Deliverable D1.2-A:

Requirements Baseline – Introduction and Use Case 1: Predicting Risks of Salmon Lice Infestation in Norway

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Preface (common to the four Use cases)

The **Earth Observations for Sustainable Aquaculture (EO4SA)** project is funded by the European Space Agency (ESA) as part of its EO for Sustainable Blue Economy project under the ESA PEOPLE program. The project is implemented by the Nansen Environmental and Remote Sensing Center (project contractor and manager) in Bergen, Norway and Plymouth Marine Laboratory, UK.

The main objective of EO4SA is to consolidate the requirements and demonstrate the information opportunities needed by the aquaculture industry and public agencies using EO and other data sources. For selected Early Adopters (EA), the project implements four Use Cases, at several locations in Norway, Spain and the Philippines, related to:

1. Predicting risks of salmon lice infestation in Norway.
2. Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway.
3. Optimising the location of sustainable shellfish farming and tourism in Galicia, Spain.
4. Mapping aquaculture structures and use of marine resources in Palawan, Philippines.

Through these four use cases, EO4SA will contribute to enhancing the future operations of aquaculture management authorities, stakeholders and industry, by taking up new information based on satellite Earth observations data.

This report is the project deliverable **D1.2: Requirement Baseline. It** includes a detailed analysis of relevant policy aspects to each use case. Further, a characterization of the target user group and their information needs are assessed with focus on how EO data can be beneficial. Direct meetings and a questionnaire survey are used to obtain the needed information from the Early Adopters. A further analysis identifies the technical requirements for the innovative EO-based solution to be developed and validated in each of the Use Cases.

This Deliverable is organised in four report documents addressing each of the Use Cases separately, denoted D.1.2.A-D. The first report also includes a common introduction to all Use Cases (Sections 1-2). From Section 3, the reports are specific to each Use Case, first describing each Use Case as proposed (3). Section 4 addresses the State-of-the-art activities and Section 5 the relevant regulatory (policy) and operational framework for each Use case. Based on direct meetings and a questionnaire survey (attached in Appendix 1), Section 6 summarises the Early adopters (further described in D1.1) and their specific requirements related to each of the use cases. In Section 7, the project Team presents the baseline and innovative algorithms to be used, and in Section 8, the available datasets to be used. The potential limitations of the approaches proposed are given in Section 9 and concluding statements in Section 10 for each Use Case.

In separate Deliverable D1.2-documents (A-D), the four EO4SA Use Cases are addressed in:

- Deliverable D1.2-A: Baseline Requirements – Introduction and Use Case 1: Predicting risks of salmon lice infestation in Norway.
- Deliverable D1.2-B: Baseline Requirements – Use Case 2: Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway.
- Deliverable D1.2-C: Baseline Requirements – Use Case 3: Optimising the location of sustainable shellfish farming and tourism in Galicia, Spain.
- Deliverable D1.2-D: Baseline Requirements – Use Case 4: Mapping aquaculture structures and use of marine resources in Palawan, Philippines

1 Introduction (common to the four Use cases)

The very first evidence of human-initiated fish cultivation goes several thousand years back in the history of both Australia and China. Since then, breeding of aquatic organisms, i.e. fish, molluscs, crustaceans or aquatic plants, has been cultivated to generate food resources all over the earth. Still, hunger or malnutrition is a global reality for as much as 40 %of the global population, who cannot afford a healthy diet (FAO, 2024). Rapidly increasing global population, projected to reach 8.5 billion by 2032, will further increase the need for food proteins. Capture fisheries harvesting will increase the pressure on natural food resources, the natural environment and the food web by using rivers, lakes, coastal waters and oceans all over the world. An increase in sustainable aquaculture or sea farming industries is accordingly envisaged.

UN Food and Agriculture Organisation (FAO) publish the State of the World Fisheries and Aquaculture (SOFIA) reports (FAO, 2024). According to FAO-SOFIA (2024), fisheries and aquaculture hit a new record in production that constituted 15% of the global animal proteins supply, however, reaching as high as 50% in several countries in Asia and Africa. According to FAO´s latest figures from 2022, capture fisheries have remained at a stable level over the last years. Nevertheless, aquaculture has increased significantly with a total production of 130.9 million tonnes, valued at USD 312.8 billion, ensuring employment for around 22.2 million people. The production for direct human consumption was 94.4 million tons, contributing to more than half (57%) of aquatic animal products from fisheries and aquaculture. Inland aquaculture dominates, and marine and coastal aquaculture represents 37,4% of the global aquaculture production (FAO, 2024). Aquaculture is mainly dominated by a few dozen key species and by a few main countries worldwide. The growth in aquaculture during recent years is dominated by finfish species and has been strongest in Asia, Latin America, the Caribbean, Europe and Africa, respectively. China is by far the dominating country in aquaculture. Several low-income countries have not exploited the potential of aquaculture, particularly in Africa and Asia. FAO's projection for 2032 is that the volume of aquaculture will increase by 17% and account for 54% of the total production from aquatic animals. Based on this, FAO conclude in SOFIA 2024 that "*Aquaculture can meet the rising global demand for aquatic foods. Future expansion must prioritise sustainability and benefit regions and communities most in need*" (FAO, 2024).

Aquaculture requires physical space on water bodies or on land, a resource that in many areas is very limited and is open to conflicts of use and availability. Aquaculture also faces major challenges from climate change and disasters, water scarcity, pollution, biodiversity loss, and impacts on the natural ecosystems and living organisms, . In sustainable aquaculture, animal welfare for the fish is an increasing challenge and concern. This imposes the need for a holistic ecosystem-based approach implemented through regulations, monitoring and management to ensure that sustainable "blue" aquaculture operations and industry contribute to generating the food resources the local and global population needs and can afford.

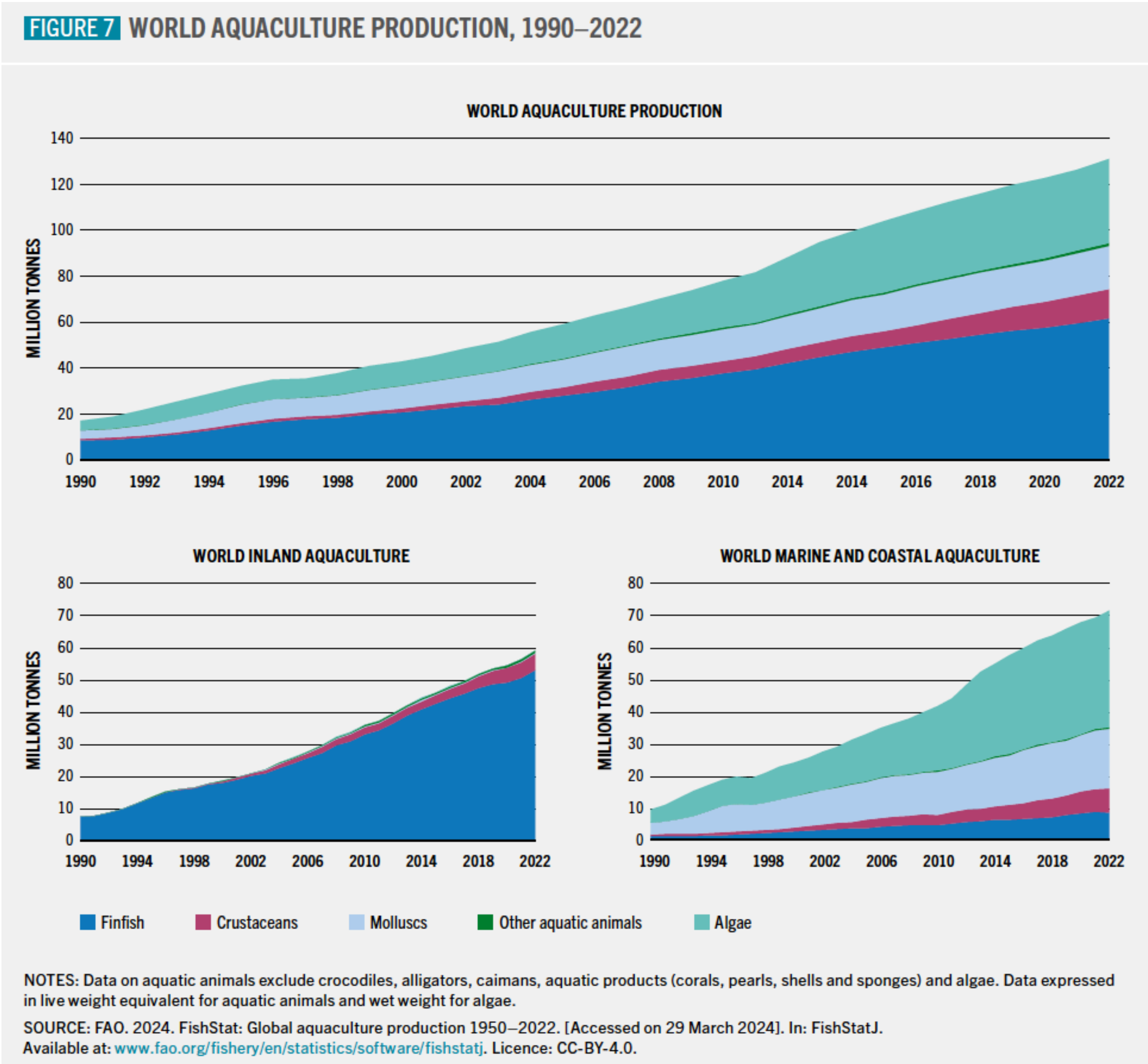

Figure 1: The global aquaculture production 1992-2022 in million tonnes (Adopted from Figure 7 in FAO, 2024).

2 The EO4SA Use Cases (common to the four Use cases)

On this background, the EO4SA project will implement four use cases that will contribute to enhancing the future operations of aquaculture management authorities, stakeholders and industry, by taking up new information based on satellite Earth observations data. In brief, these are entitled:

- Predicting risks of salmon lice infestation in Norway.
- Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway.
- Optimising the location of sustainable shellfish farming and tourism in Galicia, Spain.
- Mapping aquaculture structures and use of marine resources in Palawan, Philippines.

For each of these use cases, the EO4SA team has established contacts with Early adopters (EA). These EAs will contribute with their input to the development and assessment of each of the proposed Use cases (Table 1). The EAs will contribute to ensure relevance for further use and possible up-scaling of each Use case.

Table 1. The description of the Use Cases and their pilot geographical locations and early adopters (the Use Case addressed in this report is in bold).

Use Case	*Pilot site locations*	*Early adopters (sector)*
i. Predicting risks of salmon lice infestation in Norway	**Norwegian coastal and offshore waters**	• **Norwegian Directorate of Fisheries (governmental agency)** • **Lerøy Aurora AS (private company)** • **Grieg Seafood ASA (private company)** • **Sparebank 1 Sør Norge ASA (financial institution)**
ii. Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway	Helgeland Fosen Namsen fjord Lyngen fjord	• Norgeskjell AS (private company) • Lyngsskjellan ENK (private company) • Norwegian Directorate of Fisheries (governmental agency) • Norwegian Institute of Marine Research (research institute) • Sparebank 1 Sør Norge ASA (financial institution)
iii. Optimising multi-use of marine areas for shellfish farming and tourism in Galicia, Spain.	Galician rias of NW Spain	• FEMEX (Federación de Mejilloneros) and Angulas Aguinaga (Cambados: depuración y transformación de mejillón) (industry) • INTECMAR: Technological Institute for the Monitoring of the Marine Environment in Galicia (monitoring) • CETMAR, Centro Tecnologico del Mar, Galicia, Spain (science) • CSIC-IIM: Institute of Marine Research (science) • National Park "Illas atlánticas de Galicia" (national park)
iv. Mapping aquaculture structures and use of marine resources in Palawan, Philippines.	Puerto Princesa Bay, Palawan, Philippines	• Palawan Aqua-Agri Venture Agriculture Cooperative: 22 registered fish cage operators • Bureau of Fisheries and Aquatic Resources (BFAR)-Province and MIMAROPA Region: responsible for the development, improvement, management, and conservation of the Philippines' fishery and aquatic resources

In preparing this Requirements document (D1.2.A-D), the Early Adopters have been approached directly through individual consultation meetings, phone calls, participation in thematic fora, and written documentation presenting the objectives and the initial plans for each EO4SA Use Case. These direct contacts were used to get the EA´s feedback on each Use Case. Further, a Google questionnaire online was distributed to be filled out by each Early adopter (the questionnaire is in Appendix 1). The questionnaire was adapted for all four Use case studies.

In the following, this report addresses the baseline requirements to meet the information needs as put forward by the Early adopters for all four Use Cases and focusing on the FIRST of the four use cases: ***Deliverable D1.2-A: Baseline Requirements – Introduction and Use Case 1: Predicting risks of salmon lice infestation in Norway.***

3 Use case 1: Predicting risk of salmon lice infestation in Norway

Sea lice are crustaceans where the female parasites attach the fish and feed in its mucus, skin, tissue and blood, causing significant health issues, reduced growth rates and promoting the spread of several diseases, usually causing death of infected fish. In Norway, the main approach to managing the sea lice infestations is a requirement for each farm to regularly monitor salmon lice density at their location. Each enterprise reports the status weekly to the

Norwegian Food Safety Authorities and the Directorate of Fisheries, who use this information for advice on the employment of delouse methods. The monitoring data is also used in particle tracking ocean models for estimating the salmon lice spread once detected at a location.

For regulatory management of aquaculture licenses in coastal waters, the ”traffic light system” was implemented by the Norwegian government in 2017 as a statutory regulation monitored by the fisheries and food safety authorities. Through biennial risk assessment, fish farming (salmon and trout) is regulated through capacity adjustments of licenses and expansion or reductions of fish volumes. The Norwegian Government has very recently (12. June 2025) decided that the “traffic light system” will be modified. Full details of what the new regulatory system be is not yet available. The changes will include a more individual approach, tailored to each production location, facility or company. Those facilities who operates “well”, with low lice concentrations, low environmental impact, and good animal welfare, etc., may increase the licensed production also in production areas that have a general high impact of sea lice.

Animal welfare is regulated for all types of animal husbandry, including aquaculture. Sea lice infestation and the treatment methods are one of several causes that have a direct impact on the fish mortality and hence the fish welfare in the aquaculture pens. The annual median mortality of farmed fish in Norway was 15,5% or about 57,8 million salmon in 2024, of which mostly are direct (physical damage) or indirect (spread of diseases and delousing methods) related to sea lice (Moldal et al., 2025). This mortality level is much higher than in land-based animal husbandry and unacceptably high. Targets approaching a 5% fish mortality level in aquaculture may be suggested in Norwegian regulations soon. For the aquaculture industry, fish welfare impacts and the significant losses are difficult to quantify exactly in monetary values. Norwegian media have reported losses are about 5 billion NOK due to sea lice and diseases. In addition, the annual mortality estimations of wild salmon have reached more than 30% due to salmon lice infection in some regions (Sommerset et al., 2024), which is likely facilitated by the high-density aquaculture environment. Therefore, the direct and indirect effects of salmon lice are the main threats to the sustainability of salmon farming, and the authorities and industry demand a better knowledge base for justification and enforcement of the regulations, in which the proposed EO4SA service may contribute.

Salmon lice (Lepeophtheirus salmonis) — through their planktonic larvae stage to the female adult parasite — are substantially impacted by the environmental conditions. The water temperature often regulates the infection period (Sommerset et al, 2024). Low temperature retards the salmon louse development while low salinities decrease survival (Groner et al., 2016), hence there is a strong seasonal and latitude variability. Surface winds can modify the surface currents and influence the advection of sea lice (Brooks et al., 2005). Such environmental conditions are estimated by EO on large scales and have the potential to be used as predictors in risk models for salmon lice outbreaks. Early warning could enhance the current mitigation strategies, through e.g. protective barriers around the open net-pens or various delousing methods (mechanical, temperature, etc.) and/or medication. Risk assessment, through observations and forecasts, could empower farmers and authorities in decision-making, such as optimising the use of delouse methods and preventive medicine, which could reduce fish mortality and marine pollution. Such information could also be essential for managing the aquaculture locations, their density, and production capacity.

Predicting risk of salmon lice infestation is a promising EO-based product and achievable approach, as we will explore the large EO and salmon lice in-situ database (n>690.000) in Artificial Intelligence (AI) models. The output will be estimates of female salmon lice density and the probability of salmon lice risk infestations or outbreaks. Although no study has demonstrated such application to salmon lice to the extent of our knowledge, similar approaches used for HABs (Silva et al., 2024) could be adapted, where the probability of a HAB detection is given by environmental parameters estimated by remote sensing – SST and Photosynthetically active radiation (PAR) – and model data (salinity, MLD). The environmental conditions (SST, SSS, winds, etc.) and fish farm density maps will be matched with the in-situ salmon lice density data to calibrate models that estimate the probability of salmon-lice density above the regulatory levels. We will train the AI models using all salmon-lice data along the Norwegian coast and perform the validation focusing on the study site corresponding to Use Case 1. The study site covers all fish farms along the Norwegian coast because salmon lice infection is a national problem, and decisions made by the environmental agencies consider the production areas. Besides, new initiatives are exploring offshore farming along the Norwegian coast and in the fjords, and the salmon lice risk is an important factor for planning future operations.

4 State-of-the-art activities for the Use case

Aquaculture in Norway takes advantage of the long and partly sheltered Norwegian coastline, islands and fjords. This gives opportunities to locate open net-pens, which is the case for most of the present farms, to take advantage of natural water circulation, to maintain the optimal environmental conditions needed for efficient growth of the fish after the initial smolt stage. This includes fresh and oxygen-rich water, and during the different life stages, the fish have different environmental requirements such as water temperature, salinity and light to optimise its growth rates. Normally, the salmon reach its slaughter weight of 4 to 6 kilograms within a period of 9 to 18 months in the open net-pens, depending on water temperature and feeding. The slaughter weight is determined according to production and market strategic choices. The discharges for this type of production are primarily related to feed residues, faeces, dissolved dead fish, pharmaceuticals, chemicals, impregnation of the net in the open net-pens, escaped fish and climate gas emissions. Fish use in general little energy for their movements and hence aquaculture has a low climate footprint compared to the production of other animal protein. The major climate contribution is related to the production of food for feeding the farmed fish.

Several measures have been introduced to control biosecurity, fish welfare, pollution and productivity of the aquaculture industry in Norway. The Institute of Marine Research has since 2010 annually published a risk assessment report for the Norwegian fish farming. The "*Risk Report on Norwegian Fish Farming 2025*" (Grefsrud et al, 2025 -citations below are given in *italic*) concludes with the following nine risks associated with fish farming in Norway in 2024:

1. *Poor welfare of farmed Atlantic salmon and rainbow trout in open-cage production*
2. *High sea-lice induced mortality in migrating post-smolt salmon*
3. *Negative effects of sea lice infestation on sea trout and Arctic char*
4. *Further genetic changes in wild salmon due to interbreeding with escaped farmed salmon*
5. *Eutrophication of coastal waters due to nutrient emissions from fish farming*

6. *Negative effects on benthic communities in the influence area of fish farms*
7. *Negative effects on the marine environment due to the use of copper in fish farming*
8. *Severe effects on non-target species from the use of delousing agents*
9. *Negative effects on the marine environment from the capture and use of wild-caught wrasse in fish farming.*

Further, the report states that *The negative impact of sea lice on wild salmonids has worsened significantly in 2024. Despite temperatures not exceeding normal levels in western Norway, the marine heatwave in 2024 led to significantly higher sea lice emissions from PA5 to PA12 (*i.e. Northern parts of Norway*), particularly during late summer and fall.* …….. *With the explosive rise in sea lice production due to high temperatures, fish farmers in several areas lacked sufficient capacity to handle the situation.*

For these and other reasons the fish farm industry have experienced significant losses and the *reported figures from the Norwegian Directorate of Fisheries' biomass statistics for Norwegian fish farms as of January 20, 2025, show that a total of 60 million farmed salmon were reported dead (57 million) or in such poor condition that they were registered as discards (3 million) in 2024.* The median cumulative mortality risk for completed salmon production cycles for Norway (all production areas) was 15.5 % in 2024 and was less than the fish mortality reported in 2023, i.e. 65 million tons (Moldal et al, 2025).

The Norwegian Veterinary Institute publishes an annual report that provides an overview of the health status of Norwegian farmed fish. The fish health situation in the Norwegian fish farming industry faces many challenges, including a very high fish mortality compared to other animal husbandry (see also Figure 5). The reasons for the high fish mortality are complex; however, the veterinary report highlights that "*There are three health challenges in particular that stand out also in 2024 for farmed salmon: Injuries during delousing operations, complex gill disease, and winter wounds"* (Moldal et al., 2025).

The aquaculture industry spends considerable resources on research and management of sea lice infestations. The measures can be divided into preventive measures, either at the production area level or at the individual farm, and treatment to reduce the occurrence of lice during outbreaks – delousing. Treatment methods can be divided into pharmacological and non-pharmacological. Pharmacological treatment includes drug-based treatment to remove salmon lice from the fish, either by killing or by immobilising them. These types of treatments raise concerns about the development of resistant lice strains and the effects of the medication on non-target species. Non-pharmacological treatments are methods that do not involve the use of drugs, including mechanical delousing, the use of cleaner fish (biological delousing), thermal treatment and laser treatment. There are various challenges associated with the treatment methods, including environmental impacts, development of resistance, efficiency and how the measures affect the welfare of the farmed fish, including the use of wrasse fish and roe crackers. Extensive research efforts are made to find sustainable solutions to combat sea lice, including genetic studies on resistance in salmon and environmental management practices. These aspects are given considerable attention by both the industry itself and by the regulatory authorities, e.g. as concluded in the above-mentioned annual risks and health assessment reports.

The sea lice are currently the most severe threat and risk for productivity and causing economic losses to the fish farming industry, both through direct treatment costs, impact on the actual production and the market perception. Outbreaks of sea lice are also a major threat to the surrounding environment, and particularly the wild salmon stocks, as well as to the actual welfare of the fishes within and outside the open net-pens. These are the considerations being addressed in the abovementioned regulatory framework.

5 Current relevant regulatory (policy) and operational framework

Production of Atlantic salmon (*Salmo salar*) and rainbow trout (Oncorhynchus mykiss) accounts for only about 3 % of the aquaculture production in the world. Norway is the largest producer in the world of these species, followed by Chile, the UK, Canada and the Faroe Islands. This aquaculture industry has had a significant growth since the 1980s in Norway as well as in the other main countries (Figure 2). However, other types of aquacultures, e.g. shellfish and seaweeds, are still at the development stage and quite marginal in Norway but increasing in many countries and in the global context (Figure 3). The Norwegian production for export in 2024 was more than 1,25 million tons of salmon and 75.155 tons of rainbow trout. This was about 74% of the total Norwegian export of seafood from both capture fisheries and aquaculture. Its market value was 130,6 billion NOK (about 11,4 billion EURO), where salmon is the predominant species (94%) and is expected to continue in many years to come (Norwegian Seafood Council, 2025 – 06.01.2025). Finfish farming constitutes the largest livestock production in Norway, with more than 500 million farmed fish, primarily in open net-pens, located along the entire Norwegian Coast (Grefsrud et al, 2025). Fisheries and aquaculture are important for the Norwegian economy and employment, particularly in rural areas, and are the second largest export business after oil and gas extraction.

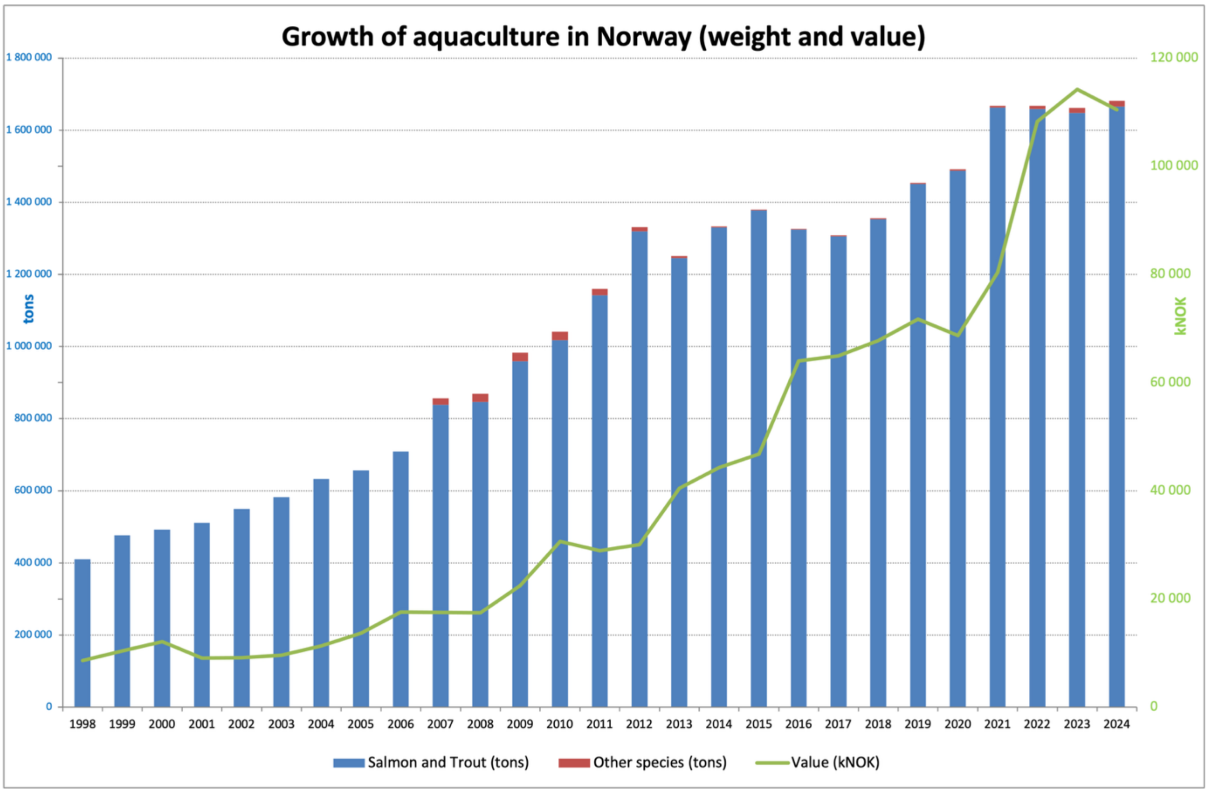

Figure 2: Development of the production (in tons round weight) from aquaculture in Norway for the period 1998 to 2024: total production Atlantic salmon (blue bars), rainbow trout and other species – including other fish species, shellfish and seaweed (orange bars). The green curve indicates the total

value of aquaculture turnover in Norwegian kroner (kNOK). Based on figures from the Directorate of Fisheries.

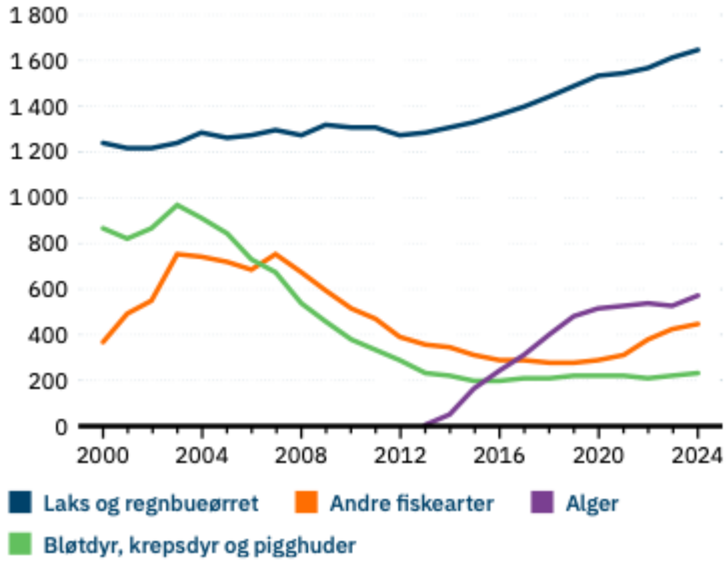

Figure 3: The number of aquaculture licenses granted in Norway for different production forms - Salmon and rainbow trout, other fish species, Algae and Molluscs, crustaceans and echinoderms during 2000–2024. (Source: Directorate of Fisheries, 2025).

The Acts and regulations for aquaculture permits – in brief

Finfish farming has been a business activity with huge growth during the last half century. Accordingly, the legislation, legal framework and regulations have been significantly (and abruptly) developed and implemented. The core of the present specific regulations related to aquaculture in Norway is founded on the *Act on Aquaculture* (Loven om akvakultur - Akvakulturloven), which came into force in 2006. Its purpose is that: *The Act shall promote the profitability and competitiveness of the aquaculture industry within the framework of sustainable development and contribute to value creation on the coast.* The Act allows for both profitable business development and conservation of nature.

Establishment of aquaculture facilities is regulated through applications, permits and licenses handled under a (complex) regime of different national laws, i.e. the Acts on Aquaculture, Food, Animal Welfare, Pollution, Ports and Waters, and Water Resources and their allocation regulations managed by various authorities. The respective authorities include the local and county municipalities, as well as national agencies being responsible for fisheries, food and food safety, health, animal welfare, pollution, environment, sea navigation, and water resource regulations (Figure 4). The processing of the applications is made under a coordinated case management between the different authorities involved and a common portal for submission of applications.

For salmon, trout and rainbow trout, aquaculture enterprises must first obtain a "commitment on aquaculture permit", which is a decision on the allocation of production capacity. This first permit is related to the maximum allowable production capacity (MTB – maximum allowable living fish biomass in the water) for each enterprise and their geographical location. The MTB is determined for 13 geographical regions along the coast and regulated under the soon to be modified, Traffic Light System, mentioned below. New production capacity is allocated in the "green production areas" following fixed-price growth offers and granted by auction. The normal size of a license is 780 tons MTB and an enterprise can apply for several production capacity licenses.

The second step in the application is related to the actual geographical location of each aquaculture production site. This includes mapping the ecological status, spawning areas for marine species, biodiversity and the possible presence of endangered species in the area. The applicant is responsible for generating the needed documentation according to various standards, e.g. *Environmental monitoring of food fish farms – NS 9410*, which describes a method for measuring and monitoring bottom conditions in fish farm locations. Other surveys measuring biomass and calculating fish density, measuring oxygen levels in the sea, measuring current, surveys of water quality, measuring visibility, diving, etc., are also relevant for license applications and monitoring at each site location. Such assessments shall be made by use of independent consultants, and similar mapping is regularly carried out periodically during the site operations. The monitoring is risk-based in the sense that poor condition leads to more frequent surveys at the site. The assessment at the local level depends primarily on the environmental carrying capacity of the locality, local plan regulations, other uses of the waters, etc. For other aquaculture species than salmon, trout and rainbow trout, the application process is made jointly following only this step 2.

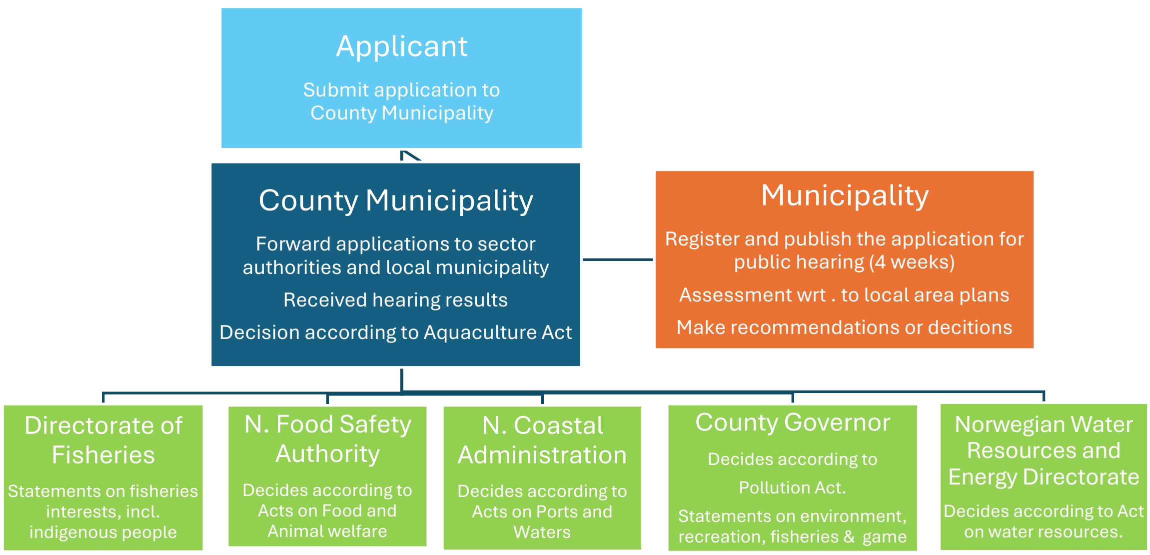

Figure 4: Schematic overview of the assessment and granting of applications for aquaculture licenses, including their respective areas of responsibility. Based on Figure 3.1 in NOU, (2023).

Assuring the balance between business development and suitability in aquaculture in Norway has later, among other, been addressed in the Government's white paper to the Norwegian Parliament on *Predictable and environmentally sustainable growth in Norwegian salmon and trout farming* (Stortings Melding 16 (2014–2015) «*Forutsigbar og miljømessig bærekraftig vekst i norsk lakse- og ørretoppdrett*» - the so-called *Havbruksmeldingen*). This whitepaper states that "*environmental sustainability must be used as the most important prerequisite for regulating further growth in the aquaculture industry*".

As in all livestock farming, fish health and fish welfare are essential to maintain sustainable operations or growth in fish farming. Biosecurity is the collective term for the measures intended to contribute to preventing the introduction and spread of infectious agents (infection control) as well as the release of aquaculture organisms from the aquaculture site locations. Biosecurity is closely linked to fish health, both within the open net-pens and to the surrounding natural environment and wildlife. Further, the health status of the fish is important for, among others, the fish growth, the efficiency of the feed utilisation, the quality of the fish product and the probability of the fish dying before optimal slaughter weight (mortality). Biosecurity aspects are accordingly essential for compliance with animal welfare and pollution legislation. It is also important for the profitability of the enterprises and the market perception of the sustainability and quality of the food products.

Based on the above Havbruksmeldingen, the Norwegian Ministry of Trade, Industry and Fisheries adopted the Production Area Regulation - Forskrift om produksjonsområder for akvakultur av matfisk i sjø av laks, ørret og regnbueørret (Produksjonsområdeforskriften, 2017) in 2017. This is a rule of action for capacity adjustment of salmon and trout farming based on predefined geographical areas and environmental indicators. The regulation was founded on the assumption that there is a relation between the biomass in the open net-pens (i.e. number of fish) and the discharges of sea lice to the surrounding environment. The regulation is currently implemented and monitored through the so-called Traffic Light System (Trafikklyssystemet) that was introduced to the aquaculture management later the same year. The traffic light indicator is based on an assessment of the risk of spreading sea lice to the wild salmon and the fish farm site location structure. The entire Norwegian coast was divided into 13 production areas (PO – produksjonsområder) based on biophysical properties that consider the ocean currents, temperature and the biology of sea lice, with the goal is to minimize the risks for spread and interactions between the different PO´s through the water masses along the entire Norwegian coast (Figure 5). The Traffic light system is a rule of action where the environmental status of sea lice-induced fish mortality in wild salmonids (post-smolt) is assessed every second year for each PO by an expert committee – the Scientific Council for Salmon Management (VRL). Based on the assessment, the Norwegian Ministry of Trade, Industry and Fisheries determines the capacity regulations for each PO. This is the basis for whether the total aquaculture production will be allowed to increase, should it remain unchanged or must it be reduced in each of the production areas. The Norwegian Parliament decided on 12. June 2025, a major change in the criteria for providing aquaculture licenses in the 13 production areas. Still, salmon lice infestation is regarded as the major issue for fish aquaculture, but this decision indicates a transformation of the Traffic Light System from area-based assessment to individual location or/and company-based assessments. The actual implementation and changes following this has not yet been decided, but these developments will be followed closely in the EO4SA project.

Through BarentsWatch, public agencies and research institutions collaborate to collect, develop and share knowledge and statistics about coastal and marine areas using various GIS-based web solutions. Their systems provide the basis for better cooperation, professional development and sharing of information, both for public agencies, trade and industry, and the public. Of relevance to EO4SA, BarentsWatch distributes data related to Norwegian fish health (Fishhealth) and the aquaculture industry locations and licenses (AquaInfo). The FishHealth data service includes data on the salmon lice density per fish as well as the delousing methods employed, which are the main variable used in the prediction model and important assessment information.

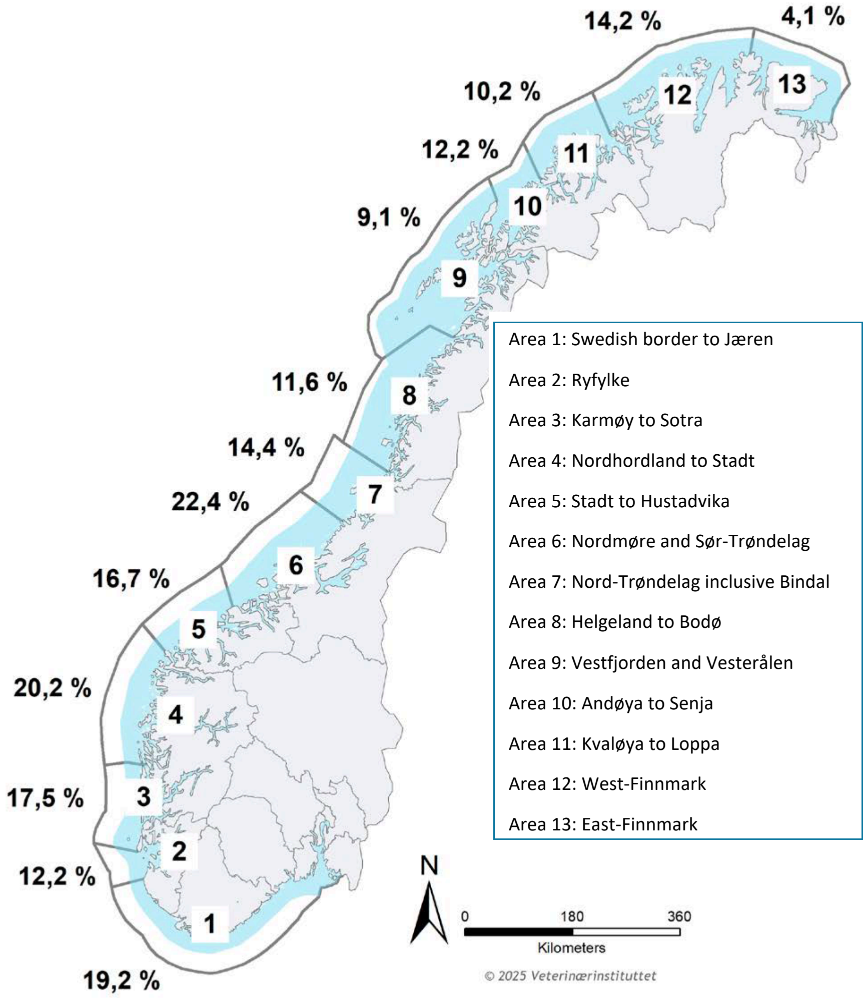

Figure 5: The 13 fish farm production areas (PO) along the coast of Norway. The geographic distribution per PO of the annual cumulative mortality risk (in percent) for farmed salmon is indicated for 2024. Based on Moldal et al. 2025.

6 Early adopters and their specific requirements

This Norwegian Use Case have four Early Adopters (Table 1). Compared to the Tender, one additional Early Adopter from the private company sector – Grieg Seafood ASA (Section 6.3) – has joined this EO4SA Use Case.

6.1 Norwegian Directorate of Fisheries (governmental agency)

Early Adopter: the national body for fisheries and aquaculture management and their senior advisor(s) in aquaculture and IT-solutions.

Website: https://www.fiskeridir.no/English

Use case 1: Predicting risks of salmon lice infestation

Quote from the Early Adopter: "*High spatial resolution is important to be able to implement potential countermeasures against salmon lice and HAB events*."

Response to survey: The Norwegian Directorate of Fisheries will contribute to the two Norwegian Uses Cases in the EO4SA project, i.e. the one on Predicting risks of salmon lice infestation and the one Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway. In addition, predicting and monitoring HAB outbreaks of other algae species is also essential to salmon and other fin fish farming. In 2019, thousands of tonnes (more than 13.000 tons) of salmon were lost due to HAB events of *Chrysochromulina leadbeateri* in northern Norway.

One of the main tasks of the Directorate of Fisheries is to make sure that fisheries and aquaculture are being carried out to meet the demands of the given regulation within the limits of sustainability.

The Directorate, amongst other governmental agencies, make sure that necessary environmental surveys are carried out before a site is approved for aquaculture. They also ensure that environmental surveys at the sites are carried out during production. They also regulate and supervise that necessary risk assessments are made in relation to the safe use of pharmaceuticals to combat salmon lice.

The Directorate uses monitoring data collected by others (e.g. sampled by the aquaculture industry or their consultants) and carries out its own monitoring related to aquaculture sites. The data used includes Physical, Chemical and Biological variables. For salmon aquaculture, they also have access to information about salmon lice density and medication or treatment actions, implemented and reported at the various site locations.

The Directorate of Fisheries is currently not explicitly using any satellite-derived Earth observation data or products. However, they find it useful to obtain such information about sea surface temperature and salinity, dissolved and particulate organic carbon concentration, pH, turbidity (or visibility), chlorophyll concentration, harmful algal species, algae toxins, salmon lice density, and locations of aquaculture cages. In addition, updated information about water oxygen concentration, pollution, marine litter and microplastics is highly relevant.

The Directorate would like to have predictions on future sea lice infestation risks, including salmon lice density, probability levels (risks), regional risk assessment, impacts of delousing /medications, as well as advice on mitigation actions.

The use case predictions shall be updated weekly and cover the local areas of their operations, i.e. the entire Norwegian coast. Primarily, they need future or present time forecasts. Local information is important to be able to implement potential countermeasures against salmon lice infestation and spread between different aquaculture sites, each covering about 30-40.000 m^2. Hence, the resolution should be sufficient to resolve the conditions at different production locations.

The Directorate would like to have Use Case data for inclusion in its own existing decision support system (Yggdrasil), delivered via email initially and when operational through API.

6.2 Lerøy Aurora AS (private company)

Early Adopter: private seafood corporation and its Fish Health Manager

Website: *https://www.leroyseafood.com*

Use case 1: Predicting risks of salmon lice infestation

Response to survey: Access to forecasts or real-time measurements of sea lice larvae in water bodies provides Lerøy with information about ongoing and expected infection pressure on fish in the sea and enables preparations (estimate optimal treatment time) as well as initiation of relevant preventive measures.

The company uses internal prediction tools that estimate lice development based on the levels of lice on the fish, together with dynamic oceanographic models that enable spread simulations from and between their site locations. The sea lice levels on fish are counted daily using digital tools at all their production sites. These sea lice data are provided to the national monitoring program, and they have access to all national sea lice measurements through the IMR´s Lakseluskartet portal.

The company monitors physical and biological variables and tracks the use of medications and treatment actions at all its production sites. These measurements are made to monitor salmon lice infestation, to support the selection of new areas to locate cages or aquaculture sites, as well as to fulfil obligations with environmental standards or regulations. Knowledge about and reporting of sea lice levels at the locations is a regulatory requirement. Other measures are self-initiated by the company to optimise its operations. To the extent relevant, Lerøy will use its own monitoring data for assessment and validation of the EO4SA use case. These data will be limited to those relevant for the sea lice predictions, the actual location(s) and period(s). The EO4SA project has not made a specific agreement for its own use or access to actual environmental data from Lerøy. In case such data will be available and used in a scientific publication, we will ask for permission to also publish these data, in accordance with good scientific publishing practice.

Lerøy has no direct previous experience of using data from satellite Earth observations; however, they have identified that information about sea surface temperature, sea surface salinity, turbidity (or visibility), chlorophyll concentration, harmful algal species, algae toxins, and salmon lice density will be useful for their operations.

For Lerøy Aurora, predictions of sea lice infestation should provide useful information related to: Predicting salmon lice density, Probability levels (risks), Regional risk assessments and impacts of delousing methods or medications. The forecasts shall be at local coverage, be for the present time and updated at weekly intervals and covering the entire Norwegian coast. Lerøy would like to receive the forecasts through a dedicated EO4SA Web-map portal.

6.3 Grieg Seafood AS (private company)

Early Adopter: private seafood corporation and their Global Sustainability Advisor.

Website: https://griegseafood.com

Use case 1: Predicting risks of salmon lice infestation

Quote from the Early Adopter: *"Power BI reports that could be included in our daily operations dashboard, supporting decision makers and operational managers. Providing predictions together with production data, allowing operational managers to have a holistic data information. This will improve decision making and mitigating risks for early and late lice infestation intervention."*

Response to survey: Grieg Seafood are required to report amount of lice infestation at all sites as part of their regulatory licenses to operate. When the lice infestation reaches a threshold, they must mitigate by intervention, which has negative impact on their business. They carry out own physical counting of lice on salmon (lice density) each week on all production sites and report on medication of other treatment actions. They also have environmental data sensors at the sites that monitors water temperature, salinity, etc. The measurements are taken at several depths, comprising physical, chemical and biological variables. To the extent relevant, Grieg Seafood will use its own monitoring data for assessment and validation of the EO4SA use case. These data will be limited to those relevant for the sea lice predictions, the actual location(s) and period(s) presented. The EO4SA project has not made a specific agreement for its own use or access to actual environmental data from Grieg Seafood. In case such data will be available and used in a scientific publication we will ask for permission to also publish these data, in accordance with good scientific publishing practice.

They use these environmental data for monitoring sea lice infestations, occurrences of HAB events, optimization time of fish slaughter, selection of new locations for their aquaculture pens or sites, fulfilling internal and external obligations for environmental and food/health standards, quality certification of their products, as well as support to scientific research studies. The monitoring is also done to fulfil compliance with the Norwegian Act on Aquaculture (Akvakulturloven), and certification schemes such as Global GAP (internal impacts) and ASC (external impacts). Global GAP ensures that the aquaculture processes follow strict environmental, social, and animal welfare standards while following high standards of food safety and traceability. ASC focuses specifically on sustainable fish farming and reducing the impact on surrounding ecosystems.

Grieg Seafood have operations in British Columbia, Canada, that make use of satellite remote sensing data to support their operations. Such information is not available or used in their aquaculture activities in Norway. Potential satellite-based parameters **essential** for their operation include sea surface temperature and salinity, Harmful algae species, algae toxins, salmon lice density and locations of cages. Other **useful** parameters include Dissolved and Particulate Organic Carbon, pH, turbidity and chlorophyll concentration.

For the EO4SA Use Case, Grieg Seafood will need predictions on future lice infestation risks, including salmon lice density, probability levels (risks), regional risk assessment, impacts of delousing or medications, as well as advice on mitigation actions. The predictions shall be updated weekly and cover the local areas of their operations. Primarily, they need future and present time predictions in the provided forecasts. The Use Case #2 HAB and algae toxin forecasting may provide essential information related to the probabilities of toxic algae occurrences and the actual algae toxins present. This Use Case should cover the regional area or fjord of their operations, with monthly updates.

The deliverables from the EO4SA Use Case should be integrated into the existing web-map portal and available in formats to be integrated into their own BI Book analytics and decision support system. Power BI reports that could be included in their daily operations dashboard, supporting decision makers and operational managers. Providing predictions together with production data, allowing operational managers to have a holistic information. This will improve their decision-making and mitigate risks for early and late lice infestation intervention.

Adopted from public company resources (https://griegseafood.com/finnmark-lakselus):

At Grieg Seafood facilities in Finnmark, they use nature's own class of tools to combat sea lice infestations with very good results. This includes:

Fallowing (periodically not used) of production areas

Salmon production takes place at an approved location. Here, food fish live and grow from 14-22 months until they have reached a slaughter weight of between four and six kilograms. After production is complete, they fallow the area for a longer period. Fallowing means that there are no fish in the cages at the location. The larger the areas that are fallowed at the same time, the better. They do not release new salmon here, because they have experienced that the locations, by "resting" before the next production cycle, create poor breeding conditions for the salmon lice when access to new hosts ceases. At the same time, the bottom conditions at the pen also have better time to renew themselves and rebuild. They experience that fallowing helps ensure a gentler use of nature.

Larger smolt - shorter time in the sea

While the smolt is normally from 80 to 100 grams when released into the sea, they let the smolt grow on the land facility until it is 200 grams. The fish are then larger and more robust. At the same time, this means a shorter growth time in the sea, which means that the time the salmon is exposed to lice is reduced, and that it is easier to work preventively against lice. Shorter time in the sea generally results in better fish health and lower mortality.

Lice skirts

They use lice skirts at all our locations. The lice skirt is made of plankton cloth that is attached around the cage and extends 10 meters into the sea. Water and oxygen pass through the cloth, which protects the fish by preventing lice and larvae from getting through and attaching to the salmon.

Roe crackers

The roe crackers are active lice eaters at lower sea temperatures than wrasses and are therefore well suited as cleaner fish in our northern waters. It is important for the roe crackers to have places to hide. That is why they have installed an artificial kelp forest in the cage. Cleaner fish is an important preventive measure to keep lice incidences down, but roe crackers are also vulnerable farmed fish that require vigilance to safeguard the health and welfare of the fish while they do an important job in the cage. The mortality rate for cleaner fish in Norway is unfortunately high, which is why extensive work is now underway to improve the welfare of the cleaner fish.

Fewer drug treatments

In periods, these measures may not be enough, so they carry out mechanical delousing by bathing in temperate freshwater, which allows the lice to get rid of them. Ultimately, they choose strictly regulated drug treatment. These are measures they try to avoid, as they know that they both stress the fish and can lead to fish death. Drug treatment also has an impact *on the environment. For the sake of the health and welfare of the fish, the development of wild salmon and consideration for other species they live in contact with,* ***prevention is the absolute most important effort in the fight against salmon lice.***

The farmers cooperate

When several companies operate in the same region, cooperation on lice control becomes important. In Finnmark, they have established a regional cooperation, with an external coordinator who shares information on the lice status and measures between the companies. Such information and overview are of great importance in our joint work to combat lice, care for wild salmon and prevent other environmental challenges from lice treatment.

6.4 Sparebank 1 Sør-Norge ASA (financial institution)

Early Adopter: a financial institution and their senior credit analyst.

Website: https://www.sparebank1.no/nb/sorost

Quote: EO4SA addresses *important elements within aquaculture that affect credit risk.*

Response to survey: SPAREBANK 1 SØR-NORGE ASA performs credit risk assessments of customers seeking their financial services related to the establishment and operations of aquaculture activities. Aquaculture is, in financial terms, a capital-intensive business. They serve clients primarily in finfish aquaculture from the production of smolt to fish for the consumer market, providing a working capital guarantee – a financing scheme for export-oriented companies. Sparebank 1´s activities are primarily relevant for Use Case #1 on Sea Lice predictions and to some minor extent to shellfish aquaculture, i.e. Use Case #2 on forecasting algae toxins.

The bank does its own financial assessments of the clients as well as carrying out its own environmental assessments to quantify the risks. The environmental risk survey and assessments are conducted by their clients or by independent third-party consultants. These are made for the actual aquaculture locations using the standard methods for environmental monitoring of finfish aquaculture locations. The so-called MOM-B environmental assessment (M - production facility O – monitoring, and M – modelling) includes monitoring of the impacts on the seabed at aquaculture production sites. The MOM-B survey covers sampling of the seabed under and near the pens. The survey is carried out according to a national standard, e.g. for Environmental monitoring of food fish farms (Miljøovervåking av matfiskanlegg) – NS 9410, that covers:

- Fauna survey
- Chemical survey (pH and redox potential)
- Sensory survey (gas, colour, odour, consistency, dredging volume and mud depth)

All parameters are given a score according to the degree to which the seabed is affected by organic matter, and the site is given a total score. The score also determines the repeat frequency of required MOM-B surveys during the operational phase.

Essential considerations include careful selection of good locations with the right depth and current conditions. Industries targeting, e.g. electrifying equipment and new feed recipes for better fish health and lower greenhouse gas emissions.

Sea lice are a very important variable for fish welfare and health. It is also essential for the profitability, and accordingly, a topic discussed with clients. Predictions of salmon lice density will be a useful variable to monitor and predict. Monitoring of other relevant environmental parameters includes sea surface temperature, sea lice density, harmful algae species and locations of the cages.

For Sparebank 1, the use case on prediction of sea lice infestation should provide useful information related to: Predicting salmon lice density, Probability levels (risks), Regional risk assessments, Impacts of delousing methods/medications and Advice on mitigation actions. The forecasts shall be for the present time and updated at a monthly interval and cover the entire Norwegian coast. The actual prediction data are not needed for their own use; however, the analysis and assessment should be delivered in a descriptive text and mapbased bulletin, preferably received via e-mail.

6.5 Summary of the Early Adopters Requirements

Four private companies, one financial institution, one governmental agency and one research institute have responded to the EO4SA questionnaire survey for the two Norwegian Use Cases (Table 1, Figure 6). All except one organisation collects and uses their environmental data (86%) of relevance to the assessment of this Use Case. The last EA use such information collected and analysed by others in their assessments. Some of their responses are relevant for both Norwegian Use Cases and some are unique. In Table 2 we have extracted and summarized the Early Adopters responses to the survey questions of importance for their requirements to the implementation of the Use Case on Predictions of salmon lice (see Attachment 1 for questions presented and Attachment 2 for the EA responses). There is some overlap with the other Norwegian Use Case on algae toxins and harmful algae blooms, since the same questionnaire was used for both (see Attachment 1).

Table 2: Summary of the EAs responses to the EO4SA questionnaire survey conducted. Black indicate EA preference, Blue "not relevant", red "useful" and orange "essential". The EA responses to the individual questions are included in Appendix 2.

		Nor. Directorate of Fisheries	Sparebank 1 Sør-Norge ASA	Lerøy Aurora AS	Grieg Seafood AS
What environmental and other variables do you monitor or monitor through other sources?	Physical (e.g., temperature)	Black		Black	Black
	Chemical (e.g., DOC)	Black			Black
	Biological (e.g., Chl-a)	Black		Black	Black
	Salmon lice	Black	Black	Black	Black
	Medication or treatments	Black		Black	Black
What satellite-based products or parameters would be relevant for you? Blue for not relevant, red for useful, and orange for essential.	SST	Red	Red	Red	Orange
	SSS	Red	Blue	Red	Orange
	DOC	Red	Blue	Blue	Red
	POC	Red	Blue	Blue	Red
	pH	Red	Blue	Blue	Red
	Turbidity	Red	Blue	Red	Red
	Chl-a	Red	Blue	Red	Red
	HAB species	Red	Red	Red	Orange
	Algae toxins	Red	Blue	Red	Orange
	Salmon lice density	Red	Red	Red	Orange
	Location of cages	Red	Red	Blue	Orange
Indicate the importance of the following information for the product. Blue for not relevant, red for useful, and orange for essential.	Lice density	Red	Red	Red	Orange
	Probability levels	Red	Red	Red	Orange
	Regional risk assessments	Red	Red	Red	Orange
	Impact of medications	Red	Red	Red	Orange
	Advice on mitigation	Red	Red	Blue	Orange
What would be your preferred frequency of updates of the salmon lice predictions?	Weekly	Black		Black	Black
	Monthly		Black		
	Bi-monthly				
	Seasonally				
What is your preferred temporal coverage of the salmon lice predictions?	Past				
	Present		Black	Black	
	Future	Black			Black
What would be your preferred spatial coverage of the salmon lice predictions?	Local (e.g., local farm)	Black		Black	Black
	Regional (e.g., fjord)				
	Entire Norwegian coast		Black		
How would your preference to receive information from EO4SA?	Descriptive text bulleting		Black		
	EO4SA web portal			Black	
	Existing web portal				Black
	Data for including in own system	Black			Black
	Direct consultations				

7 Algorithms available – Baseline and innovative

As outlined in Section 3, we will use AI methods for the calibration of the sea lice risk models for the entire Norwegian coastal waters. For doing this, we have compiled a comprehensive dataset, including sea lice density records from all fish farm locations in Norway since 2012, that comprises about 700.000 measurements. As outlined above, these measurements and their reporting are based on legal obligations for each farm and company. Additionally, direct and assimilated EO data is accessible through public repositories and services such as the Copernicus Marine Service. Since sea lice outbreaks are influenced not only by environmental factors but also by aquaculture practices — including the number and density of farms, fish farmed biomass, and treatment or medication strategies we will incorporate these variables as predictors alongside EO data. While most required data is already publicly available, we are working with the Directorate of Fisheries (Fiskeridirektoratet) and other private Early Adopters to secure access to fish farmed biomass records at the individual farms or at the regional level.

Our approach builds upon a previous study that assessed the risk of toxic Harmful Algal Blooms (HABs) for the shellfish farming industry, using a similar methodology (Silva et al., 2023; Silva et al., 2024). This study, however, was constrained by a much smaller observational dataset (n=5.920) and therefore relied on machine learning techniques suitable for limited data, such as Support Vector Machines (SVM). In contrast, the salmon lice dataset is significantly larger (n > 700.000), allowing us to explore more advanced AI models capable of handling large-scale data. The salmon lice are measured weekly and reported routinely every Monday to NFSA, from all active aquaculture production sites along the Norwegian coast. Increased temporal and spatial resolution of these data and the EO4SA use of EO data assimilating ocean model simulations (NorKyst-800), will significantly increase the availability both the training and validation data sets for sea lice predictions. Among the machine learning techniques to be evaluated, Convolutional Neural Networks (CNNs) stand out as a promising candidate due to their effectiveness in processing spatial and temporal patterns in EO data. However, alternative deep learning architectures may also be considered based on performance evaluations (to be further elaborated in WP3).

A key innovation of this project is the first-time calibration and implementation of an AI-based risk assessment model for salmon lice that integrates EO data. Additionally, the model will be refined iteratively based on feedback from early adopters, ensuring practical usability. The use case consists of four main steps: (1) gathering requirements from early adopters (these reports deliverable D1.2-A-D), (2) calibrating the risk models, (3) deploying the model in an online platform, and (4) testing and evaluating it in real-world scenarios.

8 Datasets available

A summary of the available and to be used data sets and their sources is given in the below Sections for 8.1 Input (training) data, 8.2 Statistical Validation data and the Use case 8.3 Output data.

The adult female lice count per fish is the variable target of the forecast models since it is used to assess the fish farms' infestation levels. Mobile lice and sessile lice are included in the forecast model as predictors because they are probably both related to the infestation of lice. Ocean information is retrieved from the Norkyst-800 hydro dynamic ocean model, including sea surface temperature (SST), sea surface salinity (SSS), and surface currents. Since the EAs are more interested in products at the fish farm locations, we have conclude to use Norkyst-800 because regular Level 4 EO will have too many data gaps in the (narrow) inner fjords, due to coarse spatial resolution and regularity of data. Besides, near-real-time EO processed images covered by clouds, which may impact the one-week forecast required by the EA. Nevertheless, Norkyst-800 assimilates EO products available in the Copernicus Marine Environment Monitoring Service (CMEMS), such as TOPAZ-4 or Arctic Ocean Physics Analysis and Forecast (https://doi.org/10.48670/moi-00001) and Baltic Sea Physics Analysis and Forecast (https://doi.org/10.48670/moi-00010). Therefore, using the Norkyst-800 ocean model provides an assessment of the impact of EO data on the sustainability of aquaculture.

The salmon lice prediction models produce weekly forecasts and will be presented as two different outputs, based on needs expressed by the EAs. The first is the forecasted **salmon lice density (counts per fish)**, and the second is **the probability (%) of salmon lice density reaching levels above 0.5 counts/fish** (the threshold for alerts). The input data (i.e., training data) and validation data are a time split of the dataset. From 2012 to 2019, all data is used for developing forecast models, and from 2020 to 2026, the output data in this period is used for salmon lice prediction model validation. Note that this validation corresponds to the statistical evaluation of the models and hence includes all local observations in Norway. The operational evaluation considering the locations where the EA operates has yet to be determined with each EA.

8.1 Input data

Variable	Spatial resolution	Temporal resolution	Time-coverage	Spatial coverage	Source
Adult female lice (count/fish)	MultiPoint	Weekly	2012-2019	Norwegian coast	Fish farms (BarentsWatch)
Mobile lice (count/fish)	MultiPoint	Weekly	2012-2019	Norwegian coast	Fish farms (BarentsWatch)
Sessile lice (count/fish)	MultiPoint	Weekly	2012-2019	Norwegian coast	Fish farms (BarentsWatch)
Sea Surface Temperature (°C)	800 m	Daily	2012-2019	Norwegian coast	Norkyst-800 (MET) (https://doi.org/10.1007/s10236-020-01378-0)
Sea Surface Salinity (PSU)	800 m	Daily	2012-2019	Norwegian coast	Norkyst-800 (MET)
Surface water velocity (m/s)	800 m	Daily	2012-2019	Norwegian coast	Norkyst-800 (MET)

8.2 Validation Data

Variable	Spatial resolution	Temporal resolution	Time-coverage	Spatial coverage	Source
Adult female lice (count/fish)	MultiPoint	Weekly	2020-2024	Norwegian coast	Fish farms (Barentswatch)

			2025 & 2026		

8.3 Output Data

Variable	**Spatial resolution**	**Temporal resolution**	**Time-coverage**	**Spatial coverage**	**Source**
Adult female lice (count/fish)	MultiPoint	Weekly	2020-2024 2025 & 2026	Norwegian coast	Life forecast model
Probability of adult female above 0.5 counts/fish (%)	MultiPoint	Weekly	2020-2024 2025 & 2026	Norwegian coast	Lice forecast model

9 Potential limitations of the approach and Conclusions

The Norwegian EAs have expressed interest in using a wide range of satellite-based products or parameters, if they are available in sufficient quality, also beyond the scope of the EO4SA Use Case. Their foci are on the same or similar parameters that they already measure using in situ methods. Through our questionnaire survey, the Early Adopters have addressed needs for access to other satellite EO data that are beyond the scope of the proposed Use Case in EO4SA. We will guide the EA to seek such information, where it may be available.

The EA´s particularly find the salmon lice predictability relate to the lice density, probability, regional risk assessments and the impacts of delousing methods or medications, as at least “useful” and some EAs also as “essential” for their relevant operations (see also Table 2). In the implementation of the sea lice prediction model, we initially expected to prioritise between providing predictions of salmon lice density or probability (risk) predictions. However, based on the EAs requirements we will provide forecasted both salmon lice density (counts per fish), and the probability (%) of salmon lice density reaching levels above 0.5 counts/fish (the threshold for alerts). This operational priority and their usefulness will be assessed later in the project implementation in consultation with each of the EAs.

Concerning the geographical, temporal and frequency of prediction updates, all EAs seem to be consistent. The Use Case predictions shall be updated weekly. Concerning analysis of past-time data, this will primarily be done for validations of the sea lice prediction models and research studies of our own interest. The EO4SA Use Case predictions will focus on near-real-time and short-term weekly forecasting, in consistency with the EA requirements. The geographical coverage will be multi point following the fish farms' locations along the entire Norwegian coastal waters. Information in multi-point format that discriminates between different production areas is important to be able to implement potential countermeasures against salmon lice infestation.

Concerning the dissemination of the output of the Use Case, the various EAs have different requirements covering integration into their own or external systems and to be served by the EO4SA team. Here, the project will develop flexible solutions and data formats, including API services for its own further use of the output data. Automation of descriptive assessment reports will be further investigated, since this will require regular human interface in the service operations.

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ATTACHMENT 1: Questionnaire used for Early Adopters Survey of the two Norwegian Use Cases (12 pages)

Added PDF file with 12 pages

Earth Observations for Sustainable Aquaculture (EO4SA) Early Adopters Requirements

Thank you for being willing to participate as an Early Adopter to the project **Earth Observations for Sustainable Aquaculture (EO4SA)** funded by the European Space Agency (ESA).

In the EO4SA project the Nansen Center (NERSC) in Norway, Plymouth Marine Laboratory in UK, the Institute of Marine Research (IIM-CSIC) in Spain and the Western Philippines University will implement four use cases related to:

1. Predicting risks of salmon lice infestation in Norway.
2. Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway.
3. Optimising location of sustainable shellfish farming and tourism in Galicia, Spain.
4. Mapping aquaculture structures and use of marine resources in Palawan, Philippines.

In this questionnaire we wish to obtain information about your current activities relevant to one or more of the four Use Cases and gather your initial requirements for Earth Observation based products that can be used in your operations/responsibilities related to aquaculture. If multiple Use Cases are relevant, we kindly ask you to respond to the survey separately for each Use Case.

We will use your responses in the questionnaire, together with a follow up meeting, to tailor the Earth Observation products to your needs. During the implementation of the EO4SA project, we will further discuss and iterate with you how best to develop these information products, to be useful to you and your operations. Towards the end of the EO4SA project (fall 2026) we will ask you to contribute to our assessment and validation of the final products developed for each Use Case.

The questionnaire will take about 30-40 minutes to complete. **Spørsmålene kan også besvares på norsk.**

The information you give will be stored under UK/Norwegian General Data Protection Regulation (GDPR) to ensure that all data are secure. Answers that you will give will be shared amongst the EO4SA project Team, as well as with the European Space Agency. They may also be used in scientific publications, presentations and reports to ESA, however the respondent will be anonymised. Your response is solely to advance the usefulness of the EO4SA information products to be developed. Please do let us know if it is not acceptable for you to respond under these conditions.

The EO4SA Team

* indikerer at spørsmålet er obligatorisk

1. E-postadresse *

Information about you

In this section we want to identify who you are, your organisation, and your position in it.
Spørsmålene kan også besvares på norsk.

2. What is your name? *

3. What is your surname? *

4. In which organisation or company do you work? *

5. What is your role or position in your organisation? *

6. What type of organisation is it? (Select as many as relevant) *

Merk av for alt som passer

- [ ] Non-Govermental Organisation (NGO)
- [ ] Government Agency
- [ ] Research institute
- [ ] Park or local management authority
- [ ] Private Company
- [ ] Financial institution
- [ ] Andre: ______________________

Information about your interest in and potential use of the EO4SA Use Cases

NERSC and PML will implement, demonstrate and validate EO-based information products for four Use Cases related to aquaculture in Norway, Spain and the Philippines.

7. In which of the four EO4SA Use Cases are you participating? Multiple choices are possible, but preferably respond separately for each Use Case (by completing the questionnaire once for each Use Case).

Merk av for alt som passer

- [ ] 1. Predicting risks of salmon lice infestation in Norway.
- [ ] 2. Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway.
- [ ] 3. Optimising multi-use of marine areas for shellfish farming and tourism in Galicia, Spain.
- [ ] 4. Mapping aquaculture structures and use of marine resources in Palavan, Philippines.

8. Briefly describe the responsibilities or activities of you/your organisation of relevance to the Use Case selected above.

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Your current monitoring and assessment activities relevant to the EO4SA Use Case.

If you have any ongoing activities /responsibilities related to the topic of the selected Use Case, we would like to know about this.

9. Do you, your organisation or any others carry out or use regular (environmental) monitoring for your site-location or area of responsibility, in this context?

Markér bare én oval.

- Yes
- No *Hopp til spørsmål 18*

10. If you carry out/use any relevant monitoring or assessment activities, please elaborate thi briefly:

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11. What environmental and other variables do you monitor - carried out yourself or through other sources? (please select those relevant to you)

Merk av for alt som passer

- [ ] Physical variables (temperature, salinity, currents, etc.)
- [ ] Chemical variables (Dissolved Organic Carbon , Particulate Organic Carbon, pH, turbidity, etc.)
- [ ] Biological variables (Chl-a, Harmful Algal Blooms, primary production, toxins, etc.)
- [ ] Salmon lice density
- [ ] Medication or treatment actions
- [ ] I don't know
- [ ] Andre: _______________

12. Why do you measure the environmental or other variables selected in the previous question? (choose as many as relevant)

Merk av for alt som passer

- [ ] To monitor salmon lice infestation
- [ ] To monitor toxic HABs occurrences
- [ ] To predict optimal harvesting time
- [ ] To select new areas to locate my cages/aquaculture site
- [ ] To fulfil obligations with environmental standards or regulations
- [ ] To fulfil obligations with food/health standards or regulations
- [ ] To obtain (organic) certification for my product
- [ ] To support scientific studies
- [ ] Other, please elaborate below

13. Is your monitoring or assessment done to fulfill obligations with environmental regulations other directives or own company requirements? Please elaborate (national, EU- regulations or within your company, etc.)?

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14. Do you use satellite remote sensing based data for any of the above environmental variables? Please select:

Merk av for alt som passer

- [ ] Physical variables
- [ ] Chemical variables
- [ ] Biological variables
- [ ] Other, please elaborate below
- [ ] Andre: ______________________

15. If you already use any satellite based product(s), can you describe them briefly? Please be as specific as possible, and give: variable(s) measured, spatial resolution, frequency of updates, data provider etc..

16. If available, what satellite based products or parameters would be relevant for you? You can you assign their priority.

Merk av for alt som passer

	Not relevant	Useful	Essential
Sea surface temperature	☐	☐	☐
Sea surface salinity	☐	☐	☐
Dissolved Organic Carbon concentration	☐	☐	☐
Particulate Organic Carbon concentration	☐	☐	☐
pH	☐	☐	☐
Turbidity (or visibility)	☐	☐	☐
Chlorophyll concentration	☐	☐	☐
Harmful algal species	☐	☐	☐
Algae toxins	☐	☐	☐
Salmon lice density	☐	☐	☐
Location of cages	☐	☐	☐
Other, please elaborate below	☐	☐	☐

17. Please specify any other products and provide any other information you may find relevan

Initial requirements for the Use Cases to be developed in EO4SA

EO4SA will integrate use of EO data, in our development of information products for each Use Cases. Here you have the opportunity to give us feedback on your preferred requirements for these products and how they need to be shaped to better to fit your information needs.

18. **Predicting risks of salmon lice infestation** (in Norway). Please indicate the importance of the following information:

Merk av for alt som passer

	Not relevant	Useful	Essential
Predicting salmon lice density	☐	☐	☐
Probability levels (risks)	☐	☐	☐
Regional risk assessments	☐	☐	☐
Impacts of de-liceification/medications	☐	☐	☐
Advice on mitigation actions	☐	☐	☐
Other, please elaborate below	☐	☐	☐

19. **Predicting risks of salmon lice infestation:** What would be your preferred frequency of updates of the salmon lice predictions?

Markér bare én oval per rad

	weekly	bi-monthly	monthly	seasonally
One forecast	⬭	⬭	⬭	⬭

20. **Predicting risks of salmon lice infestation:** Please indicate your preferred spatial coverag
of the salmon lice predictions?

Markér bare én oval per rad

	local	regional/production area	entire Norway
Spatial coverage:	⬭	⬭	⬭

21. **Predicting risks of salmon lice infestation:** What is your preferred temporal coverage of th
salmon lice predictions?

Markér bare én oval per rad

	past period (2012 -)	present time	future time
Temporal coverage	⬭	⬭	⬭

22. **Predicting risks of salmon lice infestation**: To complement your above selections, do you
have any other requirements to share with us? Please list them and provide a short rationa

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23. **Forecasting toxic algal blooms (HABs) impacting shellfish farming** (in Norway). Please indicate the importance of the following products or information:

Merk av for alt som passer

	Not relevant	Useful	Essential
Predicting abundance/concentration	☐	☐	☐
Probability of toxic algae occurrences	☐	☐	☐
Actual algae toxins	☐	☐	☐
Regional risk assessments	☐	☐	☐
Advice on mitigation actions	☐	☐	☐
Other, please elaborate below	☐	☐	☐

24. **Forecasting toxic algal blooms (HABs) impacting shellfish farming**: What would be your preferred frequency of updates of the HAB forecasts?

Markér bare én oval per rad

	daily	weekly	bi-monthly	monthly
Updated	⬭	⬭	⬭	⬭

25. **Forecasting toxic algal blooms (HABs) impacting shellfish farming**: Please indicate your preferred spatial coverage of the HAB forecasts?

Markér bare én oval per rad

	local	regional/fjord	entire Norwegian coast
Spatial coverage:	⬭	⬭	⬭

26. **Forecasting toxic algal blooms (HABs) impacting shellfish farming**: What is your preferre temporal coverage of the HAB forecasts?

Markér bare én oval per rad

	past period (2016 -)	present time	future time
Temporal coverage:	⬭	⬭	⬭

27. **Forecasting toxic algal blooms (HABs) impacting shellfish farming**: To complement your above selections, do you have any other requirements to share with us? Please list them and provide a short rationale.

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Dissemination, data access and other suggestions

We would like to know how we can share the Use Case information and products with you.

28. How would your preference to receive information from EO4SA?

Merk av for alt som passer

- [ ] Descriptive text bulletin (distributed via e-mail, web-portal etc)
- [ ] Dedicated EO4SA Web-map portal
- [ ] Existing Web-map portal (please elaborate below)
- [ ] Data for inclusion in own or external existing decision support system etc.
- [ ] Direct consultations
- [ ] Other, please elaborate below

29. Are you already using any relevant information framework in which the Use Case information can be included?

Markér bare én oval.

- Yes
- No

30. **Information and data access:** Please elaborate on your preferred way of receiving information and data from the EO4SA User Case?

31. **Finally**: Do you have any other input or "success criteria" that you would like to share with us, to help us tailor the EO4SA Use Case development to better meet your information needs?

Many thanks!

We will follow up your response with a direct meeting with you.
If you have any questions or other information that we have not included in the questionnaire, please contact Lasse H. Pettersson, NERSC at lasse.pettersson@nersc.no or Victor Martinez Vicente, PML at vmv@pml.ac.uk.

Many thanks for your help.
The EO4SA team

ATTACHMENT 2: Summary of the EAs replies to the questions in the survey

As summarized in Table 2 (above) the following Figure 6 to Figure 15 presents the EAs responses to the questions addressed in the EO4SA questionnaire survey (Annex 1).

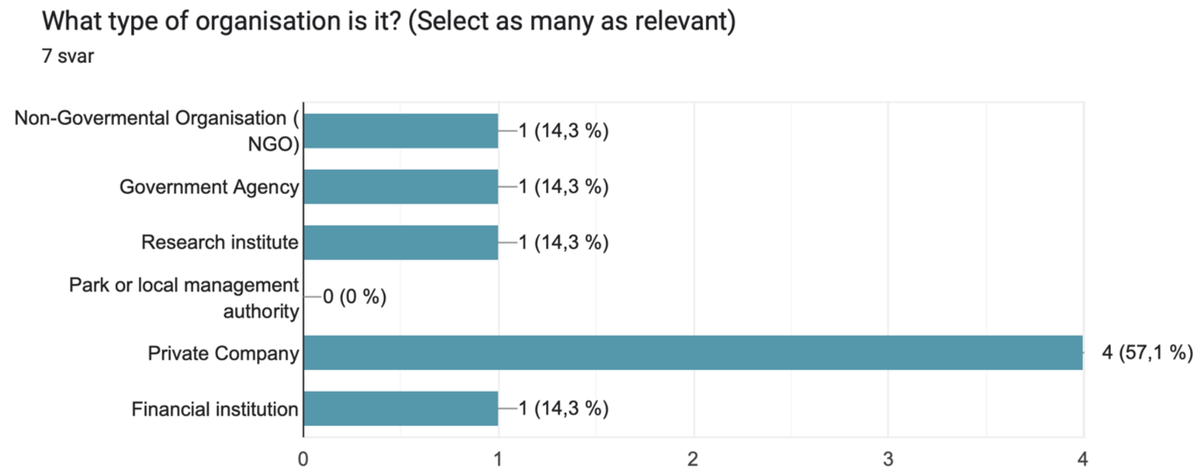

Figure 6: Types of organizations participating in the Norwegian use cases.

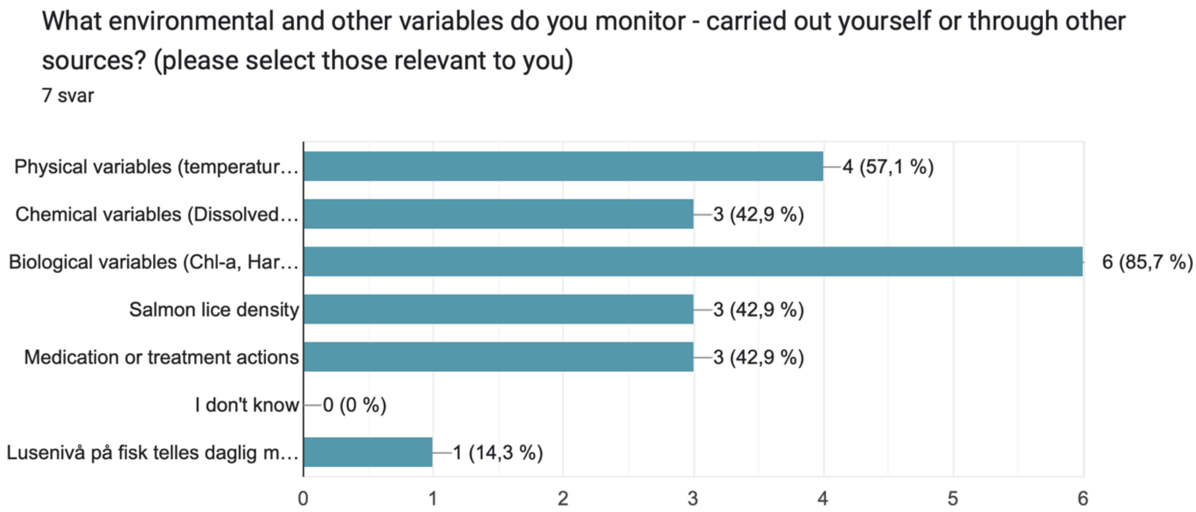

Figure 7: The EA´s have focus on the wide range of environmental data (physical, chemical and biological), as well as sea lice infestation and treatments, with a preference to the biological variables.

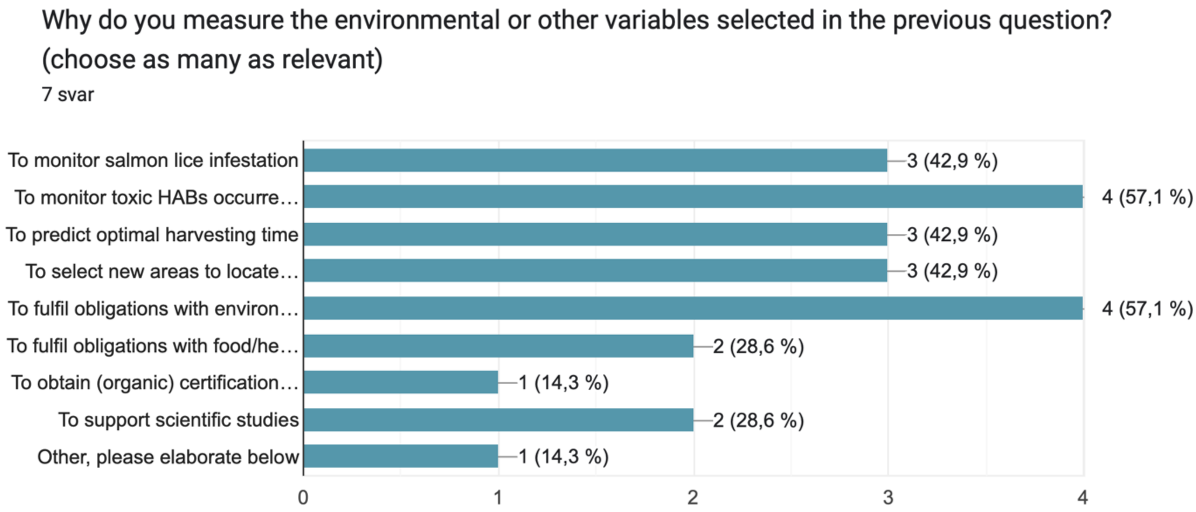

Figure 8: The EA´s need for data and information is triggered by own monitoring needs, optimalization of their operations, planning of new sites, to comply with regulations, and certification as well as to support scientific research studies.

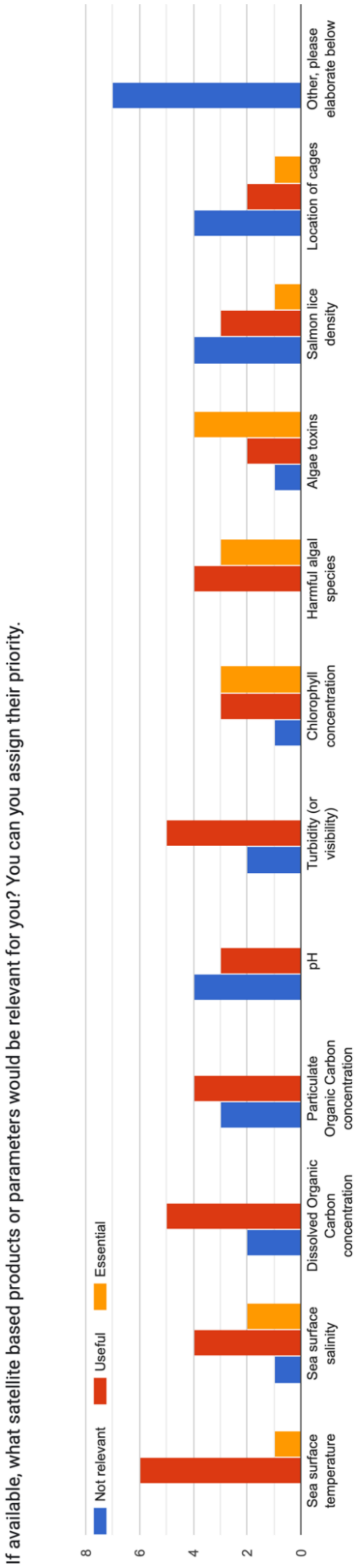

Figure 9: The EAs have interests in using a wide range of satellite-based products or parameters if they were available in sufficient quality, compared to the quality of similar measurements of in situ variables or provide (additional) insight into salmon lice predictability. The focus is on parameters that they already measure using in situ methods. Here, the responses "not relevant" are associated with EA´s prime interest in the other Use Case.

Predicting risks of salmon lice infestation (in Norway). Please indicate the importance of the following information:

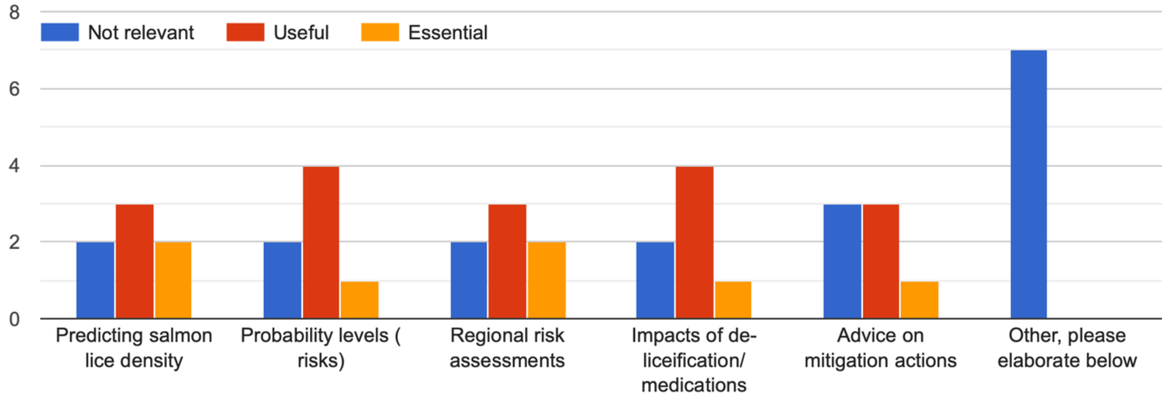

Figure 10: The EA particularly finds the salmon lice predictability relates to the lice density, probability, regional risk assessments and the impacts of delousing methods or medications, as at lease "useful" and some also as "essential". Here the responses "not relevant" are associated with EA´s prime interest in the other Use Case.

Predicting risks of salmon lice infestation: What would be your preferred frequency of updates of the salmon lice predictions?

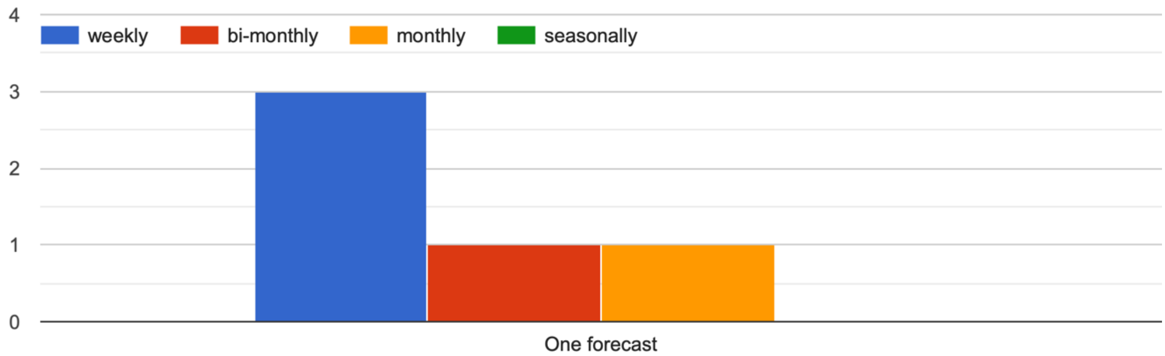

Figure 11: Most of the operational Early Adopters will require the frequency of the predictions are updated at weekly intervals. For the financial sector monthly up-dates are sufficient.

Predicting risks of salmon lice infestation: Please indicate your preferred spatial coverage of the salmon lice predictions?

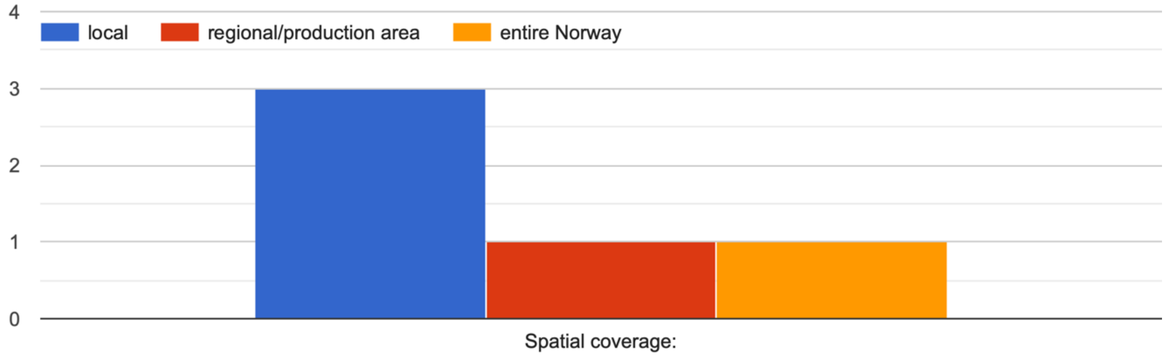

Figure 12: Most of the operational Early Adopters will use cases to cover the local area of operations. For the research institute and governmental agency, coverage of the entire Norwegian coast is needed.

Predicting risks of salmon lice infestation: What is your preferred temporal coverage of the salmon lice predictions?

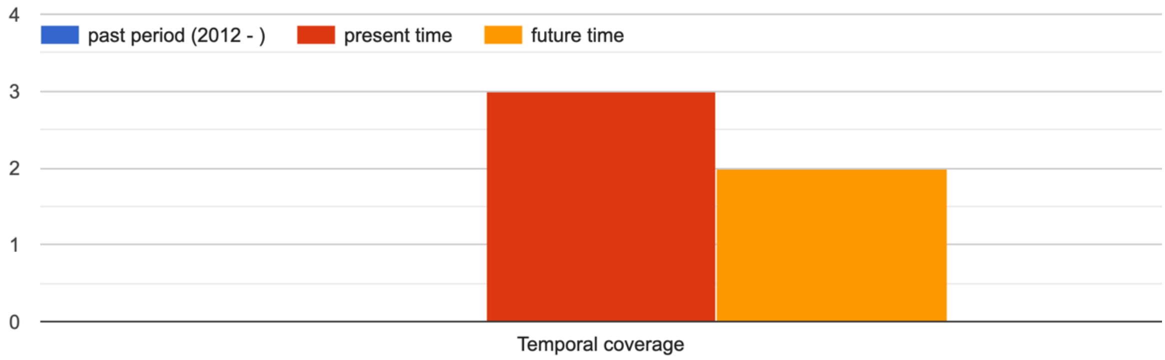

Figure 13: The Early Adopters are primarily interested in forecasting and nowcasting. None have explicitly expressed interests in past period data from 2012.

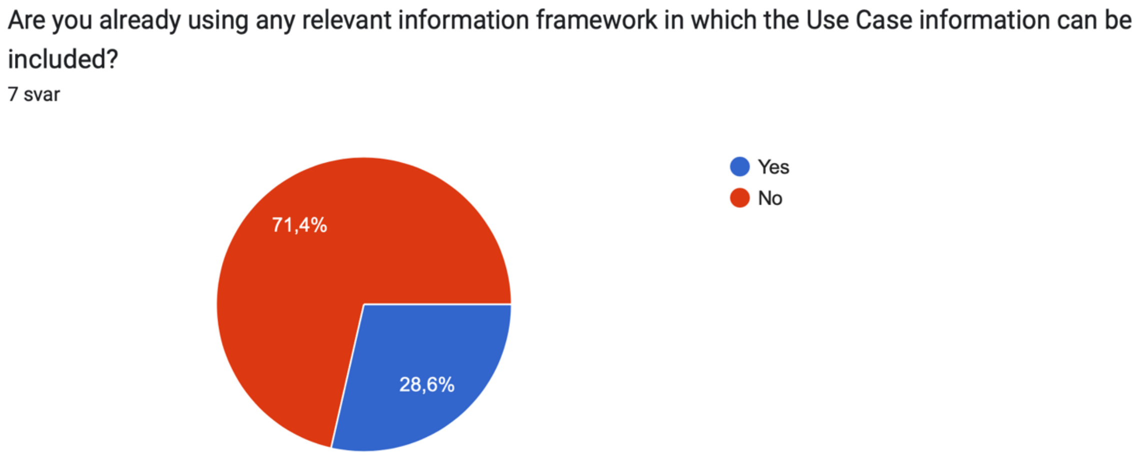

Figure 14: Many of the Early Adopters are already using some information system (internal or external) in which EO4SA Use cases may be integrated.

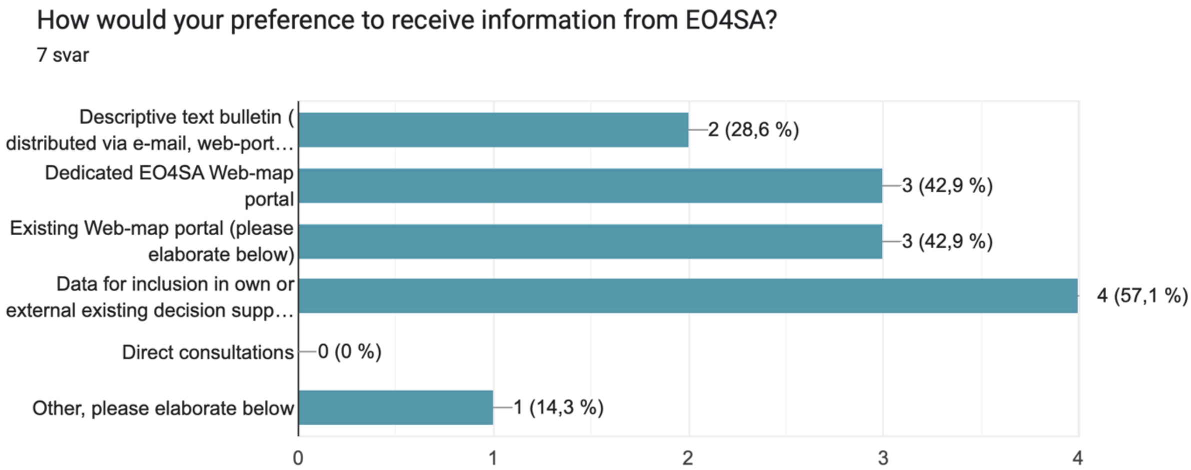

Figure 15: Based on the EA´s responses, we conclude that the distribution of the EO4SA Use Cases must provide data for presentation and dissemination via both project and other decision support systems, including a dedicated EO4SA web-map portal.

------- END of Document -------