Climate risks in Norwegian aquaculture

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Executive summary

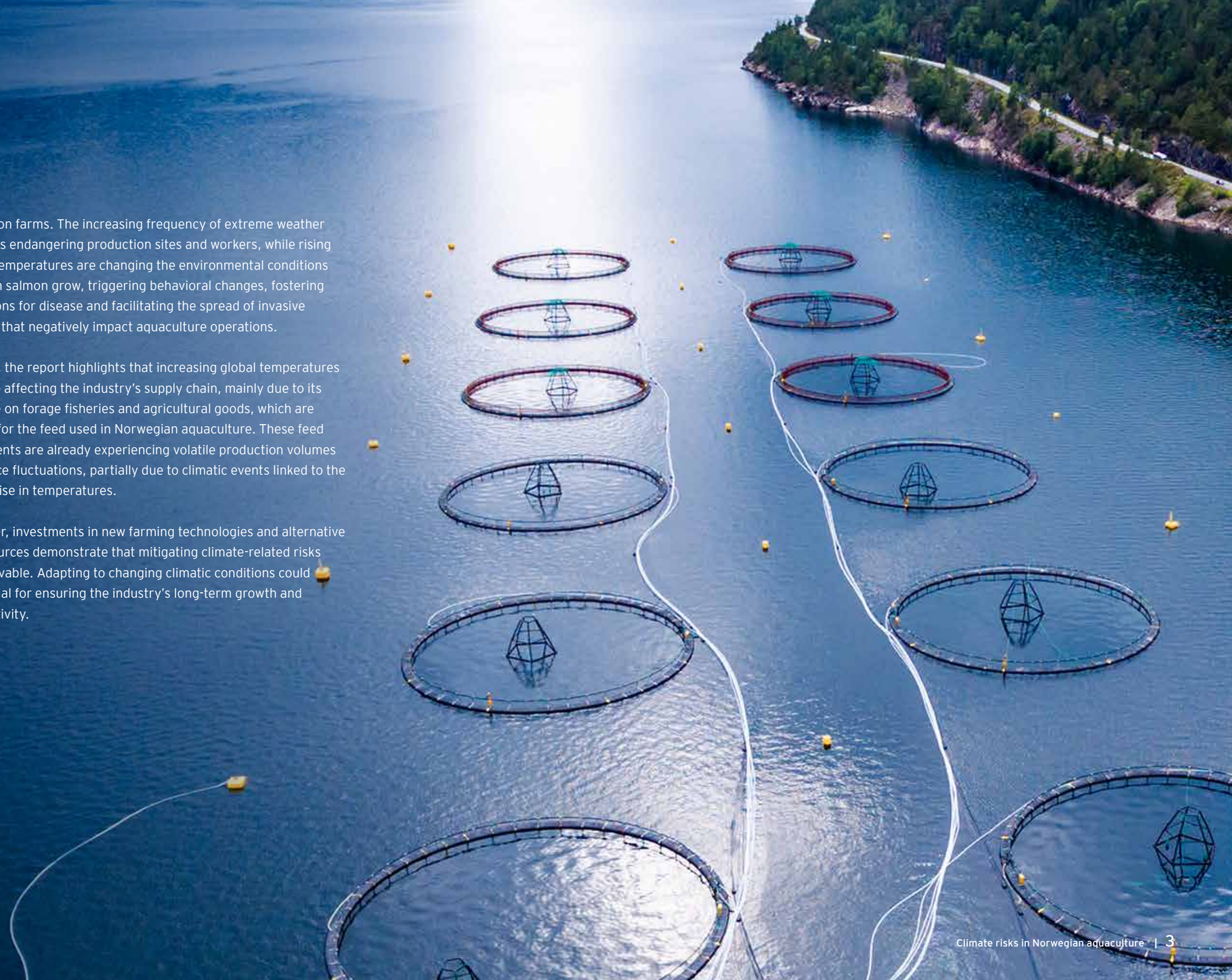
The unique environmental and climatic conditions along the Norwegian coastline have been a key factor in the aquaculture industry's rise to become one of the most important sectors of the Norwegian economy. The extensive coastline offers ideal conditions for Atlantic salmon to thrive, which has fueled the industry's rapid growth over the past three decades, significantly contributing to Norwegian exports and serving as a crucial economic backbone for many coastal communities.

However, the industry's heavy reliance on environmental conditions also makes it particularly vulnerable to climate change. Rising global and local temperatures are triggering environmental shifts that affect salmon on multiple levels. Furthermore, increasing public and regulatory pressure is compelling companies in the sector to assess the risks associated with climate change, which is crucial for developing effective risk mitigation strategies.

This report covers both physical and regulatory climate risks, discussing a variety of climate impacts on the industry's supply chain and operations. It reveals that climate change is already posing significant risks to the secure and profitable operation of salmon farms. The increasing frequency of extreme weather events is endangering production sites and workers, while rising ocean temperatures are changing the environmental conditions in which salmon grow, triggering behavioral changes, fostering conditions for disease and facilitating the spread of invasive species that negatively impact aquaculture operations.

Further, the report highlights that increasing global temperatures are also affecting the industry's supply chain, mainly due to its reliance on forage fisheries and agricultural goods, which are crucial for the feed used in Norwegian aquaculture. These feed ingredients are already experiencing volatile production volumes and price fluctuations, partially due to climatic events linked to the global rise in temperatures.

However, investments in new farming technologies and alternative feed sources demonstrate that mitigating climate-related risks is achievable. Adapting to changing climatic conditions could be crucial for ensuring the industry's long-term growth and productivity.



Introduction

With the ongoing growth of the global population, the Food and Agriculture Organization of the United Nations (FAO) has predicted that food production must increase by about 70% by 2050 to meet the rising demand. Additionally, increasing per capita income is driving higher demand for animal protein, the production of which is resource intensive, requiring large amounts of feed, land and freshwater. Aquaculture, particularly the farming of fish such as Atlantic salmon, offers a crucial advantage over land-based animal farming, as it requires fewer resources per unit of mass and involves less land use since operations mainly take place at sea. Thus, aquaculture is an attractive alternative to land-based animal farming and could significantly contribute to future food security.

However, as global temperatures rise due to climate change, we are already witnessing and anticipating major ecological and societal changes. Changing weather patterns, increasing sea temperatures and rising sea levels are just a few examples of the direct impacts of climate change on the planet. These challenges, including floods, droughts and extreme weather, affect industries across the board, including aquaculture. Further, increasing regulatory pressures are pushing industries to adapt to support a more sustainable economy.

The Norwegian aquaculture sector has become a vital economic contributor to many coastal communities and is the second-largest export industry in Norway, only surpassed by the oil and gas sector. Most of the fish produced through aquaculture in Norway comes from the farming of Atlantic salmon in open cages, a production method that highly benefits from the natural conditions along the Norwegian coastline. However, this reliance on the natural environment also makes the industry highly vulnerable to environmental changes, which can directly affect production.

This report explores the various climate risks that impact the Norwegian aquaculture industry across multiple areas of the value chain, covering aspects of both upstream and own operations. It also highlights potential strategies to mitigate climate-related risks.

Background

Norwegian aquaculture

While Norwegian aquaculture has been an economic success story, there has been a significant increase in fish mortality in recent years (Norwegian Veterinary Institute, 2024). This rise is attributed to several factors, including increased salmon lice infections, fatalities related to stress and injuries during the production phase and bacterial infectious diseases. Moreover, climate change plays a natural role in exacerbating these issues. Changes in the marine environment caused by climate change affect not only the salmon directly but also its natural habitat, intensifying these challenges. These consequences of climate change – rising sea temperatures, higher sea levels and ocean acidification – pose considerable risks to the industry. Therefore, evaluating climate risks within aquaculture operations is essential for maintaining long-term sustainability and stable yields.

Changes in marine climates significantly harm fish welfare, which directly impacts the efficiency and stability of production. However, risks within the aquaculture industry extend beyond fish welfare. The sector is also experiencing more frequent and unpredictable extreme weather events, which pose considerable risks to the upstream value chain, particularly in securing access to raw materials. Furthermore, workers on fish farms have been ranked among those with high-risk jobs in Norway (Sintef, 2017, p.5). Considering the increasingly weather-exposed and unpredictable nature of their work, climate risk is a critical factor in these areas of the operation as well.

The Norwegian aquaculture industry has started implementing measures to reduce its environmental impact. This response has been driven by rising fish mortality, stakeholder pressure and regulations aimed at fostering innovation. These measures range from electrification of operations to large investments in new technological projects. Examples include land-based farming, closed- and semi-closed pens and offshore farming. The Norwegian government has also introduced various incentives to encourage research and development within the sector. These initiatives include development licenses, which permit the expansion of existing operations or the establishment of new farms to support innovation-focused projects (Norwegian Directorate of Fisheries, 2024). These efforts reflect Norway's commitment to fostering an ecologically responsible aquaculture industry while maintaining its global leadership in fish farming.

Physical risk and transitional risk

Climate change risks can take various forms, but they are usually classified into physical climate risks and transitional climate risks. Physical risks refer to the direct impacts of climate change, such as extreme weather events and flooding. Transitional risks, on the other hand, stem from the need to adapt to climate change, which may include increased regulatory pressures or higher R&D costs to develop more climate-resilient products.

Climate risks are usually dependent on the trajectory of climate change, which has been standardized into three scenarios defined by the UN's International Panel on Climate Change (IPCC) as Representative Concentration Pathways (RCPs). These scenarios represent different projections for global greenhouse gas (GHG) emissions (IPCC, 2021). The first scenario, RCP 2.6, assumes an immediate and significant reduction in GHG emissions, limiting global warming to 1.5 degrees Celsius. The second, RCP 4.5, is a moderate scenario where emissions peak mid-century and then decline, resulting in a two-to-three-degree temperature rise. Lastly, RCP 8.5 assumes continued growth in emissions, potentially leading to warming of more than four degrees Celsius, with severe climate consequences.

Additionally, the IPCC has introduced Shared Socioeconomic Pathways (SSPs), which, unlike the RCPs, focus on different social trajectories based on factors such as population growth, economic development, technology and politics (IPCC, 2021). These SSPs present five possible future scenarios (SSP1 – SSP5), offering more detailed insights into how society might evolve under each RCP scenario and how communities could be impacted and adapt to climate change.

This report discusses some of the most relevant physical and transitional climate risks currently facing the industry along the value chain, including supply chain risks.

Climate risks in the supply chain

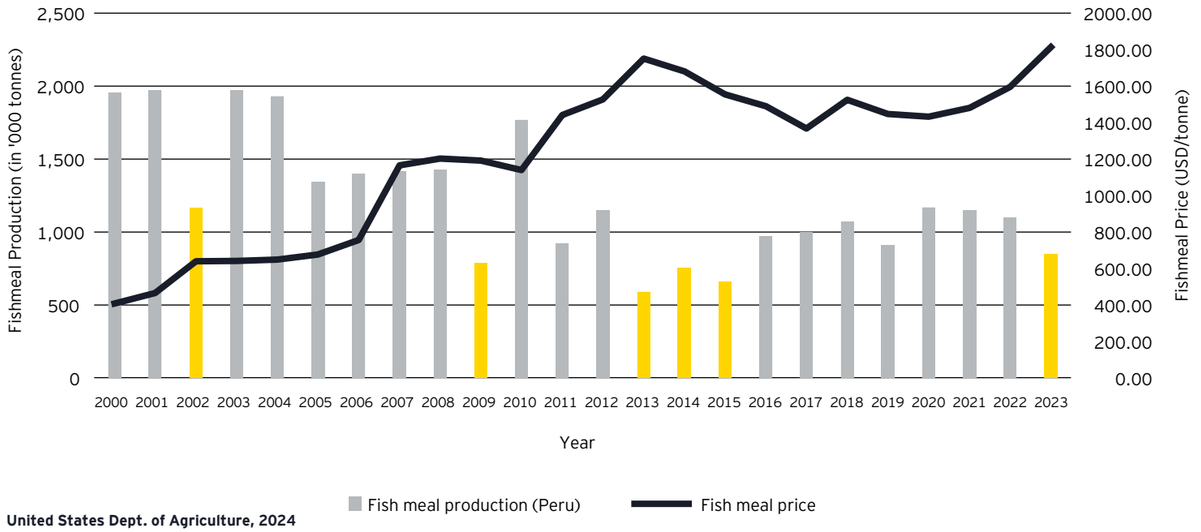
The upstream value chain in the aquaculture industry covers various business activities, such as R&D efforts to optimize production, hatcheries or development, and the development and production of materials, raw materials and equipment. While the climate crisis affects all aspects of upstream activities, this report focuses on the production of feed ingredients.

Fish feed is the largest operating cost for aquaculture companies today, as these expenses account for more than 50% of total production costs (Asche et al., 2019). Although the exact salmon feed recipes vary between different producers and are subject to strict confidentiality, a typical formulation contains around 35% marine ingredients (fish oil and fish meal) and around 45% plant-based ingredients, such as soy protein. Since these raw materials are sourced from agriculture and fisheries, the availability – and therefore their price – can be highly dependent on climatic influences, as these sectors are very vulnerable to extreme weather events like drought and increased temperatures.

Climate risks in the production of fish oil and fish meal

In general, the industrial production of fish meal is mainly dependent on the availability of certain wild-caught pelagic fish, which are predominant in subtropical and temperate regions. These fish stocks are very vulnerable to changing climatic conditions, as even slight temperature increases can significantly affect them. In Peru, the largest producer of fish meal and a main supplier to the global aquafeed industry, production has already experienced significant fluctuations. Overall, production has dropped by more than 50% since 2000, while the global price of fish meal has increased by more than 400% during the same period (United States Dept. of Agriculture, 2024).

Fishmeal: Production volume and price development



United States Dept. of Agriculture, 2024
Data source: IndexMundi.com

The change in climatic conditions is a key driver of the decrease in fish meal production volumes. Increased temperatures have a severe impact on the stocks of forage fish, which are indispensable for fish meal production. This effect can already be seen when looking at years where the ocean temperatures have increased due to the weather phenomenon "El Niño", which leads to increased water temperatures, especially in the southeast Pacific Ocean. The years in which El Niño has occurred have led to a significant decrease in fish meal production in Peru and increasing prices on the world market (see years marked in yellow in the graph).

The world's oceans have never been as warm as they were in 2023, and due to the general warming of global temperatures, this trend is unlikely to reverse in the foreseeable future. It is very likely that this trend will continue to impact the global production volumes and prices of fish meal significantly, posing a high risk for the production costs of salmon.

Climate risks in the production of soy

Though marine ingredients such as fish meal and fish oil are still crucial components to most salmon feeds, the main protein content of modern salmon feeds stems from agricultural ingredients such as soy meal and soy protein concentrate.

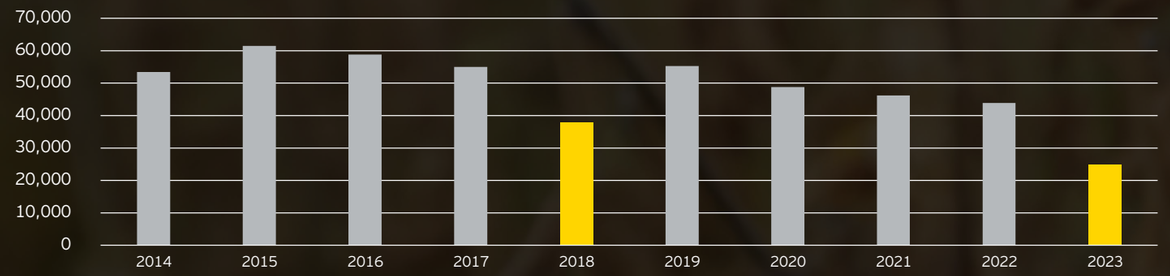
However, as an agricultural commodity, the availability of soy is also highly dependent on climatic conditions, as droughts and extreme precipitation can significantly reduce crop harvests. Graph 2 shows the soybean production of Argentina, one of the world's largest exporters of soy.

The production data from Argentina shows that changing climatic conditions can significantly impact the availability of soy. In 2018 and 2023, Argentina experienced severe droughts, which led to a drastic decrease in crop yields compared to the previous years. As the likelihood of droughts and other extreme weather events continues to increase, the probability of reduced harvests is rising equally, potentially leading to potential shortages of soybean supply, and consequently, higher prices.

The increased global demand for soy meal, coupled with uncertainties in production, is already driving up commodity prices.

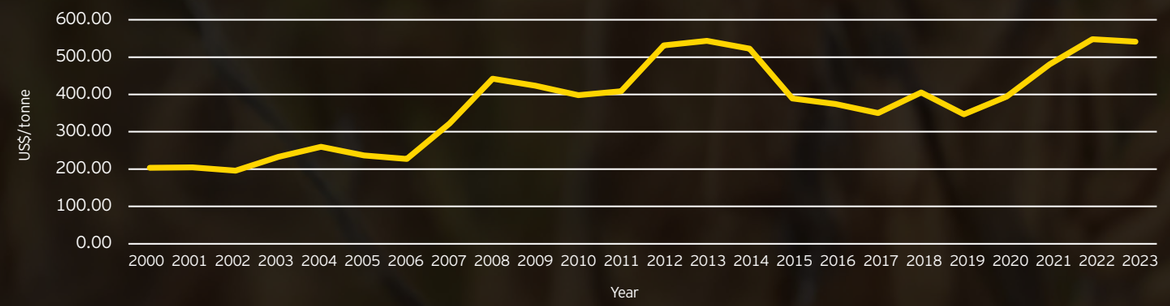
The prices for soy meal have already increased by more than 100% during the past 20 years. Combined with increasing weather-related uncertainties due to climate change, this trend could continue, significantly impacting the prices for salmon feed and, consequently salmon production.

Soybean production (in '000 tonnes)



United States Dept. of Agriculture, 2024

Soy meal price



United States Dept. of Agriculture, 2024

The role of certification in feeds

The most frequently used sustainability certification for farmed salmon is the Aquaculture Stewardship Council (ASC) certification. Besides setting standards for farmed salmon production, the specific ASC feed standard also sets requirements for feed production. This standard requires that the value chain for all ingredients, including non-marine ones, must be fully traceable. It also requires feed suppliers to closely monitor and report their greenhouse gas emissions. Combined with legislative bodies that impose similar requirements on larger feed producers, these standards can lead to higher feed prices, as monitoring and reporting emissions and value chain characteristics require resource investments from feed producers, which can increase production costs. (also see regulatory risks).

Mitigating climate risks in feed production

Diversifying feed ingredients is an effective way to mitigate climate-related uncertainties in the supply chain for companies in the aquaculture sector. Alternative feed ingredients can partially replace crucial proteins and omega-3 fatty acids traditionally sourced from soy and fish oil or fish meal. Several players in the aquafeed market are already developing feeds where soy protein is replaced by alternative proteins, such as insect meal, which can be produced locally at low costs with minimal environmental impact and reduced dependencies. Further, alternative marine ingredients like microalgae, mussels or macro-algae (e.g., sugar kelp) can provide omega-3 fatty acids as a potential replacement for fish meal and fish oil. Several trials, such as those conducted by the Norwegian Institute for Marine Research, have shown promising results.

Investing in the diversification of feed ingredients is an effective strategy for mitigating climate risks in the upstream value chain, including using ingredients less vulnerable to climatic changes and that can be sourced locally. This approach reduces dependencies on fish meal, fish oil and soy, which are significantly impacted by global temperature rise and are subject to increasingly volatile market prices.

Climate risks in aquaculture operations

Norwegian aquaculture companies undertake various operational activities, ranging from the production of roe and smolt to post-smolt and product-fish farming. Their activities may also include slaughtering and secondary processing. This report primarily focuses on the sea phase of production.

Daily operations within the sea phase are comprehensive and span from sea to land. They include fish care within the cages – providing and adjusting feed, conducting timely checks for lice and illnesses and removing deceased fish to ensure good fish welfare. Additionally, these operations often involve maintaining equipment, boat operations, conducting repairs and other operational elements.

Impacts on the salmon's behavior and welfare

Climate risks in salmon production are prominently represented by increasing sea temperatures, rising sea levels, ocean acidification and more frequent occurrences of extreme weather. Ocean temperatures have been rising due to increased atmospheric temperatures, affecting the waters around Norway. These environmental shifts directly impact the wellbeing and behavior of salmon, thereby influencing productivity and stability within operations.

Rising temperature and acidification

According to the Norwegian Royal Climate and Environmental Department, the average temperature of surface water is expected to rise from around 6.5 degrees Celsius to about 9 to11 degrees Celsius (Meld. ST. 21 (2023-2024), p.46). This prediction correlates with the moderate climate scenario of GHG emissions (RCP 4.5). In addition, the ocean absorbs approximately 30% of all emitted CO_2. As a result, pH levels decrease, leading to ocean acidification. During the 21st century, it is likely that the Norwegian coast will experience significant acidification, as acidification increases proportionally with the rising concentrations of CO_2 in the atmosphere.

Climate change has tested the adaptability of salmon. While salmon have proven to be a versatile species with flexible traits, they also depend on environmental variables that ensure healthy performance and behavior. Stressed by environmental shifts, salmon will alter their behavior to try and reduce stress. This can result in relocation, changes in activity levels, social behavior and appetite. Water temperature influences crucial aspects of salmon health and welfare, such as respiration, digestion, and the nervous and hormonal systems. Atlantic salmon, being an ectothermic species, lacks the ability to regulate its own temperature. Instead, it adjusts to the temperature of its environment, making surrounding temperature the most important environmental factor for the salmon's wellbeing.

In correlation with rising temperatures, we find an increasing frequency of extreme weather events, including marine heatwaves. Evidence of this is already apparent, such as the 2019 incident in Chile, where a large quantity of farmed salmon perished in open-sea cages due to a period of high sea temperatures. Incidents like this are becoming increasingly common, as demonstrated by data indicating that half of all marine heatwaves in the Barents Sea between 1980 and 2020 occurred in just the last decade (UNRIC, 2023).

Sea lice, bacterial infections and illness

In 2023, infectious diseases were the main cause of fish mortality in Norwegian salmon farming. The steep increase in disease transmission and parasitic infestations can be attributed to multiple factors, including climate change, which is adversely affecting the marine environment. Notably, a warmer and more acidic ocean impacts the welfare of farmed salmon while simultaneously creating favorable conditions for species like sea lice, exacerbating already existing risks.

Sea lice prefer to stay near the surface, where the temperature is milder, an area commonly referred to as the "lice belt." With rising temperatures, sea lice may travel deeper into the cages, increasing the infection risk for salmon. Additionally, salmon attempt to avoid the spreading lice by descending further down in the cage, leading to a higher density of fish in the lower areas and increased territorial stress.

Infectious diseases among farmed and wild salmon pose a substantial health risk, one that is exacerbated by the rising temperatures of marine habitats. Certain diseases, such as furunculosis and proliferative kidney disease (PKD), are expected to become more prevalent with the onset of marine climate change. Similarly, vibriosis, an already common bacterial infection in both farmed and wild salmon in Norway, is highly infectious and can rapidly elevate infection risk in warmer sea temperatures. (Norwegian Veterinary Institute, 2024)

Furthermore, Norway is witnessing a concerning trend where pathogens typically associated with farms in the southern regions are gradually spreading northward. Notably, amoebic gill disease (AGD), caused by the pathogen Paramoeba perurans, was detected in the northern territories of Norway in 2023 (Norwegian Veterinary Institute, 2024). As sea temperatures in these northern regions begin to warm, environments that were once hostile to certain pathogens are now becoming more conducive, allowing diseases to thrive where they previously could not.

Alien species

In addition to the direct effects of temperature on the health and wellbeing of farmed salmon, the changing marine environment can create ideal conditions for alien species. Typical species that thrive in warmer climates include algae and plankton. One of the most well known in Norwegian aquaculture is the jellyfish, Perlesnormanet. This jellyfish is dangerous to fish in net-pens, as its tentacles, which can grow up to 10 meters long, contain toxins harmful to the fish. The impact of these jellyfish on farmed salmon varies, but common issues include abnormal behavior, skin wounds and markings and an increased number of "floaters" (fish exhibiting abnormal behavior, such as gasping for oxygen). In 2023, jellyfish were ranked among the top five biggest problems, excluding infectious diseases, affecting Norwegian farmed salmon (Norwegian Veterinary Institute, 2024).

Extreme weather

In addition to changing marine climates, extreme weather also poses significant risks to aquaculture operations. These can be divided into two categories.

More frequent instances of extreme weather can expose equipment and infrastructure to damage, such as from storms and flooding. One example in Norway is the extreme weather event "Hans," which struck the southern region in 2023 and caused damage estimated at approximately €250m. In extreme cases, such events can damage cages or netting, resulting in salmon escapees.

Moreover, extreme weather events can significantly impact the health and safety of employees. As storms and heavy precipitation become more frequent and unpredictable, such events can lead to severe injuries or worse for employees already working in high-risk, demanding and exposed professions at sea.

Case study

Physical climate risk assessment for selected sites

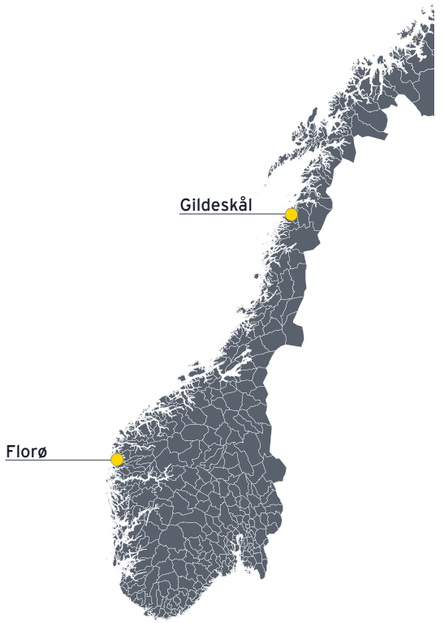
A thorough assessment of physical climate risks is part of various reporting standards and frameworks that require companies to map and evaluate the climate risks they face. The EU Taxonomy and the EU Corporate Sustainability Reporting Directive (CSRD) – both mandatory reporting standards for eligible companies operating in the EEA market – require climate risk assessments from reporting entities. Additionally, a variety of widely used voluntary reporting frameworks, such as the Taskforce on Climate-related Financial Disclosures (TCFD), list climate risk assessment as an integral part of sustainability reporting.

The EY organization uses widely acknowledged climate models to estimate future climate impacts. Combined with various location-specific datasets, EY teams can assess physical climate risks for any given geographic location.

The EY organization has selected fictional yet representative salmon production sites in Norway, Scotland, Chile and Canada. For each site, EY teams have then identified the physical climate hazards that could severely impact production, both at sea-based open net-pens and land-based processing facilities. The selected climate hazards include storms, which pose risks to the stability of production sites and worker safety; floods, which could damage land-based processing facilities; and water temperatures, which have a variety of biological implications for salmon production (see section Climate risks in aquaculture operations).

The EY organization has assessed the probability of severe occurrences of these three selected hazards over the next 25 years, using IPCC-approved climate models. The results are displayed in the table below.

Country	Region	Asset type	Storms	Flooding	Water temperature
Norway	Florø	Farm	Low	n/a	Medium
		Processing site	Low	Very high	n/a
	Gildeskål	Farm	High	n/a	Medium
		Processing site	High	Very high	n/a
Chile	Los Lagos	Farm	Medium	n/a	No data
		Processing site	Medium	Very low	n/a
Canada	New Brunswick	Farm	Medium	n/a	No data
		Processing site	Medium	High	n/a
UK (Scotland)	Shildeigh	Farm	High	n/a	Medium
		Processing site	High	Very high	n/a



The climate risk assessment shows that the fictional site in Gildeskål is exposed to an increased risk of storms, which could disturb the operations and damage assets (e.g., the net-pens). Further, the processing sites located along the coast are highly exposed to the risk of tidal flooding, which could also impact operations and cause significant damage to the facilities. The sites in Chile and Canada show a medium risk of storms, while the processing site in New Brunswick has a high exposure to flooding. In Scotland, the risk of storms is also high, and the processing site faces a very high risk of flooding.

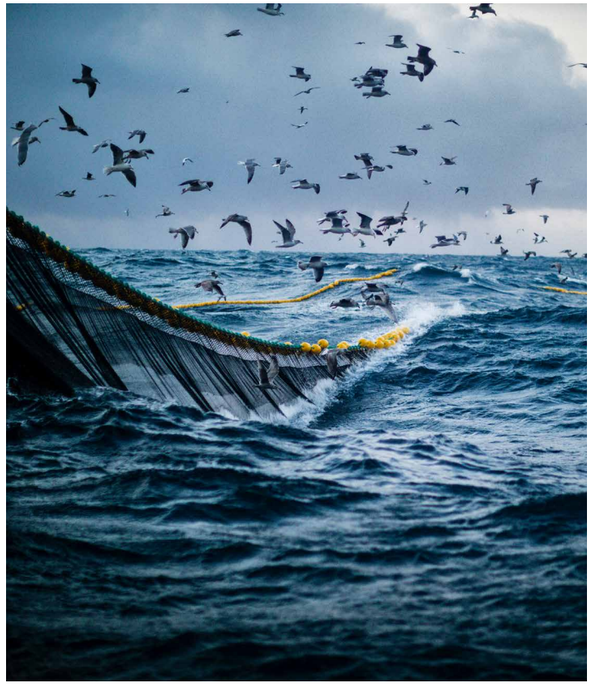
Further, all locations of fictional farms, for which sufficient water temperature data is available, show an increased exposure to rising water temperatures. This could potentially impact the physiology and health of farmed fish (e.g., lice, bacterial infections and illnesses).

Based on the results of these risks assessments conducted by EY teams, operators of facilities could enhance their risk management systems, adapt to the risk exposure (e.g., through flood protection measures) or consider these risks when choosing locations for new facilities.

Alternative production methods to mitigate climate risks

Alternative production methods are gaining traction in the aquaculture industry. Offshore-based farms significantly reduce the spread of pathogens, as stronger currents lead to higher water exchange, which reduces the spread of diseases and parasites despite rising water temperatures. Investment in offshore facilities can thus be an effective measure to address biological climate risks.

Further, the industry is seeing increasing investments in land-based aquaculture farms, which allow operators to fully control environmental conditions, such as water temperature and acidity. This eliminates negative climate impacts on production, such as rising water temperatures and ocean acidification. Land-based aquaculture facilities are also less exposed to climate risks like storms and floods, which are more likely to damage net-pens that are fully exposed to the weather.



Regulatory risks

There is growing global awareness of the environmental consequences of human actions. In response, the Norwegian government, in line with most of the EU, is setting ambitious climate goals and plans to enforce stricter regulations on activities that contribute to climate change. As part of the EU Green Deal, the Corporate Sustainability Reporting Directive (CSRD) and the EU Taxonomy are already raising reporting standards for climate-related matters of companies in the Norwegian aquaculture industry. Among other requirements, these standards mandate thorough assessments of company-specific physical and transitional climate risks, the reporting of GHG emissions and increased value chain transparency. Further, the regulations require companies to formulate emission-reduction targets and related strategies and policies.

Thus, upcoming regulations impose several risks for salmon farming companies subject to these guidelines, as non-compliance could harm the company's reputation or increase capital costs through loans tied to climate goals. A timely and effective assessment of these regulatory pressures can help minimize financial impacts when preparing the documentation required by these regulatory reporting frameworks.

Concluding remarks

As an industry highly dependent on the environment, the Norwegian salmon aquaculture sector is highly exposed to climate risks. The global rise in air and sea temperatures is affecting the industry at various levels across the value chain.

However, effective risk assessment and the development of comprehensive risk management and mitigation measures can help companies in the sector prepare for and adapt to financial impacts stemming from increasing feed prices, reduced production volumes due to illnesses or asset loss caused by severe weather events such as floods or storms. Parts of these risk assessments are already required by upcoming regulatory frameworks, and timely implementation ensures regulatory compliance and alignment with stakeholder expectations.

Moreover, investments in alternative production technologies can mitigate climate risks. Land-based recirculating aquaculture systems allow operators to fully control environmental conditions, thereby reducing risks associated with changing water temperatures. Additionally, offshore production sites can mitigate the effects of rising water temperatures, as offshore water temperatures are more stable and increased circulation helps prevent the spread of diseases. While these new production methods remain vulnerable to other climate risks like flooding or storms, they can contribute to lower mortality rates and thus higher production volumes.

When combined with diversification of feed ingredients, which can reduce dependence on products subject to price volatility caused by climate-related production challenges, this can be an effective strategy to mitigate climate risks in the Norwegian salmon aquaculture sector.

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