Environmental impacts of aquaculture and coexisting industries Environmental impacts of aquaculture and coexisting industries

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Environmental impacts of aquaculture and coexisting industries

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Preface

This is a summary of the project "Environmental impact of aquaculture and coexisting industries - scope for comprehensive regulation" - "MILJØREG" (Akvaplan-niva report 2023 63547.01). The project is funded by the Norwegian Fisheries and Aquaculture Industry's research funding. The main goal of the project has been to prepare a broad overview of the knowledge base related to the environmental impact of aquaculture, as well as environmental impact from other industries with activities in the same areas as aquaculture. Requirements for the regulation of aquaculture were compiled and the scope for a more direct and differentiated regulation of the environmental impact from aquaculture was explored, based on the collected knowledge base. The project has been a collaboration between Akvaplan-niva, the Norwegian Institute for Water Research (NIVA) and Nofima, where NIVA has had the main responsibility for chapter 3, Akvaplan-niva for chapter 4 and Nofima for chapters 5 and 6. However, all institutes have contributed to all chapters.

See the different chapter in the main report for limitations, reservations and judgements related to e.g. data gathering, baseline data and conclusions.

1 Introduction

In recent decades, the Norwegian aquaculture industry has been through a phase of rapid expansion, with good profitability, great value creation and increasing importance for communities along the entire coast. Possibilities for a doubling of value creation towards 2050 are pointed out by politicians, however, growing concerns related to both fish welfare and environmental impacts have resulted in regulations that have slowed down production growth. Growth in the industry is mainly regulated through the traffic light system, which per today is based on one environmental indicator, namely the salmon lice. Entire production areas are basically regulated as one, and local conditions are taken into account to a lesser extent. Growth is also limited by access to locations prioritized for aquaculture, and by social acceptance.

The term green shift has been established as a central political goal on the Norwegian agenda (Haarstad and Rusten, 2018,). Both the industry and management aim environmentally sustainable growth, following a holistic and ecosystem-based management (St.meld. nr. 12 (2001-2002), Rent og rikt hav, St mld 29 (2020-2021), Sjømat Norge – Sjømat 2030). Comprehensive ecosystem-based management requires an understanding of the ecosystem's function and structure and overall effects of different types of human influence on the ecosystems. In Norway, there are currently various regimes that are based on holistic and ecosystem-based management, e.g. "vannregion-forvaltning gjennom vannforskriften" (water region management through the water regulations), comprehensive management plans, coastal zone planning, and wild salmon management.

The aquaculture industry is not the only stakeholder in Norway's coastal and marine areas. Other industries, such as mining, oil and gas operations (offshore), maritime industry, fisheries, tourism and renewable energy (offshore wind, liquid solar, hydropower) can potentially overlap with the aquaculture industry in terms of need for areas and resources. These industries can also have an influence on each other so that they can be mutually exclusive within an area. According to the water regulations (vannforskriften), which cover rivers, lakes, coastal waters and groundwater in Norway, sector-wide regional water management plans must be prepared for each water region. This means that the management must consider the overall impact of all types of human activity, but in practice the various environmental impacts are mainly addressed individually. The environmental management aims to become more holistic, considering the environmental impact from both aquaculture and other industries to a greater extent. The industries' impact on the environment should be assessed, but it is also important to assess how the industries indirectly affect each other. Also, the overall environmental impact in different ecosystems with different carrying capacities should be assessed, as well as the socio-economic costs of environmental regulation of the various industries.

In the current project, we have compiled and evaluated the knowledge base related to environmental impact from the aquaculture industry. The impact of other industries on aquaculture, through their environmental impacts, was also addressed. An overview of requirements and practices related to environmental regulation of the aquaculture industry is summarized. Finally, it was analyzed to what extent the existing knowledge base can provide a fundament for a more comprehensive ecosystem-based management. The review has revealed both opportunities and knowledge gaps within the existing knowledge base for further exploring a new management regime in Norway based on a more holistic approach. This summary report is a short version of the main report and provides an overview of the main findings.

2 Methodological approach

The project is not an extensive compilation of all possible environmental impacts from and on aquaculture and their possible interaction, as this is outside the project's time and financial framework. An overview sketch developed by the Norwegian Environmental Agency (Figure 1) was used to identify the main stressors associated with finfish aquaculture, but some additional stressors were added by the review team. The stressors/classes of stressors which the knowledge acquisition focused on were: particulate organic waste, dissolved nutrients, diseases and parasites, environmental contaminants (pharmaceuticals & other substances), escapes, light, noise and artificial structure.

An exhaustive review or risk assessment of each stressor has not been carried out in this project. However, we have provided a broad overview of literature available for the various stressors from aquaculture and other industries (mainly from 2010 - 2023), and this knowledge is presented and summarized in an objective manner using a quick scoping review (QSR) method. Further, environmental requirements and regulations for the various stressors were assessed. The knowledge base was also assessed for suitability for use to explore and develop new types of requirements and regulations, based on a more holistic approach. Finally, all results were integrated to explore possibilities for holistic local ecosystem-based management. In the main report, the topics were addressed in several chapters:

Chapter 3: Compilation of the knowledge base related to environmental impact of the aquaculture industry. The compilation was performed by using a "Quick Scoping review" approach (QSR). Through the compilation, we addressed the most important environmental impacts.

Chapter 4: Compilation of the knowledge base on environmental impacts from other industries and activities that operate in the same ecosystems as aquaculture. A case study aiming using the knowledge base to assess cumulative impacts is also presented in chapter 4.

Chapter 5: Review of the regulation of environmental impact from the aquaculture industry, including the knowledge base that is used today and how trade-offs are made.

Chapter 6: Analyzes of possible opportunities for a more differentiated and locally adapted aquaculture management, as well as a more holistic and economically efficient management of environmental impact from both the aquaculture industry and other industries.

A summary of each the chapters from the main report is provided below (3.1, 3.2, 3.3).

3 Results

3.1 Environmental impacts from aquaculture industries

The objective of this study was to compile a knowledge base related to environmental impacts arising from aquaculture, with a main emphasis on Atlantic Salmon (*Salmo salar*) and Rainbow trout (*Oncorhynchus mykiss*) farming. Stressors are drivers of environmental impact and the stressors addressed were; particulate organic waste, dissolved nutrients, diseases & parasites, environmental contaminants (pharmaceuticals & other substances), escapes, light, noise and artificial structures. Our primary research question was; What is the impact of stressor X on the marine environment? The secondary research questions were; What is the spatial and temporal scale of the impact? Which species, habitats and/or ecosystem components are affected? Which indicators, monitoring and assessment tools are used to measure and assess the impacts? Do the identified indicators, monitoring and assessment tools reflect the impact's spatial and temporal scale?

For each stressor (see examples in Figure 1) the characteristics of the evidence base was described, and the main knowledge gaps identified. There were clear differences in the volume of the evidence base between stressors, where some stressors have received far more research focus than others. Where over 230 papers were addressing impacts of escapes, 40 were addressing impacts of dissolved nutrients, and about 20 papers were addressing the impacts of each of the stressors noise, light and artificial structure. Also, within a single stressor the research focus could be skewed, e.g towards impacts on a specific ecosystem component, of a specific type of compound. The first can be exemplified by the stressor particulate organic waste. Here the impacts on softbottom habitats have been extensively studied and are well understood while our understanding of impacts on hardbottom habitats and associated epifauna is limited. The latter can be illustrated by the stressor environmental contaminants where delousing agents accounted for almost 50 % of the articles. The importance of temporal and spatial scale for the assessment of impact were evident for several of the stressors, where the "value" of the evidence e.g for management purposes is depending on appropriate scale. Since the main focus of this literature review where on salmon and rainbow trout farming, the outputs naturally reflect the research focus in the main producer countries for these species, which again reflects the environmental impacts of concern in the management and the public in these countries.

The output of the literature review formed the basis for the wider discussion on the feasibility of achieving a more ecosystem-based management approach of aquaculture in Norway.

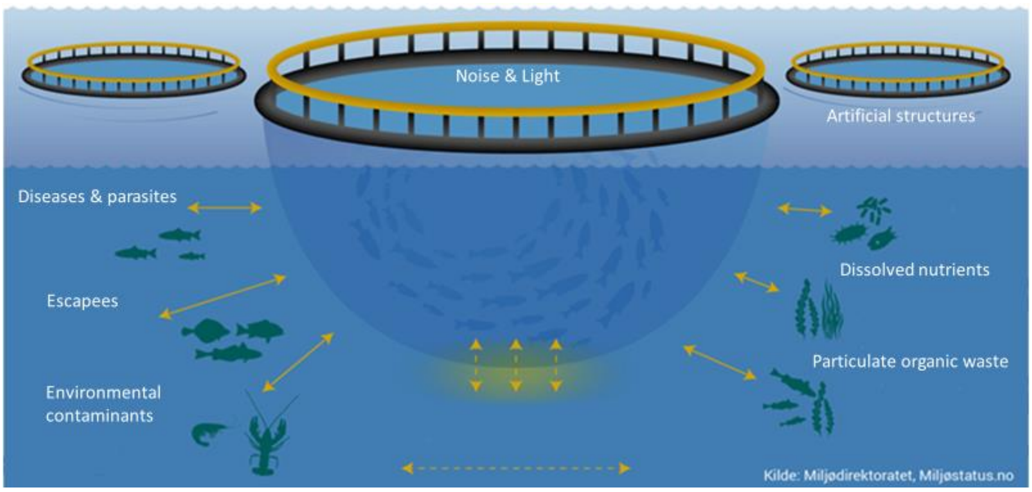


Figure 1. Identified stressors from finfish aquaculture. Modified from Norwegian Environmental Agency.

3.2 Cumulative environmental impacts from coastal industries and risk posed to aquaculture

Human activities on our shores (land-based activities), in estuaries, coastal waters and the open ocean (sea-based activities) provide benefits to us, but these activities also affect and change the marine environment and the health of marine ecosystems. These activities can in turn also affect other human activities and benefits (e.g., pose risk to each other). Coastal areas are the most affected because of the intensity of overlapping activities. Understanding the cumulative effects of these overlapping activities is crucial for managing the activities, understanding associated changes, risks and minimizing their effects. These wide-ranging changes are often referred to as drivers or stressors and can include for example temperature (increasing sea surface temperature), carbon dioxide and pH (ocean acidification (OA)), oxygen (deoxygenation), salinity, density, irradiance, sound, light, nutrients, eutrophication, UV exposure, plastics (entanglement from fishing/aquaculture gear), point source pollutants (chemical pollution) and physical destruction of marine habitats.

The purpose of this study was to compile a knowledge base and gain an insight in environmental risks on aquaculture from other industries and activities (direct and indirect effects) that operate in the same ecosystems along the coast and at sea.

The assessment showed that available information to identify industries and activities operating in the same areas as aquaculture was good, both for land-based industries and sea-based industries. The dominance of industry activity varied geographically especially for the land-based activities where dominance was greater in the south, whilst sea-based activities such as fisheries and aquaculture dominated in the north of Norway. A broad search showed that pressures, related to the identified key industries, overlapped well the pressure categories identified for the aquaculture industry.

The literature collection gave no results for direct impacts of other industries on aquaculture. For most of the stressors, there was limited information (easily accessible data) on contribution of emissions of key industries on the marine environment and sometimes the information was lacking. In the few cases this information could be found (nutrients, pesticides, and copper), aaquaculture had by far the largest anthropogenic emission input into the coastal waters, due to their extensive activities. There was also lacking information on the "general" extent of stressor exposures from each of the key industries. Information on scale (spatial and temporal distribution) of emissions from key industries to the marine environment were also lacking. The assessment did not identify much information on multistress effects nor cumulative impacts (although the search was not exhaustive on multi-pressure effects /cumulative impacts, as it was a too large topic for the project time frame). It seems like this knowledge does not exist to date. The lacking information on contribution, scale, impact, and cumulative impact of the activities of the key industries, resulted in challenges to evaluate risks to aquaculture. Risk evaluations had to be based on subjective judgement of key experts on the information available, and qualified assumptions where information was lacking.

For environmental overlapping impact risk, almost all the evaluated stressors could have possible overlap with the industries emissions, and also possible overlap with each other. However, for aquaculture, we could not identify major risks from other industries on aquaculture (caged fish), based on the knowledge gathering.

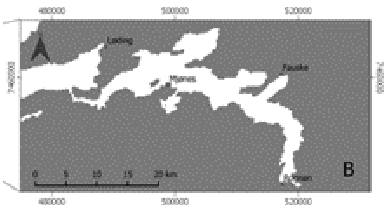
Plastics (nanoplastics) originating from other key industries was the only stressor assessed as a possible risk to fish health and consumption (public health), based on the information available.

However, this plastic is also released by the aquaculture industry itself, and there is a need for more information about plastic and possible impacts. With a better knowledge base in the future, the outcome may therefore look different. Aquaculture may be increasingly adversely impacted in the future by sources of pollution from the external environment, from agricultural, industrial effluents and wastewater, foremost if cages are installed in public water bodies or close to point source outlets. However, major, and mostly adverse external environmental impacts on aquaculture are likely from climate change and ocean acidification.

This highlights the need to estimate emission contribution of each industry and the pressing need to consider many possible permutations of these stressors, and their additive and interactive effects. Understanding and gain insight on cumulative effects of ocean pressures is critical to project their impact and risk.

In Norway there is currently several ongoing research projects investigating multiple ocean stressors and cumulative impact on the oceans. Gaining new knowledge and applying results from this research in the development of Ecosystem-Based Management (EBM) strategies and informing policy decisions is crucial. EBM is an ideal science-based approach for managing the impacts of cumulative stressors on marine ecosystems, as it addresses and reduces conflicts, the negative cumulative impacts of human activities thus ensuring ecosystem resilience and sustainability. Furthermore, a better understanding of the potential cumulative impacts of fish farming itself, could help marine aquaculture become more environmentally sustainable.

A case study to assess the feasibility of the development of cumulative impact assessment models, based on the knowledge base and an advanced quantitative GIS solution, was performed for Skjerstadfjorden, inner Saltfjorden and associated waterbodies. Skjerstadfjorden is located in Nordland County within the municipalities of Fauske and Bodø. It is a sill fjord with water exchange to the outer coast only via two straits – Godøystraumen and the renowned tidal strait of Saltstraumen. Skjerstadfjorden is highlighted as fjord with infrequent bottom water exchange, making it more vulnerable to anthropogenic pressure. It is boardered to the East and West by Saltfjorden and thus forms to some extent the middle part of this fjord. Here we only focus on Skjerstadfjorden, the inner part of Saltfjorden and the adjacent waterbodies: Valnesfjorden, Klungsetvika and Fauskevika to the North and Misværfjorden to the South.



The spatially resolved output of the case study is thought to be a suitable and supportive decision-making tool for ecosystem-based management. Multi-pressure studies are complex and challenging to conduct, which clearly was reflected in the case study. The results showed that finding suitable input data for a cumulative impact assessment was challenging, and raw data, essential for a quantitative analysis, were often not available. There is a need for a database which collates cumulative impact assessment relevant data from various sources and to provide direct open access to raw data. GeoNorge (geonorge.no) and Marine Grunnkart already contains a wide spectrum of data, and these could be used as a base to further expand upon.

A number of research effort needed to fill gap of knowledge is listed in the case study in the main report. Shortly summarized, these key points were related to: quantifying contributions of key industries and improving tools for tracing emissions, as well as developing in-situ monitoring technology and dispersion modelling approaches. In addition, improved understanding of interactions of multi-pressures across a wide range of environmental conditions were highlighted. There is a need to quantify sensitivity and susceptibility of the receiving ecosystem component towards the impact of multi-stressors (threshold values) and identify suitable indicators for ecosystem health. Another important key point is to develop cumulative impacts assessment models for different spatial scales and explore their suitability within the Norwegian planning framework. Finally, developing solutions to mitigate the effects of multiple stressors, and find solutions to identify and recommend which individual sources (drivers/human activities) for individual stressors that should be reduced or eliminated to limit the effects of multiple stressors most efficiently. For a detailed summary of the chapter and research needs see chapter 4.4 Summary and research needs in the main report.

Summary of key industries/activities, related pressures and potential impacts are presented in Figure 2, and an overview of a conceptual framework for ecosystem risk assessment are shown in Figure 3. For more details and information on the literature base and case study, see chapter 4 in the main report.

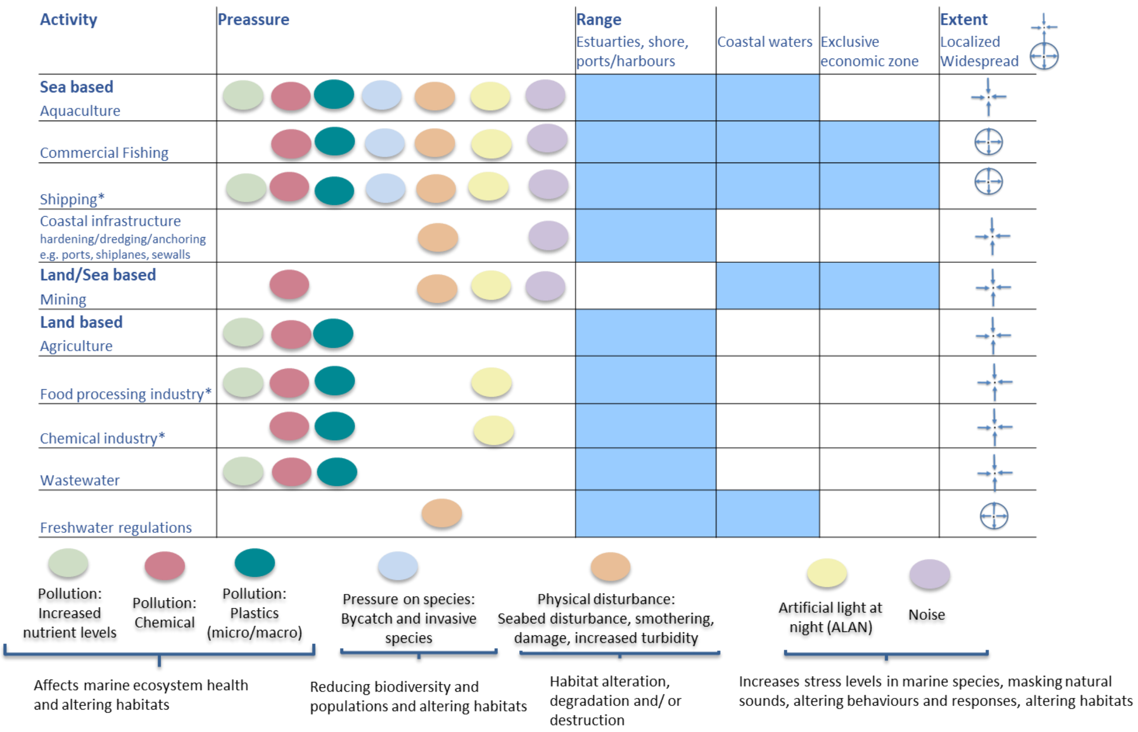


*Figure 2. Priority industries/activities (land based and sea based) in Norway and related pressures, scale and extent of activities, risks and impacts. The scale depends on the intensity and extent of the activities. An improved understanding of the risks and impacts is crucial for better management of our activities. * Food processing (dairy, meat, brewery, fish refining), chemical industry (pharmaceutical, oil refinery, paint, metallurgical industry) (Adopted from Ministry for the Environment (2019)).*

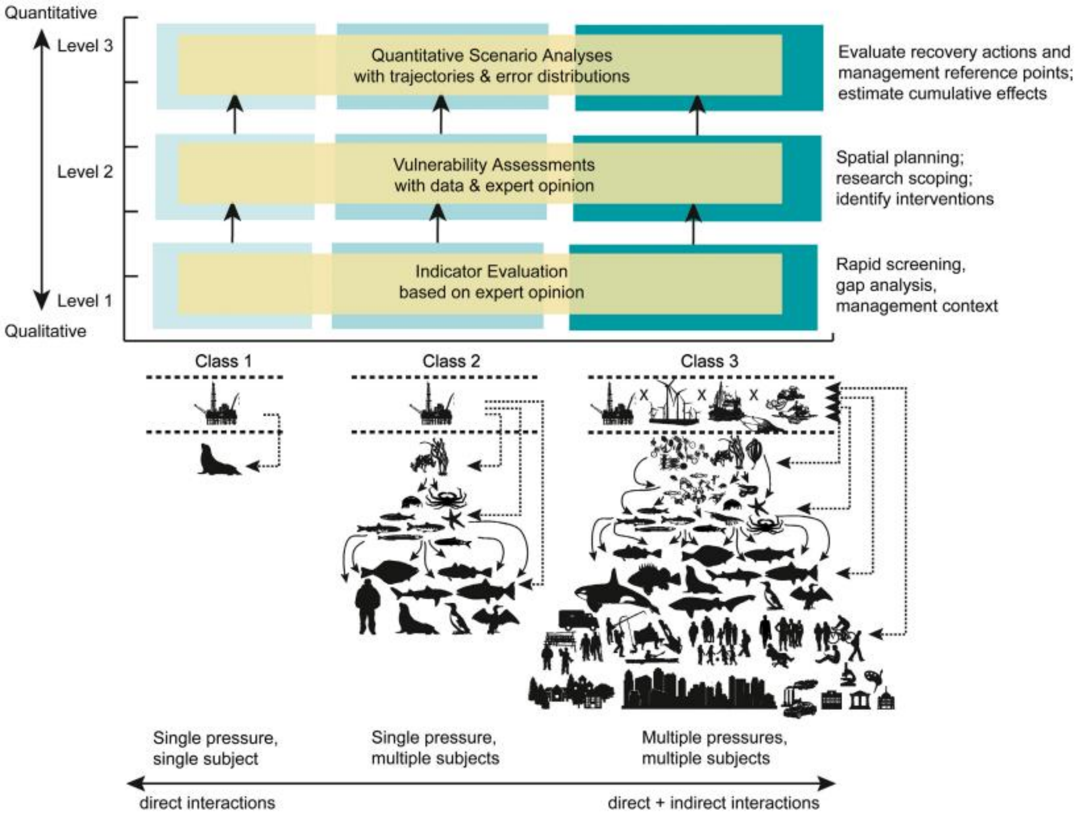


Figure 3. Conceptual framework for ecosystem risk assessment. Scoping and stakeholder engagement increases left to right, and data requirements and computational costs increase diagonally from lower left to upper right. Far right column highlights example applications of each level of ecosystem risk assessment. Class 1 represents evaluations of a single pressure on a single focal subject, Class 2 analyses consider impacts of a single pressure on multiple ecosystem subjects or multiple pressures on a single subject, and Class 3 analyses consider the reciprocal and cumulative interactions among multiple (interacting) pressures and multiple interacting subjects. (Source; Holsman et al. 2017).

3.3 Environmental regulations

The management of various types of environmental effects in the coastal zone is complex and extensive and includes many management regimes and actors. There are no stressors that only are assessed in one regime or only by one administrative authority. This is natural given the structure of the Norwegian coastal management system, where different sector authorities and authorities at different administrative and democratic levels are involved.

For all management regimes, we find that there is a broad knowledge base that is used for assessments and decisions. In aquaculture management, there is nevertheless a lack of knowledge about environmental effect of dissolved nutrients, impacts of particulate organic particles on hard bottoms, vulnerable species and habitats, about possible effects of aquaculture on marine fish, and environmental risks from cod farming. For assessments that are made, a significant degree of discretionary judgment is used. There is some use of standardized indicators to assess the condition of recipients or possible impacts from aquaculture, but this is limited.

In municipal coastal zone planning, legally binding limitation are made for land use in the coastal zone, which in turn can have a major impact on environmental impact and environmental condition. Aquaculture locations must be placed in areas set aside for aquaculture in the municipalities' spatial plans. It is particularly in the impact assessment of alternative land disposals that the systematic collection of knowledge and assessment of the environmental effects of aquaculture come into play. Assessments include a number of quantitative criteria or ordinal qualitative criteria, but also discretionary criteria. It varies how clearly the discretionary assessments are described in the impact assessment for each proposed aquaculture area. There must also be a combined and holistic assessment of all the proposed activities in a coastal zone plan. Effects on the water environment (including assessment according to §12 of the Water Regulations), as well as overall risk must be assessed. We find that the reviews have thorough descriptions of both status, risk factors and assessments. Since discretion has been used in most cases, and it is demanding to describe in detail, it can still be difficult to fully grasp trade-offs or what makes it considered justifiable in one case and not in another.

Water management must classify the environmental condition of water bodies and create water management plans where environmental targets are set to be achieved during the planning period, identify relevant measures to improve or prevent deterioration of the environmental status, and ensure monitoring. However, the prioritization and implementation of measures are up to the various sector authorities within their areas of responsibility, and not something that can be determined in the water management. For the assessment of environmental status of water bodies, there are clearly defined goals and assessment criteria, and there are established monitoring programs linked to these. To identify existing and possible influences on the water environment, clear guidance is provided, and databases, other sources of information and methods for doing this are available. The main challenge is to assess the total effects of different stressors on the state of the environment. Often, reference is made to the sector authorities' own systems and assessment methods, and to the use of discretionary judgement. The situation is similar both for identifying and assessing possible measures to maintain or improve the environmental condition of water bodies, and also when exceptions pursuant to §12 of the water regulations are to be assessed. Both parts can be extensive tasks if they are to be done properly. There is little guidance and few established methods for assessments of social benefits or costs related to a changed environmental condition. It is again referred to professional discretionary judgement.

In coastal zone planning and water management there are no stressors that are assessed only based on standardized indicators. There are also few cases where there are only standard methods for decision-making in management related to single stressors. There is therefore room for discretionary judgement for all stressors and administrative authorities. Alternatively, discretion must be exercised because one has not been able to create a system with a sufficient knowledge base and clear enough criteria for assessment and decision.

There is an extensive knowledge base that goes into all these management regimes. Most knowledge, and the most quantitative and systematically collected knowledge, is about the state of the environment and about industrial activities. The latter is, however, to a lesser extent linked to stressors than to other variables. The biggest and most important knowledge gaps seem to be for the connection between human activity, stressors and environmental impact. Correspondingly, there is limited help in guidelines and guides on how assessments of that connection should be made. There is limited use of standardized indicators in administration to indicate environmental status or impacts, but more are being added all the time. There are limited methods available for making assessments of cumulative impact, and those that do exist require specialist expertise and a lot of resources. Good methods for comparing and assessing environmental effects against social effects (cost and benefit) are also not available, although environmental accounting and frameworks for analyzing ecosystem services are under development. Consequently, there is a great need to exercise professional discretionary judgment in key areas in several of the management regimes. This is partly due to lack of knowledge, and partly because it is difficult to create standardized assessment methods that can handle local complexity and an uncertain future development well enough. The use of local knowledge and professional judgment can open up for good local adaptations and innovative solutions, but can also involve unreasonable differential treatment between areas or sectors.

Where it is difficult to predict the effects of new measures or other developments, an adaptive approach makes sense. There are a number of conditions that contribute to adaptive management. Furthermore, there are still several obstacles to achieving proper ecosystem-based management. The biggest challenge is perhaps to assess cumulative impacts, in the same way that it was pointed out as a central challenge above, as well as the connection between activities, impact and environmental effect/condition. It has also been pointed out that there is a need for a more holistic and integrated management to achieve ecosystem-based management. The three management regimes we have studied here have many points of contact and interdependence in the management of the environmental stressors that we have studied. It is a system of "checks and balances", where different considerations, democratic power and professional authorities influence the final result. In addition to the involvement of authorities, there are also significant opportunities for stakeholders to play a part in and influence the processes, not least with knowledge. At the same time, there are some limitations to integration and holistic thinking. This applies, among other things, to the fact that various sector authorities largely decide on their own measures and their own sector. Of what we have looked at here, it is perhaps most obvious for the identification, assessment and implementation of measures linked to water management plans. However, a much greater degree of integration across sector authorities will be complex and administratively resource-intensive.

3.4 Exploring opportunities for more precise regulations

A significant increase in aquaculture production towards 2050 is expected by many, including a strong increase in value creation. However, growing concerns related to both fish welfare and environmental impact have led to regulations that have slowed down growth in production. There is thus an obvious contradiction in the desire for growth and the concerns about the environmental impact of farming. It is also possible that the current regulations do not sufficiently balance these conflicting considerations. This raises two types of questions: Do we currently have regulations that adequately regulate the environmental impacts from the industry? And do we have regulations that unnecessarily limit growth?

A more locally adapted and precise regulation, as well as a more comprehensive management of aquaculture and other activities, place great demands on the knowledge about environmental impacts. Knowledge of impact mechanisms is required, as well as an overview of the occurrence and extent of various environmental impacts. Knowledge of origins is also required where multiple sources are present, and scientifically based and accepted targets and limits for various stressors are required. The project has identified several stressors that should be included in the management to a greater extent: effects of effluents on hardbottom habitats, escaped cleaner fish, anti-fouling agents (copper), lice (well covered, but still not good enough) and de-licing agents.

There is potential for better use of knowledge collected by aquaculture companies, both through certification processes and through ongoing operations. Real-time data on a large scale can also provide better management, as assessments of carrying capacity and load in a fjord system can be made, both to monitor ongoing operations and when assessing expansions, new capacity, etc.

New species face regulations that are often designed for salmon, which can inhibit development. We have looked at regulations for cod, kelp (as an example of low-trophic species) and wolffish. New species should be partially regulated with their own regulations, on their own terms, and as part of an overall management, where existing regulations are adapted for the various species. In order to achieve a holistic management where one considers both farming, mutual benefit between different species and the improvement of ecosystems in imbalance, the management must have broader knowledge.

New farming concepts, where the fish are shielded from stressors, and that can document lower impact on the ecosystem than the traditional (inshore, net-based) concepts, can potentially allow growth with the same environmental impact. New technology may also benefit from more direct regulations on measurable environmental parameters. In areas where lice and disease are currently limiting growth, for example, closed facilities in the sea could be permitted, given that other stressors are within tolerance limits.

The state of knowledge and the tools the authorities are using for collecting, analyzing and disseminating data today point in the direction that strategic decisions are being based on effects for specific species and habitat types rather than for ecosystems. For a more comprehensive and ecosystem-based management, it will be important to strengthen the knowledge base and further develop decision support tools for management, with better data on ecosystems and all human activity that has an impact on the same recipient in the ecosystem and on each other. However, it will not be sufficient to further strengthen the (natural science) knowledge base and produce decision support tools, but also to achieve a less fragmented management and to handle sector barriers, politics and power dynamics in order to be able to achieve the goal of ecosystem-based comprehensive management. A more accurate overall regulation can provide room for growth without major environmental impact, but it requires knowledge of both overall environmental impact and efficient management.

4 Summary and conclusions

An improved research-based knowledge base can contribute to improved management, which in turn will contribute both to increased predictability as well as more environmentally sustainable industries. A large amount of information (thousands of articles) has been systematized and summarized using the QSR method in this project. This has resulted in a broad overview, (encyclopedia), which can be updated regularly as the foundation is laid in the form of existing search strings. A few key points/findings from the project are provided below:

- Much research-based knowledge is available on environmental effects of certain stressors, e.g. organic enrichment on soft bottom and de-licing agents.
- Different amounts of knowledge available are available for different stressors. For some stressors there is available knowledge which can be used directly to improve regulations/management, for other stressors there is little research-based knowledge.
- There are some environmental impacts that are not covered well enough in current environmental regulations.
- There is available knowledge base for some stressors which are suitable for improving regulations.
- The literature-based assessment showed that there is little knowledge available for combined effects of different industries, hence it is difficult to assess cumulative environmental impacts, which in turn limits the possibility of performing ecosystem-based management (EBM).
- EBM marine spatial planning and cumulative effect assessments are key to foster sustainable use of marine ecosystems, to promote ocean conservation and United Nations Sustainable Development Goal 14 (UN SDG 14), Life Below Water. A method for cumulative impact assessments (CIA) based on a geospatial index describing the relative impact of multiple human pressures on the marine environment, has been developed, to assist marine spatial planning. The case study was exploring using this approach in Norwegian context (the feasibility a practical application of EBM in selected areas along the Norwegian coastline). The assessment showed that input data was challenging and raw data, essential for thorough analysis, was often not available. Therefore, development of CIA models for the Norwegian coastline or more localised focus areas with the currently available database is limited or implementation is not feasible.
- There are currently a few ongoing research programs on cumulative effects and impacts in Norway already, but both the literature based, and the case study assessment showed that more knowledge and research is urgently needed (detailed description on research needs can be found in section 4.4).
- Environmental management of aquaculture can be seen by some as a technical exercise, but management is weighing different interests against each other, which implies that it is a value-based and social process. There are therefore limits to how much the environmental management of aquaculture should be standardized and made into a technical exercise. There should be room for subjective assessment and local adaptations.
- The project has shown that the knowledge base used in administration is extensive, including scientific knowledge. It is nevertheless pointed to a lack of knowledge for many areas and topics, and this will also be the situation in the future. The environmental authorities must therefore have good ways of handling the uncertainty.

- To be credible, the authorities must also show and convey the uncertainty and the assessments that are made. The fact that it in some cases it is difficult to understand which assessments have actually been made, not only weakens the credibility of the decisions, but also reduces the possibilities for quality assurance, learning and more harmonized practice across administrative bodies.
- Some types of assessment are very challenging, and those who carry out actual case management want more support and guidelines. This applies in particular to balancing growth in aquaculture against environmental risk/environmental effects, and to assessing "overall effects".
- Our review finds several areas where there is still room for improvement in the interaction between management regimes and administrative bodies linked to the environmental management of aquaculture. This applies to aquaculture sector management and municipal coastal zone planning, particularly linked to environmental quality requirements, and to some extent to coastal zone management and water management.
- The project has identified several stressors that should be included in the management to a greater extent: particulate organic waste on hard/mixed bottoms, escaped cleaning fish, anti-fouling agents (copper), lice (well covered, but still not good enough) and de-licing agents.
- Most of the known and available knowledge is used by the authorities, but especially for de-licing agents and copper there is more knowledge that should be used.
- Knowledge and data gathered by the aquaculture industry can be utilized better.
- Own regulation of new farming concepts, that can document lower environmental impact than the traditional ones (inshore, net-based), can facilitate growth without an increase in environmental impact.
- More accurate regulation can provide room for growth without major environmental impacts.

5 Literature

FN, i det internasjonale havpanelet og havtiår (https://www.oceandecade.org/decade-news/).

Forskrift om rammer for vannforvaltningen (https://lovdata.no/dokument/SF/forskrift/2006-12-15-1446).

Haarstad, H. og Rusten, G. (red.) 2018. Grønn omstilling: Norske veivalg. Universitetsforlaget. 232 sider.

Holsman, K., Samhouri, J., Cook, G., Hazen, E., Olsen, E., Dillars, M., Kasperski, S., Gaichas, S., Kelble, C.R., Fogarty, M., Andrews, K. (2017). An ecosystem-based approach to marine risk assessment. Ecosystem health and sustainability, 3:1, doi:10.1002/ehs2.1256

St.meld. 41 (2016–2017) [Climate Strategy for 2030. Norwegian Transformation in European Cooperation. Parliamentary White Paper 41 to the Storting (2016-2017).

St.meld. nr. 12 (2001-2002) Rent og rikt hav (internasjonal - FN, ocean panel & ocean decade; Norway specific Blått hav, grønn fremtid rapport (Solberg government), Meld St 29 (2020-2021), Sjømat Norge – Sjømat 2030).

Thousands of articles are assessed in the main report for the project. See Akvaplan-niva rapport 2023 63547.01 for the full reference list at the end of each chapter. 2023 63547.02