Climate Change and Norwegian Arctic Aquaculture: Perception, Relevance, and Adaptation

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The Norwegian aquaculture sector continues to increase both spatially and in terms of production volume, but is vulnerable to changes in weather, temperature, marine environmental conditions, and other conditions. More than a third of Norway's aquaculture production takes place in Northern Norway, a region where the rate and magnitude of climate change is already twice that of the global average. In this article, we investigate representatives from the aquaculture industry and their perceptions of climate change and how it influences their current and future operations. Our findings show that climate change is generally not a central concern for aquaculture companies and climate change is translated into and understood as a gradual intensification of already existing problems. The industry aims at balancing their production targets with the management systems' environmental and sustainable development requirements and focusing on short-term challenges such as lice, diseases, and market trends. Although most adaptive measures are not justified directly as climate related, the industry is highly adaptive and responsive to climate relevant changes through continuous adaptation and innovation strategies. The only measure that is genuinely climate related is the efforts of some of the actors to localize parts of their production capacity further north. The findings are based on semi-structured interviews with representatives of eight aquaculture companies whose facilities are localized in Northern Norway.

Introduction

Food production is an important part of the climate issue and aquaculture is important for global food security. The OECD/FAO estimates that in 2022, aquaculture production will for the first time surpass wild catch fisheries in volume (OECD/FAO, 2019: 195). The bulk of the world's aquaculture production takes place in the global south, carried out by small-scale producers (Galappaththi et al., 2020). However, important, large-scale aquaculture also takes place in the High North. Norway is the world's top producer of Atlantic salmon, and aquaculture represents Norway's second largest export industry. In 2019, Norway produced 1.366 tons of salmon (*Salmo salar*) and trout[1] (*Oncorhynchus mykiss*), which again provided a first-hand value of 71.7 billion NOK (SSB, 2020). About 40% of this production volume takes place in Northern Norway, and the

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region's share is increasing. The government aims to facilitate further growth of the aquaculture industry in the northern region (White paper no. 7, 2011-2012).

Given the location of Northern Norway, stretching from 65 to 71 degree north, the region is likely to experience climate change related weather variations that may influence the future growth of the aquaculture industry. Temperatures in Northern Norway are expected to increase at a higher rate than further south (Hanssen-Bauer 2019). Changes in water temperature, sea-levels, the frequency of extreme weather incidents, ocean acidification and sea surface salinity are just some of the climate variables that may affect development trends, as these factors have bearing on which species thrive and the interactions between them (White paper 16, 2014-2015; Winter et al., 2013; Dannevig et al., 2019).

The success of salmonid farming is dependent on the complex ecology of the aquatic environment, which makes the wide-ranging impacts of climate change important to consider (Callaway et al., 2012). The consequences of climate change require attention to sustainable management, knowledge, and technological changes in operational processes. It is important to have adequate knowledge about the effects of climate change on marine ecosystems, in order to adapt aquaculture, fisheries and coastal management to the new conditions (White paper 33, 2012-2013). Attention to and knowledge about climate change adaption in aquaculture is increasing (e.g. Callaway et al., 2012; Galappaththi et al., 2020; Karlsson & Hovelsrud, in press; Rybråten et al., 2018; Dannevig et al., 2019).

With the backdrop of high targets for production growth and the projected climate change impacts, in this study we describe the aquaculture business' perceptions of and adaptation to climate change. First, we provide a brief conceptual framework and the methods applied in this research, followed by an overview of the aquaculture industry and the expected consequences of climate change. Subsequently we present our main findings from the interviews and a concluding discussion.

Conceptual framework

In this article we approach climate adaption as broadly pertaining to adjustments in coupled natural and human systems in response to actual or expected climate stimuli or their effects. The adjustments or adaptations function in moderating harm or exploiting opportunities (Smit & Pilofosova, 2001; Adger et al., 2007). Climate adaptation as a concept has developed significantly in the past two decades. As studies of climate adaptation have multiplied, they have also revealed that adaptation is not a straightforward response to a given perturbation. It has therefore passed through many iterations and applications, consequently developing into an analytically strong concept.

Adaption is increasingly referred to as a process that takes place along multiple dimensions and in the context of multiple interacting stressors and cumulative change (e.g. AMAP, 2017: 219-252; Hovelsrud & Smit, 2010; Schipper & Burton, 2009; Leichenko & O'Brien, 2008). Adaptation processes are shaped by barriers, limits, opportunities, and governance. Such processes create adaptation strategy options that emerge across scales (institutions such as municipalities and states, sectors such as aquaculture and fisheries) and actors (businesses, policy makers, government officials, individuals) (AMAP, 2017: 219-252). Adaptation is also a context-dependent process shaped by the institutional structure of a community and the specific national climate adaptation guidelines, the range of exposure-sensitivities and cumulative change, and adaptive capacity (e.g. Hovelsrud & Smit, 2010; Smit & Wandel, 2006). Exposure-sensitivity is understood as the manner and degree to which a community - in this case, the aquaculture industry - is both exposed and sensitive to stresses given changing conditions and the situational characteristics of place and people (Smit et al., 2010: 5).

Adaptive capacity is shaped by a number of factors and processes, such as access to resources and knowledge, economic or livelihood flexibility and opportunities, enabling institutions, governance, infrastructure, and connectivity (Cinner et al., 2018; Keskitalo et al., 2011). However, adaptive capacity is not only associated with the existence of these factors, but also with the willingness and the potential of actors to translate them into adaptive responses (Bay-Larsen & Hovelsrud, 2017). Adaptation responses, whether reactive or proactive, take many forms depending on the multiple interacting effects (e.g. Smithers & Smit, 2009). There is potential for conflict between the goals and concerns of different interests or actors, because responses are not one type fits all (e.g. Westskog et al., 2017). That adaptation is a response to cumulative and interactive changes in climatic and non-climatic conditions illustrates that it is a highly complex process with multiple strategies. The perceived need to adapt to climate change can be revealed through discourses and narratives and is dependent on whether the issue of climate change is seen as salient (Dannevig & Hovelsrud, 2016). It is argued that adaptation - and the ability to adapt - to changes can be seen as a condition for sustainability (Berman, Kofinas & BurnSilver, 2017).

Methods

A combination of qualitative methods was used for this explorative study. In order to assess the climate change impacts on aquaculture industry, data collection started with a literature review of selected scientific reports and journals, governmental green and white papers, reports, and assessments. Document analysis of public business strategy documents, presentations, and media sources were used for the development of qualitative interview guides with industry stakeholders and representatives.

To examine whether and how the managerial representatives of aquaculture companies perceive and operationalize the effects of climate change, we adopted a semi-structured interview protocol (Seidman, 2019). An interview guide was developed with the intention to document the companies' perception of climatic changes. The interviewees, namely senior managers in the aquaculture companies, were recruited by suggestion from the Norwegian Seafood Federation. To secure a diversity of viewpoints, we selected representatives from local, national, and international fish farming organizations. All companies specialized in salmon farming. In total, eight representatives from eight companies were interviewed over the phone. The following topics were covered during the interviews: interviewees' background and their experience, sources for knowledge about climate change, positive and negative impacts of climate change on the industry, influences of those impacts on the choices for location, and industry cooperation with research communities and government bodies.

The interviewees were contacted prior to the interviews and received an informational letter about the project with the topics for discussion. All interviews were conducted in Norwegian, audio recorded and later transcribed. Those parts of the interviews that are used in this study were translated into English. The interviewees have been anonymized.

Aquaculture and climate change in Northern Norway

The case area comprises the two northernmost counties in Norway – Nordland and Troms & Finnmark - that represent about 40% of the national salmon production. Salmon production is regulated through government issued licensing, whereas a production volume is defined per license and varies between counties (Winther et al., 2013). The number of issued licenses has increased in Northern Norway during the past years (*ibid.*), with 403 grow-out licenses and slightly over 3000 people directly employed in the region. As such, the industry forms a vital part of the coastal communities' employment. The regions' remoteness results in long and costly transport requirements by trailers and rail to the European markets. Fish is a perishable commodity with a short selling time frame, and is therefore reliant on fast and reliable transport. Delays due to adverse weather and climate-induced challenges, such as floods, heavy snowfall, avalanches and landslides, may occur (Hanssen & Mathisen, 2011). Rougher and more unpredictable weather patterns are expected to increase.

Climate change could lead to significant structural changes in the industry, both in terms of aquaculture species, optimal range for the production, and siting patterns. Temperature is of central importance to the aquaculture industry, as it influences growth rate, algal blooms, and infestation rates of disease and parasites. A warmer thermal regime may lead to changes in the abundance, distribution, and composition of species. This also includes jellyfish, poisonous algae, parasites, pathogens, and diseases; all potentially harmful to aquaculture, and the link between climate changes and disease risks is increasingly recognized (Callaway et al., 2012). Ocean acidification presents another emerging challenge for the aquaculture industry, especially for smolt production; however, the research on this is so far inconclusive (McCormick & Regish, 2018).

Higher temperatures are likely to lead to increased salmon lice reproduction (*Lepeophtheirus salmonis*). This chronic and increasing problem – and the following government regulations – is hampering industrial growth and represents a significant economic impact on the industry. As salmon lice causes serious problems in wild salmon stocks as well, the salmon farming industry is strictly regulated with respect to lice. Norway has more than 400 watercourses with Atlantic salmon and hold approximately 25% of the world's healthy populations (Forseth et al., 2017; Hindar et al., 2011). In 2017, the government introduced a new growth system based on 13 production areas along the coast, referred to as the 'traffic light system.[2] Using the occurrence of lice as its main indicator, the system offered a way to regulate production geographically based on a surveillance program. Additionally, escapes from the cages form a threat to wild salmon as it leads to increased competition, interbreeding, and reduced breeding success for wild salmon – which are adapted to local river systems.

These challenges with current sea-based open cage technology have led the industry and the government[3] to search for other technologies, such as closed containment systems. Closed or semi-closed production systems have physical barriers that limit interaction with the environment to avoid escapes, salmon lice infestations, and other pathogens. In Norway, most of these concepts are sea-based. Land-based recirculating grow-out facilities have the additional economic and environmental advantage that it can take place at sites closer to the consumer markets, and thus increase profitability and reduce the environmental and carbon footprint by reducing transport distances for fresh salmon (Liu et al., 2016). However, in Norway, these systems are mainly addressing the lice and disease problems and regulations, and are not likely to have important beneficial climate effects.

Another development is the post-smolt strategy. Traditionally, the smolt have been transferred to sea at a weight of approximately 100 grams, but several companies are currently transferring the smolt to sea at an increasingly higher weight. This reduces the sea phase of the production, and thus the time in which fish is exposed to "uncontrollable" risks such as temperature changes, weather, poisonous algae blooms, salmon lice, and diseases (Callaway et al., 2012).

With increasing temperatures, the geographic point at which the Norwegian coast is at an optimum temperature for rearing salmonids will move northwards and enter the northern region and will likely lead to productivity changes (Hermansen & Heen, 2012). In the beginning of the salmon farming era, it was widely believed that the temperature was too cold for rearing salmonids in the north. Subsequently, however, the government wanted to stimulate fish farming in northern Norway, mainly to support job creation in vulnerable coastal communities, and thus the region was given earmarked and larger licenses than further south. Increasingly, the favorable conditions in the north regarding diseases and salmon lice also attracted and encouraged aquaculture companies to establish production plants in the region. Some companies acquired new licenses to establish themselves in the north, while others moved existing licenses into the region. The region still experiences fewer diseases and salmon lice than further south, but the difference is dwindling.

In the following section, we present our findings on interviewees' perception of the impacts of climate change in combination with other emerging challenges for fish farming operations and suggested adaptation measures.

Climate change: Perceptions, relevance, and impact on aquaculture

The interviewees are not uniform when it comes to observing the effects of climate change. Some note there is a slow ocean warming whereas others state that the observed temperature changes are within the range of normal temperature and weather variations. Some also state that in the northernmost region, Finnmark, the temperature has been colder than average in recent years. Some observe the northwards migration of new fish species and changes in the species composition along the coast (i.e. more mackerel). The optimal temperature range varies between sites and local fjord systems, but the farmers state that less than 4 degrees and higher than 14-16 degrees centigrade harms the production. Temperature is also seen as relevant for lice, bacterial, and viral infections.

The informants generally acknowledge the climate issue, and they were aware of all the debates and policies regarding the topic. Climate change is rarely considered in day-to-day operations or is on the agenda, except at occasional national or regional scientific or other aquaculture gatherings, or in communication with regional authorities. They see the long-term links to, and relevance for fish farming, but they do not relate operational issues in their daily work to climate change. The companies do not possess competence directly related to climate change; however, some have taken part in research projects where climate change has been one of many variables.

The informants generally state that the industry is to date not very weather sensitive, and there are few concerns relating to stronger and more frequent storms. Nevertheless, some interviewees indicate that the weather has always been harsh in the north, but that the patterns have become more unstable and unpredictable, which at times may also create problems. For example, when storms suddenly come from an uncommon direction, this poses new challenges to crews and equipment. Heavy storms and larger waves frequently lead to physical injuries and increased stresses for the fish, which leads to higher mortality and production losses. During storms, the fish are not fed, and frequent storms may lead to lower growth as well as disturbances of scheduled maintenance, logistics, and other operations.

The safety and well-being of crew on feed barges, and transport back and forth during heavy weather is another concern, and one informant stated that "the cages can take more bad weather than the boats and the crew". Thus, long, or frequent storms may negatively influence the feeding and tending of the fish. IT infrastructure is vital to run the operations, and storm related power outages[4] can cause production disturbances. The interviewees typically stated that the safety is addressed within existing standards and regulations. While a steady strengthening of the requirements has been observed[5], this is not seen as primarily related to climate induced extreme weather specifically. Instead, it is seen in connection with reducing fish escapes, and facilitating efficient operations in more open and wave exposed areas which may be environmentally optimal locations - so-called super sites. Some interviewees state that they take for granted that authorities have built in the effects of climate change in the technical and operative regulations and requirements.

Changes related to indirect operational issues are mentioned by some interviewees. In some production areas, the increased risk of climate induced landslides and avalanches blocking difficult access roads are regarded as a possible concern, as this may hamper supplies and the transport of fish and crew. The informants state, however, that they already experience and handle such problems and a future slight deterioration of the situation is manageable. Some also mention that climate change in the long run may have consequences for the worldwide availability of feed. These imports may become more unstable and with higher price volatility. If these inputs are not produced and exploited in a sustainable way, nature, as well as global regulations, may put the supplies at risk.

Nevertheless, the main impression is that – as one fish farmer puts it – "the challenges [facing the industry] is a result of fast growth", where climate change is not the primary frame of reference, but rather the biological or physical factors influencing the fish. Climate change is understood mainly in terms of a slow and incremental increase in ocean temperatures. This may lead to more parasites and more infection prone fish farms. In the southern regions the experience is that increasing temperature leads to increased infection pressure. In the north the experiences are not as clear cut, as increasing temperature is also making the production more efficient as the fish grow faster. Some companies even moved their production to more exposed sites further out on the coast to benefit from warmer temperatures.

Companies in position to carry out strategic re-localizations or establishments in new regions see a northward move of production capacity as relevant, and several report that they have already done so. These companies are in a constant search for new and better production sites and work with the relevant coastal municipalities to get access to such sites. Growth and diversification strategies are stated as the main motivations, and climate change is merely a legitimizing and/or background factor. Climate change is not, however, cited as an explicit factor in either of these considerations, but rather as part of growth or diversification strategies. Optimization of production is often difficult, but long-term environmental considerations are always important, as this is the key to efficient and economic production.

When the winter water temperatures suddenly increase, producers may experience problems with biomass regulations. The temperature makes the fish grow faster and at times this leads to violations of given biomass restrictions. To avoid heavy fines, producers may have to transfer or slaughter fish at an inconvenient and suboptimal phase in the production cycle. The same company representative also claims that these warm periods may lead to problems with feed availability because the fish suddenly require a lot more feed.

Increased temperatures also lead to more algae growth on the nets and moorings. Some also mention that if climate change also changes the ecology around the aquaculture plants, this may negatively affect their operations. Poisonous algal blooms are dangerous for the salmon and pose a serious threat to the industry. While such incidents are less frequent in the northernmost areas, they have occurred.

The companies' focus and concerns are, beside efficient, environmental, and safe operation, related to lice treatment and avoiding fish escape. These challenges have been present in the industry for decades but are accelerating as a consequence of climate change. Warmer ocean temperatures increase lice production. Lice is therefore perceived as indirectly related to climate change. The companies' main focus is on lice, as this is the governments' environmental and sustainability indicator that regulates growth in the industry. Thus, the concept "sustainable development" has a much stronger history, standing and presence in the industry than climate change. However, some informants indicate that they include climate change concerns in the sustainable development concept. The informants report that, to their knowledge, there are no explicit references to climate in the governance-related procedures and requirements.

Most interviewees agree that the lice problem has gradually increased and moved northwards, and that temperature rise generally lead to increased propensity for lice and virus and bacterial infections. However, the number and size of farms is also seen as a cause of increased lice infections. Several interviewees also stated that the lice outbreaks occurred earlier than previously, and that the problem has generally become bigger. Some see a potential benefit in higher precipitation levels due to climate change, as this results in more freshwater supplies to the fjords which may reduce the lice problem through "natural" delousing.

It is a general observation that climate change issues are translated to other well-known, concrete, and specific operative issues. The effects of climate change are simply interpreted as a gradual worsening of known, existing problems and challenges. Beside some examples of increasing the height of the building foundations on the waterfront to compensate for future expected sea level rise, we do not find any adaption or mitigation efforts that are directly and explicitly introduced to address the climate problem.

Concluding discussion

In Norway, climate change is recognized as a major issue and problem of growing importance; the representatives of the aquaculture industry also seek to obtain knowledge about the expected changes and the impacts on their current and future operations. However, climate change is not dealt with, or handled as climate change problems by the industry or governance system, but rather translated into various ongoing and acknowledged sub-problems in the industry they already are adapting to. Being a wealthy and knowledge intensive industry, it has a large adaptive capacity to handle seasonal variation and extreme events – algal blooms, temperature changes, wave height, storm surge, etc. The aquaculture industry carries out adaptive actions all the time, and climate change does not manifest itself as a distinct and new problem, but rather as intensification of already existing and well-known environmental and operational issues. Climate change is rather interpreted more as a background variable that is understood in terms of the cumulative impact of multiple drivers. The relevant impacts from climate change are thus translated into "environmental problems", "parasite and disease problems", "invasive species problems", or "weather problems". The only measure that is genuinely climate related is some actors' efforts to localize parts of their production capacity to northern, thus colder, regions of the country.

In addition, the adaptive capacity of the industry should be assessed along these lines: the industry is generally focused on management in terms of diseases, lice, and escapes, not on climate change or climate adaptation. Sustainable operation is a vision that is far more relevant and important to the fish farmers than climate change, partly as it more directly addresses their current problems and challenges, partly as it is at the core of the management systems. Though climate actions, including the reduction of global emissions, are addressed in one of the sustainable development goals, mitigation strategies were not a focus of this inquiry. However, climate change is interpreted into these sustainability issues and seen as an influential factor. Climate change and adaptation is thus not interpreted in a hazard frame, but rather in an incremental adaptation framework. The exact nature and magnitude of the climate change effects are generally difficult to assess, and so are the consequences they will have on aquaculture. The proximate and main problems in Norwegian aquaculture – salmon lice and escapes - are according to the interviewees only loosely and indirectly related to the climate problems, and specific climate measures are so far not very developed. Several of the innovations and measures introduced to fight lice, diseases, and stormy weather will also contribute to climate adaption, as it makes the operations less vulnerable to temperature and weather variations. Climate change is, however, not the direct reason for the industry making these changes, and it would be strange to label this as climate adaption. It is thus important to acknowledge that de facto climate adaption may hide behind different activities, labels, and discourses, and a broad understanding of what adaptation is all about is required. Climate related issues should not be separated from other considerations and decision-making about future concerns over environmental conditions.

The fish farming industry sees climate change and adaptation largely as a knowledge and management issue outside their daily realm of responsibility. Comprehended as a top-down management issue, they expect the research and government institutions to handle this and translate the climate problem into technical or operational standards and regulations, and they do not see themselves as a central part in the policy-making process. The interviewees largely regard the governmental technical standards and operative regulations as the main driver in the climate change adaptation work, as well as technology and innovations developed by research agencies and the companies themselves. Examples given are temperature adjusted feed, stronger cages, nets and mooring, and better crew training.

However, we do not see this as an indication of neither "denial" (Nordgaard 2006) nor "complacency" (Kaltenborn et.al. 2017) towards the climate change issue. Rather, the industry's confidence in their ability to adapt in general terms, leaves the climate change issue as too abstract or intangible a frame of reference for adaptive action. Moreover, when climate problems are translated into other problems such as increase in diseases and rough weather, also the climate issues are transferred to the respective management bodies that "own" these problems.

This raises the question of what can be gained through a more coherent policy coordination on climate change – through a more specific climate frame. Given the complexity of the problem, such a frame may not be easily established, but the authorities should continue to communicate the need for the industry to act in relation to climate change. Sandkjaer Hanssen et al (2012) suggest that the elected regional level (counties) has a huge potential to act as a multi-level coordinator. After recent reforms, the counties have become multi-level network nodes particularly suited for dealing with cross-cutting and comprehensive policy fields such as climate change adaptation.

Notes

1. Trout accounts for approximately 5 % of the volume.
2. According to the average lice levels in the given production area, production is allowed to grow (green), freeze (yellow) or must be reduced (red).
3. The government has issued several development licenses to facilitate different technologies to be developed, implemented and tested.
4. Most plants depend on electricity generators, but the number connected to the public power grid is increasing, using the diesel-driven generators as backup.
5. The Norwegian government is continuously developing and implementing technical regulations and standardization measures through the NYTEK and NS 9415:2009 systems.

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