

PROTEIN PRODUCER INDEX



Aquaculture



2. AQUACULTURE SECTOR RESULTS

2.1. Overview

As detailed in Table 1, the Index covers 15 aquaculture companies. Ten are pure-play aquaculture producers. Five produce other proteins, including poultry, eggs, pork, beef and dairy. Together, the companies have a total of \$63 billion in revenues (equating to 17% of the collective revenue for all Index companies) and a market capitalisation of \$50 billion (equating to 14% of the Index's total market capitalisation).

In addition to the performance indicators that are most common to the listed animal protein sector, the Index assesses aquaculture producers on a set of specific issues that account for the environmental and welfare risks unique to farmed fish. These are shown in Table 2.

Table 2

Aquaculture-specific indicators in the Index

Deforestation & Biodiversity	Animal Welfare
Ecosystem impacts	Aquatic animal welfare
Certification	
Disease management	
Feed ingredients and conversion ratios	

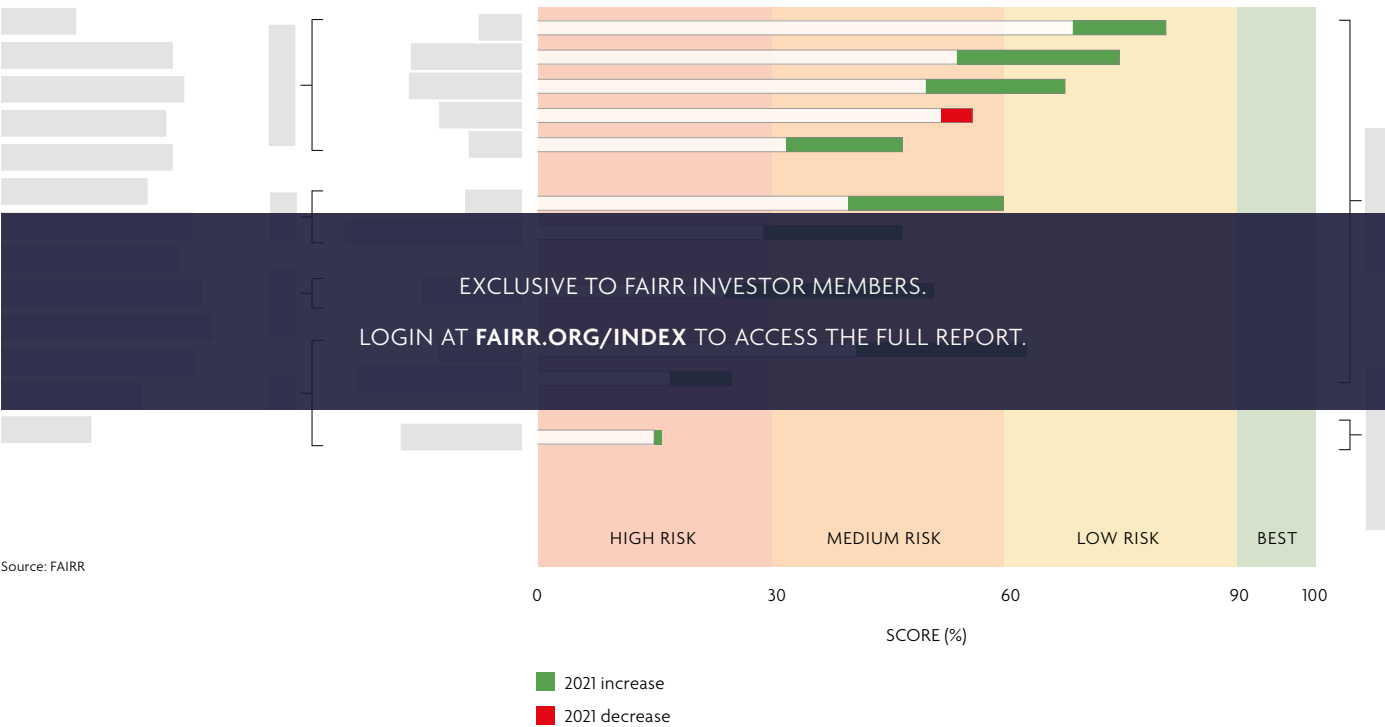
Source: Collier FAIRR Protein Producer Index



Key findings

Most companies saw improvements in 2021, as shown in Figure 1, with only Bakkafrøst recording a lower score than in 2020. The Index analysed a total of 60 businesses across all sectors. Eight of the 15 aquaculture companies scored in the top quartile overall. Better performers are generally in Europe.

Other than Thai Union, which is among the 10 lowest-risk producers, the riskier companies are clustered in Asia.



Source: FAIRR

2.2. Ecosystem impacts

Emissions: still trending up, despite better reporting

Farmed fish is often lauded as a low-carbon protein and is marketed as such to consumers who wish to reduce their carbon footprint.

When compared to other animal proteins, such as beef or pork, farmed fish does boast a lower emissions intensity due to logistical and biological factors,⁶⁴⁰ but as shown in Figure 2, not all seafood is alike.

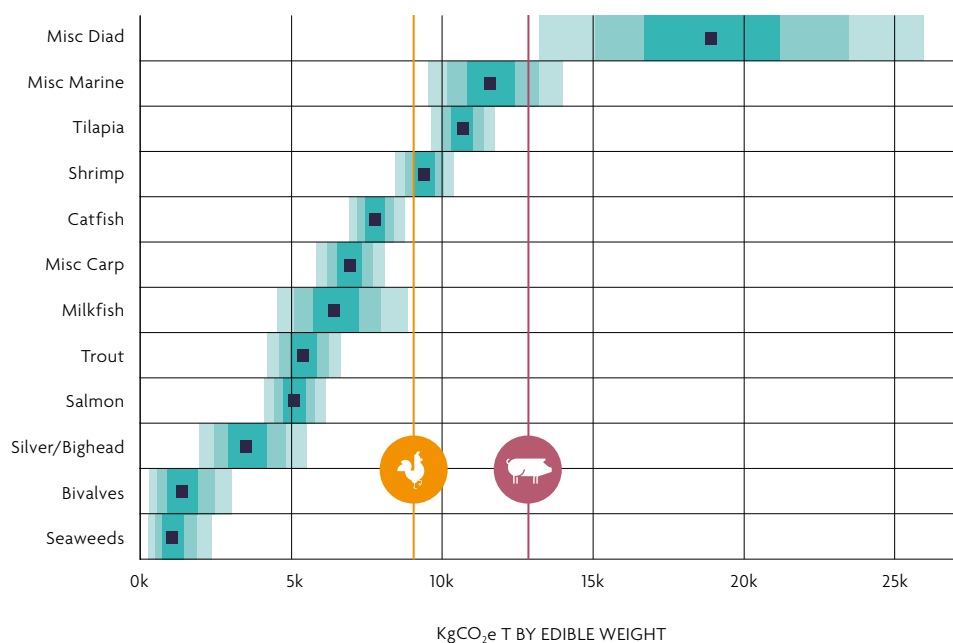
A recent analysis of farmed and wild-caught fish species found that salmon has a slightly lower carbon footprint than chicken, while shrimp comes at a higher carbon price.^{641,642} The margins of error depend on the differences in location and production. However, more work is required in this area and the good carbon credentials of salmon cannot be taken as a forgone conclusion.

Simply comparing the carbon efficiency of different animal proteins and selecting the lowest is not necessarily the goal. The key long-term objective is to improve production methods to reduce the environmental impact of *all* animal proteins. Furthermore, a carbon footprint is not the only measure of environmental performance.

The major carbon-intensity driver for shrimp is mangrove conversion.⁶⁴³ Mangrove forests are highly efficient sources of carbon sequestration, and their loss is factored into the carbon footprint of any shrimp raised in their place. Half of all mangrove forests have been lost since 1940, with 30-50% cleared for farmed shrimp production.⁶⁴⁴

Encouragingly, as shown in Figure 3, aquaculture companies have generally stepped up their disclosure and management of GHG emissions. Eleven of the 15 aquaculture companies featured in the Index have improved their scores in this regard, largely due to more ambitious target-setting and better reporting of inventories.

Figure 2
Not all seafood is alike in terms of carbon footprint



Source: Gephardt et al. Poore and Nemecek, adapted by WWF

Figure 3



Source: FAIRR

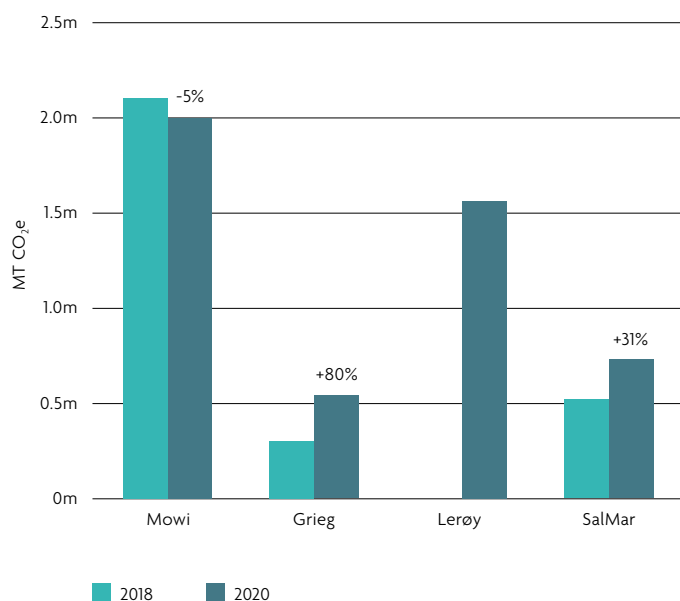
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Figure 4

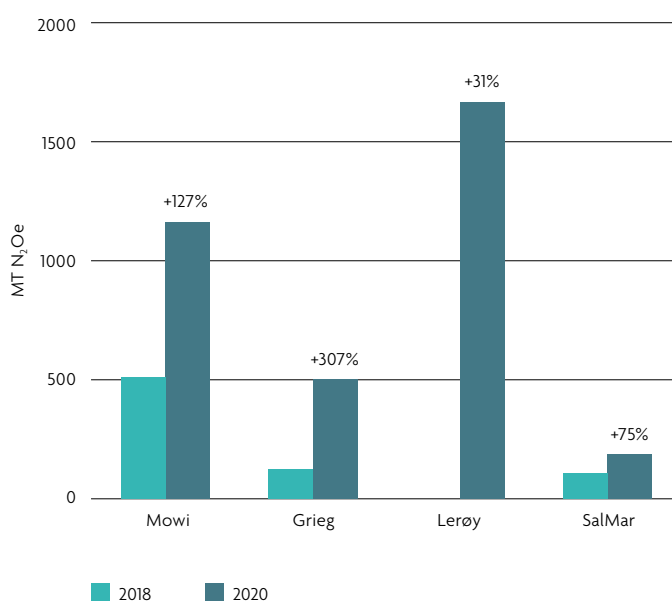
Absolute CO₂ emissions from 2018 to 2020 have grown from all companies apart from Mowi which has seen a slight decrease



Source: CDP

Figure 5

N₂O emissions are up since 2019 for Mowi, Grieg Seafood and SalMar. Greig and SalMar saw a levelling off however Mowi's emissions continue to climb. Lerøy only began reporting the GHG breakdown in 2021 and emissions are the highest of those that report



Source: CDP

Nitrous oxide: bobbing above the water and gaining attention

A key risk identified by the latest Intergovernmental Panel on Climate Change (IPCC) report is that aquaculture is among the fastest-rising contributors of nitrous oxide (N₂O) emissions.⁶⁴⁵ N₂O is what is known as a short-lived climate forcer (SLCF), meaning that it stays in the atmosphere for a much briefer period than CO₂ but is considerably more potent in terms of its global warming potential – in this instance, 273 times more powerful.⁶⁴⁶

Although the scientific understanding of the pathways of N₂O emissions from aquaculture remains limited, this issue is likely to attract greater regulatory attention,⁶⁴⁷ Figure 5, which focuses on four major companies that disclose a full inventory of emissions to CDP, confirms that N₂O emissions in this sector are on the rise. (Note: no data was available for Lerøy in 2018).

Deforestation: spotlight on soy supply chains

Soy has traditionally been used as a key ingredient in salmon feed. This makes supply chain traceability a major issue given that soy production is frequently linked to deforestation.

In an effort to create better traceability protocols for the sourcing of soy, salmon feed producers, Nutreco (Skretting), Cargill Aqua Nutrition and Biomar, joined forces in 2019 with the certification body, ProTerra, and three Brazilian soy protein concentrate producers, Caramuru, Imcopa and CJ Selecta. All companies said that they would work towards sustainable policies prohibiting the sourcing of soy products from illegally deforested land.⁶⁴⁸

Amid such positive developments, the salmon-producing aquaculture companies performed reasonably well in the 2021/22 Index in relation to the sourcing of certified soy. Following greater certification and traceability efforts, Tassal and Salmones Camanchaca showed the greatest improvement, up by 26% a piece compared to 2020. Four companies, Grieg Seafood, Mowi and Leroy Seafood, rank as 'Low Risk'. All Asian aquaculture companies rank as 'High Risk' due to the lack of disclosure. Similarly, shrimp-producing aquaculture companies offered little or no disclosure on deforestation risk in their sourcing of soy.

There is a clear regional split on this issue, with Latin American and European companies exposed to less risk than their Asian counterparts. Charoen Pokphand, Great Wall, NH Foods and QL Resources – all based in Asia – failed to improve their scores in this year's Index.

Generally, the sector is still heavily dependent on fishmeal and fish oil from wild-caught pelagic stocks. Further detail on this matter can be found later in this chapter and in section 3.2.

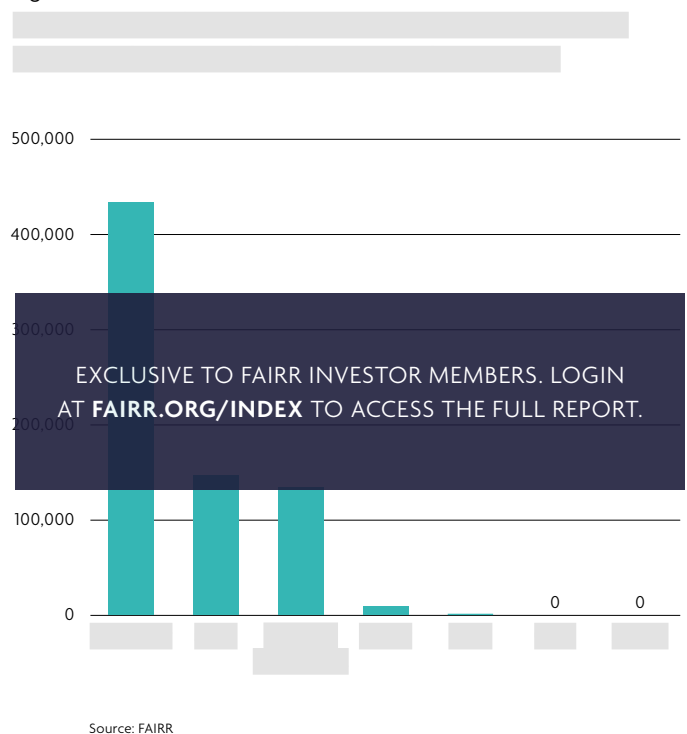
Escapes: a costly problem in every respect

Millions of fish escape from fish farms every year. They mix with native marine populations, resulting in competition for food and resources, the spread of disease and parasites and – if mating takes place – the weakening of the genetic pool of wild stocks.^{649,650}

Estimates vary widely, but more than five million fish are thought to have escaped following the 20 biggest breaches of the past 20 years. Small escapes – those involving fewer than 100,000 fish – are far more frequent.

The industry has traditionally hedged against this risk with insurance policies that have disincentivised prevention measures such as strong infrastructure, better-trained staff and superior deterrents against predators that cause escapes by ripping open nets.⁶⁵¹ However, insurers are now looking for robust risk mitigation strategies to avoid repeated pay-outs for lost stock.⁶⁵²

Figure 6



Companies that suffer escapes risk both regulatory costs and reputational damage. For example, Cooke Inc., the Canadian seafood giant, lost its licence after an escape incident in 2017 led to a blanket ban on Atlantic salmon farming in Washington State, jeopardising the company's presence in the region until it received approval to farm steelhead trout instead.⁶⁵³ With Mowi estimating the average cost of an escape event at around \$17.5 million, salmon-producing companies have been investing accordingly.

Escape numbers have reportedly fallen after hitting a high in 2019.⁶⁵⁴ However, as shown in Figure 6, only seven of the 15 companies assessed as part of this year's Index reported escape data in 2020. Bakkafrost is the only company in the Index to set a target of zero escapes, yet it suffered the year's largest breach – losing 368,998 fish in an incident blamed on extreme weather. Two companies, Grieg and Multi X, reported no escapes.

Based on these disclosures, we can infer that more than 700,000 fish escaped in 2020 following breaches involving aquaculture companies in the Index. However, the level of non-disclosure leaves much uncertainty as to the true total.

Nutrient pollution: from algal blooms to predators

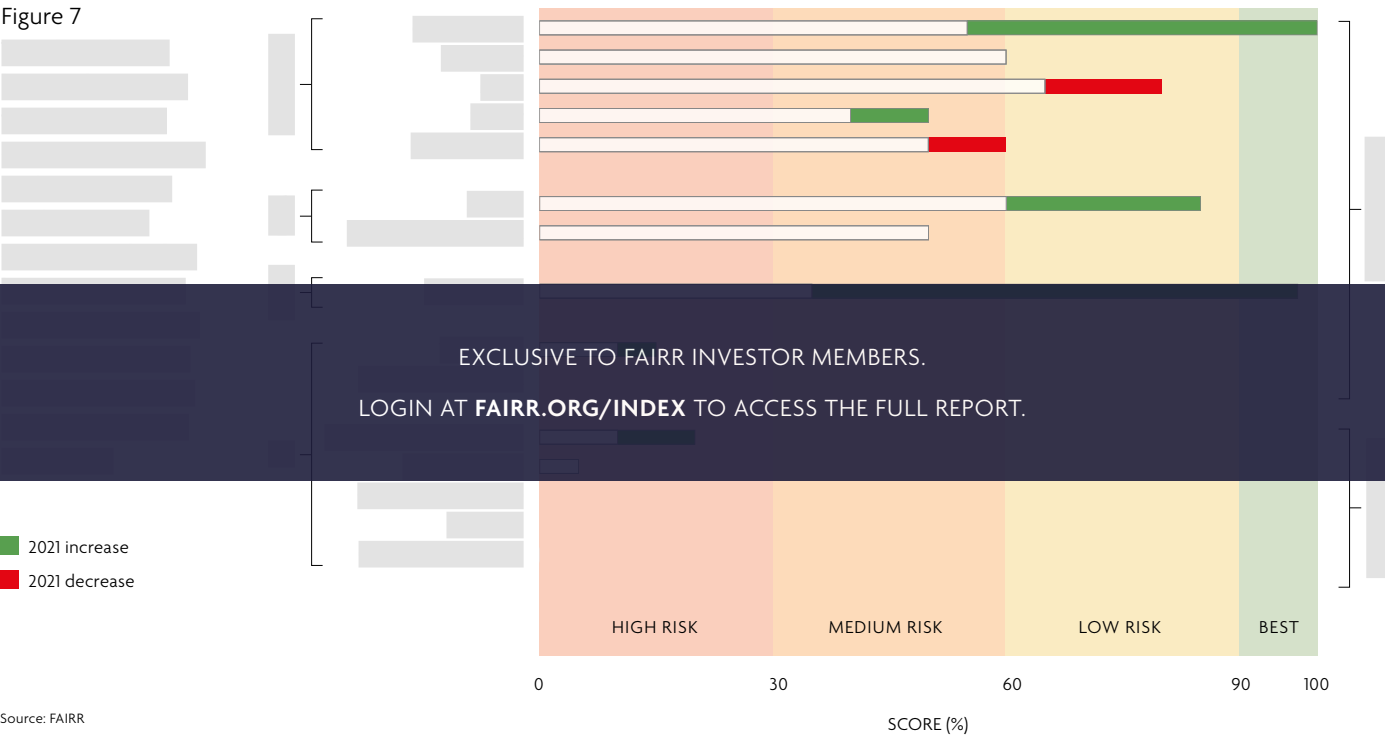
Aquaculture production systems increase effluents of organic matter, nitrogen and phosphorous. In turn, these can lead to locally increased biochemical oxygen demand (BOD), eutrophication and harmful algal blooms (HABs).⁶⁵⁵

HABs – caused by the rapid growth of algae in a marine or freshwater environment – have previously damaged the salmon industry in Norway and Chile. In 2019, Norway suffered its worst algal bloom in 30 years, with government reports indicating the loss of 10,000 tonnes of salmon.⁶⁵⁶ It was estimated to have cost to the industry of NOK2.1-2.4 billion in lost sales and NOK1.6-1.7 billion in other direct and indirect costs.⁶⁵⁷ In 2021, due to HABs and low oxygen levels on both Canadian seaboard, Mowi suffered the loss of a thousand tonnes of salmon worth €6 million – an event that contributed to Q3 EBIT falling €5 million below consensus analyst expectations.⁶⁵⁸

The overloading of the seabed from uneaten feed and fish waste also attracts predators, with dolphins, seals and birds ripping nets open, releasing fish and/or stressing them in many cases. The industry has been criticised for its often extreme approach to dealing with predators – from clubbing and shooting seals^{659,660} to using acoustic deterrent devices that ensonify entire coastlines with distressing sounds, the effects of which are not restricted to target species.⁶⁶¹ A more in-depth discussion of human-wildlife conflict in the aquaculture sector can be found in section 4.3.

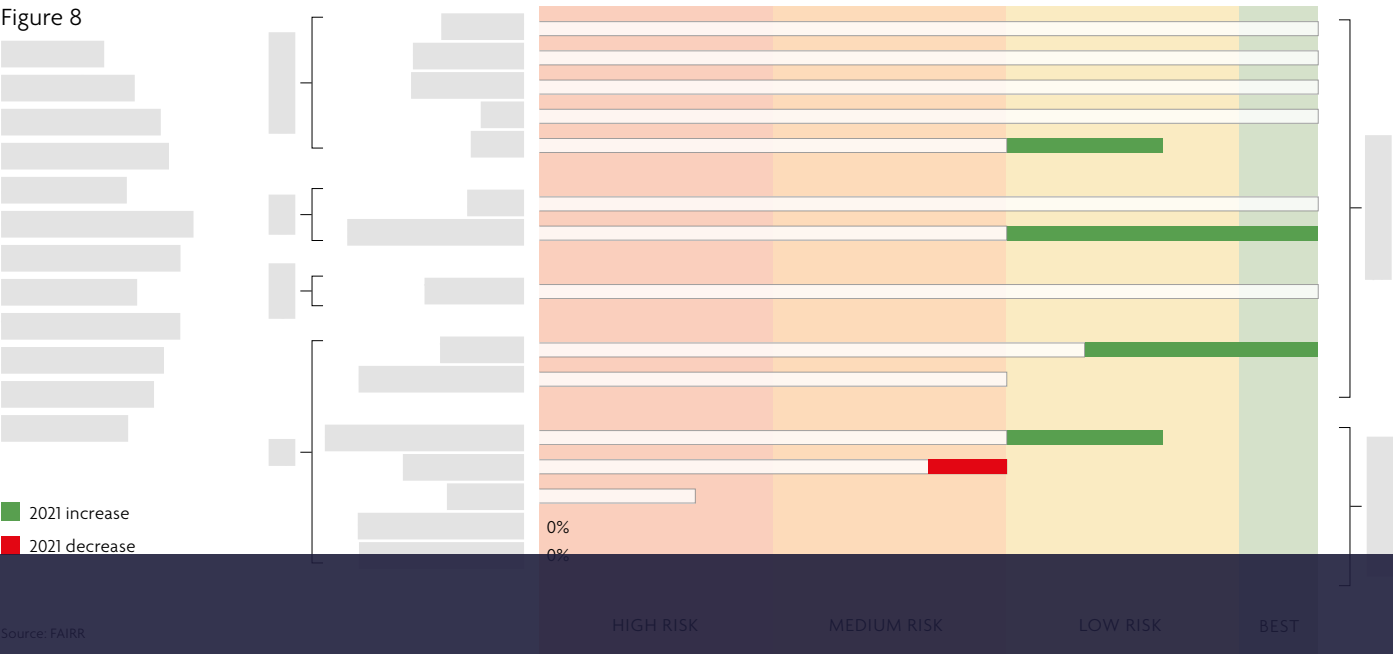
For this risk factor, aquaculture companies saw the most significant gains in certification and feed conversion ratios. Stronger targets on escapes and nutrient loading on the seabed are required to improve performance and reduce the industry’s impact on biodiversity and natural habitats.

Figure 7



Source: FAIRR

Figure 8



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60

90

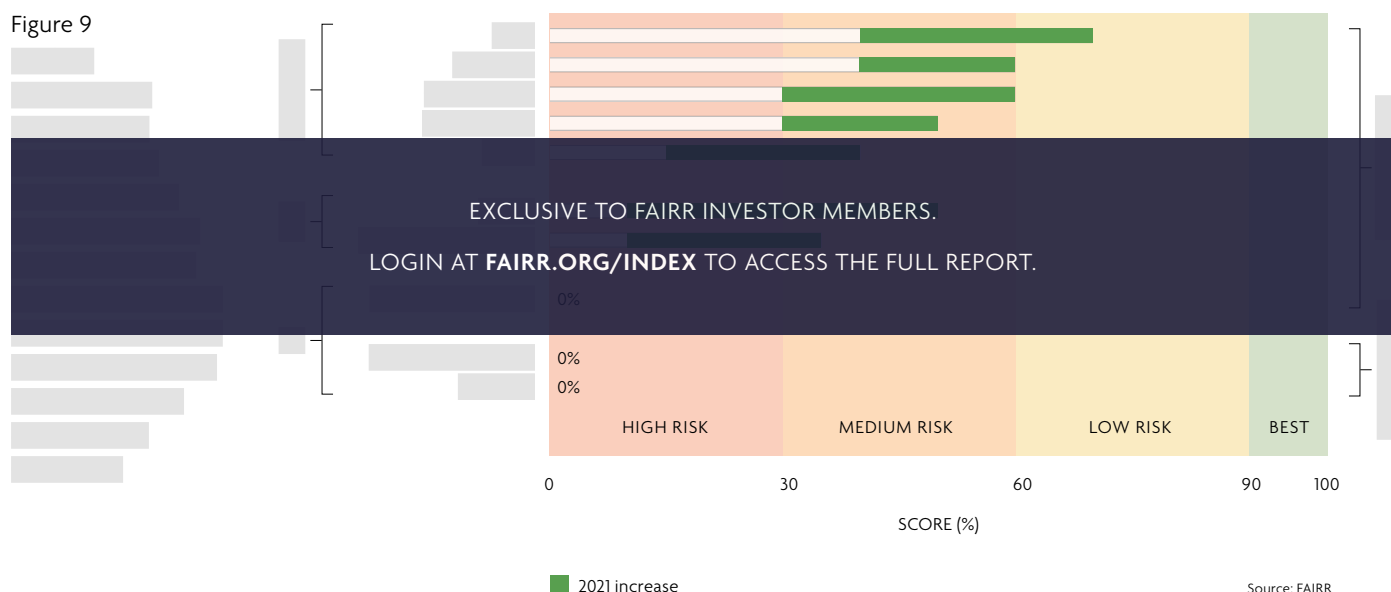
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2.3. Certification



Figure 9



2.4. Disease management

Disease and parasites: the race between innovation and evolution

Disease risks in the salmon-farming industry are driven by high stocking densities and the siting of multiple farms in close proximity. Disease and parasites represent a major cost, and current remedies are limited in their long-term effectiveness.

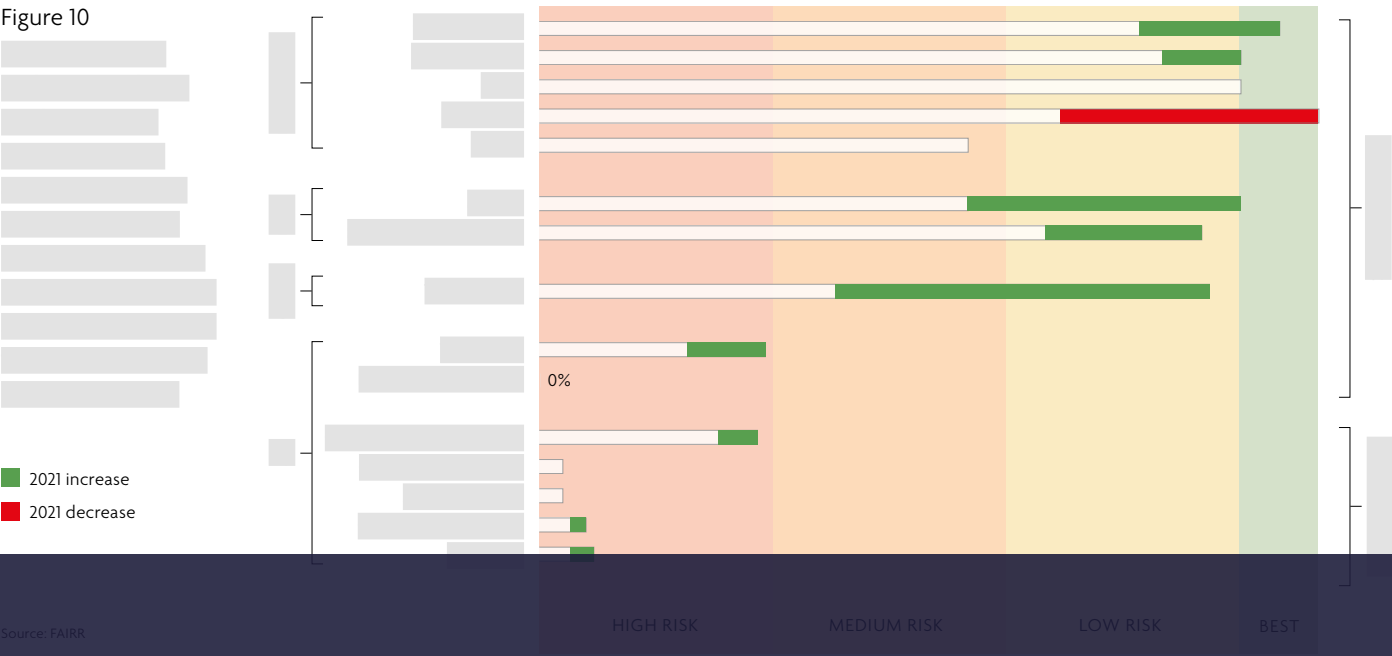
The problem of sea lice remains the industry's principal biosecurity concern. Innovation in prevention and treatment is fairly constant, but the lice themselves are developing greater resistance. It has been estimated that measures, such as sea-lice skirts, thermal licing, hydrolicing, cleaner fish, bathing and chemical treatments, cost the industry \$636 million a year in Norway alone, with this figure rising sharply since 2013.⁶⁶²

Some treatments – for example, anti-moulting chemicals that prevent lice from growing – cannot be liberally administered as they are likely to damage all crustaceans near a farm.⁶⁶³

Illnesses, such as amoebic gill disease (AGD), and new viral infections also increase pressure on farmers to innovate and protect the farms against outbreaks.^{664,665} Vibriosis, the most significant plague affecting shrimp farming, can result in 100% mortality events and bring about early mortality syndrome (EMS); it reportedly costs the industry \$3 billion a year globally.⁶⁶⁶

In addition, climate change is an accelerating factor in disease risk in both the salmon and shrimp sectors. Sea lice and AGD thrive in warmer waters, and studies suggest that climate change can also increase the risk of disease in shrimp.⁶⁶⁷

Figure 10

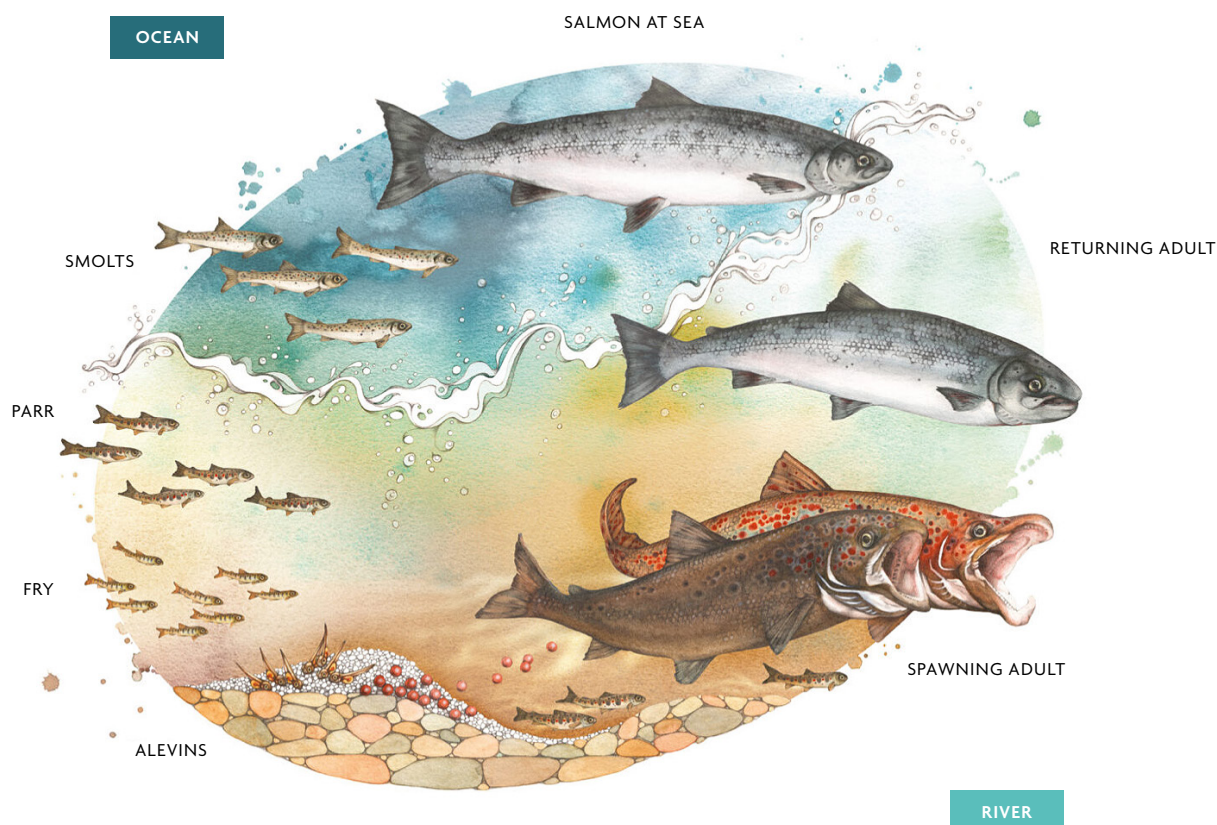


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Antibiotics: Asia drives global consumption





Source: NASCO

2.5. Aquatic animal welfare

More scrutiny, more activism

The welfare of fish is less understood than that of terrestrial animals, which have long had an internationally recognised welfare standard: the so-called “five freedoms”. These stipulate that animals under human control have freedom from hunger, malnutrition and thirst; freedom from fear and distress; freedom from heat stress or physical discomfort; freedom from pain, injury and disease; and freedom to express normal and natural behaviour.⁶⁷²

With the aquaculture industry growing at pace, this lack of scrutiny is changing. The RSPCA, Compassion in World Farming (CIWF), World Animal Protection and the Fish Welfare Initiative – an organisation dedicated solely to this issue – are among those now applying greater scrutiny. Notably, the World Organisation for Animal Health (also known as the OIE) released its first aquatic animal health and welfare strategy in 2021 and committed to a further review of the scientific basis for welfare and sentience in aquatic animals.⁶⁷³

Welfare activism now has its sights set on the aquaculture industry. Its tactics, which include the use of undercover videos, are now starting to have a similar impact on public perceptions and regulations as they did for terrestrial farmed animals. Waitrose and Co-op halted supplies after footage of poor practices in salmon farms.⁶⁷⁴

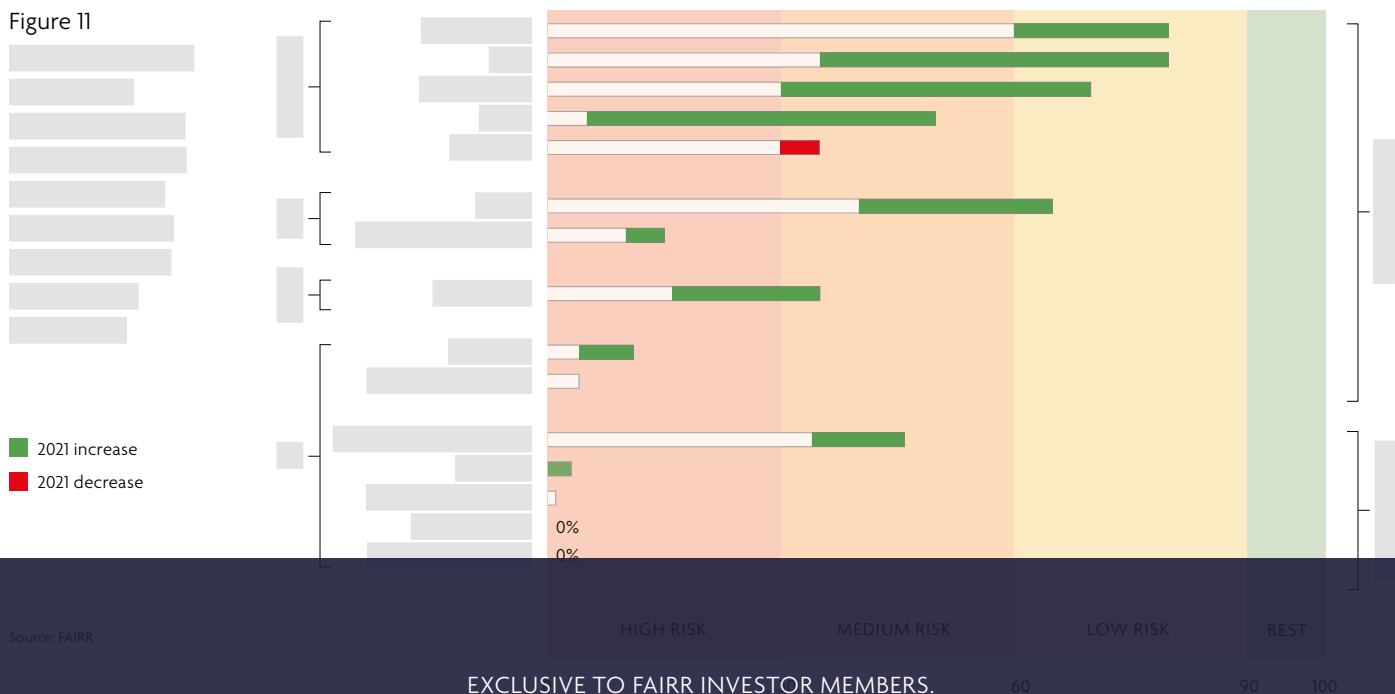
In July 2021, an activist entered a Mowi salmon pen in Scotland and filmed fish infested with sea lice, as well as deformed fish. This prompted the company to take legal action,⁶⁷⁵ with its response in many ways echoing the aggressive strategies of counterparts in the land-based farming space.^{676,677}

An evolving concept

Research has confirmed that fish feel pain and experience stress,⁶⁷⁸ but recognition of these realities constitutes only part of aquatic animal welfare. The next frontier in the efforts to broaden the concept is to include natural behaviours.⁶⁷⁹ Research published in *Science Advances* in 2021 highlighted the complex welfare needs of trout and Atlantic salmon,⁶⁸⁰ noting the lack of studies examining fish welfare.

In the wild, salmon have complex and dynamic life cycles, from hatching to spawning, and can travel thousands of miles. Juvenile salmon are diadromous, meaning they transfer slowly from freshwater to saltwater, with each deciding when it is ready to do so. Yet, juvenile salmon in a farm environment are often vacuumed up, transported and deposited into the sea within a single day, resulting in mortalities that commonly reach 10-20% in Norway.⁶⁸¹

Figure 11



Stocking densities in the sea phase are unnaturally high. Salmon in the wild are solitary animals for much of their life cycle,⁶⁸² making them less likely to suffer injury from aggression and less vulnerable to the diseases and parasites that might be prevalent on farms. CIWF has deemed them unsuited to intensive growth and has called for “a moratorium on the expansion of the industry with a view to phasing out intensive farming.”⁶⁸³

As with terrestrial farming, aquaculture breeding programmes that prioritise production efficiency over welfare are attracting particular scrutiny. Programmes intended to create larger, faster-growing fish with increased appetites are just one example of this.⁶⁸⁴

These programmes have resulted in up to 50% of all farmed Atlantic salmon having inferior vaterite-based otoliths (or inner-ear bones) rather than aragonite. In contrast, only 10% of their wild counterparts have this. Otoliths are sensory organs that contribute to hearing, balance, gravity sensation and linear acceleration; they are, therefore, crucial for survival.⁶⁸⁵

Signs of improvement



2.6. Feed ingredients and conversion ratios

Food fraud: a global problem

According to a recent meta-study, 36% of seafood products are mislabelled – suggesting “seafood fraud on a global scale.”⁶⁸⁶ A 2018 analysis found nearly 70% of samples sold as snapper in the UK consisted of 38 different species, “including many reef-dwelling species that are probably threatened by habitat degradation and overfishing.”⁶⁸⁷ This issue remains under-scrutinised, and it is unclear which aspects of the sector are most exposed. The most common form of fraud – labelling a species as one that is more expensive or desirable – is often practised with processed or tinned fish, where artifice is hard to spot. One of the difficulties surrounding the successful detection of fraud is that effective methods, such as DNA testing, are costly and time-consuming. Verification is usually attempted with only 1% of products.⁶⁸⁸ As with certification, technologies such as blockchain may have the potential to help reassure consumers over the longer term.⁶⁸⁹

Feed supplies: the most pressing concern of all?

Feed is a material cost for aquaculture, accounting for 40% and 50% of the production costs of farmed salmon and shrimp respectively.⁶⁹⁰ Its main components are fishmeal, fish oil and vegetable ingredients, such as soy, wheat or pea protein. The salmon-farming industry has made strides with respect to certified soy sourcing, but fishmeal remains a precarious supply for all buyers.

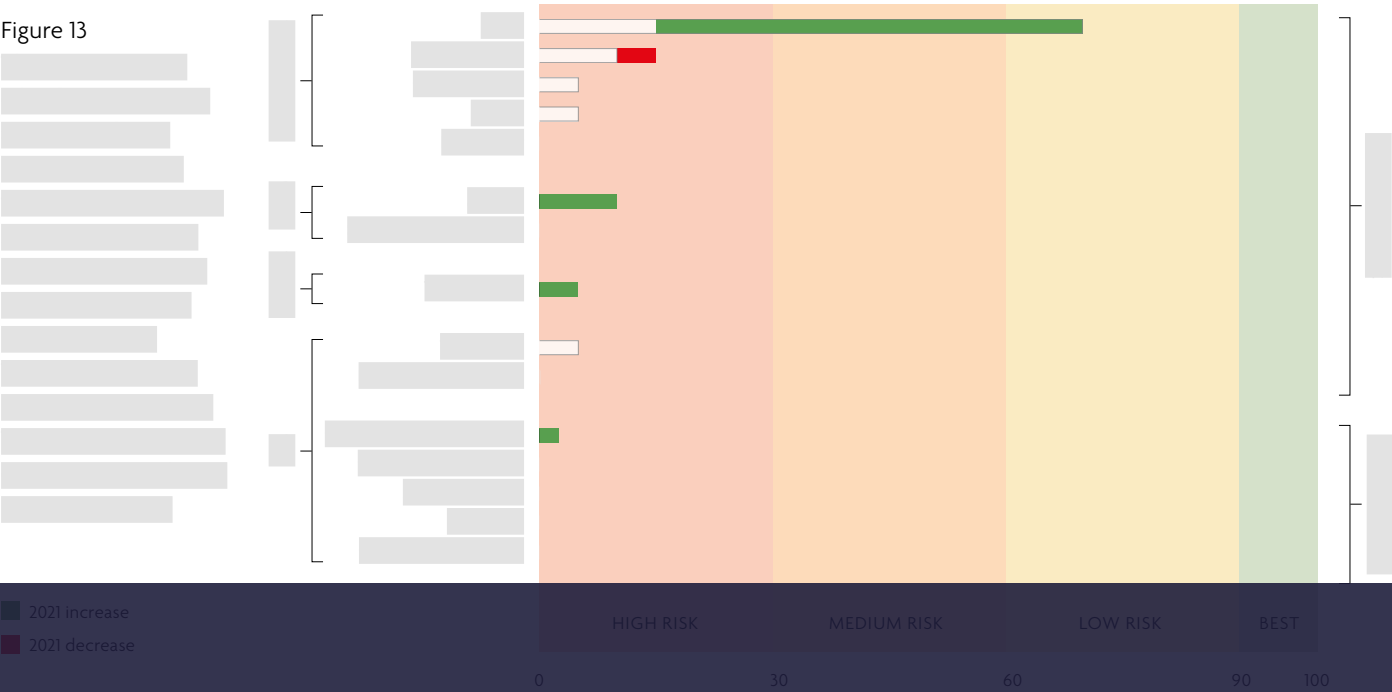
In addition, projected increases in the intensity and frequency of extreme events caused by climate change are likely to bring greater economic uncertainty, resulting in more price volatility, for small pelagic species and fisheries.^{691,692,693} Raw feed materials, have already hit record-high prices worldwide – partly driven by weather-related incidents.

Figure 12

Fish meal prices have increased 118% since 2006. Feed accounts for up to 50% of cost in salmon farming with fish meal accounting for 15-30% of feed formulations



Figure 13



Source: FAIRR

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3. ENGAGEMENT ON CLIMATE AND BIODIVERSITY RISKS IN SALMON PRODUCERS' FEED SUPPLY CHAINS

Strategy

ENGAGEMENT ASKS

1. Conduct and disclose a forward-looking risk assessment examining how marine and soy ingredient sources could constrain production and increase exposure to environmental, social and governance (ESG) risks, including climate risk.
2. Disclose strategies to increase the use of trimmings and processing waste, as informed by the risk assessment.
3. Disclose strategies to increase the use of alternative feed ingredients* (e.g., algae, insects, single-cell proteins), as informed by the risk assessment. These strategies may be in the areas of R&D, new product lines, etc.

Targets

1. Disclose a target to increase the use of alternative feed ingredients, as informed by the risk assessment.
2. Commit to sourcing certified soy and/or being deforestation/conversion-free (DCF) for 100% of soy, including all third-party suppliers and regions, and disclose progress against this commitment (included for companies without current commitments).

Disclosure/performance

1. Disclose R&D spend directed towards novel feed ingredients.
2. Disclose absolute volumes of fishmeal and fish oil (FMFO) sourced through aquafeed, including a percentage breakdown of FMFO sourced from whole fish and fish by-products.
3. Disclose the average level of EPA and DHA for finished products.
4. Disclose the forage fish dependency ratios for fishmeal (FFDRm) and fish oil (FFDRo) and achieve a downward trend over a three-year period.
5. Disclose the quantity of greenhouse gas emissions from feed production and achieve a downward trend over a three-year period.

*The choice of alternative feed ingredient is a complex question. The nutritional pattern and digestibility must line up with cost, scale, climate and biodiversity impact. The engagement, therefore, does not mandate one ingredient over another; rather, it asks for R&D, targets and disclosure to shore up the industry-wide understanding of pathways.



3.1. Overview

As Figure 14 shows, feed is the largest material cost component of salmon aquaculture production. For the biggest listed salmon producer, Mowi, it accounts for around 45% of costs.⁶⁹⁶

FAIRR’s analysis shows that there has been extensive research and development (R&D) into identifying sustainable and alternative feed sources. However, current projects lack scalability; they are not run with an overarching goal that suggests where the sector should be by a certain point; and they are not aligned with specific, science-based, industry-wide objectives.

In light of these shortcomings, we devised our engagement on this issue. Launched in January 2021, the initiative – which is ongoing – is backed by 37 investor signatories with assets under management totalling \$5.3 trillion. In this chapter, we present some of the findings and insights gained from Phase 1 of the engagement.

We began by selecting eight pure-play salmon producers: Bakkafrøst, Grieg, Lerøy, Mowi, Multi X, SalMar, Salmones Camanchaca and Tassal. We then facilitated investor meetings with seven of these companies between May and July 2021. Tassal alone did not meet with investors. Each company’s progress to date is summarised in Table 3.

Figure 14
Production cost per kg by cost component (averages for Norway, Chile, Scotland, Faroes, Canada)

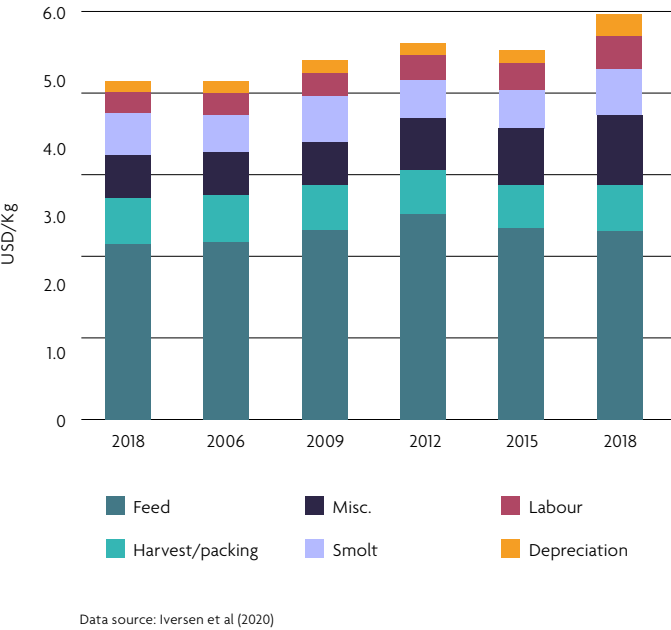


Table 3
Company progress through Phase 1

	Met with Investors	C-suite Attendees	Implemented Some Investor Recommendations
	✓	✓	✗
	✓	✗	✗
	✓	✗	✗
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	✓	✗	✗
	✓	✓	✗
	✗	✗	✗

3.2. Key findings from the engagement

i. Feed efficiency metrics lack consistency and transparency

Metrics present only a partial view of efficiency

To evaluate the efficiency feed production in salmon farming, several reporting metrics have become critical for comparing the sustainability performance of companies. These are explained in the box below.

- Fish in: fish out (FIFO) ratio:** FIFO is used to analyse the efficiency of the use of wild fish in feed. It “measures the amount of fishmeal and fish oil used to produce one weight equivalent of farmed fish”.⁶⁹⁷
- Feed conversion ratio (FCR):** FCR is a measure of production efficiency. Among farmed species, it represents “the weight of feed administered over the lifetime of an animal divided by weight gained”.^{698,699} It can be split into two sub-categories: biological FCR (bFCR), which is based solely on feed eaten, and economic FCR (eFCR), which includes production losses (e.g., uneaten feed, mortalities, escapees).⁷⁰⁰
- Forage fish dependency ratio (FFDR):** FFDR is the “amount of wild-caught fish used to produce the amount of fishmeal and fish oil required to produce 1 kilogram of salmon”.⁷⁰¹ It takes into account eFCR.⁷⁰²

Underlying assumptions are often not reported		Absolute Volumes of FMFO Purchased	Absolute Volumes of Trimmings Used
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		✓	✓
		✓	✓
		✓	✓
		✗	✗
		✗	✗
		✗	✗
		✗	✗
		✗	✗

Disclosure on how efficiencies are gained is lacking

ii. Consensus on key issues is worryingly elusive

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“It would be great to see increased knowledge-sharing and transparency within the global aquaculture industry to work towards improved sustainability. Identification of knowledge gaps across stakeholder groups would be hugely beneficial and allow a science-based scaffold to support further developments.”

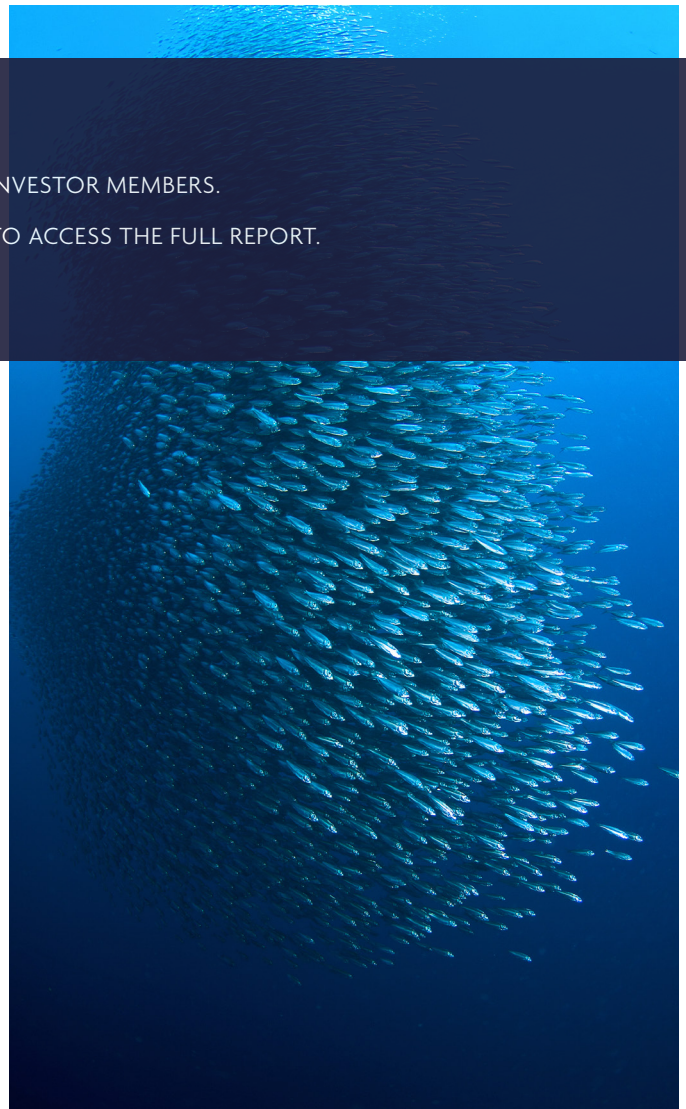
Aisla Jones

Head of Aquaculture, Co-op

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iii. Inconsistencies around alternative feeds plague the sector

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“Nutreco’s Roadmap 2025 target is quite challenging because a 5% inclusion rate in our product portfolio represents almost 400,000 metric tonnes of novel ingredients by December 2025. Today, there isn’t a quarter of that volume even close to being available on the market. In addition, some of the novel ingredients offered are at a price multiple of the conventional commodity ingredient that they are designed to replace, with variable and sometimes only marginal improvement in their carbon footprint. That equation will not work well in the animal and aquafeed industry. In the short term, there will be a premium on these ingredients until scale is achieved, and that premium would be more digestible if absorbed across the whole value chain. The feed industry is willing to take on this challenge, but it cannot achieve it without the cooperation of retailers, farmers and consumers.”

Jose Villalon

Sustainability Director, Nutreco

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iv. Investor confidence in aquaculture hinges on more granular detail

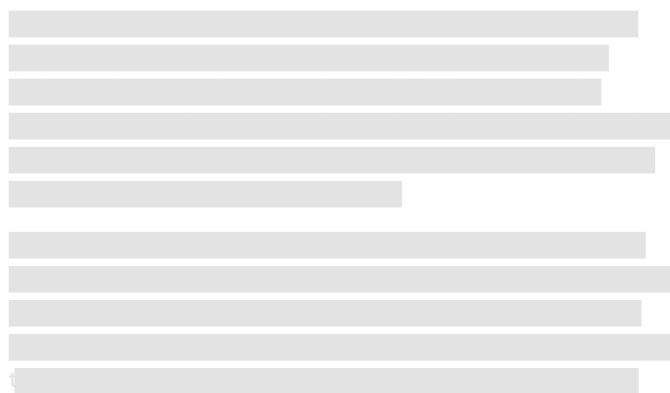


What aquaculture companies must do to boost investor confidence

- Disclose data to help facilitate comparisons of approaches to sustainable feed, including:
 - Complete definitions of reported metrics
 - Justification of their use
 - Full calculation methods, including worked examples
 - Reporting and calculation standards used, if any (e.g., GSI, ASC, BAP)
 - Detailed assumptions regarding production parameters (e.g., forage fish oil concentration per species used, development stage of fish at mortality etc.)
- Disclose absolute volumes of FMFO purchased annually, complete with species and country of origin (companies would need to source this data from their feed millers)
- Outline risk assessments on traditional and alternative feed sources, with clear implications for cost, availability sustainability, certifications and future availability
- Disclose the use of trimmings, including any targets, and how these will be achieved from a logistical basis
- Send a clear signal to the alternative ingredients market by setting time-bound targets
- Work with feed companies to agree on a strategy for all feed aspects



3.3. Next steps



4. OUTLOOK FOR THE SALMON AQUACULTURE SECTOR

4.1. Overview

In this chapter, we present our outlook for the salmon sector in aquaculture for the coming decade. Our predictions are informed by an extensive stakeholder review involving more than 40 experts in this field, including farmers, investors, feed millers, alternative ingredient providers, start-ups, academics, NGOs and community groups.

Respondents were questioned about risks and opportunities in the sector, risk mitigants and accelerants, industry preparedness, technological advances and supply chain management. The results of the review were then combined with academic literature and market analyses. This process resulted in three main predictions for the years ahead:

- Technology will change the nature of how salmon is farmed, opening the sector to newcomers and disruptors.
- Expansion of the industry will exacerbate three key risks: biosecurity, animal welfare and community resistance.
- Alternative seafood (i.e., plant-based and cell-cultured) and lower trophic options are in a strong position to scale and gain market share.

We discuss each of these predictions in detail in the following sections.

“There will be a major shift driven by digital technology. The industry is currently reliant on experienced professionals’ individual judgement rather than codified data and knowledge. There will be a tipping point, as the former is a limiting factor to scale.”

Dag Sletmo

Senior Vice President,
Seafood Division, DNB Bank

4.2. Technology and disruption

Given the pressure on wild stocks, aquaculture has a key role to play in improving the resilience of food supplies. Although innovation and productivity have stalled in recent years,⁷²⁶ we expect the industry to modernise, digitise, and adopt new technologies. This process should make way for previously untapped resources and markets.

Digitisation

Digitisation, including the use of artificial intelligence (AI), is a major source of momentum and optimism in the sector. The remote, real-time monitoring of fish stocks and their environment allows for early intervention, feeding efficiencies and potentially fewer instances of infrastructure collapse, mortalities, escapes and predator attacks.^{727,728}

Investment in digitisation brings value for money in terms of driving the industry forward in efficiency, animal welfare and environmental protection. Software programmes and sensory systems can be replicated on multiple farms and adapted for the management of other species more nimbly than large and static infrastructure projects.

Yet, digitisation is not without risks. Cybersecurity should be a priority for any farmer, given the likely impact of breaches. Documented incidents of cyber-attacks have so far centred on data theft (e.g., the January 2021 attack on aquaculture equipment manufacturer AKVA, which cost the company \$6 million).⁷²⁹ Attacks that affect automatic feeding systems could have catastrophic impacts, including overfeeding or the triggering of mass escapes.⁷³⁰



Investment in digitisation by companies in the engagement

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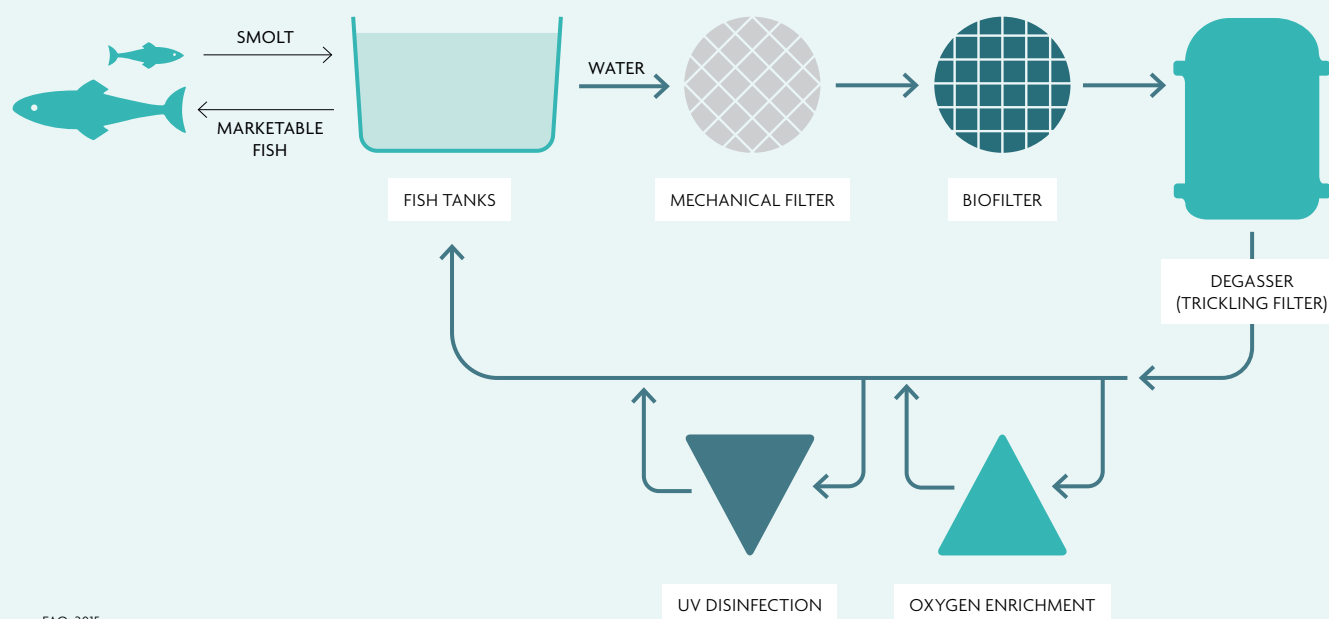
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Figure 15

How Recirculating Aquaculture Systems Work



Source: FAO, 2015

Recirculating aquaculture systems (RAS)

Recirculating aquaculture is a land-based, closed-loop system for farming fish or other aquatic organisms by biological and mechanical filtration and the reuse of water. In principle, this method – the workings of which are shown in Figure 15 – can be used for any aquatic species, including clams and seaweed, but the technology is primarily used for fish.⁷³⁶

Waste is treated by concentrating solids and removing them from the system, reducing disease risk and, by extension, the need for veterinary treatment and antibiotics. Biofiltration is used to reduce ammonia toxicity in the water, while oxygenation increases oxygen levels to improve fish productivity.⁷³⁷

“New digital and sensory solutions can optimise how the sector deals with biological risk, manages farms, buys and uses inputs or sells products and even accesses capital. This can be done relatively efficiently from a capital standpoint – thus in a short time, new digital technologies can proliferate.”

Gorjan Nikolik

Senior Analyst, Rabobank International

In theory, an RAS creates a perfect environment to grow fish to maturity without infection, predation, escape or environmental damage. Controlling temperature, oxygen and light can reduce fish stress and improve growth and FCRs⁷³⁸. There is also an opportunity for such systems to lower the sector’s carbon footprint by cutting the Scope 3 distribution emissions of a product with a decentralised supply. Decreased distribution costs can also be achieved with near-market supply. Crucially, RAS technology does not need to be sited near a coastline – unlike open-net-pen farming, which requires a specific coastal environment.⁷³⁹

Atlantic Sapphire, the world’s largest RAS operator, completed a round of private placement in June 2021, raising a further \$121 million following \$100 million raised in September 2020.^{740,741}

A report by EY found that the planned RAS production capacity in 2020, including announced projects without licences or funding to become fully operational, was 2.3 million tonnes. By contrast, the total production of Atlantic salmon in 2020 was 2.7 million tonnes.⁷⁴²

Figure 16
The rise of land-based salmon farming by 2040



Data source: EY

Table 5
The share-price fallout from Atlantic Sapphire’s March 2021 RAS mortality event

% Share Price Change Between 23/03 – 24/03	
Aquabounty	-17%
Atlantic Sapphire	-12%
The Kingfish Company	-6%
Proximarseafood	-5%
Nordic Aqua Partners	4%
Andfjordsalmon	-2%
Salmon Evolution	-1%

Data source: Intrafish 2021

It should be noted that RAS technology currently entails high energy and infrastructure costs.⁷⁴³ In 2020, a review by the European Market Observatory for Fisheries and Aquaculture Products (EUMOFA) found that the miscellaneous costs of conventional aquaculture, including energy, accounted for approximately 25% of total expenditure, with this figure increasing by up to 50% with RAS technology.⁷⁴⁴

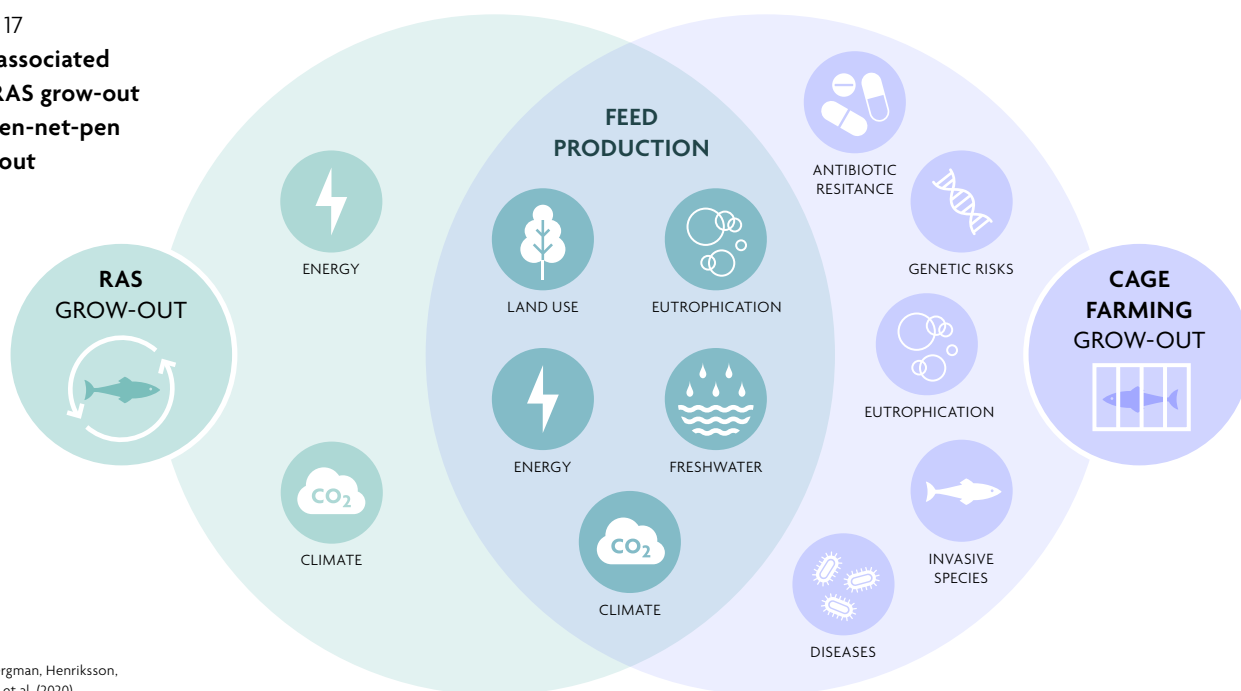
In addition, under current design parameters, human error and technical faults in RAS facilities can result in catastrophic system failure and high mortalities.⁷⁴⁵ In March 2021, Atlantic Sapphire suffered a mass mortality event at its facility in Miami, Florida, resulting in the loss of 500 tonnes of fish,⁷⁴⁶ while in September 2021, its Denmark facility lost its entire biomass in a fire.⁷⁴⁷

Atlantic Sapphire’s shares fell 12% following the March incident. As Table 5 shows, the stock prices of similar companies were also affected⁷⁴⁸. By 28 October 2021, Atlantic Sapphire’s shares were down 67%, severely underperforming both the relevant benchmark (+17%) and peers such as Mowi (+29%) while reflecting investors’ fears over the risk of similar events in the future.

Yet mass mortalities also abound in traditional net-pen farming. In September 2021, for example, Mowi lost 450,000 fish due to low dissolved oxygen levels at one of its Newfoundland sites.⁷⁴⁹

Although still in the early stages of development, modular designs have begun to make headway in reducing the impact that an RAS failure can have. The proposed Nordic Aquafarms modular RAS production sites in Maine and California, US, are examples of this approach.^{750,751} Modular systems require each tank to run on its own filtration system, preventing the “runaway train” effect of mortality events.

Figure 17
Risks associated
with RAS grow-out
vs. open-net-pen
grow-out



Source: Bergman, Henriksson, Hornborg, et al. (2020)

A crucial point about RAS technology at this stage is that it will not address key issues around feed or animal welfare; it may even exacerbate the latter since the stocking densities required to be cost-effective are significantly higher than in open-net-pen farms. The ideal maximum stocking density for Atlantic salmon is 15kg/m³,⁷⁵² but Atlantic Sapphire reportedly applies stocking densities of 85-100kg/m³.⁷⁵³ As explained in section 2.5, high stocking densities lead to stress and aggression among fish.⁷⁵⁴ RAS technology could, therefore, be seen as another step away from fish's natural environment.

Semi-closed containment systems still sit within the sea, but novel cage designs allow for approximately 90% of fish faeces to be captured and removed. These cages reportedly eliminate the risk of sea lice infestation. Semi-closed systems originated in Norway in the last decade, but optimism is picking up in Scotland with Loch Long Salmon trialling this novel design. Proponents highlight the benefit of retaining coastal salmon farming jobs, which may otherwise move onshore to RAS systems without the environmental price tag. Operating costs are estimated to be comparable to open-net pens with savings on sea lice treatment costs.^{755,756}

Figure 18
Stocking densities climb with each level of containment

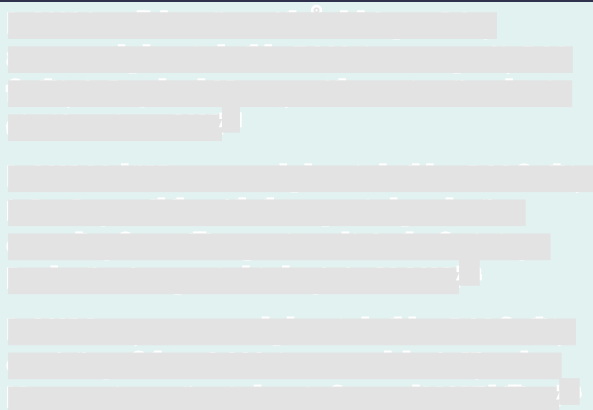


Data Source: RSPCA 2021, Fish Farming Expert 2018, Salmon Business, 2020

Investment in RAS by companies in the engagement



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Offshore farming

Offshore farms are set up in open water rather than sheltered bays. They contain fish in submerged nets secured from floating platforms, with the whole operation anchored to the ocean floor. After being moved from the hatchery as juveniles, the fish remain in the nets for as long as two years. In theory, this higher-energy environment – with stronger and faster currents – is better able to disperse waste and sea lice.

The investment required for offshore aquaculture is considerably higher than for nearshore equivalents. For a modest operation of 500 tonnes of fish, for example, capital investment of \$7-10 million is needed, along with \$5 million in annual operating costs,⁷⁶⁴ compared to an estimated \$2.2 million in annual operating costs for traditional aquaculture⁷⁶⁵. SalMar has reported that its Ocean Farm 1 facility cost approximately NOK1 billion (\$115 million) to design and develop⁷⁶⁶.

Six giant offshore farms are already operational in Norway, with Approval in Concept provided for more in Singapore and China⁷⁶⁷ – the latter is tipped to be a major player in the offshore aquaculture sector. Although information is sparse, there is a supportive regulatory environment in the region and an influx of expertise from the burgeoning European offshore market⁷⁶⁸. Rabobank analysts predict that offshore aquaculture could account for as much as 10% of global salmon supply by 2030⁷⁶⁹.



Of those qualified to answer, the vast majority of participants in FAIRR's aquaculture stakeholder review said that they had not heard enough about the risks of offshore farming. While early results from Ocean Farm 1 suggest that the project has been a success,⁷⁷⁰ the academic community claims more research is needed – particularly with regard to how “offshore” is defined in terms of the distance from shore, nutrient accumulation and water depth.⁷⁷¹

Given that facilities such as Ocean Farm 1 can hold up to 1.5 million salmon, triple the average net-pen farm's 500,000, expert stakeholders have highlighted the greater risk of fish escapes. Escaped salmon can compete with wild salmon for resources and, in many cases, threaten salmon populations.⁷⁷² Research has shown that farmed salmon can be made sterile using the CRISPR Cas-9 method,⁷⁷³ but this technology has yet to be widely adopted amid ethical and safety concerns.⁷⁷⁴

Other issues raised by stakeholders include the impacts of operations and noise on migratory patterns, predator conflict, continued reliance on stressed feed supply systems and capital expenditure. In 2019, Denmark's Minister for the Environment called a halt to offshore aquaculture farms, citing environmental risk as a cause for concern.⁷⁷⁵

Investment in offshore farming by companies in the engagement

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4.3. Expansion and exacerbation

The salmon-farming industry has ambitious targets to expand. The Norwegian government hopes to increase production by 500% by 2050⁷⁷⁷, while the Scottish government wants to facilitate a doubling of production by 2030⁷⁷⁸. China is expected to need an additional 9-27% in farmed fish supply by 2030 to keep up with demand for marine finfish⁷⁷⁹.

We believe that this expansion will exacerbate risks and costs in three main areas: new diseases, growing scrutiny of welfare and conflict with local communities and wildlife.

Threat of catastrophic disease outbreaks

High stocking densities, single-species dependence, free movement of personnel and waterborne pathogens make the salmon-farming industry a powder keg for disease.⁷⁸⁰ A significant expansion of the industry could exacerbate the risk of new viral diseases, such as pasteurellosis and infectious salmon anaemia (ISA). In the words of Ingunn Sommerset, Head of Fish Health at the Norwegian Veterinary Institute: “Salmon lice get a lot of attention, but the fish health situation...in aquaculture is under-communicated. Little public funding is given for research on infectious diseases”.⁷⁸¹

Due to the high transmissibility of waterborne pathogens, viruses can be transferred between countries and to wild populations. In May 2021, it was reported that piscine orthoreovirus had been detected in wild Chinook salmon in British Columbia, Canada, which had possibly originated in farmed salmon in Norway.⁷⁸²

Climate change will further exacerbate these issues. Warming waters reduce the suitable latitudes for Atlantic salmon farms⁷⁸³ and heighten the risk of sea lice and gill disease.^{784,785} The limitations of current data mean that climate impacts on individual farms are often drastically overestimated or underestimated, and much more work is required to reach the desired granularity.⁷⁸⁶ Opportunities for disease to break out will further increase if the industry continues to add farms and site them closer together. Disease outbreaks also bring a heavy burden of reputational risk, especially given the origins of the COVID-19 pandemic.

New technologies, such as Benchmark's CleanTreat®, have created a buzz in the market by cleaning sea lice, antibiotics and other contaminants from the water after fish have been treated in wellboats.⁷⁸⁷ However, feedback from farmers suggests that this is costly and logistically intensive, casting doubts on its uptake at scale.

Welfare, mitigation and costs

As discussed in section 2.5, aquaculture's growth has seen greater attention directed towards aquatic animal welfare. This issue will increase in materiality for producers and as more welfare measures are adopted, costs will rise as research continues to build on the complex needs of different species.⁷⁸⁸

One of the most effective means of improving fish welfare is to reduce stocking densities, which are unnaturally high in farm settings. Regulation was introduced in Chile in 2014 to lower densities for salmon, and we have already noted how some companies are now disclosing information on achieving optimal densities. Then again, lower density means higher costs – between \$0.50 and \$0.70 per kilogram, according to estimates.⁷⁸⁹

There is also nascent evidence of increased monitoring and measurement in response to welfare concerns, reflecting a trajectory seen in land-based sectors. As welfare in aquaculture continues to evolve, expectations will intensify and current commitments – only two of the companies in the engagement have set targets on welfare, and only one of these entails real-time welfare monitoring – will not be acceptable. Here, too, companies must expect higher costs.

Welfare must also be integrated into disease management systems, some of which remain controversial. For example, thermal licing treatments require salmon to be vacuumed into freshwater tanks at around 35°C, which can lead to bruising and damage to the eyes, ears and other vital organs.⁷⁹⁰

This is typical of the uncomfortable trade-offs that salmon farmers face. On the one hand, treatments are stressful and can cause injury; on the other, it is inhumane to allow fish to suffer parasites and diseases. Moreover, these processes are costly: the global cost of lice treatments was estimated at \$720 million in 2019, up from \$487 million in 2013.⁷⁹¹

Human-animal conflict, activism and regulation

The unintended consequences of aquaculture can extend to other animals, particularly predators – many of which are protected species – that are attracted to fish farms, raising welfare concerns beyond farmed fish.

For example, the Scottish Salmon Producers Organisation reported £13 million in losses as a result of seal attacks in the year to May 2020.⁷⁹² In the same year, Scottish salmon farmers were banned from shooting seals⁷⁹³ to bolster conservation efforts.

Many of the current “solutions” to human-wildlife conflict bring problems. Scottish salmon farmers are permitted by the RSPCA certification to use acoustic deterrent devices (ADDs) to deter seals and other predators, but these can harm non-target species, such as cetaceans. There is no conclusive evidence to date that ADDs are effective, and many seals have become habituated to them.⁷⁹⁴

The regulatory crackdown and public concern over the salmon industry's treatment of predators are likely to result in enhanced separation requirements.⁷⁹⁵ More effective options are currently available – but at a premium. The likes of steel-core nets – costing approximately \$200,000 per net – and closed containment systems will incur further costs for the industry.⁷⁹⁶

The impact of salmon aquaculture on wildlife could also inflame activism and generate negative public sentiment about the industry. The 2021 documentary, *Seaspiracy*, which is highly critical of the seafood industry's practices, was featured on Netflix's “Most Watched” list – inviting parallels with *Blackfish*, a 2013 documentary that criticised SeaWorld Entertainment Inc. over the deaths of two animal trainers in whale attacks and mistreatments of whales. This ultimately led to the SeaWorld settling a \$65 million lawsuit pertaining to having allegedly misled investors over the impact the documentary had on ticket sales.⁷⁹⁷

“If ADDs are used, then disclosure of the following metrics is recommended to enable a more fulsome understanding of ADD noise pollution: device model, duty cycle, number of devices and the time operational each day, and over the entire finfish production cycle. Regular checks and calibration of the acoustic outputs of ADDs, conducted by a third party, is also recommended. Alternative strategies for predator mitigation prior to the use of ADDs is also recommended to reduce potential impacts from underwater noise pollution.”

Charlotte Findlay

Marine Ecologist and Post-Doctoral Research Fellow, University of the Highlands and Islands

Community resistance and indigenous alienation

Many salmon farms are sited in places of high spiritual, economic, ecosystem or recreational importance, including the Norwegian fjords, the Scottish Highlands, the Salish Sea and the Tasmanian and Chilean coasts. This can lead to limitations in the locations available for expansion or, in some cases, to existing access being revoked.

In recent years, we have observed a general toughening of regulation in favour of local communities' opposition to salmon farming. For example, in June 2021, in the province of Tierra del Fuego, Argentina became the first country to impose an outright ban on salmon farming, with pressure from activists and scientists contributing to the rationale for the move.^{798,799}

In 2018, the provincial government of British Columbia, Canada, strengthened the veto powers of indigenous people, requiring fish farmers to gain consent from local communities for the waters in which they operate.⁸⁰⁰ This was seen as a major win for communities opposed to fish farming and has created an additional barrier for firms operating in the area. In 2021, under these rights, Kwakwaka'wakw Nation leaders objected to a newly proposed Grieg farm on the coast of British Columbia⁸⁰¹.

Similarly, in 2021, the Kawésqar and Yaghan indigenous leaders called for a halt to salmon farming on the reserve in the Kawésqar National Park, Chile. Their rationale was that the main species farmed in Chile is Atlantic salmon, which is non-native and could threaten wild populations and food supply for indigenous people if able to escape.⁸⁰²

In 2021, Richard Flanagan, author and Booker Prize winner, published *Toxic: The Rotting Underbelly of the Tasmanian Salmon Industry*. The book detailed alleged incidents of undue influence of salmon producers, including Tassal and Huon Aquaculture, and the negative experiences of local communities with issues ranging from noise and light pollution to degradation of the local environment.

Flanagan accused the Tasmanian government of being in "curious servitude" to the industry. Examples included failure to reprimand a company for overstocking Macquarie Harbour, a World Heritage site, causing a mass mortality event and environmental damage, and a salmon review panel dismissing the recommendations of two renowned environmental consultants advising against expansion.⁸⁰³

The book brought national attention and further scrutiny to the rationale behind growing Atlantic salmon in Tasmania, where frequent hot weather results in raised mortality.⁸⁰⁴ Tassal has said that many of its criticisms are "inaccurate, baseless or

not supported by independent experts or scientific facts".⁸⁰⁵

However, it announced several targets in its sustainability roadmap, released October 2021, addressing key issues raised by Flanagan – including the continued phasing out of seal deterrents, maintaining and improving local community sentiment by 10% by 2023, and moving to 100% RAS hatchery facilities by 2030.⁸⁰⁶

Mounting evidence of salmon farms' impact on wild populations,⁸⁰⁷ in addition to the increased publicity of associated environmental harm and externalities,⁸⁰⁸ could further galvanise activist groups in other salmon-producing nations. A report by Just Economics estimated that the global environmental cost of salmon farming could amount to more than \$47 billion between 2013 and 2019, with \$1.4 billion in Scotland alone.

The FAIRR Initiative has learned that social licence to operate is a key concern for many salmon farmers in Scotland and one that does not have an easy solution, with gaining community trust being a slow and protracted process. According to the Global Salmon Initiative, reputation is often based on sector performance rather than company performance⁸⁰⁹ – meaning individual companies or farms engaging with communities will have only a minor impact on increasing their social licence to operate.

“Salmon-farming companies are aggressively seeking to expand in Scotland. The industry says it engages constructively with coastal communities, but that is not the experience of the people we represent... When these communities point out that they do not agree with how the fish are treated in many farms – and that they do not want a large farm nearby that will harm their coastal environment and local jobs – the companies press ahead anyway. The Scottish government favours expansion, and the planning system is biased in its favour.”

John Aitchison

Coastal Communities Network, Scotland

“Barriers to scale include large-scale equipment/bioreactors and the infrastructure, price of media/nutrient solution for the cells, talent, and eventually logistics, supply chain, cold chain transportation when the industry reaches mass production. Cultivated seafood is expected to take a major share of the market in the next decade.

Dr Sandhya Sriram

Group CEO & Co-founder, Shiok Meats

4.4. Scale and gains in market share

The rise of alternative seafood

There will be a greater focus on meeting fish demand through different species and new production methods in the coming years. The salmon aquaculture sector, in particular, could be pushed to diversify its offering and improve resilience to disease, supply shocks and changing consumer preferences.

Conventional aquaculture faces disruption from alternative seafood products and new production methods. Cultured seafood is grown from aquatic animal cells in a laboratories, whereas plant-based fish is made wholly from plant-derived ingredients to mimic seafood. Finally, fermentation uses yeast and other microorganisms to produce plant-based alternatives and facilitate cultivated product production.⁸¹⁰

Cell-cultured fish offers a promising alternative, with some strong initial results from companies such as Blue Nalu, Shiok Meats and Wild Type, though issues of cost and scale remain. Efficiencies, however, are gained on all aspects of sustainability, from water use and carbon emissions to welfare and biodiversity.

Big Meat companies are also muscling in on aquaculture – JBS recently acquired Huon Aquaculture in Tasmania, while both Cargill and Nutreco are moving into the RAS space.

According to the Good Food Institute, alternative seafood accounted for only 1% of plant-based investment in 2019, with meat alternatives taking the other 99%. In the cell-cultured space, alternative seafood took 26% of investments, compared with 74% for alternative meat.⁸¹¹ Alternative seafood companies raised \$80 million in investment in 2020, quadrupling the 2019 figure.⁸¹²

Alternative seafood has clearly been slower to take off than alternative meats. Replicating texture, mouthfeel and aroma has proved difficult, and innovation in this space has been slower. However, the sector is predicted to experience boosted development following the recent increase in investment.^{813,814}

The alternative seafood industry is expected to grow 28% annually over the next decade and reach \$1.6 billion. By comparison, the current seafood sector has a market size of \$160 billion and a CAGR of 2.5%.⁸¹⁵

Lower trophic options

Lower trophic options, such as tilapia, carp, mussels, clams and other bivalves, have the potential to provide high-quality protein at a modest environmental price tag.

Invertebrates, such as bivalves, fall into the category of “non-fed aquaculture”, sifting nutrients directly out of the water column⁸¹⁶ and requiring no external sources of feed. Moreover, bivalve shells have by-product applications in cosmetics, pharmaceuticals, food, beverages, animal feed and water treatment,⁸¹⁷ adding economic value and contributing to the circularity of the global food system.

Bivalves currently account for approximately 20% of global aquaculture production.⁸¹⁸ Estimates for the potential economic value of bivalves from provisioning (food) and regulating (sediment and nutrient regulation) services are \$30 billion.⁸¹⁹

Another production method receiving optimism in the market is integrated multitrophic aquaculture (IMTA). This involves two or more species being cultivated in close proximity, with the waste of one becoming the feed for another – bivalves are often incorporated. IMTA methods diversify species offerings and can provide a buffer for farmers against disease or market shocks. IMTA’s positive public perception can raise margins, as consumers are willing to pay a premium for such products.^{820,821}

China’s uptake of IMTA ramped up after 2000, when the market turned from co-culture (just two species) to integrated systems to avoid the “self-pollution” that resulted from intensively fed aquaculture, leading to eutrophication and red tides. Today, as much as 80% of freshwater aquaculture in China is IMTA.⁸²²

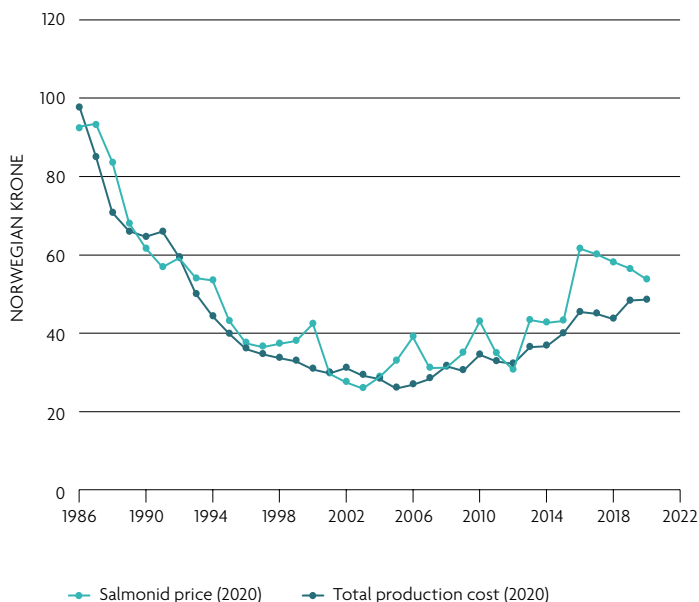
The risks of habitat destruction and community resistance may force companies to invest in this kind of natural abatement system, with molluscs and seaweed helping regulate the nutrients emitted from salmon farms.⁸²³ Lerøy has already invested in these types of systems, with its 2014 Ocean Forest project featuring sugar kelp, blue mussels and algae.⁸²⁴

5. CONCLUSION

Is the era of capital-light farmed fish nearing its end? Aquaculture as a whole, rather than marine fin-fish farming, does have a significant role to play in global food supply resilience as we head towards 2050, but the industry needs to diversify, digitise, professionalise, and become more transparent and traceable. Closed and semi-closed containment offer a viable opportunity for salmon farming to continue if welfare, feed and cost concerns are addressed. Cheaper coastal open-net-pens are responsible for much of the issues discussed in this report, such as community resistance, disease and environmental degradation. Although there is a high CapEx associated with new technologies and marketing new options to consumers, the operating costs of traditional farming will continue to creep up with rising feed costs, environmental abatement and disease management. Beyond new technologies, lower trophic options and alternative seafood are well-positioned in terms of technology and marketability to buttress food supply and take a greater market share in the next five to 10 years.

Figure 19

Salmon squeezed as production costs creep up and prices take a downturn



Data source: Prof Bård Misund

“Choosing the right species for domestication is a complex question. From a behaviour and welfare perspective, aquaculture with large carnivorous predators like tuna or salmon will repress a different suite of natural behaviours related to feeding and hunting compared with lower trophic species such as carp. Some lower trophic species seem to be less costly to feed and domesticate than higher ones. We can compare this with the logic of terrestrial farmed domesticated animals – it isn’t wise to breed a lion to feed yourself. Informed decisions are crucial, and decisions taken based on a superficial understanding can have serious consequences.”

Dr Sonia Rey Planellas

Lecturer in Animal Behaviour and Welfare,
Stirling University

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