peroxide, with 5.3 million litres applied in 2018. While overall pesticide use has declined, farms still carry out around three treatments per site each year. Orkney farms use far fewer chemicals, with just seven treatments recorded in 2020. SEPA's Sea Lice Framework[24] aims to protect wild salmon by imposing stricter controls in Wild Salmon Protection

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[21] Acts of Scottish Parliament (2007) Aquaculture and Fisheries (Scotland) Act 2007. Available at: https://www.legislation.gov.uk/asp/2007/12/contents

[22] Scottish Association for Marine Science (2023) DEPOMOD Modelling Software. Available at: https://www.sams.ac.uk/science/projects/depomod/

[23] Impacts of lice from fish farms on wild Scottish sea trout and salmon: summary of science - gov.scot

[24] Detailed proposals for a risk-based, spatial framework for managing interaction between sea lice from marine finfish farm developments and wild salmonids in Scotland - Scottish Environment Protection Agency - Citizen Space

Zones (WSPZs) along migration routes, where farms must keep lice numbers low as part of their licensing conditions.

Antibiotic Use

Scotland has significantly reduced antibiotic use in salmon farming over the years. In 2006, farmers used 5,000 kg of antibiotics to produce 130,000 tonnes of salmon, but by 2015, this had dropped to less than 200 kg, even as production increased to 170,000 tonnes[25]. However, antibiotic use rose again from 2015 to 2021, peaking at 40 mg per kg of salmon produced, before falling to 18 mg/kg in 2022, with a total of 3.1 tonnes used. The main antibiotics used are oxytetracycline and florfenicol, both classified by the World Health Organization (WHO) as highly important for human medicine. Antibiotic use varies by region, with Orkney consistently recording very low levels.

Waste

Scottish fish farms must report their waste emissions every three months, including levels of nitrogen, phosphorus, zinc, copper, and organic carbon. SEPA provides a public database showing each farm's biomass, benthic monitoring results, and chemical use. In 2019, new Depositional Zone Regulations[26] were introduced, and farms are now restricted by a 100-metre Maximum Mixing Zone[27], where waste can disperse without causing environmental harm. If pollution spreads beyond this limit, farms must take corrective action. Computer modelling is used to predict how waste moves in different environments, and continuous monitoring ensures farms comply with environmental standards set in their permits.

Plastic Use and Recycling

The Marine Litter Strategy[28] for Scotland, first published in 2014 and updated in 2022, focuses on reducing plastic pollution from aquaculture. It includes commitments to improve recycling of old fish farm equipment and create better waste management systems. Scotland is also working with the European Committee for Standardisation (CEN) to develop new sustainability standards for fishing and aquaculture gear, promoting circular design and reducing lost or abandoned equipment.

Wildlife Interactions

Until 2021, fish farms could apply for licences to shoot seals if non-lethal methods failed, but this was banned under the Animals and Wildlife Act (2020)[29]. Acoustic Deterrent Devices (ADDs) were commonly used to keep predators away, but after a Marine Scotland review, strict licensing requirements introduced in 2022 effectively banned their use. These measures aim to protect marine mammals while ensuring fish farms can still manage predator interactions responsibly.

Salmon aquaculture in Scotland remains a highly debated topic, with differing views on how the industry should be run, regulated, and what its future should entail.

5.5 Lessons learnt and mitigation strategies

The development of salmon farming in the Falklands presents an opportunity to learn from the successes and mistakes of other nations. Across the world, salmon aquaculture has expanded

[25] mba_seafoodwatch_atlantic_salmon_scotland.pdf
[26] finfish-aquaculture-annex-2019_31052019.pdf
[27] seabed-mixing-zone-limit_compliance-assessment-method.pdf
[28] Marine litter strategy - gov.scot
[29] Act of Scottish Parliament (2020) Animals and Wildlife (Penalties, Protections and Powers) (Scotland) Act 2020. Available at: https://www.legislation.gov.uk/asp/2020/14/contents/enacted

rapidly, often outpacing the regulations needed to protect the environment. Countries such as Canada and Norway have put significant emphasis on site selection and environmental impact assessments (EIAs). In Canada, cumulative environmental impacts are assessed before approving farm locations, ensuring that the wider ecological consequences of new sites are considered. Norway, on the other hand, links production limits to environmental performance, ensuring farms are held accountable for their impact. The Falklands would benefit from taking a similarly precautionary approach, carefully assessing potential sites and establishing clear environmental thresholds before granting licences. This would help avoid many of the long-term challenges seen elsewhere, where farms have been approved in unsuitable locations, leading to pollution, disease outbreaks, and conflict with local marine ecosystems.

Transparency is another crucial area where global lessons can be applied. In Norway, online dashboards provide real-time access to environmental data from salmon farms, fostering public trust and regulatory compliance. By contrast, in places where transparency has been lacking, such as Chile, public scepticism has grown, with concerns over pollution, disease management, and antibiotic use. If the Falklands were to develop a similar system of real-time data sharing, it could help reassure both the public and regulators that salmon farming operations are being properly monitored.

Selecting an appropriate site for aquaculture is crucial for the success and sustainability of operations. Several factors must be considered to ensure the optimal placement of cages, barges, and marine signals. These factors include bathymetry (site depth), current speed and direction, wind, wave height and period, seabed type, and the incidence of storms and hurricanes. Bathymetry, or the study of underwater depth and seafloor terrain, plays a significant role in site selection. The depth of the water, combined with the average current speed and direction, can influence the concentration of waste sediment around the cages. Key considerations in this regard include:

- **Farm Footprint**: Greater water depths result in a larger farm footprint because mooring lines need to be three to five times the site's depth.
- **Mooring Design**: The depth of the site affects the equipment and materials used for moorings, including their dimensions.
- **Diving Inspections**: Depths >50 m pose challenges for professional divers, requiring specialised training and equipment for anchor inspections.
- **Cage Net Depth**: Cage nets should be no deeper than one-third of the site's depth, with at least 15 m between the net base and the seabed at low tide to allow for better dispersion of waste. Shallow sites necessitate shorter nets, resulting in smaller cage volumes.

Water depth should therefore be studied using marine charts and verified through extensive field surveys during the project development phase (Cardia and Lovatelli, 2015).

Waste management has been a persistent issue in salmon farming worldwide, with organic waste from uneaten feed and faeces often degrading the seabed and surrounding waters. In Canada, rigorous monitoring of benthic conditions is required, while Chile has gone a step further by measuring additional parameters, such as dissolved oxygen levels, to assess wider water quality. However, despite these efforts, waste pollution remains a major challenge in many regions. The Falklands have an opportunity to establish a gold standard from the outset by enforcing strict waste management regulations, ensuring farms operate within the carrying capacity of their locations. Regular monitoring of sediment conditions, coupled with measures such as fallowing sites and optimising feed efficiency, could help minimise environmental damage and ensure long-term sustainability.

Plastic pollution is another growing concern, particularly from lost or discarded equipment. In Australia, a simple but effective system has been introduced, whereby all aquaculture equipment is colour-coded and registered, allowing authorities to trace plastic debris back to its source. This has made it much easier to hold polluters accountable and has encouraged better waste management within the industry. Implementing a similar system in the Falklands would be a straightforward yet highly effective measure to prevent plastic waste from accumulating in marine environments. Given the pristine nature of the Falklands' waters, it would be essential to ensure that salmon farming does not contribute to the global problem of marine plastic pollution.

One of the most pressing challenges in salmon aquaculture is disease management, particularly regarding sea lice (see Section 5.5.1) and antibiotic use. The Faroe Islands have set an excellent example by virtually eliminating antibiotic use since 2004, thanks to stringent disease control measures. Norway has also taken strong action against sea lice, linking production limits to farms' ability to control parasite levels. In contrast, Chile has struggled with excessive antibiotic use, raising concerns about antimicrobial resistance and environmental contamination. For the Falklands, adopting a proactive approach from the beginning would be wise. This could include strict biosecurity regulations, the use of cleaner fish or mechanical lice removal, and robust vaccination programmes to prevent disease outbreaks before they occur. By taking a preventative rather than reactive approach, the industry could avoid the need for excessive chemical treatments, ensuring a healthier environment for both farmed and wild fish populations.

Looking at the bigger picture, many salmon-producing nations are now recognising the need to reform their regulatory frameworks to address environmental concerns. Norway, Scotland, and Chile are all in the process of tightening regulations, often in response to public and scientific pressure. In some cases, this has led to costly retroactive measures, as governments try to fix problems that could have been prevented with better planning from the outset. The Falklands have a unique advantage in being able to learn from these experiences and implement forward-thinking policies before large-scale farming begins. Developing an adaptive regulatory framework—one that evolves based on ongoing scientific research and environmental monitoring—would ensure that the industry remains sustainable in the long run.

Finally, securing a social licence to operate is just as important as meeting environmental standards. In Iceland, opposition to foreign-owned salmon farms has highlighted the need for local communities to be involved in decision-making. Public engagement, transparency, and fair economic benefits are all essential to gaining long-term community support. The Falklands should ensure that salmon farming brings tangible benefits to local people, whether through employment, investment in infrastructure, or direct involvement in decision-making. This would help prevent the kind of public backlash seen in other regions, where communities have felt excluded from decisions that affect their environment and livelihoods.

By drawing on lessons from other jurisdictions, the Falklands can build a salmon farming industry that is both economically viable and environmentally responsible. Thoughtful site selection, transparency, waste management, disease control, and community engagement should all be central to the industry's development. If done correctly, the Falklands could establish itself as a leader in sustainable aquaculture, avoiding many of the environmental and regulatory pitfalls seen elsewhere.

5.5.1 Sea lice management strategies: comparative insights

The management of sea lice has emerged as one of the most persistent and costly challenges in global salmon aquaculture, with both Chile and Norway offering instructive, albeit contrasting, experiences. While the Falklands currently remain free of sea lice, the presence of known host species such as *Eleginops maclovinus* and the potential for future introduction of *Caligus rogercresseyi* underscore the importance of considering this issue from the outset. A comparative review of sea lice control strategies in these two major producing nations provides valuable insights into what has worked, what has not, and what might be cautiously adapted to the Falklands context.

In Chile, *C. rogercresseyi* has become the dominant parasitic threat to farmed salmonids, with the industry initially relying heavily on pharmacological treatments. Over time, however, widespread resistance to compounds such as emamectin benzoate, pyrethroids, and organophosphates has significantly reduced the efficacy of these treatments. More recently, benzoylureas such as lufenuron and hexaflumuron have been introduced, alongside hydrogen peroxide, though even these have shown variable results. Despite regulatory encouragement to reduce chemical use, pharmacological treatments remain the primary method of control in Chile, with non-chemical alternatives only slowly gaining traction.

Freshwater baths have emerged as one of the more promising non-pharmacological options in Chile, particularly against *C. rogercresseyi*, with reported reductions in adult lice exceeding 80% when applied for extended durations. However, the logistical demands of this method—especially the need for large volumes of freshwater and appropriate infrastructure—may limit its applicability in more remote or water-scarce regions. Mechanical and thermal delousing systems have also been trialled, but concerns over fish welfare and increased susceptibility to secondary infections have hindered widespread adoption. Biological control, through the use of native cleaner fish species, has so far proven unsuccessful in Chile, with trials indicating that these species may act more as reservoirs than removers of lice.

Norway, by contrast, has taken a more diversified and regulatory-driven approach. The introduction of the “traffic light system” in 2017 marked a significant shift in how sea lice are managed, linking production growth to lice pressure on wild salmon populations. While this system has attracted criticism for not accounting for broader fish health variables, it has nonetheless provided a framework for adaptive management based on environmental indicators. Norway has also invested heavily in non-chemical treatments, including mechanical and thermal delousing, as well as physical barriers such as snorkel cages and skirts designed to reduce lice attachment by limiting fish access to surface waters. These methods, while innovative, are not without their own challenges, particularly in terms of fish welfare and operational complexity.

Biological control has been more extensively developed in Norway, with the use of cleaner fish such as lumpfish and wrasse becoming widespread. However, recent evaluations have raised questions about the long-term sustainability and welfare implications of this approach, with high mortality rates and limited efficacy reported in some cases. As such, even in Norway, the search for a truly effective and sustainable lice management strategy remains ongoing.

For the Falklands, these international experiences highlight the importance of adopting a precautionary and integrated approach to sea lice management. While the current risk may be low, the potential for future introduction—particularly through the movement of equipment, stock, or natural hosts—cannot be discounted. Establishing robust baseline monitoring, investing in infrastructure that supports non-chemical treatments, and embedding integrated pest management principles into regulatory frameworks from the outset would place the Falklands in a strong position to respond effectively should lice become a concern. Crucially, the emphasis should be on prevention and preparedness, rather than reactive treatment, drawing on the lessons of major producing countries to avoid the costly cycles of resistance and retreat that have characterised sea lice management elsewhere.

5.6 Alternative approaches to cage farming

Recirculating aquaculture systems and submersible offshore cages offer alternative solutions to sea cages nearshore.

5.6.1 Offshore fish farming

Offshore fish farming has emerged as a compelling yet intricate solution to the rising demand for sustainable seafood. By moving aquaculture operations beyond nearshore sites, it is possible to expand production while mitigating the environmental degradation and spatial conflicts that have long plagued coastal fish farming. However, the offshore environment presents its own set of formidable challenges, ranging from extreme weather conditions and strong currents to the necessity of robust and costly infrastructure. The core debate, therefore, revolves around striking a balance between economic viability and environmental as well as operational sustainability.

One of the key contentions within this debate is the type of farming infrastructure that best suits offshore conditions. Open net cages remain the most widely used system due to their relatively low cost and ease of maintenance. However, their vulnerability to the high-energy offshore environment, including strong currents and storms, raises concerns about their long-term viability. Alternative designs, such as rigid and semi-submersible cages, offer greater resilience but require significantly higher capital investment, making them more appropriate for large-scale industrial operations rather than smaller, independent enterprises (Chu *et al.,* 2020).

A promising approach for the future of offshore fish farming lies in its potential integration with other offshore industries, particularly renewable energy. The co-location of aquaculture farms with offshore wind and wave energy systems could provide a more cost-effective and sustainable solution, reducing dependency on land-based infrastructure.

Another approach gaining traction is the use of offshore submersible cages. These present a mix of opportunities and challenges for marine fish farming. One of their most significant advantages is the reduction of risks associated with surface-based aquaculture, including exposure to extreme weather events and parasite infestations. By operating below the water's surface, these cages can provide more stable environmental conditions, helping to reduce fish stress and disease outbreaks. Furthermore, submerging cages allows for aquaculture to take place in locations where wave action and surface conditions would otherwise be too harsh (Sievers *et al.,* 2021).

Despite these benefits, submersible cages also pose notable biological and technical difficulties. For species with open swim bladders, such as salmonids, prolonged submergence can cause buoyancy issues, as they require surface access to regulate their swim bladder volume. This can adversely affect their swimming behaviour, welfare, and overall growth. Innovations such as underwater air domes have been developed to counteract this issue, allowing fish to maintain their buoyancy without needing to surface. Furthermore, rapid submersion can lead to barotrauma in certain fish species that regulate buoyancy through gas exchange with the bloodstream. Monitoring and feeding fish in deep-sea conditions also present logistical challenges that require further technological advancements. Nonetheless, ongoing research suggests that submersible cages could become a viable alternative for sustainable offshore fish farming in the near future (Sievers *et al.,* 2021).

Ultimately, for offshore fish farming to succeed, a combination of innovative engineering, regulatory support, and sustainable business models must align. The sector's future will likely depend on a multi-faceted approach that incorporates technological advancements, environmental stewardship, and economic feasibility. While offshore fish farming holds significant promise, its long-term viability will be determined by the industry's ability to navigate these challenges and create systems that are both profitable and environmentally responsible.

5.6.2 Recirculating Aquaculture Systems

Recirculating Aquaculture Systems (RAS) offer several advantages over traditional sea-pen farming for Atlantic salmon. One of the primary benefits is the ability to control environmental conditions, ensuring optimal water quality, temperature, and biosecurity throughout the fish's life cycle. This controlled environment reduces the risk of disease, eliminates the problem of sea lice infestations, and prevents farmed fish from escaping and potentially interbreeding with wild populations. Additionally, RAS can be located closer to markets, reducing transport costs and the carbon footprint associated with seafood distribution. The technology also minimises nutrient pollution in marine ecosystems, addressing one of the major criticisms of open-net salmon farming (Brown *et al*., 2024).

However, RAS comes with significant challenges. The most pressing issue is the high energy demand required for water filtration, circulation, and temperature regulation, which can raise concerns about the overall sustainability of these systems, especially in regions reliant on fossil fuels. Maintaining water quality is another challenge, as waste accumulation and imbalances in oxygen, carbon dioxide, and ammonia levels can impact fish health. Additionally, the cost of establishing and operating RAS facilities is considerably higher than traditional sea pens, making financial viability a key hurdle for large-scale adoption. While technological advancements continue to improve efficiency, addressing these cost and energy challenges will be crucial for the long-term success of RAS in the aquaculture industry (Brown *et al*., 2024). Land-based aquaponics offers numerous advantages, particularly in water conservation and environmental sustainability. By integrating aquaculture with hydroponic plant production, the system minimises water wastage while efficiently recycling nutrients. Aquaponics can reduce water usage by up to 90% compared to conventional aquaculture, making it a viable solution for sustainable fish farming. Furthermore, the system enhances productivity by optimising nutrient cycling, leading to improved growth rates for both fish and plants. The ability to implement vertical farming techniques also makes aquaponics space-efficient, particularly in urban environments. Additionally, the dual production of fish and crops provides economic diversification, with some farms reporting significantly higher profits compared to traditional agricultural methods. The system’s organic potential further enhances its market value, aligning well with the growing demand for sustainable and chemical-free food production (Okomoda *et al*., 2022).

However, aquaponics is not without its challenges. The high initial investment required for system setup, alongside ongoing energy demands for water circulation and temperature control, can make it less accessible, particularly for small-scale farmers. Salmon aquaponics, in particular, poses additional difficulties due to the species' need for cold, highly oxygenated water, necessitating advanced temperature regulation and aeration. The high-protein diet of salmon also results in considerable nitrogen production, which must be carefully managed to maintain optimal water quality. Balancing fish and plant production is complex, as nutrient requirements must align to prevent deficiencies or excess accumulation. Furthermore, disease management in an aquaponic system is more intricate than in conventional aquaculture, as chemical treatments must be carefully regulated to avoid contaminating plant crops. While aquaponics presents a sustainable alternative to traditional fish farming, its viability for salmon production depends on technological advancements in system design, energy efficiency, and nutrient optimisation (Okomoda *et al.,* 2022).

5.7 Environmental Monitoring and Evaluation

Environmental monitoring and evaluation in salmon aquaculture are essential yet inconsistently implemented worldwide[30]. While some nations enforce stringent assessments before approving new farms, many still lack robust, long-term monitoring strategies. Countries like Norway and Canada have taken steps to ensure cumulative environmental impact assessments, meaning they consider the wider ecosystem rather than just the immediate farm site. In contrast, Scotland has incorporated computer modelling tools like DEPOMOD to predict the impact of fish farming on the seabed, while Tasmania has introduced Broadscale Environmental Monitoring Programs (BEMPs) to track changes in water quality and biodiversity. However, despite these efforts, the industry often expands faster than regulation can keep up, leaving gaps in oversight and enforcement.

As noted earlier in the report, one of the biggest concerns in environmental monitoring is the build-up of waste—both organic and chemical—from aquaculture activities. Excess feed, faeces, and

[30] Report: Environmental legislation influencing Atlantic salmon farming in open net pen systems – A global perspective - Fidra

chemical treatments can create severe pollution, damaging seabed ecosystems and reducing water quality. Scotland has attempted to control this by enforcing maximum mixing zones, which require continuous monitoring to prevent biodiversity loss, while Norway ties permitted production levels to environmental performance. Yet, in places like the Faroe Islands, nearly half of farm sites have been classified as polluted or highly polluted, showing that current monitoring efforts are still not sufficient. The overuse of chemical treatments, particularly for sea lice infestations, further complicates matters, as resistance is growing, forcing farms to rely on non-chemical alternatives such as cleaner fish and mechanical removal.

Transparency is another major challenge. Without publicly available, real-time data, it's difficult to hold farms accountable for environmental damage. Some nations, like Norway and Australia, have made progress by implementing online dashboards that allow the public to access environmental reports on individual farms, ensuring greater regulatory compliance. However, most countries still lack such measures, making it easier for environmental breaches to go unnoticed. The report argues that no nation has properly addressed the environmental impact of salmon farming and recommends a temporary halt on industry expansion until stronger legislation, stricter enforcement, and universal monitoring standards are in place. Without these safeguards, the push for greater salmon production risks long-term damage to marine ecosystems that may be impossible to reverse.

6. Certification in the Salmon Industry

A recent development in the aquaculture sector has been the growth in so-called sustainability standards or eco-labelling, led by increased sustainability requirements by mainly western retailers. Today, virtually all retailers in developed nations have some form of 'sustainable procurement policy' which covers the purchasing of aquaculture products globally. The need for this sustainable procurement has been strongly promoted by the very active environmental NGOs in the Western world (the WWF, PEW Charitable Trusts and Greenpeace to name a few) and at first, retailers were responding from criticism from this sector. In the past five years this has changed somewhat with retailers now actively promoting their sustainability credentials to customers with the hope of increasing sales. In summary, sustainability is now a key part of most Western retailers buying and marketing approaches for aquaculture products.

Proving that your aquaculture supply chains are sustainable has mainly been done through third-party certification schemes. These are programs which use an independent auditor to verify the sustainability of your product against a set of pre-defined rules. Several different schemes exist in the aquaculture sector with the main ones being as follows;

Aquaculture Stewardship Council (ASC): The ASC was first founded in 2004 through a series of aquaculture dialogues (multi-stakeholder roundtables for best production practices in aquaculture species). It was founded directly on the back of the successful wild fisheries eco-label, the Marine Stewardship Council (MSC). Due to its importance as a sector, salmon was one of the first species to be targeted and a standard was developed and became live in June 2012. In a significant development, ASC introduced its new Farm Standard in May 2025, which consolidates species-specific standards into a single, unified framework. This new standard becomes effective from August 2025 and will be mandatory from May 2027, marking a major transition in ASC's approach to certification.

Global G.A.P Aquaculture: Global G.A.P. was set up by European retailers in 1997 to develop independent certification systems for Good Agricultural Practice (G.A.P.). It has now developed into the world's leading farm assurance program with certificates in over 135 countries. It expanded into Aquaculture in 2004 and now runs a third-party certification program like the ASC but with one difference being it has a single standard which covers all finfish species (salmon included).

Global Aquaculture Alliance (GAA) Best Aquaculture Practices (BAP): The GAA was founded in 1997 in the United States and was dedicated to the advocacy, education, and leadership of responsible aquaculture. As part of this process, they developed the BAP standards which includes a Salmon Farm standard, and which has proven especially popular in North America. GAA announced it was transitioning into the Global Seafood Alliance (GSA) in April 2021.

Friends of the Sea (FoS): FoS was founded in the 1990s commencing with the creation of standards for wild capture fisheries. In 2013, they released a Marine Aquaculture standard which has limited uptake in the salmon industry (proving more popular for the bass and bream, industry). Due to its lack of market penetration for salmon it is not considered in greater detail in this review below.

6.1. Aquaculture Stewardship Council (ASC)

As previously set out, the first Salmon standard was developed and became live in June 2012. It is now on its fourth[31] iteration and has developed significantly since its start. In 2025, ASC launched its most transformative update to date: the ASC Farm Standard, a unified framework that replaces individual species standards. This new standard becomes effective from August 2025 and will be mandatory for all audits from May 2027[32].

The ASC standards work by outlining a series of Principles (in the case of Salmon, eight). Each Principle is supported by multiple Criteria and Indicators, which define measurable and auditable requirements. This structure ensures clarity, consistency, and a holistic approach to sustainability across all certified species, including salmon.

To become ASC certified a company (or group of companies) must apply to a Conformity Assessment Body (CAB) which is accredited to perform audits against the ASC Farm Standard. This accreditation is provided by the ASCs Accreditation Body, Accreditation Services International (ASI), who are basically responsible for making sure that the CABs are properly qualified to audit against the standard and perform the job to the required standard. ASC is currently transitioning to a broader accreditation model involving IAF-recognised bodies.

Once the client has chosen a CAB to complete the assessment, they will complete an audit against the standard, using the predefined checklist developed by the ASC. The auditors must complete a site visit at the farm (or farms) in question and will go through each of the Criterion to determine if they are met or not. In doing this the auditor will mark each one as Compliant (meets the requirement) or will issue a 'Non-Conformity'. Three types of Non-Conformity can be issued;

Minor Non-Conformity: The Criterion is mostly met however some small areas require further work. A deadline of one year is usually provided for resolution of these.

Major Non-Conformity: The Criterion is partially met but has some major areas that still require addressing for full alignment. A deadline of three months is usually provided for resolution of these.

Critical Non-Conformity: The Criterion is not met. A Critical Non-Conformity would result in the farm failing its ASC assessment.

Following the audit, a client is either recommended for Certification or is Failed. Should it be recommended, then a Draft Certification Report is uploaded to the ASC website and a period of fifteen days provided for any stakeholders to object. If after the fifteen days no objection is received, then the Farm is Certified and will receive a certificate which is valid for three years. The farm will

[31] ASC-STD-010-Salmon-Standard-V-1.4.1-May-2024.pdf
[32] ASC-STD-001-ASC-Farm-Standard-V1.0-May-2025.pdf

also be required to complete yearly surveillance audits during this period to ensure certification is being maintained (and to check progress against any Non-Conformities). At the end of the three-year period a farm would be required to complete a full re-assessment against the standard.

In addition to the Farm Standard, ASC operates a Chain of Custody (CoC) certification scheme to ensure traceability of certified products throughout the supply chain. This is based on the MSC CoC Standard, supplemented by ASC-specific requirements. This is designed to audit the product that is being or will be sold as certified and ensure it is being correctly identified and sold at all stages right through to the consumer. To sell product as ASC certified, the company in question (whether farm or processor or retailer) will require ASC Chain of Custody certification as well. Again, CoC Certificates are issued for three years and have regular audits (scheduled depending on the risk of the business).

6.1.1. The ASC Salmon Standard

Above we have set out how the ASC scheme works in principle. In this section we will consider the ASC Salmon Standard in more detail and the requirements it sets. With the release of the new ASC Farm Standard in 2025, the Salmon Standard is now being phased out and will be fully replaced by the unified framework by May 2027. However, it remains relevant for understanding the evolution of ASC certification and the foundations upon which the new standard is built.

The current Salmon Standard consists of Seven principles and one separate Section relating to the supply of Smolts. Prior to audits being completed though, a client needs to be confirmed as eligible under the scope requirements.

For salmon, a client is eligible for ASC certification if it is farming a species belonging to the Genus, *Salmo* or *Oncorhynchus* in any marine location using any farming production system. In summary, this would cover any cage-farm or land-based RAS system that is using predominantly seawater (although one using predominantly freshwater would not be covered). For smolt production, which is done in freshwater, certification is done under the Fresh Water Trout Standard.

The ASC has developed a Recirculating Aquaculture Systems (RAS) Module to strengthen sustainability requirements for land-based fish farms. This module complements the existing ASC standards, setting clearer guidelines on water use, effluent discharge, waste management, and energy consumption. It aims to reduce environmental impact while ensuring responsible aquaculture practices[33].

The ASC also operate a Group certification scheme which allows for 'groups of farms or farmers' to be certified under one certificate. The requirements for Group certification are beyond the scope of this report but would allow a salmon farm with multiple cage locations (for example) to receive a single certificate. In return they would receive a sampled audit (the CAB would not visit every farm) but would also need to introduce a program of internal audit to show conformity for all the sites.

With the above in mind, we will now consider the specific principles and how they generally apply to a classic 'cage-based' salmon farming operation.

Principle 1: Comply with all applicable National laws and local regulations.

Principle 1 is relatively straight forward and requires farms to simply produce evidence that shows that they are meeting all national and local regulations. This is likely to require evidence of licences and permits.

Principle 2: Conserve natural habitat, local biodiversity and ecosystem function

[33] RAS-Module.pdf

Principle 2 covers the major environmental impacts of salmon farming, specifically around water quality and maintaining ecosystems and biodiversity.

Under Criterion 2.1 the Standard considers the effects of cage farming on benthic biodiversity. It requires farms to take measurements for sulphide or Redox potential outside an Allowable Zone of Effect (AZE) defined in as an area of 30 metres around the site (and through a credible modelling system). These measurements must show zero of greater Redox potential or less than 1,500uMol/l of sulphide. At the same time, a faunal index sample must be obtained which shows that the sediment outside the AZ is of ahigh ecological quality and that over two of the abundant taxa are not pollution indicator species.

Criterion 2.2 covers water quality requirements and requires weekly Dissolved Oxygen levels to be above 70% saturation (when completed against a defined methodology) and that readings under 2mg/l represent less than 5% of the weekly samples

Criterion 2.3 deals with the release of nutrients directly through the fines of feed (which must be less than 1% of the weight of the feed.

Criterion 2.4 requires the farm to complete an assessment of potential impacts on biodiversity against specified components in the standard. It also specifies that the farm cannot be confirmed as present in a Protected or High Conservation Value Area (HCVA)[34].

Criterion 2.5 relates to interactions with wildlife (and specifically predators). It requires no use of Acoustic Deterrent Devices and states that the farm cannot be responsible for any deaths in red-listed or endangers species. It also sets rules relating to the use of lethal force (no more than 9 lethal incidents every two years and evidence that other methods have been tried first).

Principle 3: Protect the health and genetic integrity of wild populations

Principle 3 aims to avoid harm to wild salmon populations from the farming activity.

Criterion 3.1 deals with the introduction and amplification of parasites and pathogens and specifically sea lice. It requires the farm to develop and Area-Based Management (ABM) scheme for disease treatment. IT then specifies that regular sea lice testing is completed and sets some levels for on-farm lice levels. These thresholds have been subject to ongoing review and public consultation[35].

Criterion 3.2 requires that a farm does not introduce a non-native species unless specific exceptions are met (i.e., the use of 100% sterile fish, or the presence of effective physical barriers to prevent fish from persisting outside of the farm area). In this case this means that the salmon species being farmed must be a native species (or evidence is provided to show why it is as good as native species already).

Criterion 3.3. of the ASC standard prohibits the use of transgenic (genetically modified) fish because of concerns about their unknown impact on wild populations. However, culture of “genetically enhanced” salmon is acceptable under the ASC Salmon Standard. This includes the cultivation of triploid or all female fish, which are not defined as transgenic since as the triploidy process does not involve the insertion of foreign DNA. Instead, it alters the number of chromosome sets to induce sterility.

[34] This is an important consideration for the Falklands since it would potentially mean that no farm could be certified if located in an MPA.

[35] This is in response to increased public concern on the interaction of sea lice with salmon farms and wild populations.

Finally, Criterion 3.4 deals with escapes and provides an upper maximum limit of 300 in the most recent production cycle (unless shown to be outside the farms control) and that systems for checking and confirming escapees' numbers are in place.

Principle 4: Use resources in an environmentally efficient and responsible manner

Principle 4 deals with the use of other resources in farming so specifically feed and chemicals.

Criterion 4.1 requires all raw materials in feed to be traceable (as demonstrated by the feed producer).

Criterion 4.2 sets out a Fishmeal and Fish Oil Forage Dependency Ratio (FFDRm and FFDRo) of less than 1.2 and 2.52 respectively. This effectively means that the farm should try to reduce the amount of fishmeal from wild fish that it uses in its feed.

Criterion 4.3 has created numerous issues since the standard was created by the ASC. Effectively the original requirement was that all fishmeal was to come from a certified scheme (for example the MSC) within 5 years of the publication of the Salmon Standard (so by June 2017). However, the availability of certified fishmeal in 2017 made meeting this target impossible. The ASC therefore released an interim measure which basically removed the time requirement on this and replaced it with a requirement that a lower standard was met in the meantime. ASC has also developed a Feed Standard[36] ensuring that aquaculture feed is sourced and produced responsibly, recognising its significant environmental and social impact. It sets clear requirements for sustainable ingredient sourcing, ethical labour practices, and minimising ecological harm. By following this standard, feed mills contribute to a more sustainable and accountable seafood industry.

Criterion 4.4 requires non-marine raw materials to be from a responsible sourcing policy and that all Soya derived ingredients are certified against the Roundtable for Responsible Soy (RTRS).

Criterion 4.5 sets out requirements for the treatment or disposal of non-biological waste. The requirements are not specific but need to show that the waste is not being disposed in an irresponsible way and that recycling occurs when it is possible.

Criterion 4.6 deals with the release of greenhouse gases by farms and requires an energy assessment to be completed and to be repeated annually. It does not currently set any requirements for the reduction in greenhouse gas emissions though.

Criterion 4.7 provides requirements relating to the use of non-therapeutic chemicals. This mainly focuses on requirements for copper treated nets and ensures that cleaning is done with effluent treatment and that Cu measurements are taken from the sediment and are not seen to be present in high levels (above 34mg Cu/kg).

Principle 5: Manage disease and parasites in an environmentally responsible manner

Principle 5 covers the management of disease and parasites in the farmed fish (while Principle 3 considered it from the view of wild populations).

Criterion 5.1 sets out the need for a farm to have a Fish Health Management Plan and to receive regular (four times a year) by a designated veterinarian. The farm is also required to remove and dispose of 100% of its mortalities and to record them all. The farm must not experience mortality because of viral diseases in more than 10% of the fish from a recent production cycle and

[36] ASC-Feed-Standard_v1.01.pdf

unexplained mortalities should be less than 40% of all mortalities seen on the farm (over two production cycles).

Criterion 5.2 covers the use of therapeutic treatments and effectively bans the use of a variety of antibiotics and chemicals (which are already outlawed in most major salmon producing countries). When treatments are allowed they must be overseen by a veterinarian and are limited in use (for example, antibiotic treatment is only allowed 3 times in a production cycle). The use of prophylactic antimicrobial treatments is also not allowed.

Criterion 5.3 attempts to deal with the development of resistance in parasites, viruses and bacteria by requiring rotation of treatment regimens and the use of bio-assay analysis to determine if and when resistance might be forming.

Criterion 5.4 sets out the requirements for a functioning biosecurity plan. This includes the notification of diseases, the use of single year class salmon and actions to take in the case of a disease outbreak.

Principle 6: Develop and operate farms in a socially responsible manner

Principle 6 covers the social compliance areas of the ASC standard, these are wide ranging but include areas such as freedom of association, child labour, forced labour, working hours, discrimination, fair pay and health and safety.

The requirements of Principle 6 are usually assessed by a separate trained social auditor and are of particular importance for some of the farm assessments competed in higher risk countries (for example some parts of Asia).

They still require assessment for salmon farming but since most farms are in relatively well-developed countries, issues are seen less regularly than for some of the other species' standards (shrimp, tilapia etc…)[37].

Principle 7: Be a good neighbour and conscientious citizen

Principle 7 aims to address broader social impacts associated with salmon farming and specifically in relation to interactions with local communities.

Criterion 7.1 requires the farm to engage in regular and meaningful consultation with community representatives and to have a suitable policy in place to deal with complaints. It also has a specific requirement for farms to place notices if they are to use therapeutic treatments (due to the potential human health risks).

Criterion 7.2 deals with the need for farms to consult with indigenous and/or aboriginal groups to try to develop a protocol agreement. In essence, it is attempting to remove some of the previous issues that have arisen in Alaska with local people and farming operations.

Criterion 7.3 seeks to ensure that farms do not remove or restrict access for local communities to local resources. While it is accepted that some restriction is likely (for example an area of water is no longer open to vessels) this must not be deemed as unacceptable.

Section 8: Requirements for supplier of Smolts

[37] This is not to say issues do not arise in the salmon sector. However, they are usually minor in nature and certainly less common.

Section 8 sets out some requirements for farms to meet with regards to the supply of salmon smolts. Basically, a farm can either buy from a certified smolt producer (under the Freshwater Trout standard) or they must prove the smolt producer meets a host of the Salmon standard requirements directly through evidence.

6.1.2. Current uptake of the ASC Salmon Standard

The Salmon standard went live in 2012 and now has 601 live certificates for Atlantic Salmon *(Salmo salar).* These are summarised by Company and Country of Location in Table 5 and Figure 17.

Table 5: ASC Salmon Certifications in 2024

Company Name	Australia	Chile	Denmark	Faroe Islands	Iceland	Norway	UK	US	TOTALS
Aquachile Magallanes		5							5
Arctic Offshore Farming AS						1			1
Arctic Sea Farm					1				1
Arnarlax					4				4
Arnøy Laks						2			2
Atlantic Sapphire								1	1
Australis Mar SA		16							16
Bakkafrost Scotland							26		26
Ballangen Sjøfarm						4			4
Cultivos Yadran		3							3
Cermaq Chile		13							13
Cermaq Norway Salmon AS						33			33
Cooke Aquaculture Chile		8							8
Danish Salmon A/S			1						1
Edelfarm						2			2
Empresas AquaChile S.A.		37							37
Flakstadvåg Laks						6			6
Folla Alger AS						1			1
Granja Marina Tornagaleones S.A.		10							10
Gratanglaks AS						3			3
Grieg Seafood Norway AS						23			23
Hofseth Sea Farming AS						4			4
Invermar S.A.		1							1
Kaldvík hf					5				5
Kleiva Fiskefarm AS						4			4
Kvarøy Fiskeoppdrett AS						6			6

Lerøy Aurora Sjø AS						20			20
Lerøy Midt Sjø AS						23			23
Lingalaks AS						1			1
Lovundlaks Sjø AS						3			3
MULTIEXPORT PATAGONIA S.A.		4							4
Mowi Chile		23							23
Mowi Faroes				2					2
Mowi Scotland							22		22
Mowi Seawater Norway AS						62			62
Nordlaks Havbruk AS						10			10
Nova Austral		6							6
Nova Sea Havbruk AS						21			21
Ocean Farming AS						1			1
P/f Bakkafrost Farming				17					17
Productos del Mar Ventisqueros S.A.		10							10
SALAKS PRODUKSJON AS						4			4
SALMONES BLUMAR S.A.		13							13
SALMONES PACIFIC STAR S.A.		4							4
SalMar Farming AS						1			1
Salmar Oppdrett AS						83			83
Salmon Evolution Norway AS		0				1			1
Salmones Blumar Magallanes SpA		7							7
Salmones Camanchaca		11							11
SEASHORE SJØ AS						20			20
Selsøyvik Havbruk AS						1			1
Skagen Salmon Partnerselskab			1						1
TRUSAL S.A.		4							4
Tassal Operations Pty Ltd.	4								4
Wenberg Fiskeoppdrett						2			2
Country Totals	**4**	**175**	**2**	**19**	**10**	**342**	**48**	**1**	**601**

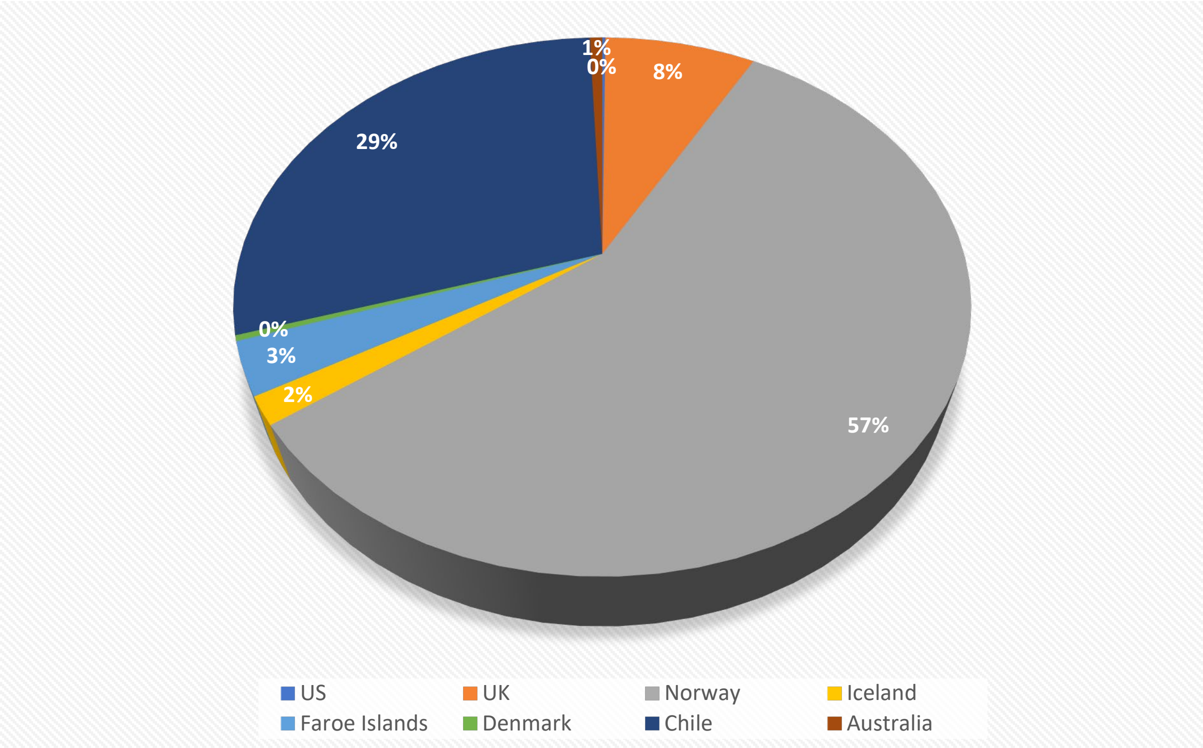

Figure 17: ASC Certifications in 2024 by Country

The data above shows us that the ASC push in the salmon sector is dominated by Norway (57% of certificates), Chile (29% of certificates) and UK (8% of certificates). This is clearly not that surprising since they also represent the three biggest producers globally. In terms of producers again the world's biggest producer, Mowi, are also the biggest holder of certificates with 109 across the globe (they have committed to becoming 100% ASC certified by 2020[38]). The next three, Salmar Oppdrett AS, Cermaq and Leroy, follow and again, unsurprisingly they are also next in terms of global revenue. All have also committed to a varying timescale for ASC certification across all their sites.

6.1.3. The ASC Farm Standard

In May 2025, the Aquaculture Stewardship Council (ASC) released its new unified Farm Standard, marking a significant evolution in its approach to aquaculture certification. This standard consolidates the previously species-specific standards—including the ASC Salmon Standard—into a single, integrated framework applicable across all eligible aquaculture species and production systems. While the Farm Standard becomes effective from August 2025, it will not be mandatory until May 2027, allowing farms and auditors time to transition.

The inclusion of this section reflects the importance of understanding how the ASC's requirements for salmon farming are evolving. While the ASC Salmon Standard remains in effect during the transition period, the Farm Standard will ultimately replace it. This section outlines the key components of the new standard as they relate to salmon farming, highlighting where requirements remain consistent with the previous standard and where notable changes have occurred.

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[38] Aquaculture Stewardship Council - MOWI - Scotland

The ASC Farm Standard is structured around four overarching principles:

1. Legal compliance and effective business management
2. Environmental stewardship
3. Respect for human rights
4. Animal health and welfare

As before, each principle is supported by detailed criteria and indicators, which are measurable and auditable. The following summary focuses on how these principles apply to salmon farming.

Principle 1: The aquaculture industry ensures legal compliance and effective business management.

This principle sets out the foundational requirements for legal operation and responsible governance.

Under Criterion 1.1, the Standard requires farms to demonstrate that they are operating legally. This includes holding all necessary licences and permits and complying with national and local regulations. For a cage-based salmon farm, this would typically involve providing evidence of seabed leases, discharge consents, and aquaculture licences.

Criterion 1.2 introduces the requirement for a formal management system to support implementation of the ASC requirements. This means that a salmon farm must have documented procedures, designated responsibilities, and a system for reviewing and updating its operations — a more structured approach than was previously required.

Criterion 1.3 deals with business ethics and requires farms to discourage corruption and ensure that all information submitted for certification is accurate. For a salmon farm, this would involve adopting a code of conduct and ensuring transparency in audit documentation and stakeholder engagement.

Criterion 1.4 sets out detailed requirements for traceability and disclosure. Farms must be able to demonstrate that ASC-certified product is kept separate from non-certified product at all times. For a cage-based salmon farm, this means maintaining batch-level records from smolt input through to harvest, and ensuring that all documentation clearly identifies certified product.

Under Criterion 1.5, the Standard requires farms to map their supply chain and ensure that any upstream cage sites (such as marine smolt sites) are also ASC certified. This builds on the previous smolt supply requirements and ensures that all marine stages of salmon production are covered under certification.

Principle 2: The aquaculture industry demonstrates environmental stewardship

This principle addresses the environmental impacts of aquaculture, including site selection, water quality, and biodiversity.

Under Criterion 2.1, the Standard introduces a formal Environmental Risk Assessment (ERA) process. This must be completed for each site and reviewed annually. For a cage-based salmon farm, the ERA would typically assess risks such as benthic impact, escapes, wildlife interactions, and nutrient discharge, and identify mitigation measures for each.

Criterion 2.2 sets out requirements relating to ecologically important habitats. Farms must not be located in Protected Areas (PAs) unless specific conditions are met. This remains consistent with the Salmon Standard and would typically exclude cage-based salmon farms from operating in marine reserves or other sensitive coastal zones.

Criterion 2.3 relates to interactions with wildlife, including predators. It requires farms to assess and minimise the risk of human-wildlife conflict and prohibits the use of Acoustic Deterrent Devices (ADDs). It also states that farms must not be responsible for the mortality of red-listed or endangered species. These requirements are consistent with the Salmon Standard and would apply directly to cage-based salmon farms operating in areas with marine mammals or seabirds.

Under Criterion 2.4, the Standard sets out requirements for escape prevention and biodiversity protection. It retains the 300-fish escape threshold for marine salmonids and requires farms to implement containment measures, conduct regular inspections, and report any known escapes. This is directly applicable to cage-based salmon farms, where net integrity and storm resilience are key considerations.

Criterion 2.5 covers benthic impact and requires farms to monitor the seabed beneath and around the cages using ASC's tiered sampling methodology. This builds on the Allowable Zone of Effect (AZE) concept from the Salmon Standard but introduces a more structured approach to sampling and analysis. For a cage-based salmon farm, this means taking sediment samples at defined distances from the cage edge and demonstrating that the benthic environment remains within acceptable thresholds.

Criterion 2.6 deals with water quality and nutrient discharge. It requires weekly monitoring of dissolved oxygen levels, which must remain above 70% saturation, and that readings below 2 mg/l represent less than 5% of weekly samples. It also limits feed fines to less than 1% of total feed weight. These thresholds are unchanged from the Salmon Standard and remain directly applicable to cage-based salmon farms.

Criterion 2.7 introduces new requirements relating to salinisation. While this is primarily relevant to land-based or brackish water systems, it is not typically applicable to marine cage-based salmon farms.

Criterion 2.8 covers biosolids management. It requires farms to ensure that biosolids (such as mortalities and net-cleaning waste) are contained and not discharged into the environment. For a cage-based salmon farm, this would involve proper collection and disposal of mortalities and ensuring that net-cleaning effluent is treated before discharge.

Under Criterion 2.9, the Standard introduces requirements for freshwater use. Farms located in water-stressed areas must implement a Water Efficiency Management Plan. This is not generally applicable to marine cage sites but may apply to freshwater hatcheries or RAS facilities supplying smolts.

Criterion 2.10 deals with energy use and greenhouse gas emissions. Farms must calculate their energy use and emissions annually and develop a GHG Management Plan. For a cage-based salmon farm, this would typically involve tracking fuel use for workboats and generators and identifying opportunities for emissions reduction.

Criterion 2.11 sets out requirements for material use, waste, and pollution control. Farms must manage waste responsibly, including plastics and hazardous materials. For cage-based salmon farms, this includes proper handling of copper-treated nets, ensuring that sediment copper levels remain below 34 mg/kg, and retrieving any lost gear.

Finally, Criterion 2.12 covers feed. Farms must use ASC-conforming feed and meet species-specific feed efficiency metrics. For salmon, the FFDRm and FFDRo thresholds remain unchanged from the Salmon Standard, and feed must be sourced from certified mills.

Principle 3: The aquaculture industry is committed to respecting and promoting human rights.

Principle 3 sets out a comprehensive framework for social responsibility, drawing on international labour conventions and human rights instruments. It expands significantly on the social elements of the previous Salmon Standard and introduces more detailed and enforceable requirements.

Under Criterion 3.1, the Standard requires farms to have a written human rights policy approved by senior management. This policy must cover key areas such as freedom of association, non-discrimination, and safe working conditions. For a cage-based salmon farm, this would typically involve publishing the policy, training staff, and ensuring it is communicated to all workers and relevant stakeholders.

Criterion 3.2 addresses forced labour and prohibits any form of coercion, debt bondage, or restriction on workers' freedom to leave employment. It also requires farms to implement remediation procedures if forced labour is identified. While this is not commonly an issue in salmon farming regions, farms must still demonstrate compliance through transparent recruitment practices and employment contracts.

Criterion 3.3 deals with child labour. It prohibits the employment of children under the age of 13 and sets strict conditions for the employment of young workers. For salmon farms, this would typically involve maintaining age verification records and ensuring that any youth employment is non-hazardous and does not interfere with schooling.

Criterion 3.4 focuses on discrimination and harassment. Farms must ensure equal treatment in hiring, promotion, and working conditions, and must not tolerate any form of violence or harassment. For a salmon farm, this would involve having clear anti-discrimination policies and grievance mechanisms in place.

Under Criterion 3.5, the Standard sets out detailed requirements for health and safety. Farms must conduct a site-specific risk assessment, provide appropriate training and personal protective equipment, and ensure access to clean facilities and first aid. For cage-based salmon farms, this includes ensuring boat safety, diving protocols, and emergency response procedures are in place and regularly reviewed.

Criterion 3.6 requires farms to respect workers' rights to freedom of association and collective bargaining. Where these rights are restricted by law, farms must provide alternative means for worker representation. This is typically addressed through engagement with trade unions or worker committees.

Criterion 3.7 relates to transparent contracts. Farms must provide all employees with written terms and conditions of employment before work begins. For salmon farms, this includes clear documentation of wages, working hours, benefits, and termination conditions.

Criterion 3.8 addresses wages. Farms must pay at least the legal minimum wage and work towards providing a living wage. They must also calculate and report on any wage gaps. For salmon farms, this may involve benchmarking wages against national or regional living wage estimates and developing improvement plans where necessary.

Under Criterion 3.9, the Standard sets limits on working hours and requires adequate rest periods. For a cage-based salmon farm, this means ensuring that shift patterns comply with national labour laws and that overtime is voluntary and compensated appropriately.

Criterion 3.10 introduces requirements for workplace conduct response. Farms must have a fair and transparent disciplinary process that respects workers' dignity. For salmon farms, this would typically involve documenting procedures for addressing misconduct and ensuring that penalties are proportionate and lawful.

Criterion 3.11 sets standards for employee accommodation where it is provided. Housing must be safe, clean, and meet basic needs. While not all salmon farms provide accommodation, those that do — particularly in remote areas — must ensure compliance with these requirements.

Criterion 3.12 requires farms to have grievance mechanisms for both employees and local communities. These must be accessible, confidential, and include non-retaliation provisions. For salmon farms, this means having a clear process for submitting and resolving complaints, with records maintained.

Finally, Criterion 3.13 focuses on community engagement. Farms must engage with Indigenous and local communities, avoid infringing on customary rights, and support local development. For cage-based salmon farms, this may involve consultation with coastal communities, especially where farms operate near traditional fishing grounds or culturally significant areas.

Principle 4: The aquaculture industry upholds responsible animal health and welfare practices.

Principle 4 consolidates and expands the animal health and welfare requirements previously found in the Salmon Standard. It introduces a more structured approach to monitoring, planning, and continuous improvement.

Under Criterion 4.1, the Standard requires farms to implement a Health and Welfare Management Plan (HWMP). This plan must include regular veterinary oversight, mortality tracking, and welfare scoring. For a cage-based salmon farm, this means conducting routine health checks, recording causes of mortality, and monitoring indicators such as fin damage, emaciation, and abnormal behaviour.

The Standard also requires farms to monitor water quality parameters relevant to fish health and to respond to any signs of stress or disease. For salmon farms, this includes maintaining optimal oxygen levels, monitoring temperature, and adjusting feeding practices accordingly.

Criterion 4.4 deals with the use of veterinary therapeutants. It prohibits the prophylactic use of antibiotics and restricts the use of Critically Important Antimicrobials (CIAs) for human medicine. Farms must also disclose antibiotic use and monitor for resistance. For cage-based salmon farms, this means that any antibiotic treatment must be prescribed by a veterinarian, limited to no more than three treatments per cycle, and supported by sensitivity testing.

Under Criterion 4.5, the Standard sets out detailed requirements for sea lice management. Farms must participate in Area-Based Management (ABM) schemes, conduct regular lice counts, and publicly report lice levels. During sensitive periods for wild salmonids, lice levels must remain below defined thresholds. For a cage-based salmon farm, this involves coordinated treatment planning with neighbouring farms, use of non-chemical control methods where possible, and transparent reporting of lice data.

The Standard also requires farms to monitor for treatment efficacy and resistance, rotate treatments, and reduce reliance on medicinal interventions over time. These requirements build on the Salmon Standard but introduce more prescriptive and transparent expectations.

The ASC Farm Standard represents a significant evolution in aquaculture certification, offering a more unified, structured, and transparent framework than its predecessor. While many of the core environmental and social requirements from the ASC Salmon Standard remain intact, the Farm Standard introduces new expectations around risk assessment, traceability, animal welfare, and human rights. For cage-based salmon farming operations, the transition to the Farm Standard will require some adjustments — particularly in documentation, monitoring, and reporting — but the underlying principles of responsible aquaculture remain consistent. The below table summarises the key similarities and differences between the two standards.

Table 6: Comparison between the ASC Salmon Standard and ASC Farm Standard

Topic/Area	ASC Salmon Standard	ASC Farm Standard	Notes
Standard Structure	Species-specific standard with 7 principles and a separate smolt section.	Unified standard with 4 principles applicable to all species and systems.	Farm Standard consolidates all species standards into one framework.
Legal Compliance	Requires evidence of compliance with national/local laws.	Same requirement under Criterion 1.1.	No substantive change.
Environmental Risk Assessment	Not explicitly required.	Mandatory site-specific ERA under Criterion 2.1.	New structured requirement.
Benthic Monitoring	AZE-based sulphide/Redox and faunal index sampling.	Tiered sampling methodology under Criterion 2.5.	More structured but similar intent.
Water Quality	DO >70% saturation; <5% samples <2mg/l.	Same thresholds under Criterion 2.6.	No change in thresholds.
Wildlife Interactions	No ADDs; no red-listed species mortality; limits on lethal control.	Same requirements under Criterion 2.3.	Requirements retained.
Escapes	Max 300 escapes per cycle.	Same threshold under Criterion 2.4.	No change.
Feed Requirements	FFDRm <1.2; FFDRo <2.52; certified fishmeal encouraged.	Same FFDR thresholds; ASC-conforming feed mandatory.	Feed certification now formalised.
Social Responsibility	General requirements assessed by social auditor.	Expanded criteria (3.1â€“3.13) aligned with ILO and UNGPs.	Significant expansion and formalisation.
Animal Welfare	Fish Health Management Plan; limits on antibiotic use.	Health and Welfare Management Plan; same antibiotic limits; more detailed welfare scoring.	Expanded monitoring and planning.
Sea Lice Management	ABM required; lice thresholds under review.	ABM, lice monitoring, public reporting under Criterion 4.5.	More prescriptive and transparent.
Smolt Supply	Certified smolt supplier or evidence of compliance.	Upstream cage sites must be ASC certified (Criterion 1.5).	Requirement formalised and expanded.

6.2. Global G.A.P Aquaculture

As previously mentioned, Global G.A.P. moved into the aquaculture certification world in 2004 and operate a general certification system which is similar in many ways to the ASC but with a few general exceptions.

1. Global G.A.P. does not operate an independent accreditation body as the ASC does with ASI. Instead, they rely on the use of so-called ‘international accreditation bodies’. These are usually country based (for example in the UK, it is the body called UKAS) and they are responsible for the accreditation of CABs against the main ISO Accreditation Standards. In short, this means that a CAB has to be accredited against ISO 17065 by the international accreditation body in that country to be approved by Global G.A.P. but is not specifically accredited against their rules (as they are by ASI for the ASC accreditation process).

2. Global G.A.P. operate a single standard which covers all aquaculture operations together. This remains a key distinction, although ASC has now moved to a unified Farm Standard that also applies across species and systems.
3. A Global G.A.P. certificate is only valid for one year (not three as for ASC).
4. Finally, as will be seen below, the Global G.A.P. standard touches on areas which the ASC **previously did not cover in detail**, including food hygiene and Health and Safety.

The audit process is relatively similar to that for ASC, however CABs are required to determine if each condition is either 'Met' or 'Not Met'. If 'Not Met' is applied, then the farm is not eligible for certification until this is rectified (i.e. it does not operate a Major/Minor Non-Conformity System as the ASC does).

Finally, Global G.A.P. also operate a separate chain of custody standard as the ASC do which it required by all farms to allow for the sale and use of the logo.

6.2.1. Global G.A.P Aquaculture Standard

The Global G.A.P Aquaculture standard consists of two separate modules, the Farm Module and the Aquaculture Module. The Farm Module is the same that is used across the terrestrial farming standards and covers generic requirements (across sixteen separate principles) which are considered good practice for virtually all farming enterprises (water or land based). In summary, the main areas covered are as follows;

<u>Record Keeping:</u> This is a very general requirement which expects all required records to be maintained for a period of at least two years (unless longer is specifically required). It also requires all certified farms to complete a yearly self-assessment against the Global G.A.P. Standard and record any non-conformances and corrective actions taken.

<u>Hygiene:</u> The farm shall have a hygiene-based risk assessment in place and a documented hygiene procedure, which includes the provision of annual training for staff in relation to hygiene. This is an area where Global G.A.P. includes food hygiene requirements, which were not addressed in detail under the ASC Salmon Standard.

<u>Health and Safety:</u> As previously mentioned, the coverage of H&S is something that differs from the ASC requirements. Here farms are required to have a written H&S policy based on a risk assessment and to provide training to staff as required. They must also have a clear accident and emergency procedure, provide first aid kits and PPE (as required) for staff use.

<u>Waste and Pollution Management:</u> The farm requires a documented waste management plan which identifies sources of waste and the processes that are completed to dispose of it suitably. It also requires that the farm specifically composts organic wastes (if no risk exists from the waste product).

<u>Conservation:</u> the farm must have a Wildlife and Conservation Management Plan which identifies the environmental impacts of its activities and considers how to enhance the environment whenever possible. It also requires the farm to monitor is energy use and recommends (this is not a requirement) that the plan leads to improvements in energy efficiency and makes use of non-renewable energy sources.

<u>Complaints:</u> The farm needs to have a system for dealing with complaints and ensuring they are properly followed up on (identical to the ASC).

<u>Recall Procedure:</u> A system for recalling product from the marketplace if required, needs to be in place.

<u>Traceability and Segregation:</u> The farm needs an effective traceability system in place and one that always ensures the segregation of certified and non-certified products.

Mass Balance: The Mass Balance test requires a producer to be able to record all inputs and outputs by weight and through the use of agreed conversion ratios account for all products sold through this method. The idea is that the mass balance ensures that the product being sold as certified can be shown to of originated from a corresponding amount of certified source product. In principle, this is fine for processing facilities but is very hard to complete accurately at the farm level.

The aquaculture module provides the more specific requirements for fish farming which need to be met. It covers sixteen separate principal areas, and these are now discussed in more detail below (areas that are not relevant to Salmon farming are not considered).

Site Management: The site management requirements under the Aquaculture Module are very similar to those put forward by the ASC as well. Firstly, they require a farm to be able to prove that it is meeting required country legislation (licensing, registered etc.). This needs to be backed up with proper maps and locational information on the farm(s) locations.

Secondly a management structure with defined organisational responsibilities must be in place.

Finally, farms must also be able to demonstrate that they have been meeting the standard requirements for the past three months. This is an area that differs from standard to standard with some requiring a previous full period of production under requirements and others no historical time requirement at all.

Reproduction: The reproduction component requires all broodstock to be obtained from a breeding program or if from the wild, through an ecologically managed fishery. GM farming techniques are prohibited (as with ASC). This does NOT include the use of triploid fish which may be of importance to the Falklands.

The Global G.A.P. standard provides more specific requirements than the ASC one on specific area requirements for hatchery management. Of importance for salmon farming are the following;

- Fish stripping must be done under anaesthetic (which must be approved for use by the competent authority).
- Fingerling transportation must be done at densities and water oxygenation levels that are suitable for the species (although these are not specifically provided).

Chemical Compounds: Global G.A.P. provide extremely prescriptive requirements on the use and storage of chemicals. These are mainly procedural and aimed at reducing the risk of spillage and or human health implications.

Occupational Health and Safety: These requirements build on the farm module requirements already discussed above. Of particular interest to salmon farming is that diving operations are covered by a specific health and safety risk assessment. This is a notable inclusion in Global G.A.P. and is now also addressed under the ASC Farm Standard.

Fish Welfare, Management and husbandry: The requirements on fish health and welfare are relatively similar to the ASC. They require the farm to have a suitable Health Plan which is signed off by a recognised veterinarian. They must notify authorities of disease outbreaks, maintain records of stock numbers and average weights, monitor health indicators and mortalities collected, recorded and the causes investigated.

Treatments are not allowed for products banned under the FAO/WHO Codex Alimentarius list and all must be approved by a vet. Antibiotics can only be used to treat infectious diseases (although there are no specific limits on the number of treatments, unlike ASC).

The farm mut have a bio-security plan which covers all areas of operation including the sterilisation of equipment, people and inputs (feed and seed).

Finally, specific husbandry requirements are set out for the use of fish nets. These are not allowed to touch the seabed, must be well maintained and considered suitable in terms of location and net mesh sizes etc…They must also be well marked with navigation aids.

In summary, the requirements here are similar to the ASC Farm Standard but are less prescriptive or specific to salmon farming.

Feed Management: The feed requirements state that all fish stocks should receive a compound feed diet which is suitable to the species and that it must be obtained from a recognised source. Specifically, this means that the source needs to be certified against the Global G.A.P. feed standard, another benchmarked standard or against another accredited scheme. Global G.A.P. face many of the same issues that the ASC do with feed management and sustainability concerns.

Pest Control: Farms are required to maintain a pest control system which prevents the risk of infestation. To be clear, this is dealing with pests and not predators and is normally met by the installation of baits and traps by an external pest control company.

Environmental and Biodiversity Management: This principle covers most of the key requirements for salmon farming and are based on very similar principles to those outlines in the ASC standard (although they are less prescriptive). Once again, the farm cannot be located in an area of High Conservation Value and must be developed in line with a full Environmental Impact Assessment (EIA) program. A sampling program needs to be set up for monitoring benthic sediment (although unlike the ASC, how this is done is not prescribed).

Predators need to be excluded whenever possible and lethal force must be a final solution and cannot be completed on endangered (IUCN) species.

The farm must have a plan in place for avoiding and dealing with any escapes that may occur.

In general, these requirements are aimed more at mangrove habitats than those faced by salmon farms. They are also less prescriptive than the ASC Farm Standard (although generally cover the same areas).

Water Usage and Disposal: This area really deals with the abstraction of water and so is only relevant to smolt production facilities. It attempts to ensure that local communities still have access to drinking water, fishing areas and that water abstractions is only undertaken in line with consents.

Harvesting and Crowding Facilities: This is an interesting area of divergence from the ASC which does not specifically cover harvesting in detail. The requirements here are mainly hygiene related (temperature requirements and clean equipment etc.).

Slaughter Activities: Again, an interesting area of divergence. Global G.A.P. provide specific requirements on the slaughter of fish. Firstly, all must be 'effectively stunned' prior to bleeding (if used). It does not specifically state that certain methods may not be used but that these must 'consider fish welfare'.

Social Criteria: Social requirements are assessed under the GRASP (Global Risk Assessment on Social Performance) Module (a separate social module is required to be completed). The requirements are similar in many ways to the ASC Farm Standard's social criteria, covering areas such as worker rights, health and safety, and grievance mechanisms.

6.2.2. Current uptake of the Global G.A.P. Aquaculture Standard

Obtaining data on certificates by species from Global G.A.P. is difficult due to the complex system they use to report (the Global G.A.P database). However, an estimate is made that Global GAP currently has around 100 live certificates for Salmon related producers.

Of these 100, the majority appear to be located in Norway, with other producers in Australia and the UK. Interestingly, it appears that many of the producers represent Smolt production units only (i.e. Global GAP may be chosen for smolt facilities and not on-growing in some cases).

What is clear though is that Global G.A.P. is a much less significant player in the salmon sector that either the ASC or GSA BAP.

6.3. Global Aquaculture Alliance (GAA) Best Aquaculture Practices (BAP)

Now the Global Seafood Alliance (GSA), the Global Aquaculture Alliance (GAA) was founded in 1997 in the USA and is an NGO which dedicates itself to the advocacy, education and leadership of responsible aquaculture practices. In 1999, the GAA set out a Code of Practice for Responsible Shrimp Farming which has since led to the creation of the Best Aquaculture Practices (BAP).

BAP is part of the GSA group but is run as a separate certification scheme on its own. The certification scheme is run along similar principles to the ASC one.

The audits are completed by third-party CABSs which in turn are approved by GSA. To become recognised as a CAB they must show experience in aquaculture, accreditation to a national certification body (as explained under the Global G.A.P. requirements), and must complete specific GSA training courses.

A company that wants to be certified against the BAP Standards must first complete and submit a self-assessment form to ensure they are prepared for the full audit. Once completed, they select a CAB to complete the on-site audit and the audit is completed.

CABs will go through all the requirements of the Farm Standard and will raise Minor, Major or Critical non-conformities (as described in the ASC section). The company must present Corrective Actions to these NCs within 35 days to the CAB to then be recommended for certification.

The certificate lasts for a maximum of one year with a follow up audit required before the anniversary to maintain the certification.

BAP have developed the standards they employ considerably over the past decade and now have a combination of generic and species-specific standards which apply. For salmon farming specifically, the BAP Salmon Farm Standard is used and applies to salmonids raised in net pens in marine waters. A separate standard (the BAP Hatchery and Nursery Standard) applies to smolt production facilities. For farms that are producing salmonids in land-based grow-out systems (for example RAS), the BAP Farm Standard applies.

6.3.1. GSA Best Aquaculture Practices (BAP) Salmon Standard

The BAP Salmon Farm Standard is for all cage based marine operations and covers 12 separate principles. Each principle is briefly considered below.

Area 1: Community - Property Rights and Regulatory Compliance

In comparison with the other standards considered here this requires companies to be able to prove they are compliant with national legislation (water use, operating licences, environmental requirements etc…). It also includes a requirement to show that farms are compliance with any specific area management agreements that they may have agreed to.

Area 2: Community - Community Relations

The farms relationship with the community is assessed here. It seeks to ensure local inhabitants are not blocked from access to fishing areas or other public resources (and if they are it is justified and well signed). The farm must also demonstrate interaction with the local community to help avoid and resolve conflicts. It must have a system for recording complaints and deadline with them in a fair and effective manner.

Separately the farm is required to cooperate with other BAP certified farms in an area of up to 5km radius on stocking, fallowing and biosecurity (effectively the creation of an Area Management Agreement).

Area 3: Community - Worker Safety and Employee Relations

Area 33 covers health and safety specific areas and employee relations (in effect the social requirements for the farm). The requirements under this area are quite detailed and in-line with the social compliance requirements of the other standards (although maybe not quite as detailed). However, it does provide additional requirements in relation to diving operations and PPE requirements.

Area 4: Environment - Sediment and Water Quality

The farm is required to monitor sediment and water quality, but this is done in line with 'local standards' (i.e. it refers to country requirements and does not set specific levels as the ASC standard does). When a country does not require sediment monitoring, the farm is required to implement a process which is in line with "generally accepted methods".

For water quality sampling, data is required to be collected, and it is specified that this may be required to be submitted to the BAP database for future research (again though, no limits are set).

This area provides one of the biggest differences between BAP and ASC. The ASC is far more prescriptive on what is required while BAP tends to rely on the countries on water quality standards and basically confirms that these are being met.

Area 5: Environment - Fishmeal and Fish Oil Conservation

Farms are required to source feed from a BAP-certified feed mill (or one that declares its compliance with BAP feed mill standards). They must be able to demonstrate traceability of feed and display records of feed used.

The facility must also calculate an FCR for each year class and achieve a fish in fish out ratio of 1.5 or less for each year class harvested. This is broadly aligned with ASC's feed efficiency metrics, though ASC uses FFDRm and FFDRo.

Area 6: Environment – Control of Escapes

Escape controls are like those of the ASC with requirements for an escape prevention plan to be in place. The farm must also complete an analysis of its actual harvest biomass to confirm it is not more than 3% different from the predicted biomass (i.e., escapes have occurred without knowledge).

Again, the farm cannot be in an area of critical or sensitive habitat. The use of transgenic fish is banned, and fish species must be approved for production in the country.

Area 7: Environment – Predator and Wildlife Interactions

The requirements here are virtually identical to the ASC. However, the use of acoustic harassment devices can be permitted if supported by independent expert opinion (the ASC have an outright ban).

Lethal controls must be reported but no limits are placed on farms (although the frequency should aim to decrease over time).

Area 8: Environment – Storage and Disposal of Farm Supplies

Requirements here require the safe storage of feed, fuel and lubricants to avoid spillage and the proper disposal of garbage (under national legislations). A written waste reduction plan must be in place for the farm and compliance must be demonstrated.

Specific requirements for the cleaning of copper treated nets are also provided, though BAP does not set sediment copper thresholds as ASC does.

Area 9: Animal Health & Welfare – Health and Welfare

The fish welfare must be overseen by a fish health professional and fish should be inspected daily (when weather allows). Dead fish should be recorded, and stocking densities should be below 25kg per m^3 on average for the production cycle.

Interestingly, the BAP standard requires all fish to be stunned prior to slaughter — a requirement that is now also included in the ASC Farm Standard, though BAP was the first to mandate it.

Area 10: Animal Health & Welfare – Biosecurity and Disease Management

The requirements for disease management and biosecurity are very similar to the ASC but generally less prescriptive. The rules require strict reporting and processing of disease treatments (by a qualified health professional), but they do not ban any specific treatments. Instead, they state that treatments must be conducted within national regulations.

Area 11: Food Safety – Control of Potential Food Safety Hazards

This section is different to the ASC (who do not audit against food safety within its farm-level certification scope). It requires producers to provide documented proof that antibiotics have not been added to feed. It also requires fish to be checked for traces of contaminants, should a contamination incident occur within 5 kilometres of the farm. Finally, it requires all ice to be made from potable water or water that has been disinfected to an equivalent standard.

Area 12: Traceability – Record Keeping Requirement

Area 12 is rather generic and simply requires standard records to be kept relating to each production cycle for a minimum of 12 months (or the expected shelf life of the product if longer). This is broadly similar to ASC's traceability requirements, though ASC includes more detailed chain of custody provisions.

6.3.2. Current uptake of the GSA BAP Standard and Issues

The BAP Salmon standard has 427 live certificates for Atlantic Salmon *(Salmo salar)*. These are summarised by Company and Country of Location in Table 7 and

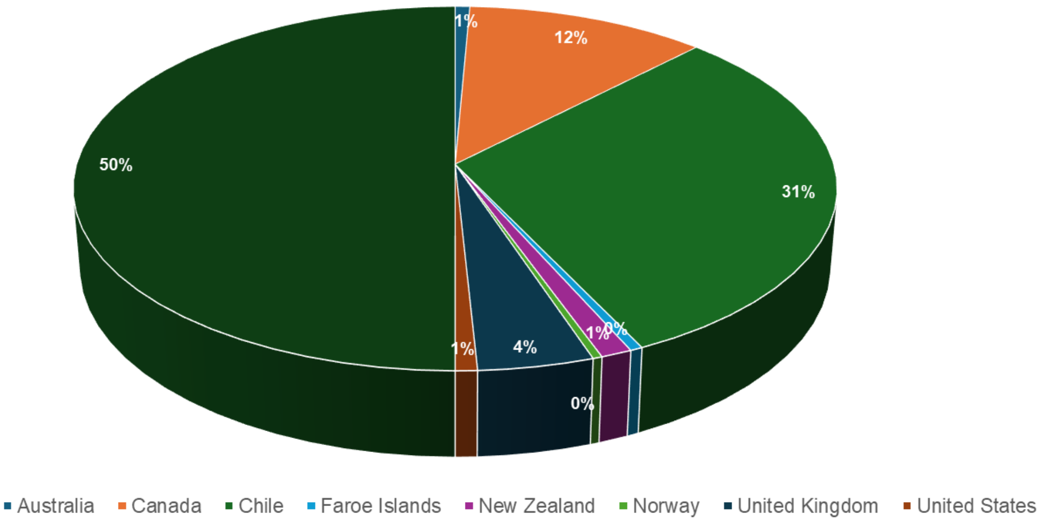
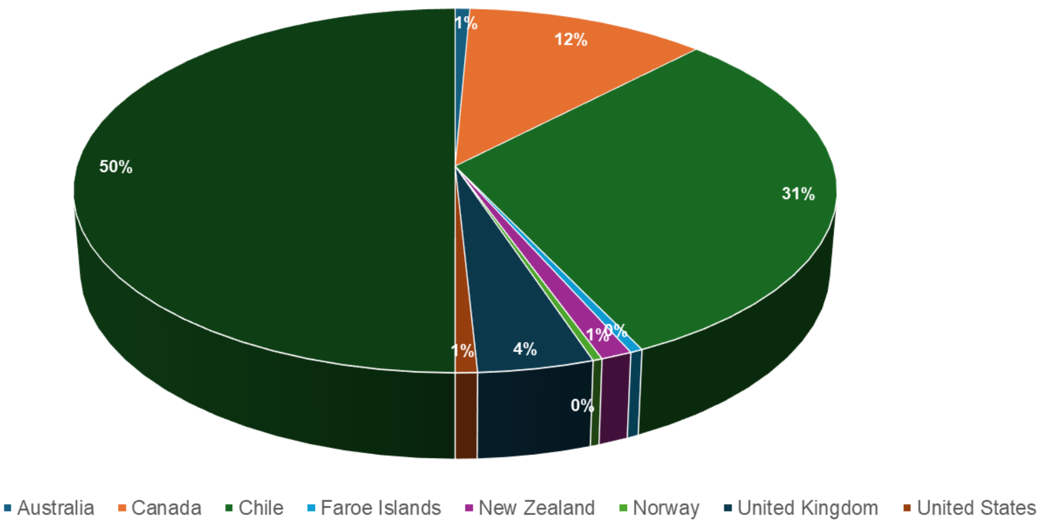


Figure 18.



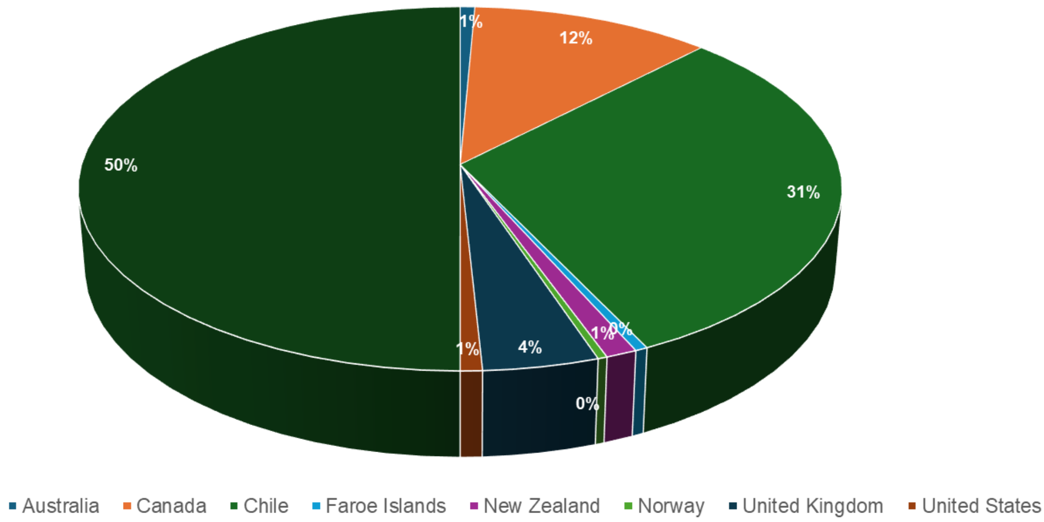


Figure 18: GSA BAP Certifications in 2025 by Country

Table 7: GSA BAP Certifications in 2025

Company	Australia	Canada	Chile	Faroe Islands	New Zealand	Norway	United Kingdom	United States	TOTALS
Acuimag S.A.			6						6
Aguas Clara S.A			1						1
AquaChile S.A.			10						10
Australis Mar S.A			17						17
Aysen SPA			1						1
Bakkafrost Scotland Limited							35		35
Cermaq Canada Ltd.		5							5
Cermaq Chile			27						27
Cooke Aquaculture Chile S.A.			7						7
Cooke Aquaculture USA		8							8
Cooke Aquaculture USA								4	4
Cultivos Yadran S.A.			9						9
Deer Island Offshore		1							1

Empersas Aquachile S.A.			17						17
Exportadora Los Fiordos			28						28
Finger Lakes Fish, Inc.								1	1
GRANJA MARINA TORNAGALEONES S.A			14						14
Grieg Seafood BC, Ltd.		12							12
Hudson Valley Fish Farms Inc.								1	1
Invermar S.A.			12						12
Kelly Cove Salmon Ltd.		52							52
Kvarøy Fiskeoppdrett AS						3			3
MOWI Canada East - Cluster - Cinq Island Cove		21							21
Mount Cook Alpine Salmon Ltd. - Benmore					10				10
Mowi - Chile - Isla Sanchez			18						18
Multi X S.A. - Apiao Farm			18						18
Multiexport Patagonia S.A. - Taraba 6			3						3
NOVA AUSTRAL S.A. - ARACENA 14			3						3
P/F Luna - Hiddenfjord - Hestfjordur				4					4
Petuna Aquaculture Pty., Ltd.	3								3
Piscicultura Recirculación Astilleros (Patagonia King Salmon)			1						1
Productos del Mar Ventisqueros S.A			14						14
SALMONES ANTARTICA - CHOLGO			2						2
Salmones Austral S.A.			7						7
Salmones Aysen S.A			45						45
Superior Fresh LLC.								1	1
Van Diemen Aquaculture Pty., Ltd.	1								1
Wester Ross Fisheries							2		2

Yarra Valley Caviar	2								2
Granja Marina Tornagaleones S.A.			1						1
Country Totals	**6**	**99**	**261**	**4**	**10**	**3**	**37**	**7**	**427**

As is clear from this data, the main areas of uptake for BAP have been Chile, Canada and the UK, with Norway having relatively few certificates (the reasons for this are discussed later in this report).

6.4. Organic Salmon Production

The term 'Organic' can be considered one of the most confusing and misunderstood in modern day food production and this is no different in fish production. In reality, defining something as Organic has no set criteria and can cover a host of different requirements and considerations which vary from location to location. Interestingly, during recent consumer surveys in the UK, the term organic was most clearly linked to the "absence of pesticides".

Within the salmon farming sector, the production of 'organic salmon' has been going since the 1990's. Determining what is required to determine that some salmon are organic though remains open to interpretation and varies greatly between countries. For example, in the UK and EU, the use of tanks is forbidden in organic production but in the US it is not. For this discussion though we will focus on the UK/EU system which is considered by many to be the best developed.

Defining the term Organic through the development of a certification standard was a job that was pioneered in the UK by the Soil Association. It was them who first developed a standard for organic farming in the 1960s and this was followed by an aquaculture standard in the early 2000's. However, to somewhat confuse matters, the EU decided to create its own rules for organic products. For aquaculture, these rules were developed in 2007 through EU Regulation 834/2007. By setting these rules the EU were stating that any product that entered its jurisdiction had to have proof that the requirements of 834/2007 were being met to be called 'Organic'. As a result of this and some adjustments by the Soil Association the two standards then became aligned, and the Soil Association effectively became a Certification Body for the EU and the UK standard they had developed. Since Brexit however, the situation has changed again but the detail of this is beyond the scope of this report, and we will simply consider the Soil Association requirements below. However, it is important to note that when exporting organic product, it is the country into which the product enters who defines what organic means (and so a producer needs to know what organic market it is targeting and then produce under those specific rules).

With regards to the Soil Association/ UK requirements, certification activities are completed by Soil Association Certification or SAC (a separate entity which completes audits) who are accredited under ISO 17065 by UKAS. SAC will complete the initial audit against the organic requirements, and this must be followed by a yearly audit to maintain the certification. As with other standards, SAC will raise Minor, Major or Critical non-conformances depending on any issues which are found.

Below we have set out the 'key requirements' for organic salmon farming under the Soil Association standard.

<u>Environmental Assessments</u>: If producing more than 20 Tonnes of product per year then the farm is required to draw up an environmental assessment (in most cases an EIA is used).

<u>Sustainable Management Plan</u>: The farm is required to develop an SMP which sets out perceived risks and mitigation measures. This should include areas such as waste management, predator control etc….

Non-Native Species: The standard states that locally produced species should be used which is believed to exclude species that are non-native (or at least not already grown in the region).

GMO Products: Unsurprisingly, the production of Genetically modified product is not allowed. It is also not allowed to use products from GMO origins in areas such as feed (for example, soy protein) and you must have statements to confirm this is the case from suppliers. Importantly, the use of triploids is also not allowed under organic farming principles.

Site Suitability and Separation: Organic farming operations are required to be operated in areas which are free from pollution or pollutants that would affect the organic integrity of the product. A classic example here would be another non-organic fish farm. No specified distances etc… are provided but you need to provide evidence that they are 'adequately separated'.

Furthermore, it is possible to produce non-organic and organic product under the same company, but the production units will need to meet the requirements for separation specified above.

Stocking Density: The regulations specify a specific maximum stocking density in cage farms of 10 kg/m^3. This is the maximum it can reach (at maximum biomass) and so normally levels will be much lower. This is probably one of the key differences between organic and 'normal' salmon farming.

Feed requirements: This is another major areas of difference in organic production. Basically, feed sources that are allowed are from organic products themselves, products derived from trimmings from human consumption in sustainable fisheries or whole fish sources derived from sustainable fisheries. This presents a very similar problem to the other certification standards but due to the lower quantities involved it is possible to achieve.

Other feed requirements include the need for astaxanthin to be sourced from organic crustacean shells, and for only certain permitted minerals and additives (a long list is provided in the standard) to be included.

The result is that all organic salmon producers will buy an 'organic pelleted feed' which has been specially formulated to meet the above requirements (and is subsequently much more expensive). As an example, the feed producer Aller Aqua produce an organic salmon feed (https://www.aller-aqua.com/feed-products-and-concepts/organic-feeds).

Slaughter Techniques: All farmed fish must be stunned before killing and killing must use an effective and efficient method (excluding ice, CO_2 or suffocation).

Fallowing: It is a recommended requirement that after every production cycle, cages are cleaned and left fallow for a period of time (to allow seabed regeneration). This though is not an actual requirement and is rarely practised.

Disease Treatment: This is probably one of the most controversial areas of organic salmon farming with many people incorrectly believing that the use of treatments would be banned in organic farming.

Organic farming allows for the use of homeopathic remedies, plant and plant extracts and trace element and authorised probiotics. However, if this is not found to solve the problem a range of allopathic (drug) treatments are permitted up to two times per year.

Specifically, for the treatment of parasites, you can use chemical treatments a maximum of two times per year (but prior approval from the Certification Body is required). The use of biological controls (cleaner fish) is preferred, however.

So, in summary, organic production allows the same treatment of disease and parasites as normal production but with limits on the treatment amounts allowed in a year.

Cleaning Methods: Removal of bio-foul is only allowed by physical means (no use of copper in nets is allowed for example).

Disinfection of equipment is allowed but a list of prescribed products is provided for this purpose.

6.4.1. Current Organic Salmon Production

Data is not available on the global status of organic salmon production with organic requirements so different from region to region making comparison difficult. However, certain areas or countries are known to have organic salmon production occurring and these are discussed in more detail below.

Ireland: Although a small producer, Ireland is one of the main producers of Organic salmon with over 80% of total annual production in Ireland being organic and certified[39]. Current Irish organic salmon production is estimated at around 9,400 Tonnes in 2023 and has actually fallen in recent years. The vast majority of this product is exported to France and other European markets.

Production in Ireland is mainly based in the North (around 50%), followed by the Atlantic coast. The exact reason that Organic salmon farming has dominated in Ireland is not entirely clear. However, the licensing process in the country is known to be incredibly slow (with licenses taking over 10 years in some cases for approval).

The main producer of Organic Salmon is Mowi Ireland (sold through trading name The Irish Organic Salmon Company) which has been producing since 1996.

In Scotland, organic salmon farming has seen significant growth in recent years. According to the Scottish Fish Farm Production Survey 2023[40], there were 12 certified organic seawater pen sites, producing 13,530 tonnes of organic Atlantic salmon. In this niche market, companies such as Cooke Aquaculture Scotland have significant operations—especially in the Orkney Islands—playing a key role in this dominant production setup.

Norway: As of 2023, specific statistics on organic salmon farming in Norway are not readily available[41].

6.5. Summary and Discussion on Certification in the Salmon industry

The analysis above has shown how the use of sustainable certification schemes has grown dramatically in recent years within the salmon sector. Three schemes, ASC, BAP and Global GAP are responsible for virtually all third-party certifications across the globe. Each has been analysed and above and although many similarities exist, some generic differences have been identified;

ASC: Considered the most environmentally robust of the three standards. It sets its own specific requirements (rather than relying on national legislation for example). With the introduction of the ASC Farm Standard in 2025, the scheme now also includes comprehensive social and welfare criteria, addressing previous gaps in areas such as health and safety. The ASC Standard has gained the most traction amongst the salmon industry and leads the way in terms of certificates and up take, particularly in Norway.

BAP: The second most popular standard in the industry. Although quite detailed, the standard is less robust than the ASC one with many requirements being based on local legislation (rather than setting actual levels). The standard does cover other areas such as H&S, food safety and humane

[39] BIM - Irish organic salmon well positioned as demand continues to grow
[40] Atlantic Salmon - Production - Scottish Fish Farm Production Survey 2023 - gov.scot
[41] Microsoft Word - nok-rap23-engelsk-ny.docx

slaughter, however. The standard has been particularly popular in Chile and has also gained some traction in the UK.

Global GAP: The standard is very similar to BAP but has failed to gain the same traction (despite being the first on the scene). It is now generally only used for specific clients or for smolt operations and is not considered a major player in the salmon sector anymore. Its continued relevance is largely tied to supply chain requirements or regional buyer preferences.

So, what has driven the different uptake rates of these three standards? The answer lies in multiple reasons but the most important has been stakeholder acceptance. In short, the farms are keen to meet the requirements which will give them the greatest purchasing power but are, at the same time, as easy to achieve as possible. For most, the ASC is the highest level and so this is the one that many Western retailers are requesting. It is though the most difficult to achieve and so is not taken lightly. The ASC standard has received major backing through the support of the Global Salmon Initiative (GSI). GSI[42] was established in 2013 by leading salmon farming companies to collaboratively address sustainability challenges. As of now, GSI comprises 14 member companies operating across six countries—Australia, Canada, Chile, Faroe Islands, Norway, and the United Kingdom—collectively representing approximately 40% of the global farmed salmon sector. Notably, Mowi, the world's largest salmon producer, departed from the GSI in mid-2020. The GSI has committed to the ASC as its 'standard of choice' and aims to achieve 100% certification amongst all its members (although no date is set). At the same time, Mowi has also set the ASC standard as its preferred standard of choice and is aiming for 100% certification (although again with no date set). When you add the commitment of GSI and Mowi together you are covering around 50-60% of production, so it is easy to see why the ASC standard is proving the most popular.

The BAP standard though has also gained traction in Chile. The reasons for this are partly due to it being easier to achieve but also because of the US market which Chile is more active in supplying. GSA BAP is a US based standard and so has much better presence in this market than the European one.

It is also true that some companies have decided to simply take on both certifications to cover all options! For some, it is the case that certain retailers are requiring BAP and others are requiring ASC. Although efforts have been ongoing to benchmark these standards to avoid the need for multiple certification standards this is still developing and so some companies still adopt the multiple certification approach.

How the use of these certifications may play out in a future Falklands industry now needs some consideration. Firstly, it is important to understand that no country has yet placed a sustainability standard as a 'requirement for licensing'. Instead, the schemes are voluntary and driven more by the industry and public opinion with the regulatory process being separate. That said, it is true that many regulatory systems are becoming closer and closer aligned to the requirements of the standards. What is not desirable is a regulatory system in which the requirements are substantially different from the standard requirements as this can create problem for the standard setters who will struggle to argue that companies should be doing something different to the law[43].

[42] Our People | Global Salmon Initiative

[43] A good example here might be that a country makes certain treatment requirements for salmon law but that this then goes against the standard. In this case the farmer has an impossible choice between breaking the law or meeting the certification requirements. It is therefore important that the two do not contradict each other whenever possible.

Considering the above, it is our opinion that future regulatory requirements should consider the requirements of the main standards carefully and ensure at least alignment whenever possible. However, we do not think that legislation should place an absolute requirement of farms being certified against specific certification requirements. In this regard, the legislation and regulatory framework can be seen as setting the right environment for allowing operators to achieve third party certification.

Despite the above though, one specific area is likely to create a major problem for any farm wishing to become certified against any of the standards specified above and this relates to the fact that salmon (coho or Atlantic) are not native species to the Falklands or currently introduced in the Islands. The wording in relation to this is set out for each standard below in Table 8.

Table 8: Standard requirement wording in relation to non-native species use

ASC Salmon Standard	3.2.1 If a non-native species is being produced, demonstration that the species was widely commercially produced in the area by the date of publication of the ASC Salmon Standard. Exceptions shall be made for production systems that use 100% sterile fish or systems that demonstrate separation from the wild by effective physical barriers that are in place and well-maintained to ensure no escapes of reared specimens or biological material that might survive and subsequently reproduce. 3.2.2 If a non-native species is being produced, evidence of scientific research completed within the past five years that investigates the risk of establishment of the species within the farm's jurisdiction and these results submitted to ASC for review
ASC Farm Standard	2.4: ASC certified farms are required to implement robust escape management practices and mitigation measures in line with the EICAT classification to minimise the risks posed by alien species and their impacts. 2:4:10 The Unit of Certification shall implement appropriate mitigation measures according to the contextualisation of the Environmental Impact Classification for Alien Taxa (EICAT) category
Global GAP	None found
GSA BAP	6.8: The applicant shall provide documents that prove the species of salmon farmed is approved for farming in that country and that the stocked fish are not transgenic. Where the species farmed is not native or not already farmed, further documents shall be provided to demonstrate that approval for farming is based on the 2005 ICES Code of Practice on Introductions and Transfers of Marine Organisms.

The above wording suggests that certification under the ASC Farm Standard may be possible for salmon production in the Falklands, but only if the farm can demonstrate that the ecological risk of escape and establishment is low. This would likely require the use of 100% sterile fish (e.g. triploids), land-based or closed containment systems, or other effective physical barriers that materially reduce the risk of interaction with native ecosystems. Elaboration on what the ASC defines an "effective physical barrier" to be is not available, but the intent is likely toward closed or semi-closed systems (which are mentioned elsewhere in the standard), or land-based or isolated water bodies (e.g., lochs or lakes not connected to the sea), particularly where the risk of escape and reproduction is materially reduced. While the Farm Standard no longer includes a specific exemption clause for sterile fish, the EICAT framework allows for contextual mitigation, and such measures would likely be viewed favourably.

For BAP, the wording is less clear but following discussions with BAP staff it appears that the production would need to be reviewed on a case-by-case basis and would require approval from the BAP committee first. Either way, achievement of certification in the Falklands is not likely to be a straightforward process at all.

The other area that we have considered in the analysis above is that of 'organic salmon farming'. While it is noted that the principles of what is organic can vary considerably, a growing industry in the EU for organic salmon still exists. To date, no country has set the precedent of requiring all salmon farming operations to follow organic requirements as part of licensing requirements. As mentioned, Ireland is currently producing salmon virtually 100% organic, but this is not a regulatory requirement but simply a result of company policy making and slow licensing by the Government.

It would certainly be an option for the FIG to develop its future salmon farming industry based on 'organic production' and this would represent a 'world first'. A few key points are raised at this stage which require further consideration;

- The idea of 'organic only' would most likely be better received by the NGO and local community than traditional salmon farming.
- Having a whole region classed as organic would make the process of certification easier and would avoid issues linked with 'cross contamination'.
- The legislation would have to specifically link to the key organic requirements to ensure that it is clear
- What is classed as 'organic' though would need careful consideration and is partly linked to the market that producers would supply
- Whether a market and business model exist which would make it attractive to operators is not clear. Certain specific issues (such as sourcing organic feed in the Falklands) would need to be overcome and it is noted that the current major markets for Organic are considerable distance from the Falklands.
- It does not though appear that non-indigenous species can be grown under the organic requirements (although the wording is not very clear) and this would require further confirmation.

7. Summary of Findings & Key Conclusions

In this report we have set out the key issues which have been shown to affect the salmon farming industry and current best practices which are being implemented to resolve these issues. In the table at the end of this section we have further attempted to summarise these risks and mitigation solutions for the reader.

It is though true that the commencement of any salmon farming in the Falklands Islands will result in *some* negative environmental outcomes, however small they may be or well controlled the system is. MEP considers it a vital first step for the FIG to develop a vision on how it wishes to move forward with the potential salmon farming in the Islands. It is our opinion that this vision can fall into one of four options which are set out below along with the strengths and weaknesses of each approach.

Option 1: No salmon farming in the Falkland Islands	
FIG takes the decision that the financial benefits of salmon farming (employment and GDP) are not strong enough to warrant the environmental risks that exist from the activities (even is managed through best practices).	
Advantages	**Disadvantages**
• NGOs will be happy • Local community concerns will not be realised • Falklands environmental reputation is not jeopardised by potential salmon farming activities	• No revenue generated • No employment generates

Option 2: Commercial salmon farming takes place and is limited only by the carrying capacity of the environment.	
FIG takes the decision to allow salmon farming and to limit by the carrying capacity of the water system (as done in Norway). Licensing will be completed always using best available management practices but will allow development up to capacity limits as determined by the regulatory system (and with potential reduction reference points built in for areas such as sea lice for safety).	
Advantages	**Disadvantages**
• GDP and employment generation can be maximised	• Likely to be highly unpopular with NGOs and some of local community • May tarnish environmental reputation (whatever the outcome) • Highly likely to be issues of disease etc. even despite the use of best management practices (no system is perfect).

Option 3: Commercial salmon farming takes place but is limited well below the carrying capacity of the environment.	
FIG takes the decision to allow salmon farming but to limit the licensing volumes to well below anticipated carrying capacity (either through a carrying capacity assessment or using the precautionary principal approach). Best management practices will still be employed for all licenses which are granted.	
Advantages	**Disadvantages**
• Some GDP and employment generation • Can appease NGOs by showing precautionary approach and limited licensing • Potential to increase in future if process proves successful	• Some activity still unlikely to fully appears NGOs and local community concerns • Likely that some negative outputs may still occur from licensed facilities • Requires development of high-quality management and regulatory systems but for limited GDP/employment generation

Option 4: Commercial salmon farming is allowed but through niche methods such as 'organic production'	
FIG decides to allow only niche salmon farming production through a model that aligns with the principles of an 'organic only' approach to aquaculture. All licenses will only be issued to companies that commit to implementing best management practices consistent with becoming organically certified. Best management practices (in line with organic requirements) will still be employed for all licenses which are granted.	
Advantages	**Disadvantages**
• Some GDP and employment generation • Creation of a 'niche industry with strong environmental credentials' • May help appease NGO and community concerns • Allows for the use of triploid fish while maintaining high standards	• Unlikely that a non-native species such as Salmon could be produced in Falklands under Organic requirements, are may not qualify for formal organic certification or associated market premiums • Requires clear definition and enforcement of "organic-aligned" practices

	• Unclear if it would be financially viable for commercial operations • Likely that some negative outputs may still occur from licensed facilities

Of the four options above, it is likely that Option 3 represents the most likely path forward for FIG. It provides a compromise between the commencement of some commercial activities while also maintaining caution through the limitation of licensing activities. What scale those limited activities should be is dependent on the capacity that could be supported on the Islands and at what level FIG considers farming to be 'acceptable'.

To implement Option 3 (and 2 and 4 for that matter), a well-defined regulatory environment covering all areas of best practice highlighted in this report will need to be developed in the country. The rough outlines and structure of this system (in Scotland) is presented in Annex 2 of this report and shows just how complex and intertwined the process often is!

It must also be stated that his report makes no assessment of the economic potential which companies may see in farming opportunities in the Falklands Islands. If restrictions are placed which are economically prohibitive, then the result will be no commercial enterprises will want to invest in salmon farming on the Islands in the first place. Furthermore, the isolated location of the Falklands clearly presents some specific infrastructure and market supply considerations which are likely to only add costs to the process. It is also important that FIG consult with the wider commercial producers to understand what may or may not be feasible. Creating a regulatory environment which would not allow any profitable commercial activity would be considered counter intuitive.

In summary, this report has presented the variety of issues which have and continue to be faced by the global commercial salmon farming industry. Should the FIG decide to begin the licensing of farming operations on the island, it is inevitable that some of the issues described in this report will be experienced at some point, even providing that the best available management measures are implemented. Clearly these negative associations will need to be outweighed by the positives which developing this sector will bring (in employment and GDP). In this approach, caution is seen as the most sensible option, and it would be recommended that farming is started on a single pilot scale basis to provide the NGOs and community with an opportunity to get used to the new sector and make improvements and refinements to the regulations and policies prior to additional licensing being agreed.

With good management and strong regulatory framework, it should be possible to reduce the impacts of the negative outfall (both real and perceived) from salmon farming in the Islands to low levels. Furthermore, the semi-autonomous and relatively simple legislative structure should present additional advantages to the islands as it develops its policies and regulations.

Source	Impact	Best Management Practices
Interaction with endemic wildlife		
Use of non-native species *(Salmon salar)*	• Development of wild stocks of non-native species • Interaction with existing food chain	• Do not introduce non-native species • Possible use of triploid species (noting issues however)
Farmed fish escapes	• Development of wild stocks of non-native species • Interaction with existing food chain	• Possible use of triploid species (noting issues however) • Limited biomass production (reduces risk) • Predator netting system (to avoid escapes) • Locations of farms in protected areas (to avoid escapes) • Escape Management Plans at farm level (legal requirement) including staff training
Predator interaction	• Farmed fish escapes • Loss of revenue and farm mortality • Harm to protected marine mammals and seabirds	• Use of predator netting • Use of Acoustic Deterrent Devices (ADDs) (limited and approved) • Strict legal process for authorising lethal action
Disease		
Infectious diseases (bacterial, viral and parasitic)	• Transmission of pathogens to wild species	• Aquatic animal health management plan in place on all farms • Regular veterinary checks (Norway: 4-6 times annually, depending on the size of the farm) • Farms to have a location structure and zoning to reduce the risk of disease transmission. • Advanced vaccination programmes in place • Optimised biosecurity (legal requirements) • Use of functional feeds and immune modulators etc. • Improved husbandry methods to reduce stress • Fallowing
Sea lice	• Transmission of sea lice to wild species in greater numbers • Loss of revenue and farm mortality	• Caps on maximum sea lice threshold (Norway: 0.2 lice during wild salmon migration period, otherwise 0.53 motile lice per salmon always, Chile: 3 motile lice per salmon at all times) • Potential reference points for reduction of biomass production (like traffic light system) • Use of treatments allowed but under strict regulatory approval • Encouragement of alternative measures (skirt nettings, lumpfish)
Pathogen transfer and	• Transmission of pathogens to wild species	• Adequate biosecurity

transboundary aquatic animal diseases		• Quarantining • Use of pathogen free stocks
Chemical discharge		
Chemotherapeutants/parasiticides	• Residual effects on wild species	• Use of chemotherapeutants only after consultation and prescription by a licensed veterinarian • Improved biosecurity • Functional feeds and immune modulators etc.
Antibiotics	• Residual effects on wild species • Immunity to antibiotics	• Minimal use of antibiotics and strict use control and approval • Vaccination programmes • Functional feeds and immune modulators etc.
Feed		
High dependency on fish resources in feed	• Overexploitation of wild marine resources.	• Production of fish aligning with the principle of organic certifications only? • Encouragement of certification schemes (including feed certification schemes)
Waste control		
Benthic flora/fauna	• Emissions of organic materials to the surrounding environment both local and regional resulting in unacceptable changes in sediment chemistry and faunal communities	• Environmental Impact Assessment (EIA) before site licence given • Location of site in area of high-water currents, aiding organic matter dispersal and prevent accumulation below the cages • Optimised management, e.g. moving the cages and the fallowing of sites between production cycles, enforcing minimum distances between farm sites/zones, establishing sustainable biomass limits • Benthic monitoring system around farms implemented by the FIG with specific requirements on changes in faunal communities • Use of RAS in hatchery systems through incentivisation.
Inorganic waste	• Local and regional emissions of nutrients to the surrounding environment resulting in eutrophication	• Environmental Impact Assessment (EIA) before site licence given (and to include predictive inorganic waste modelling (DECAPOD) • Location of site in area of high-water currents, aiding organic matter dispersal and prevent accumulation below the cages • Optimised management, e.g. moving the cages and the fallowing of sites between production cycles • Use of RAS in hatchery systems through incentivisation. •

Freshwater Use		
Significant freshwater use at hatchery level	• High use of freshwater which is an important resource (although maybe not limited in the Falklands)	• Use of RAS in hatchery systems through incentivisation.
Social-Economic Considerations		
Negative response from NGOs and community	• Negative feedback and ill feeling to industry	• Public consultation in the regulatory phase • Public consultation at the individual licensing phase • Regular feedback on process and responses to points raised • Identification of benefits of industry to islands • Initial pilot phase
Complaints and Issues arising after licenses provided	• Negative feedback and ill feeling to industry	• Licensees required to have a functioning complaints procedure • Regular stakeholder workshops to discuss issues

References

Aarestrup, F. M. (Ed.). (2006). Antimicrobial resistance in bacteria of animal origin.

Aas TS, Åsgård T, Ytrestøyl T. Utilization of feed resources in the production of rainbow trout (Oncorhynchus mykiss) in Norway in 2020. Aquaculture Reports. 2022 Oct 1;26:101317.

Abihssira-García IS, Kögel T, Gomiero A, Kristensen T, Krogstad M, Olsvik PA. Distinct polymer-dependent sorption of persistent pollutants associated with Atlantic salmon farming to microplastics. Marine Pollution Bulletin. 2022 Jul 1;180:113794.

Abolofia, J., Asche, F., & Wilen, J. E. (2017). The cost of lice: quantifying the impacts of parasitic sea lice on farmed salmon. *Marine Resource Economics*, *32*(3), 329-349.

Adams, A., & Subasinghe, R. (2019). Use of Fish Vaccines in Aquaculture (including methods of administration). *Veterinary Vaccines for Livestock (1st Edition), published by The Food and Agriculture Organization of the United Nations*.

Adams, C. M., Mayer, L. M., Rawson, P., Brady, D. C., & Newell, C. (2019). Detrital protein contributes to oyster nutrition and growth in the Damariscotta estuary, Maine, USA. *Aquaculture Environment Interactions*, *11*, 521-536.

Alderman, D. J., & Hastings, T. S. (1998). Antibiotic use in aquaculture: development of antibiotic resistance–potential for consumer health risks. *International journal of food science & technology*, *33*(2), 139-155.

Alonso, A., Sanchez, P., & Martínez, J. L. (2001). Environmental selection of antibiotic resistance genes. *Environmental microbiology*, *3*(1), 1-9.

Altizer, S., Dobson, A., Hosseini, P., Hudson, P., Pascual, M., & Rohani, P. (2006). Seasonality and the dynamics of infectious diseases. *Ecology letters*, *9*(4), 467-484.

Alvial, A. (2017). Chile case: the spatial planning of marine cage farming (Salmon). *Aquaculture Zoning, Site Selection and Area Management Under the Ecosystem Approach to Aquaculture*.

Alvial, A., Kibenge, F., Forster, J., Burgos, J. M., Ibarra, R., & St-Hilaire, S. (2012). The recovery of the Chilean salmon industry. *Puerto Montt: World Bank*.

Amoroso, G., Cobcroft, J. M., Adams, M. B., Ventura, T., & Carter, C. G. (2016). Concurrence of lower jaw skeletal anomalies in triploid Atlantic salmon (Salmo salar L.) and the effect on growth in freshwater. *Journal of fish diseases*, *39*(12), 1509-1521.

Amundrud, T. L., & Murray, A. G. (2009). Modelling sea lice dispersion under varying environmental forcing in a Scottish sea loch. *Journal of fish diseases*, *32*(1), 27-44.

Angulo, F. J., & Griffin, P. M. (2000). Changes in antimicrobial resistance in *Salmonella enterica* serovar typhimurium. *Emerging infectious diseases*, *6*(4), 436.

Aquaculture and Fisheries (Scotland) Act (2007) https://www.legislation.gov.uk/asp/2007/12/contents

Albrektsen S, Kortet R, Skov PV, Ytteborg E, Gitlesen S, Kleinegris D, Mydland LT, Hansen JØ, Lock EJ, Mørkøre T, James P. Future feed resources in sustainable salmonid production: A review. Reviews in aquaculture. 2022 Sep;14(4):1790-812.

Arriagada, G., Sanchez, J., Stryhn, H., Vanderstichel, R., Campistó, J. L., Ibarra, R., & St-Hilaire, S. (2018). A multivariable assessment of the spatio-temporal distribution of pyrethroids performance on the sea lice Caligus rogercresseyi in Chile. *Spatial and spatio-temporal epidemiology*, *26*, 1-13.

Arriagada, G., Valenzuela-Muñoz, V., Arriagada, A. M., Núñez-Acuña, P., Brossard, M., Montecino, K., Gallardo-Escárate, C. (2019). First report of the sea louse Caligus rogercresseyi found in farmed Atlantic salmon in the Magallanes region, Chile. *Aquaculture*, *512*, 734386.

Asche, F., & Bjorndal, T. (2011). *The economics of salmon aquaculture* (Vol. 10). John Wiley & Sons.

Asche, F., Roll, K. H., & Trollvik, T. (2009). New aquaculture species—the whitefish market. *Aquaculture Economics & Management*, *13*(2), 76-93.

Asplin, L., Johnsen, I. A., Sandvik, A. D., Albretsen, J., Sundfjord, V., Aure, J., & Boxaspen, K. K. (2011). Dispersion of salmon lice in the Hardangerfjord. *Marine Biology Research*, *10*(3), 216-225.

Austin, B., Austin, D. A., & Munn, C. B. (2007). *Bacterial fish pathogens: disease of farmed and wild fish* (Vol. 26). Dordrecht, The Netherlands: Springer.

Ayalew, A., Fufa, A., Wubet, B., & Samson, L. (2018). Assessment of post-harvest fish losses in two selected lakes of Amhara region, northern Ethiopia. *Heliyon*, *4*(11).

Barría, C., Vásquez-Calderón, P., Lizama, C., Herrera, P., Canto, A., Conejeros, P., Beltrami, O., Suárez-Isla, B.A., Carrasco, D., Rubilar, I. and Guzmán, L., 2022. Spatial temporal expansion of harmful algal blooms in Chile: A review of 65 years records. *Journal of Marine Science and Engineering*, *10*(12), p.1868.

Bacher, K. (2015). Perceptions and misconceptions of aquaculture: a global overview. *GLOBEFISH Research Programme*, *120*, I.

Baquero, F., Alvarez-Ortega, C., & Martinez, J. L. (2009). Ecology and evolution of antibiotic resistance. *Environmental Microbiology Reports*, *1*(6), 469-476.

Barrett, L.T., Oppedal, F., Robinson, N. and Dempster, T., 2020. Prevention not cure: a review of methods to avoid sea lice infestations in salmon aquaculture. *Reviews in Aquaculture*, *12*(4), pp.2527-2543.

Barton, J. R. (1998). Salmon aquaculture and Chile's 'export–led' economy. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, *52*(1), 37-47.

Barton, J. R., & Murray, W. E. (2009). Grounding geographies of economic globalisation: globalised spaces in Chile's non-traditional export sector, 1980–2005. *Tijdschrift voor economische en sociale geografie*, *100*(1), 81-100.

Bassi A, Love OP, Cooke SJ, Warriner TR, Harris CM, Madliger CL. Effects of artificial light at night on fishes: A synthesis with future research priorities. Fish and Fisheries. 2022 May;23(3):631-47.

Bergheim, A., Drengstig, A., Ulgenes, Y., & Fivelstad, S. (2009). Production of Atlantic salmon smolts in Europe—current characteristics and future trends. *Aquacultural Engineering*, *41*(2), 46-52.

Bjørndal, T. (2002). The competitiveness of the Chilean salmon aquaculture industry. *Aquaculture Economics & Management*, *6*(1-2), 97-116.

Bjørndal T, Mrdalo ZP. Salmon aquaculture in the Faroe Islands–historical developments and future prospects. Aquaculture Economics & Management. 2023 Oct 2;27(4):693-713.

Bjordal, Å. (1991). Wrasse as cleaner-fish for farmed salmon.

Bolstad GH, Karlsson S, Hagen IJ, Fiske P, Urdal K, Sægrov H, Florø-Larsen B, Sollien VP, Østborg G, Diserud OH, Jensen AJ. Introgression from farmed escapees affects the full life cycle of wild Atlantic salmon. Science Advances. 2021 Dec 22;7(52):eabj3397.

Bondad-Reantaso MG, MacKinnon B, Karunasagar I, Fridman S, Alday-Sanz V, Brun E, Le Groumellec M, Li A, Surachetpong W, Karunasagar I, Hao B. Review of alternatives to antibiotic use in aquaculture. Reviews in aquaculture. 2023 Sep;15(4):1421-51.

Bøhn T, Strøm JF, Sanchez-Jerez P, Keeley NB, Johansen T, Gjelland KØ, Sandlund N, Sæther BS, Sætra I, Olsen EM, Skjæraasen JE. Ecological interactions between farmed Atlantic salmon and wild Atlantic cod populations in Norway: A review of risk sources and knowledge gaps. Reviews in Aquaculture. 2024 Jun;16(3):1333-50.

Bravo, S. and Treasurer, J., 2023. The management of the sea lice in Chile: A review. *Reviews in Aquaculture*, *15*(4), pp.1749-1764.

Brown AR, Wilson RW, Tyler CR. Assessing the Benefits and Challenges of Recirculating Aquaculture Systems (RAS) for Atlantic Salmon Production. Reviews in Fisheries Science & Aquaculture. 2024 Nov 30:1-22.

Bjørndal, T., & Aarland, K. (1999). Salmon aquaculture in Chile. *Aquaculture Economics & Management*, *3*(3), 238-253.

Boyd, C. E., & Massaut, L. (1999). Risks associated with the use of chemicals in pond aquaculture. *Aquacultural engineering*, *20*(2), 113-132.

Boxall, A. B. (2004). The environmental side effects of medication: How are human and veterinary medicines in soils and water bodies affecting human and environmental health?. *EMBO reports*, *5*(12), 1110-1116.

Bravo, S., Boxshall, G. A., & Conroy, G. (2011). New cultured host and a significant expansion in the known geographical range of the sea louse Caligus rogercresseyi. *Bulletin of the european association of fish pathologists*, *31*, 156-160.

Broch, O. J., Daae, R. L., Ellingsen, I. H., Nepstad, R., Bendiksen, E. Å., Reed, J. L., & Senneset, G. (2017). Spatiotemporal dispersal and deposition of fish farm wastes: a model study from central Norway. *Frontiers in Marine Science*, *4*, 199.

Brooks, K. M., Mahnken, C., & Nash, C. (2002). Environmental effects associated with marine netpen waste with emphasis on salmon farming in the Pacific Northwest. *Responsible marine aquaculture*, 159-203.

Brooks, K. M. (2005). The effects of water temperature, salinity, and currents on the survival and distribution of the infective copepodid stage of sea lice (Lepeophtheirus salmonis) originating on Atlantic salmon farms in the Broughton Archipelago of British Columbia, Canada. *Reviews in Fisheries Science*, *13*(3), 177-204.

Burka, J. F., Fast, M. D., & Revie, C. W. (2012). 22 Lepeophtheirus salmonis and Caligus rogercresseyi. *Fish parasites*, 360-380.

Burridge, L., Weis, J. S., Cabello, F., Pizarro, J., & Bostick, K. (2010). Chemical use in salmon aquaculture: a review of current practices and possible environmental effects. *Aquaculture*, *306*(1-4), 7-23.

Cabello, F. C., Godfrey, H. P., Buschmann, A. H., & Dölz, H. J. (2016). Aquaculture as yet another environmental gateway to the development and globalisation of antimicrobial resistance. *The Lancet Infectious Diseases*, *16*(7), e127-e133.

Ceballos-Concha, A., Asche, F. and Cárdenas-Retamal, R., 2025. Salmon Aquaculture in Chile: Production Growth and Socioeconomic Impacts. *Reviews in Aquaculture*, *17*(1), p.e12993.

Cadillo-Benalcazar, J. J., Giampietro, M., Bukkens, S. G., & Strand, R. (2020). Multi-scale integrated evaluation of the sustainability of large-scale use of alternative feeds in salmon aquaculture. *Journal of Cleaner Production*, *248*, 119210.

Callier MD, Byron CJ, Bengtson DA, Cranford PJ, Cross SF, Focken U, Jansen HM, Kamermans P, Kiessling A, Landry T, O'beirn F. Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: a review. Reviews in aquaculture. 2018 Dec;10(4):924-49.

Cantillo J, Deshpande PC. Carbon footprint of alternative protein sources for Atlantic salmon (*Salmo salar*) aquaculture: A two-step systematic literature review. Aquaculture Reports. 2025 Mar 15;40:102601.

Capone, D. G., Weston, D. P., Miller, V., & Shoemaker, C. (1996). Antibacterial residues in marine sediments and invertebrates following chemotherapy in aquaculture. *Aquaculture*, *145*(1-4), 55-75.

Cardia, F. & Lovatelli, A. 2015. Aquaculture operations in floating HDPE cages: a field handbook. FAO Fisheries and Aquaculture Technical Paper No. 593. Rome, FAO. 152 pp.

Carias, J., Vásquez-Lavín, F., Barrientos, M., Oliva, R.D.P. and Gelcich, S., 2024. Economic valuation of Harmful Algal Blooms (HAB): Methodological challenges, policy implications, and an empirical application. *Journal of Environmental Management*, *365*, p.121566.

Carroll, M. L., Cochrane, S., Fieler, R., Velvin, R., & White, P. (2003). Organic enrichment of sediments from salmon farming in Norway: environmental factors, management practices, and monitoring techniques. *Aquaculture*, *226*(1-4), 165-180.

Carvajal, J., Gonzalez, L., & George-Nascimento, M. (1998). Native sea lice (Copepoda: Caligidae) infestation of salmonids reared in netpen systems in southern Chile. *Aquaculture*, *166*(3-4), 241-246.

Carvajalino-Fernandez, M. A., Sævik, P. N., Johnsen, I. A., Albretsen, J., & Keeley, N. B. (2020). Simulating particle organic matter dispersal beneath Atlantic salmon fish farms using different resuspension approaches. *Marine Pollution Bulletin*, *161*, 111685.

Cashion, T., Le Manach, F., Zeller, D., & Pauly, D. (2017). Most fish destined for fishmeal production are food-grade fish. *Fish and Fisheries*, *18*(5), 837-844.

Castellani, M., Heino, M., Gilbey, J., Araki, H., Svåsand, T., & Glover, K. A. (2018). Modeling fitness changes in wild Atlantic salmon populations faced by spawning intrusion of domesticated escapees. *Evolutionary Applications*, *11*(6), 1010-1025.

Chen, H., Liu, S., Xu, X. R., Liu, S. S., Zhou, G. J., Sun, K. F., & Ying, G. G. (2015). Antibiotics in typical marine aquaculture farms surrounding Hailing Island, South China: occurrence, bioaccumulation and human dietary exposure. *Marine pollution bulletin*, *90*(1-2), 181-187.

Chen, B., Lin, L., Fang, L., Yang, Y., Chen, E., Yuan, K., & Luan, T. (2018a). Complex pollution of antibiotic resistance genes due to beta-lactam and aminoglycoside use in aquaculture farming. *Water research*, *134*, 200-208.

Chen, S., Su, Y., & Hong, W. (2018b). Aquaculture of the large yellow croaker. *Aquaculture in China*, *10*, 297-308.

Chowdhury, R., Haque, M. N., Islam, K. M. S., & Khaleduzzaman, A. B. M. (2009). A review on antibiotics in an animal feed. *Bangladesh Journal of Animal Science*, *38*(1-2), 22-32.

Chu YI, Wang CM, Park JC, Lader PF. Review of cage and containment tank designs for offshore fish farming. Aquaculture. 2020 Mar 30;519:734928.

Chu, J., Anderson, J. L., Asche, F., & Tudur, L. (2010). Stakeholders' Perceptions of Aquaculture and Implications for its Future: A Comparison of the USA and Norway. *Marine resource economics*, *25*(1), 61-76.

Chuah, L. O., Effarizah, M. E., Goni, A. M., & Rusul, G. (2016). Antibiotic application and emergence of multiple antibiotic resistance (MAR) in global catfish aquaculture. *Current environmental health reports*, *3*(2), 118-127.

Costanzo, S. D., Murby, J., & Bates, J. (2005). Ecosystem response to antibiotics entering the aquatic environment. *Marine pollution bulletin*, *51*(1-4), 218-223.

Costello, M. J. (2006). Ecology of sea lice parasitic on farmed and wild fish. *Trends in parasitology*, *22*(10), 475-483.

Costello, M. J. (2009). How sea lice from salmon farms may cause wild salmonid declines in Europe and North America and be a threat to fishes elsewhere. *Proceedings of the Royal Society B: Biological Sciences*, *276*(1672), 3385-3394.

Cubillo, A. M., Ferreira, J. G., Robinson, S. M., Pearce, C. M., Corner, R. A., & Johansen, J. (2016). Role of deposit feeders in integrated multi-trophic aquaculture—a model analysis. *Aquaculture*, *453*, 54-66.

Dadar, M., Dhama, K., Vakharia, V. N., Hoseinifar, S. H., Karthik, K., Tiwari, R., & Joshi, S. K. (2017). Advances in aquaculture vaccines against fish pathogens: global status and current trends. *Reviews in Fisheries Science & Aquaculture*, *25*(3), 184-217.

Deutsch, L., Gräslund, S., Folke, C., Troell, M., Huitric, M., Kautsky, N., & Lebel, L. (2007). Feeding aquaculture growth through globalization: Exploitation of marine ecosystems for fishmeal. *Global Environmental Change*, *17*(2), 238-249.

Díaz-Tapia, P., Varela, D., Pérez-Santos, I., Díaz-Valdés, M., Molinet, C., Seguel, M., Aguilera-Belmonte, A., Álvarez, G., Uribe, E., Rengel, J.A. and Hernández-López, C., 2019. Impacts of harmful algal blooms on the aquaculture industry: Chile as a case study. *Centro Oceanográfico de A Coruña*.

Einum, S., & Fleming, I. A. (1997). Genetic divergence and interactions in the wild among native, farmed and hybrid Atlantic salmon. *Journal of Fish Biology*, *50*(3), 634-651.

Elvines DM, MacLeod CK, Ross DJ, Hopkins GA, White CA. Fate and effects of fish farm organic waste in marine systems: Advances in understanding using biochemical approaches with implications for environmental management. Reviews in aquaculture. 2024 Jan;16(1):66-85.

Espinosa-Miranda, C., Cáceres, B., Blank, O., Fuentes-Riquelme, M. and Heinrich, S., 2020. Entanglements and Mortality of Endemic Chilean Dolphins (Cephalorhynchus eutropia) in Salmon Farms in Southern Chile. *Aquatic mammals*, *46*(4).

FAO. (1995) Code of Conduct for Responsible Fisheries Rome, FAO. 1995.

FAO. 2019. Report of the Round-Table Discussion: Moving Forward through Lessons Learned on Response Actions to Aquatic Animal Disease Emergencies, Rome, 16–18 December 2019. *FAO Fisheries and Aquaculture Report No.1333. Rome.*

FAO. (2020). *The State of World Fisheries and Aquaculture 2020*. *Sustainability in action*. Rome.

Ferguson, A., Fleming, I. A., Hindar, K., Skaala, Ø., McGinnity, P., Cross, T., & Prodöhl, P. (2007). Farm escapes. *The Atlantic salmon: Genetics, conservation and management*, 367-409.

Fields WG. 1965. The structure, development, food relations, reproduction and life history of squid, Loligo opalescens Berry. Calif Dep Fish Game Fish Bull 131:1–108.

Findlay, C. R., Ripple, H. D., Coomber, F., Froud, K., Harries, O., van Geel, N. C. F., & Wilson, B. (2018). Mapping widespread and increasing underwater noise pollution from acoustic deterrent devices. *Marine pollution bulletin*, *135*, 1042-1050.

Finstad, B., Sandvik, A. D., Ugedal, O., Vollset, K. W., Karlsen, Ø., Davidsen, J. G., & Lennox, R. J. (2021). Development of a risk assessment method for sea trout in coastal areas exploited for aquaculture. *Aquaculture Environment Interactions*, *13*, 133-144.

Fischer, C., Guttormsen, A. G., & Smith, M. D. (2017). Disease risk and market structure in salmon aquaculture. *Water Economics and Policy*, *3*(02), 1650015.

Fivelstad, S., Olsen, A. B., Stefansson, S., Handeland, S., Waagbø, R., Kroglund, F., & Colt, J. (2004). Lack of long-term sublethal effects of reduced freshwater pH alone on Atlantic salmon (Salmo salar) smolts subsequently transferred to seawater. *Canadian Journal of Fisheries and Aquatic Sciences*, *61*(4), 511-518.

Fivelstad, S., Bergheim, A., Hølland, P. M., & Fjermedal, A. B. (2004). Water flow requirements in the intensive production of Atlantic salmon (Salmo salar L.) parr–smolt at two salinity levels. *Aquaculture*, *231*(1-4), 263-277.

Fleming, I. A., Hindar, K., MjÖlnerÖd, I. B., Jonsson, B., Balstad, T., & Lamberg, A. (2000). Lifetime success and interactions of farm salmon invading a native population. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *267*(1452), 1517-1523.

Folke, C., Kautsky, N., & Troell, M. (1994). The costs of eutrophication from salmon farming: implications for policy. *Journal of environmental management*, *40*(2), 173-182.

Ford, J. S., & Myers, R. A. (2008). A global assessment of salmon aquaculture impacts on wild salmonids. *PLoS biology*, *6*(2), e33.

Forseth, T., Barlaup, B. T., Finstad, B., Fiske, P., Gjøsæter, H., Falkegård, M., & Wennevik, V. (2017). The major threats to Atlantic salmon in Norway. *ICES Journal of Marine Science*, *74*(6), 1496-1513.

Fred-Ahmadu OH, Ahmadu FO, Adedapo AE, Oghenovo I, Ogunmodede OT, Benson NU. Microplastics and chemical contamination in aquaculture ecosystems: The role of climate change and implications for food safety—a review. Environmental Sciences Europe. 2024 Oct 14;36(1):181.

Fry, J. P., Mailloux, N. A., Love, D. C., Milli, M. C., & Cao, L. (2018). Feed conversion efficiency in aquaculture: do we measure it correctly?. *Environmental Research Letters*, *13*(2), 024017.

Fuentes, J., Engler, C., & VanderZwaag, L. (2016). Three pillars for sustainable marine aquaculture: the evolving regulatory framework in Chile. *Aquaculture Law and Policy: Global, Regional and National Perspectives*, 213-237.

Gaitán-Espitia, J. D., Gómez, D., Hobday, A. J., Daley, R., Lamilla, J., & Cárdenas, L. (2017). Spatial overlap of shark nursery areas and the salmon farming industry influences the trophic ecology of Squalus acanthias on the southern coast of Chile. *Ecology and evolution*, *7*(11), 3773-3783.

Gallardo-Escárate, C., Arriagada, G., Carrera, C., Gonçalves, A. T., Nuñez-Acuña, G., Valenzuela-Miranda, D., & Valenzuela-Muñoz, V. (2019). The race between host and sea lice in the Chilean salmon farming: a genomic approach. *Reviews in Aquaculture*, *11*(2), 325-339.

Gephart, J.A., Henriksson, P.J., Parker, R.W., Shepon, A., Gorospe, K.D., Bergman, K., Eshel, G., Golden, C.D., Halpern, B.S., Hornborg, S. and Jonell, M., 2021. Environmental performance of blue foods. Nature, 597(7876), pp.360-365.

Gismervik, K., Gåsnes, S. K., Gu, J., Stien, L. H., Madaro, A., & Nilsson, J. (2019). Thermal injuries in Atlantic salmon in a pilot laboratory trial. *Veterinary and Animal Science*, *8*, 100081.

Gjedrem, T. (2010). The first family-based breeding program in aquaculture. *Reviews in Aquaculture*, *2*(1), 2-15.

Gjedrem, T. (2012). Genetic improvement for the development of efficient global aquaculture: a personal opinion review. *Aquaculture*, *344*, 12-22.

Global Antimicrobial Resistance and Use Surveillance System (GLASS) Report: 2021 https://www.who.int/publications/i/item/9789240027336

Glover, K. A., Skår, C., Christie, K. E., Glette, J., Rudra, H., & Skaala, Ø. (2006). Size-dependent susceptibility to infectious salmon anemia virus (ISAV) in Atlantic salmon (Salmo salar L.) of farm, hybrid and wild parentage. *Aquaculture*, *254*(1-4), 82-91.

Glover, K. A., Otterå, H., Olsen, R. E., Slinde, E., Taranger, G. L., & Skaala, Ø. (2009). A comparison of farmed, wild and hybrid Atlantic salmon (Salmo salar L.) reared under farming conditions. *Aquaculture*, *286*(3-4), 203-210.

Glover, K. A., Pertoldi, C., Besnier, F., Wennevik, V., Kent, M., & Skaala, Ø. (2013). Atlantic salmon populations invaded by farmed escapees: quantifying genetic introgression with a Bayesian approach and SNPs. *BMC genetics*, *14*(1), 1-19.

Glover, K. A., Solberg, M. F., McGinnity, P., Hindar, K., Verspoor, E., Coulson, M. W., & Svåsand, T. (2017). Half a century of genetic interaction between farmed and wild Atlantic salmon: status of knowledge and unanswered questions. *Fish and Fisheries*, *18*(5), 890-927.

Golpour, A., M. A. M. Siddique, D. H. Siqueira-Silva, and M. Pšenička. 2016. Induced sterility in fish and its potential and challenges for aquaculture and germ cell transplantation technology: A review. Biologia (Bratisl) 71:853–64. doi:10.1515/biolog-2016-0118.

Gonzalez, L., Carvajal, J., & George-Nascimento, M. (2000). Differential infectivity of Caligus flexispina (Copepoda, Caligidae) in three farmed salmonids in Chile. *Aquaculture*, *183*(1-2), 13-23.

González, M. T., Leiva, N. V., Sepúlveda, F., Asencio, G., & Baeza, J. A. (2021). Genetic homogeneity coupled with morphometric variability suggests high phenotypic plasticity in the sea louse Caligus rogercresseyi (Boxshall and Bravo, 2000), infecting farmed salmon (Salmo salar) along a wide latitudinal range in southern Chile. *Journal of Fish Diseases*, *44*(5), 633-638.

González, L., & Carvajal, J. (2003). Life cycle of Caligus rogercresseyi,(Copepoda: Caligidae) parasite of Chilean reared salmonids. *Aquaculture*, *220*(1-4), 101-117.

Götz, T., & Janik, V. M. (2013). Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. *Marine Ecology Progress Series*, *492*, 285-302.

Groom, C.J. and Coughran, D.K., 2012. Entanglements of baleen whales off the coast of Western Australia between 1982 and 2010: patterns of occurrence, outcomes and management responses. Pacific Conservation Biology, 18(3), p.203.

Grøntvedt, R. N., Kristoffersen, A. B., & Jansen, P. A. (2018). Reduced exposure of farmed salmon to salmon louse (Lepeophtheirus salmonis L.) infestation by use of plankton nets: Estimating the shielding effect. *Aquaculture*, *495*, 865-872.

Gudding, R., & Van Muiswinkel, W. B. (2013). A history of fish vaccination: science-based disease prevention in aquaculture. *Fish & shellfish immunology*, *35*(6), 1683-1688.

Güralp, H., K. O. Skaftnesmo, E. Kjærner-Semb, A. H. Straume, L. Kleppe, R. W. Schulz, R. B. Edvardsen, and A. Wargelius. 2020. Rescue of germ cells in dnd crispant embryos opens the possibility to produce inherited sterility in Atlantic salmon. Scientific Reports 10:18042. doi:10.1038/s41598-020-74876-2

Gutierrez, A. P., Lubieniecki, K. P., Fukui, S., Withler, R. E., Swift, B., & Davidson, W. S. (2014). Detection of quantitative trait loci (QTL) related to grilsing and late sexual maturation in Atlantic salmon (Salmo salar). *Marine Biotechnology*, *16*(1), 103-110.

Gutierrez, A. P., Yáñez, J. M., & Davidson, W. S. (2016). Evidence of recent signatures of selection during domestication in an Atlantic salmon population. *Marine genomics*, *26*, 41-50.

Hall, T. E., & Amberg, S. M. (2013). Factors influencing consumption of farmed seafood products in the Pacific northwest. *Appetite*, *66*, 1-9.

Hall-Spencer, J., & Bamber, R. (2007). Effects of salmon farming on benthic Crustacea. *Ciencias Marinas*, *33*.

Hammer AJ, Millar C, Hennige SJ. Reducing carbon emissions in aquaculture: Using Carbon Disclosures to identify unbalanced mitigation strategies. Environmental Impact Assessment Review. 2022 Sep 1;96:106816.

Hargreaves, J. A., Brummett, R., & Tucker, C. S. (2019). The future of aquaculture. *Aquaculture: Farming aquatic animals and plants*, 617-636.

Harris, R. N., Harris, C. M., Duck, C. D., & Boyd, I. L. (2014). The effectiveness of a seal scarer at a wild salmon net fishery. *ICES Journal of Marine Science*, *71*(7), 1913-1920.

Harms MJ, Larraín-Barrios B, Arregoitia LD, Gelcich S, Alvarez RR, Tecklin D. Spatial assessment of risks faced by marine protected areas in Chilean Patagonia. Ecology and Society. 2024 Dec 31;29(4).

Harvell, C. D., Mitchell, C. E., Ward, J. R., Altizer, S., Dobson, A. P., Ostfeld, R. S., & Samuel, M. D. (2002). Climate warming and disease risks for terrestrial and marine biota. *Science*, *296*(5576), 2158-2162.

Hastings, P. J., Rosenberg, S. M., & Slack, A. (2004). Antibiotic-induced lateral transfer of antibiotic resistance. *Trends in microbiology*, *12*(9), 401-404.

Haya, K., Burridge, L. E., & Chang, B. D. (2001). Environmental impact of chemical wastes produced by the salmon aquaculture industry. *ICES Journal of Marine Science*, *58*(2), 492-496.

Haya, K., Burridge, L. E., Davies, I. M., & Ervik, A. (2005). A review and assessment of environmental risk of chemicals used for the treatment of sea lice infestations of cultured salmon. *Environmental effects of marine finfish aquaculture*, 305-340.

Hektoen, H., Berge, J. A., Hormazabal, V., & Yndestad, M. (1995). Persistence of antibacterial agents in marine sediments. *Aquaculture*, *133*(3-4), 175-184.

Henderson, A. R., & Davies, I. M. (2000). Review of aquaculture, its regulation and monitoring in Scotland. *Journal of Applied Ichthyology*, *16*(4-5), 200-208.

Hersoug, B., Mikkelsen, E., & Osmundsen, T. C. (2021). What's the clue; better planning, new technology or just more money?-The area challenge in Norwegian salmon farming. *Ocean & Coastal Management*, *199*, 105415.

Heuch, P. A., Bjørn, P. A., Finstad, B., Holst, J. C., Asplin, L., & Nilsen, F. (2005). A review of the Norwegian 'National Action Plan Against Salmon Lice on Salmonids': the effect on wild salmonids. *Aquaculture*, *246*(1-4), 79-92.

Hosono, A., Iizuka, M., & Katz, J. (2016). *Chile's Salmon Industry* (Vol. 10, pp. 978-4). Springer Japan.

Houde, A. L. S., Fraser, D. J., & Hutchings, J. A. (2010). Reduced anti-predator responses in multi-generational hybrids of farmed and wild Atlantic salmon (Salmo salar L.). Conservation Genetics, 11, 785-794.

Hucke-Gaete, R., 2013, April. SC/65a/Forinfo01-A historical feeding ground for humpback whales in the eastern South Pacific revisited: the case of northern Patagonia, Chile. In *Scientific Committee Annual Meeting 2013 (SC65A)*.

Imsland, A. K., Reynolds, P., Eliassen, G., Hangstad, T. A., Nytrø, A. V., Foss, A., & Elvegård, T. A. (2015). Feeding preferences of lumpfish (Cyclopterus lumpus L.) maintained in open net-pens with Atlantic salmon (Salmo salar L.). *Aquaculture*, *436*, 47-51.

Jacobs, S. R., & Terhune, J. M. (2002). The effectiveness of acoustic harassment devices in the Bay of Fundy, Canada: seal reactions and a noise exposure model. *Aquatic Mammals*, *28*(2), 147-158.

Jevne, L. S., Guttu, M., Båtnes, A. S., Olsen, Y., & Reitan, K. I. (2021). Planktonic and Parasitic Sea Lice Abundance on Three Commercial Salmon Farms in Norway Throughout a Production Cycle. *Frontiers in Marine Science*, *8*, 2.

Johnsen, B. O., & Jensen, A. J. (1994). The spread of furunculosis in salmonids in Norwegian rivers. *Journal of Fish Biology*, *45*(1), 47-55.

Johansen U, Nistad AA, Ziegler F, Mehta S, Wocken Y, Hognes ES. (2022) Greenhouse gas emissions of Norwegian salmon products.

Johnson, S. C., Bravo, S., Nagasawa, K., Kabata, Z., Hwang, J., Ho, J., & Shih, C. T. (2004). A review of the impact of parasitic copepods on marine aquaculture. *Zoological studies*, *43*(2), 229-243.

Jones, S., & Beamish, R. (2011). *Salmon lice: an integrated approach to understanding parasite abundance and distribution*. John Wiley & Sons.

Karlsson, S., Diserud, O. H., Fiske, P., Hindar, K., & Handling editor: W. Stewart Grant. (2016). Widespread genetic introgression of escaped farmed Atlantic salmon in wild salmon populations. *ICES Journal of Marine Science*, *73*(10), 2488-2498.

Karvonen, A., Halonen, H., & Seppälä, O. (2010). Priming of host resistance to protect cultured rainbow trout Oncorhynchus mykiss against eye flukes and parasite-induced cataracts. *Journal of fish biology*, *76*(6), 1508-1515.

Keeley, N. B., Forrest, B. M., Crawford, C., & Macleod, C. K. (2012). Exploiting salmon farm benthic enrichment gradients to evaluate the regional performance of biotic indices and environmental indicators. *Ecological Indicators*, *23*, 453-466.

Klinger, D., & Naylor, R. (2012). Searching for solutions in aquaculture: charting a sustainable course. *Annual Review of Environment and Resources*, *37*, 247-276.

Kolavani, N.J. and Mather, C., 2025. Regulating a 'fish out of place': A global assessment of farmed salmon escape policies and frameworks. *Marine Policy*, *173*, p.106572.

Kristensen, T., Åtland, Å., Rosten, T., Urke, H. A., & Rosseland, B. O. (2009). Important influent-water quality parameters at freshwater production sites in two salmon producing countries. *Aquacultural Engineering*, *41*(2), 53-59.

Krkošek, M., Bateman, A., Proboszcz, S., & Orr, C. (2010). Dynamics of outbreak and control of salmon lice on two salmon farms in the Broughton Archipelago, British Columbia. *Aquaculture Environment Interactions*, *1*(2), 137-146.

Lafferty, K. D., Harvell, C. D., Conrad, J. M., Friedman, C. S., Kent, M. L., Kuris, A. M., & Saksida, S. M. (2015). Infectious diseases affect marine fisheries and aquaculture economics. *Annual review of marine science*, *7*, 471-496.

Lees, F., Baillie, M., Gettinby, G., & Revie, C. W. (2008). The efficacy of emamectin benzoate against infestations of Lepeophtheirus salmonis on farmed Atlantic salmon (Salmo salar L) in Scotland, 2002–2006. *PLoS one*, *3*(2), e1549.

Leung, T. L., & Bates, A. E. (2013). More rapid and severe disease outbreaks for aquaculture at the tropics: implications for food security. *Journal of applied ecology*, *50*(1), 215-222.

Lillehaug, A., Lunestad, B. T., & Grave, K. (2003). Epidemiology of bacterial diseases in Norwegian aquaculture a description based on antibiotic prescription data for the ten-year period 1991 to 2000. *Diseases of aquatic organisms*, *53*(2), 115-125.

Liu, Y., & vanhauwaer Bjelland, H. (2014). Estimating costs of sea lice control strategy in Norway. *Preventive veterinary medicine*, *117*(3-4), 469-477.

Liu, X., Steele, J. C., & Meng, X. Z. (2017). Usage, residue, and human health risk of antibiotics in Chinese aquaculture: a review. *Environmental Pollution*, *223*, 161-169.

Lizuka, M., & Katz, J. (2011). Natural resource industries,'tragedy of the commons' and the case of Chilean salmon farming. *Institutions and Economies*, 259-286.

Lizuka, M., & Zanlungo, J. P. (2016). Environmental collapse and institutional restructuring: the sanitary crisis in the Chilean salmon industry. In *Chile's Salmon industry* (pp. 109-135). Springer, Tokyo.

Lozano, I., Díaz, N. F., Muñoz, S., & Riquelme, C. (2018). Antibiotics in Chilean aquaculture: a review. *Antibiotic use in animals*, *3*, 25-44.

Lulijwa, R., Rupia, E. J., & Alfaro, A. C. (2020). Antibiotic use in aquaculture, policies and regulation, health and environmental risks: a review of the top 15 major producers. *Reviews in Aquaculture*, *12*(2), 640-663.

Luthman, O., Jonell, M., & Troell, M. (2019). Governing the salmon farming industry: Comparison between national regulations and the ASC salmon standard. *Marine Policy*, *106*, 103534.

Madhun AS, Karlsbakk E, Isachsen CH, Omdal LM, Eide Sørvik AG, Skaala Ø, Barlaup BT, Glover KA. Potential disease interaction reinforced: double-virus-infected escaped farmed A tlantic salmon, S almo salar L., recaptured in a nearby river. Journal of Fish Diseases. 2015 Feb;38(2):209-19.

Madhun AS, Karlsbakk E, Skaala Ø, Solberg MF, Wennevik V, Harvey A, Meier S, Fjeldheim PT, Andersen KC, Glover KA. Most of the escaped farmed salmon entering a river during a 5-year period were infected with one or more viruses. Journal of Fish Diseases. 2024 Jul;47(7):e13950.

Marti, E., Huerta, B., Rodríguez-Mozaz, S., Barceló, D., Marcé, R., & Balcázar, J. L. (2018). Abundance of antibiotic resistance genes and bacterial community composition in wild freshwater fish species. *Chemosphere*, *196*, 115-119.

Martinez, J. L. (2009). Environmental pollution by antibiotics and by antibiotic resistance determinants. *Environmental pollution*, *157*(11), 2893-2902.

McCallum, H., Harvell, D., & Dobson, A. (2003). Rates of spread of marine pathogens. *Ecology Letters*, *6*(12), 1062-1067.

McCallum, H. I., Kuris, A., Harvell, C. D., Lafferty, K. D., Smith, G. W., & Porter, J. (2004). Does terrestrial epidemiology apply to marine systems?. *Trends in Ecology & Evolution*, *19*(11), 585-591.

McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Maoiléidigh, N. O., Baker, N., & Cross, T. (2003). Fitness reduction and potential extinction of wild populations of Atlantic salmon, Salmo salar, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *270*(1532), 2443-2450.

McKibben, M. A., & Hay, D. W. (2004). Distributions of planktonic sea lice larvae Lepeophtheirus salmonis in the inter-tidal zone in Loch Torridon, Western Scotland in relation to salmon farm production cycles. *Aquaculture Research*, *35*(8), 742-750.

Minett J. *Brown trout in the Falkland Islands: invasion ecology, population structure and genetic diversity* (Doctoral dissertation, Swansea University).

Miranda, C. D., Godoy, F. A., & Lee, M. R. (2018). Current status of the use of antibiotics and the antimicrobial resistance in the Chilean salmon farms. *Frontiers in microbiology*, *9*, 1284.

Molinet, C., Cáceres, M., Gonzalez, M. T., Carvajal, J., Asencio, G., Díaz, M., & Codjambassis, J. (2011). Population dynamic of early stages of Caligus rogercresseyi in an embayment used for intensive salmon farms in Chilean inland seas. *Aquaculture*, *312*(1-4), 62-71.

Monteiro, S. H., Garcia, F., Gozi, K. S., Romera, D. M., Francisco, J. G., Moura-Andrade, G. C., & Tornisielo, V. L. (2016). Relationship between antibiotic residues and occurrence of resistant bacteria in Nile tilapia (*Oreochromis niloticus*) cultured in cage-farm. *Journal of Environmental Science and Health, Part B*, *51*(12), 817-823.

Morejohn GV, Harvey JT, Krasnow LT. 1978. The importance of *Loligo opalescens* in the food web of marine vertebrates in Monterey Bay, California. Calif Dep Fish Game Fish Bull 169:67–98.

Morton, A. B., & Symonds, H. K. (2002). Displacement of Orcinus orca (L.) by high amplitude sound in British Columbia, Canada. *ICES Journal of Marine Science*, *59*(1), 71-80.

Mørk, T., & Hellberg, H. (2003). Surveillance and control programmes for terrestrial and aquatic animals in Norway. *Norsk Veterinaertidsskrift*, *115*, 707-717.

Myksvoll, M. S., Sandvik, A. D., Albretsen, J., Asplin, L., Johnsen, I. A., Karlsen, Ø., & Ådlandsvik, B. (2018). Evaluation of a national operational salmon lice monitoring system—From physics to fish. *PLoS One*, *13*(7), e0201338.

Nash, C. E. (2003). Interactions of Atlantic salmon in the Pacific Northwest: VI. A synopsis of the risk and uncertainty. *Fisheries Research*, *62*(3), 339-347.

Naval-Sanchez, M., McWilliam, S., Evans, B., Yáñez, J. M., Houston, R. D., & Kijas, J. W. (2020). Changed patterns of genomic variation following recent domestication: selection sweeps in farmed Atlantic Salmon. *Frontiers in genetics*, *11*, 264.

Naylor, R. L., Hardy, R. W., Bureau, D. P., Chiu, A., Elliott, M., Farrell, A. P., & Nichols, P. D. (2009). Feeding aquaculture in an era of finite resources. *Proceedings of the National Academy of Sciences*, *106*(36), 15103-15110.

Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., & Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature*, *591*(7851), 551-563.

Neiland, A. E., Shaw, S. A., & Bailly, D. (1991). The social and economic impact of aquaculture: a European review. *Aquaculture and the Environment*, (16), 469-482.

Newton, R.W., Little, D.C., 2018. Mapping the impacts of farmed Scottish salmon from a life cycle perspective. Int. J. Life Cycle Assess. 23 (5), 1018–1029.

Nilsson, J., Moltumyr, L., Madaro, A., Kristiansen, T. S., Gåsnes, S. K., Mejdell, C. M., & Stien, L. H. (2019). Sudden exposure to warm water causes instant behavioural responses indicative of nociception or pain in Atlantic salmon. *Veterinary and Animal Science*, *8*, 100076.

NOAA Fisheries. (n.d.). Salmon Life Cycle and Seasonal Fishery Planning. Available at: https://www.fisheries.noaa.gov/west-coast/sustainable-fisheries/salmon-life-cycle-and-seasonal-fishery-planning [Accessed 3 April 2025].

Northridge, S., Coram, A., & Gordon, J. (2013). Investigations on seal depredation at Scottish fish farms. *Report to Marine Scotland, Scottish Government*.

Okomoda VT, Oladimeji SA, Solomon SG, Olufeagba SO, Ogah SI, Ikhwanuddin M. Aquaponics production system: A review of historical perspective, opportunities, and challenges of its adoption. Food science & nutrition. 2023 Mar;11(3):1157-65.

Olaussen, J. O. (2018). Environmental problems and regulation in the aquaculture industry. Insights from Norway. *Marine Policy*, *98*, 158-163.

Olsen, L. M., Holmer, M., & Olsen, Y. (2008). Perspectives of nutrient emission from fish aquaculture in coastal waters. *Literature review with evaluated state of knowledge. FHF project*, *542014*, 87.

Olsen, M. S., & Osmundsen, T. C. (2017). Media framing of aquaculture. *Marine Policy*, *76*, 19-27.

Overton, K., Dempster, T., Oppedal, F., Kristiansen, T. S., Gismervik, K., & Stien, L. H. (2019). Salmon lice treatments and salmon mortality in Norwegian aquaculture: a review. *Reviews in Aquaculture*, *11*(4), 1398-1417.

Overton, K., Barrett, L. T., Oppedal, F., Kristiansen, T. S., & Dempster, T. (2020). Sea lice removal by cleaner fish in salmon aquaculture: a review of the evidence base. *Aquaculture Environment Interactions*, *12*, 31-44.

Penston, M. J., McKibben, M. A., Hay, D. W., & Gillibrand, P. A. (2004). Observations on open-water densities of sea lice larvae in Loch Shieldaig, Western Scotland. *Aquaculture Research*, *35*(8), 793-805.

Penston, M. J., Millar, C. P., Zuur, A., & Davies, I. M. (2008). Spatial and temporal distribution of Lepeophtheirus salmonis (Krøyer) larvae in a sea loch containing Atlantic salmon, Salmo salar L., farms on the north-west coast of Scotland. *Journal of Fish Diseases*, *31*(5), 361-371.

Pillay, T. V. R., & Kutty, M. N. (2005). *Aquaculture: principles and practices* (No. Ed. 2). Blackwell publishing.

Plant, K. P., & LaPatra, S. E. (2011). Advances in fish vaccine delivery. *Developmental & Comparative Immunology*, *35*(12), 1256-1262.

Poore, J. and Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science, 360(6392), pp.987-992.

Powell, D. B. (2000). Common diseases and treatment. In *The Laboratory Fish* (pp. 79-92). Academic Press.

Powell, A., Treasurer, J. W., Pooley, C. L., Keay, A. J., Lloyd, R., Imsland, A. K., & Garcia de Leaniz, C. (2018). Use of lumpfish for sea-lice control in salmon farming: challenges and opportunities. *Reviews in Aquaculture*, *10*(3), 683-702.

Quezada, F., & Dresdner, J. (2017). What can we learn from a sanitary crisis? The ISA virus and market prices. *Aquaculture Economics & Management*, *21*(2), 211-240.

Quick, N. J., Middlemas, S. J., & Armstrong, J. D. (2004). A survey of antipredator controls at marine salmon farms in Scotland. *Aquaculture*, *230*(1-4), 169-180.

Quinones, R. A., Fuentes, M., Montes, R. M., Soto, D., & León-Muñoz, J. (2019). Environmental issues in Chilean salmon farming: a review. *Reviews in Aquaculture*, *11*(2), 375-402.

Rico, A., Phu, T. M., Satapornvanit, K., Min, J., Shahabuddin, A. M., Henriksson, P. J., & Van den Brink, P. J. (2013). Use of veterinary medicines, feed additives and probiotics in four major internationally traded aquaculture species farmed in Asia. *Aquaculture*, *412*, 231-243.

Riera, R., Pérez, Ó., Cromey, C., Rodríguez, M., Ramos, E., Álvarez, O., & Tuya, F. (2017). MACAROMOD: A tool to model particulate waste dispersion and benthic impact from offshore sea-cage aquaculture in the Macaronesian region. *Ecological Modelling*, *361*, 122-134.

Riley WD, Bendall B, Ives MJ, Edmonds NJ, Maxwell DL. Street lighting disrupts the diel migratory pattern of wild Atlantic salmon, Salmo salar L., smolts leaving their natal stream. Aquaculture. 2012 Feb 17;330:74-81.

Rumpold, B. A., & Schlüter, O. K. (2013). Potential and challenges of insects as an innovative source for food and feed production. *Innovative Food Science & Emerging Technologies*, *17*, 1-11.

RUMA, 2024. Responsible Use of Medicines in Agriculture Alliance (RUMA) Targets Task Force 2: A report summarising the fourth year of progress against antibiotic use targets identified by the UK livestock industry's Targets Task Force 2 (TTF2) in November 2020. Available at: https://www.ruma.org.uk/wp-content/uploads/2024/11/RUMA-TTF-Report-FINAL-published-November-19-2024.pdf

Sadler, J., Pankhurst, P. M., & King, H. R. (2001). High prevalence of skeletal deformity and reduced gill surface area in triploid Atlantic salmon (Salmo salar L.). *Aquaculture*, *198*(3-4), 369-386.

Sapkota, A., Sapkota, A. R., Kucharski, M., Burke, J., McKenzie, S., Walker, P., & Lawrence, R. (2008). Aquaculture practices and potential human health risks: current knowledge and future priorities. *Environment international*, *34*(8), 1215-1226.

Schar, D., Klein, E.Y., Laxminarayan, R., Gilbert, M. and Van Boeckel, T.P., 2020. Global trends in antimicrobial use in aquaculture. Scientific reports, 10(1), p.21878.

Serra-Llinares, R. M., Bjørn, P. A., Finstad, B., Nilsen, R., & Asplin, L. (2017). Nearby farms are a source of lice for wild salmonids: a reply to Jansen *et al*.(2016). *Aquaculture Environment Interactions*, *8*, 351-356.

Shamsuzzaman, M. M., & Biswas, T. K. (2012). Aqua chemicals in shrimp farm: A study from south-west coast of Bangladesh. *The Egyptian Journal of Aquatic Research*, *38*(4), 275-285.

Shefat, S. H. T. (2018). Vaccines for use in finfish aquaculture. *Acta Scientific Pharmaceutical Sciences*, *2*(11), 19.

Shelton, W. L., & Rothbard, S. (2006). Exotic species in global aquaculture-A review.

Sievers M, Korsøen Ø, Warren-Myers F, Oppedal F, Macaulay G, Folkedal O, Dempster T. Submerged cage aquaculture of marine fish: A review of the biological challenges and opportunities. Reviews in Aquaculture. 2022 Jan;14(1):106-19.

Su, H., Liu, S., Hu, X., Xu, X., Xu, W., Xu, Y., & Cao, Y. (2017). Occurrence and temporal variation of antibiotic resistance genes (ARGs) in shrimp aquaculture: ARGs dissemination from farming source to reared organisms. *Science of the Total Environment*, *607*, 357-366.

Silbergeld, E. K., Graham, J., & Price, L. B. (2008). Industrial food animal production, antimicrobial resistance, and human health. *Annu. Rev. Public Health*, *29*, 151-169.

Skilbrei, O. T., Heino, M., & Svåsand, T. (2015). Using simulated escape events to assess the annual numbers and destinies of escaped farmed Atlantic salmon of different life stages from farm sites in Norway. *ICES Journal of Marine Science*, *72*(2), 670-685.

Solberg, M. F., Skaala, Ø., Nilsen, F., & Glover, K. A. (2013a). Does domestication cause changes in growth reaction norms? A study of farmed, wild and hybrid Atlantic salmon families exposed to environmental stress. *PloS one*, *8*(1), e54469.

Solberg, M. F., Zhang, Z., Nilsen, F., & Glover, K. A. (2013b). Growth reaction norms of domesticated, wild and hybrid Atlantic salmon families in response to differing social and physical environments. *BMC evolutionary biology*, *13*(1), 1-23.

Sommerset, I., Krossøy, B., Biering, E., & Frost, P. (2005). Vaccines for fish in aquaculture. *Expert review of vaccines*, *4*(1), 89-101.

Sørum, M., Johnsen, P. J., Aasnes, B., Rosvoll, T., Kruse, H., Sundsfjord, A., & Simonsen, G. S. (2006). Prevalence, persistence, and molecular characterization of glycopeptide-resistant enterococci in Norwegian poultry and poultry farmers 3 to 8 years after the ban on avoparcin. *Applied and Environmental Microbiology*, *72*(1), 516-521.

Soto, D., Arismendi, I., Olivos, J.A., Canales-Aguirre, C.B., Leon-Muñoz, J., Niklitschek, E.J., Sepúlveda, M., Paredes, F., Gomez-Uchida, D. and Soria-Galvarro, Y., 2023. Environmental risk assessment of non-native salmonid escapes from net pens in the Chilean Patagonia. *Reviews in Aquaculture*, *15*(1), pp.198-219.

Soto, D., Jara, F., & Moreno, C. (2001). Escaped salmon in the inner seas, southern Chile: facing ecological and social conflicts. *Ecological applications*, *11*(6), 1750-1762.

Soto, D., León-Muñoz, J., Dresdner, J., Luengo, C., Tapia, F. J., & Garreaud, R. (2019). Salmon farming vulnerability to climate change in southern Chile: understanding the biophysical, socioeconomic and governance links. *Reviews in Aquaculture*, *11*(2), 354-374.

Soto, D., & Norambuena, F. (2004). Evaluation of salmon farming effects on marine systems in the inner seas of southern Chile: a large-scale mensurative experiment. *Journal of Applied Ichthyology*, *20*(6), 493-501.

Sprague, M., Dick, J. R., & Tocher, D. R. (2016). Impact of sustainable feeds on omega-3 long-chain fatty acid levels in farmed Atlantic salmon, 2006–2015. *Scientific reports*, *6*(1), 1-9.

Stentiford, G. D., Sritunyalucksana, K., Flegel, T. W., Williams, B. A., Withyachumnarnkul, B., Itsathitphaisarn, O., & Bass, D. (2017). New paradigms to help solve the global aquaculture disease crisis. *PLoS pathogens*, *13*(2), e1006160.

Strain, P. M., & Hargrave, B. T. (2005). Salmon aquaculture, nutrient fluxes and ecosystem processes in southwestern New Brunswick. In *Environmental Effects of Marine Finfish Aquaculture* (pp. 29-57). Springer, Berlin, Heidelberg.

Stien, L. H., Dempster, T., Bui, S., Glaropoulos, A., Fosseidengen, J. E., Wright, D. W., & Oppedal, F. (2016). 'Snorkel'sea lice barrier technology reduces sea lice loads on harvest-sized Atlantic salmon with minimal welfare impacts. *Aquaculture*, *458*, 29-37.

Stien, L. H., Lind, M. B., Oppedal, F., Wright, D. W., & Seternes, T. (2018). Skirts on salmon production cages reduced salmon lice infestations without affecting fish welfare. *Aquaculture*, *490*, 281-287.

Storlund RL, Cottrell PE, Cottrell B, Roth M, Lehnhart T, Snyman H, Trites AW, Raverty SA. Aquaculture related humpback whale entanglements in coastal waters of British Columbia from 2008–2021. Plos one. 2024 Mar 20;19(3):e0297768.

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

Tamminen, M., Karkman, A., Lõhmus, A., Muziasari, W. I., Takasu, H., Wada, S., & Virta, M. (2011). Tetracycline resistance genes persist at aquaculture farms in the absence of selection pressure. *Environmental science & technology*, *45*(2), 386-391.

Taranger, G. L., Karlsen, Ø., Bannister, R. J., Glover, K. A., Husa, V., Karlsbakk, E., & Svåsand, T. (2015). Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. *ICES Journal of Marine Science*, *72*(3), 997-1021.

Tecklin, D. (2016). Sensing the limits of fixed marine property rights in changing coastal ecosystems: salmon aquaculture concessions, crises, and governance challenges in southern Chile. *Journal of international wildlife law & policy*, *19*(4), 284-300.

Thodesen, J., Grisdale-Helland, B., Helland, S. J., & Gjerde, B. (1999). Feed intake, growth and feed utilization of offspring from wild and selected Atlantic salmon (Salmo salar). *Aquaculture*, *180*(3-4), 237-246.

Thorstad, E.B., Finstad, B. 2018. Impacts of salmon lice emanating from salmon farms on wild Atlantic salmon and sea trout. NINA Report 1449: 1-22.

Tlusty, M., Tyedmers, P., Ziegler, F., Jonell, M., Henriksson, P., Newton, R., Little, D.C., Fry, J.P., Love, D. and Cao, L., 2018. Commentary: comparing efficiency in aquatic and terrestrial animal production systems. Environmental Research Letters, 13(12).

Torrissen, O., Olsen, R.E., Toresen, R., Hemre, G.I., Tacon, A.G., Asche, F., Hardy, R.W. and Lall, S., 2011. Atlantic salmon (Salmo salar): the “super-chicken” of the sea?. Reviews in Fisheries Science, 19(3), pp.257-278.

Torrissen, O., Jones, S., Asche, F., Guttormsen, A., Skilbrei, O. T., Nilsen, F., & Jackson, D. (2013). Salmon lice–impact on wild salmonids and salmon aquaculture. *Journal of fish diseases*, *36*(3), 171-194.

Troell, M., Naylor, R. L., Metian, M., Beveridge, M., Tyedmers, P. H., Folke, C., & De Zeeuw, A. (2014). Does aquaculture add resilience to the global food system?. *Proceedings of the National Academy of Sciences*, *111*(37), 13257-13263.

Verbeke, W., Sioen, I., Brunsø, K., De Henauw, S., & Van Camp, J. (2007). Consumer perception versus scientific evidence of farmed and wild fish: exploratory insights from Belgium. *Aquaculture International*, *15*(2), 121-136.

Volpe, J. P., Glickman, B. W., & Anholt, B. R. (2001). Reproduction of aquaculture Atlantic salmon in a controlled stream channel on Vancouver Island, British Columbia. *Transactions of the American Fisheries Society*, *130*(3), 489-494.

Wang, X., Olsen, L. M., Reitan, K. I., & Olsen, Y. (2012). Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture. *Aquaculture Environment Interactions*, *2*(3), 267-283.

Welch, T. J., Fricke, W. F., McDermott, P. F., White, D. G., Rosso, M. L., Rasko, D. A., & Ravel, J. (2007). Multiple antimicrobial resistance in plague: an emerging public health risk. *PloS one*, *2*(3), e309.

Whitmarsh, D., & Wattage, P. (2006). Public attitudes towards the environmental impact of salmon aquaculture in Scotland. *European Environment*, *16*(2), 108-121.

Whitmarsh, D., & Palmieri, M. G. (2011). Consumer behaviour and environmental preferences: a case study of Scottish salmon aquaculture. *Aquaculture Research*, *42*, 142-147.

Winther U, Hognes ES, Jafarzadeh S, Ziegler F. Greenhouse gas emissions of Norwegian seafood products in 2017. SINTEF Ocean. 2020 Jun.

Wringe, B. F., Jeffery, N. W., Stanley, R. R., Hamilton, L. C., Anderson, E. C., Fleming, I. A., & Bradbury, I. R. (2018). Extensive hybridization following a large escape of domesticated Atlantic salmon in the Northwest Atlantic. *Communications biology*, *1*(1), 1-9.

Young, M.O., 2015. Marine animal entanglements in mussel aquaculture gear. *Master's thesis, University of Akureyri*.

Ytrestøyl, T., Aas, T. S., & Åsgård, T. (2015). Utilisation of feed resources in production of Atlantic salmon (Salmo salar) in Norway. *Aquaculture*, *448*, 365-374.

Zagmutt-Vergara, F. J., Carpenter, T. E., Farver, T. B., & Hedrick, R. P. (2005). Spatial and temporal variations in sea lice (Copepoda: Caligidae) infestations of three salmonid species farmed in net pens in southern Chile. *Diseases of Aquatic Organisms*, *64*(2), 163-173.

Ziegler F, Nistad AA, Langeland M, Wocken Y, Hognes ES, Mehta S. Greenhouse gas emission reduction opportunities for the Norwegian salmon farming sector-can they outweigh growth?. Aquaculture. 2024 Feb 25;581:740431.

Annex 1: Chilean Regulatory Aquaculture Framework

Box 1: General regulatory framework for aquaculture in Chile

- The **General Law of Fisheries and Aquaculture (GLFA, 1991)** provides the general national framework for aquaculture;

- The **Ministry of Economy, Development and Tourism** includes;

  - The **Undersecretary of Fisheries and Aquaculture (UFA)** which is the regulatory authority for fishing and aquaculture activities
  - The **National Fisheries and Aquaculture Service (SERNAPESCA)** which is in charge of monitoring and enforcing the regulations
  - A number of other regulatory agencies with both regulatory and enforcement responsibilities in specific aquaculture related matters, *e.g.* environmental and fish health and disease related regulations, use of marine space and farm siting, *etc*.

- There are also other forms of self-regulatory initiatives by the **private sector** including voluntary agreements for clean production, integrated management system, *etc*. (Chavez *et al.,* 2019), mainly coordinated by Salmon Chile A.G. , an association of the **major private companies** in the salmon farming industry, along with public institutions, including regional governments, the UFA, the Ministry of Health and the National Environmental Commission (currently the Ministry of

Annex 2: Overview of Regulations required for Aquaculture

National Frameworks and Policies

Strategic Framework for Aquaculture: In most countries, the first step of developing an aquaculture sector is the development of a strategic framework. This framework aims to set out the potential options and subsequent advantages and disadvantages of each. This is done at a National level and requires a large amount of stakeholder interaction. In essence it sets out the vision for the aquaculture industry usually for the next decade.

In Scotland, a new strategic framework was published in 2009, entitled 'A Fresh Start[44]'. This document provides an overriding vision for aquaculture in Scotland which is focused on sustainable growth. To achieve this, it identifies a variety of strategic objectives (for example 'Smarter', 'Wealthier' and 'Greener') which it requires future development and policy making to focus on.

National Marine Plan: A national marine plan aims to develop a joined-up policy which considers all uses of the marine environment (including aquaculture). The aim is to develop a policy which can then feed into national and local planning requirements and ensures that a fair and agreed process, which targets growth areas is being achieved. In simple terms this plan determines how difficult or easy it is for aquaculture facilities to gain planning consent!

National Legislation

Marine Act: The Marine act sets out the rules and regulations associated with all areas of marine use. For aquaculture, this usually covers the requirements for a marine licence and so ensuring safe navigation in marine waters.

Aquaculture Act: An aquaculture act covers the general rules and regulations associated with aquaculture. This includes enforcement requirements and general legal requirements for operators. Often this is combined with wild capture fisheries in a joint Fisheries and Aquaculture Act (but not always).

Water Environment Regulations: In most countries, specific water environment regulations have been developed which deal with issues such as acceptable discharges from aquaculture facilities. In Scotland, these are covered by The Water Environment (Controlled Activities) (Scotland) Regulations 2011. It is these regulations which form the basis of the CAR licensing process set out below.

Aquatic Health Regulations: Regulations are required to cover the health and welfare of fish species. Part of this requires the establishment of a competent authority who are responsible for health licensing and inspections on farms. In Scotland, this is covered by the Aquatic Animal Health (Scotland) Regulations 2009.

Licensing Requirements

Usually, a host of licensing requirements need to be in place before the business can begin production. In Scotland, this would include the following;

Seabed Lease: In Scotland, the seabed (up to 12 Nautical Miles) is effectively 'owned' by the Crown Estate (as determined by the Crown Estate Act) and they have a statutory duty to 'obtain a return for any area of seabed or foreshore within its ownership'. As a result, usually the first step for an operator is to agree to a lease of the seabed which it is considering placing its farm on. To allow an operator the time to develop a potential area (and jump through all the other regulatory hoops

[44] https://www.gov.scot/publications/fresh-start-renewed-strategic-framework-scottish-aquaculture/

required) it is normal for a Lease Option Agreement (LOA) to be granted. This lasts for three years with the condition that relevant planning is submitted within two. If all required licences are obtained within the three years, they the Crown Estate will convert the LOA to a full seabed lease. In this regard the Crown Estate has the unique situation of determining on licensing requirements at both the beginning and end of the process.

Controlled Activity Regulation (CAR) Licence: The issuing of a CAR licence in Scotland is completed by the Scottish Environmental Protection Agency (SEPA). The licence is issued to confirm that the operator is not likely to be exceeding site specific limits on the number of fish in the cages, the amount of medicines and chemicals that it can use and the dispersal of nutrients. To do this the operator needs to collect baseline data from the site (water current speed, depth etc.) which is then fed into a modelling system (Scotland uses AutoDepomod) which makes predictions on the disbursement of chemicals around the site. This modelling is then analysed to ensure that statutory requirements are not likely to be breached. If all is in order, then a CAR is issued. It should be noted that although it is a requirement that a notification is publicly made of an application for a CAR no specific consultation process occurs in Scotland. The granting of a CAR usually takes around 16 weeks and is completed after an LOA is made but before planning permission is commenced.

Planning Permission: This is required for all salmon farming activities in Scotland and is overseen by the Local Authority (LA). It is governed by the Town and Country Planning Act (the Planning Regulation).

Planning is a vital and time-consuming part of the licensing consent process and gives the commercial activity permission to develop a farm on the site identified (although it does not grant permission to actually start farming).

In Scotland, the planning process usually takes around 2-3 months from commencement to sign off. Large-scale applications involve a Pre-Planning Application (effectively a screening activity) requirement which lengthens the process considerably.

The process involves the submitting of an application followed by a period of open consultation (usually around three weeks). It is then considered at the council level (who decide based on national planning regulations and guidelines but also local consultation outcomes). A determination is then made and consent either approved or denied.

Environmental Impact Assessment (EIA): The completion of an EIA really forms part of the planning permission process. Again, it is covered by the Town and Country Planning Act in Scotland and follows a set template developed by the Scottish Authorities. The process has many steps but in simple terms, requires the company to set out its activities and identify any environmental impacts that might be incurred. It then provides mitigation and monitoring strategies to minimise these impacts. This process results in the development of an Environmental Statement which is attached to the planning application and forms part of the public consultation process.

Marine Licence: The granting of a marine licence is more to do with ensuring the navigational safety associated with the presence of a floating structure. In Scotland, it is required for all cages and moorings. In Scotland, it is governed by the Marine Scotland Act and requires the completion of a single application form, and it has a target timeframe for completion of 14 weeks. The process also involves a period of open consultation with stakeholders.

Authorisation to operate an Aquaculture Production Business (APB): An APB is issued in Scotland by the Marine Scotland Science Fish Health Inspectorate (MSS-MHI). The licence is in relation to animal health requirements only and issued when the operator will not lead to 'an unacceptable risk of spreading disease'. The requirements which inform this decision-making process are set out in the Aquatic Animal Health Regulations (2009) in Scotland. One of the main requirements under this is for the occurrence of regular fish health inspections of farms by the authorities. During these inspections, areas such as Health Management, Biosecurity and the general health of the fish are checked. The authorities have the regulatory power to suspend farming activities at any time if they feel it is required. The licence application process usually takes around three months to complete.