Deliverable D1.2-B:

Requirements Baseline –
Use Case 2: Forecasting Toxic Harmful Algal Blooms (HABs) Impacting Shellfish Farming in Norway

by
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an ESA funded project implemented by
Nansen Environmental and Remote Sensing Center, Norway and
Plymouth Marine Laboratory, UK

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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 monitoring 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 groups 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 identify 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

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 in D1.2-A). 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 second of the four use cases: ***Deliverable D1.2-B: Baseline Requirements – Use Case 2: Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway.***

3 Use case 2: Forecasting toxic algal blooms (HABs) impacting shellfish farming in Norway

Shellfish or bivalve molluscs are filter-feeding organisms that are exposed to and accumulate microorganisms, natural algae toxins, heavy metals or other contaminants in the water masses. Human consumption of shellfish is therefore associated with health risks for consumers. This is a major security constraint and challenge for both the harvesting of naturally grown shellfish and the shellfish farming aquaculture industry.

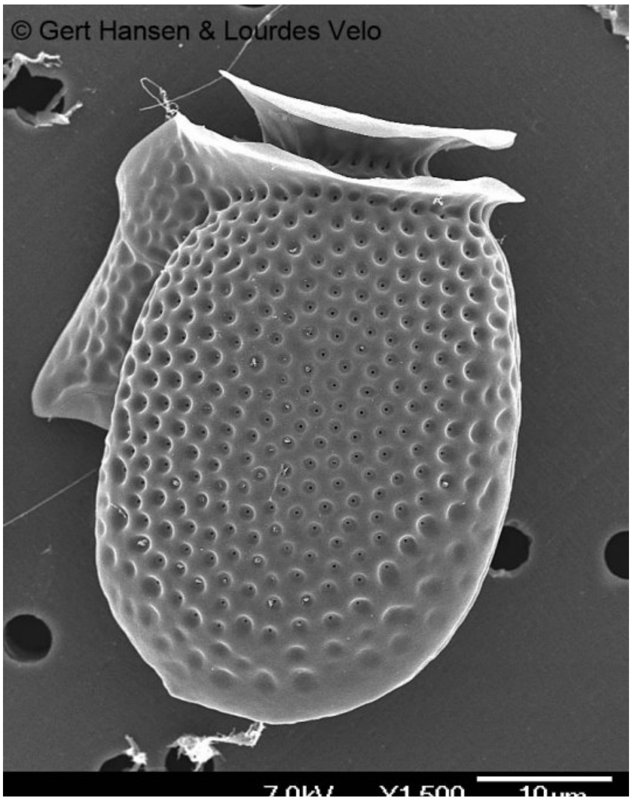

Figure 1. Dinophysis acuminata as an example of algae that produces toxins. ***Photo: Gert Hansen and Lourdes Velo.***

Some micro-algae produce toxins (Figure 1) as a survival strategy and become a problem when their abundance rapidly grows and cause harmful algae blooms (HAB) in coastal waters. These events have been one of the significant factors related to the decline of shellfish production in Europe, which has experienced a 20% decrease from 1990 to 2016 (Avdelas et al., 2021). Once shellfish are contaminated with toxins from HABs, they can remain poisonous for long periods, leading to substantial revenue losses for farmers (Jin et al., 2008). This issue is further exacerbated when the depurated shellfish, post-HAB, do not align with market demands and remain unsold (Martino et al., 2020). In Norway, the fish farming (salmon and trout) industry has significantly expanded over the last 50 years (see EO4SA Use case 1), while shellfish farming production has remained very small and relatively unchanged (*Figure 2*). In addition to domestic market demands, HABs have been identified as one of the main reasons for this stagnation and why some shellfish farmers have difficulties in establishing sustainable businesses (Ytrøy, 2008).

Shellfish farming is a low-trophic-level and sustainable aquaculture practice with a low CO_2 footprint (Suplicy, 2018). Therefore, there is a strong interest in expanding shellfish farming and developing more sustainable operations in supplying shellfish for the commercial consumption market. Also, harvesting of naturally grown shellfish is common in some areas.

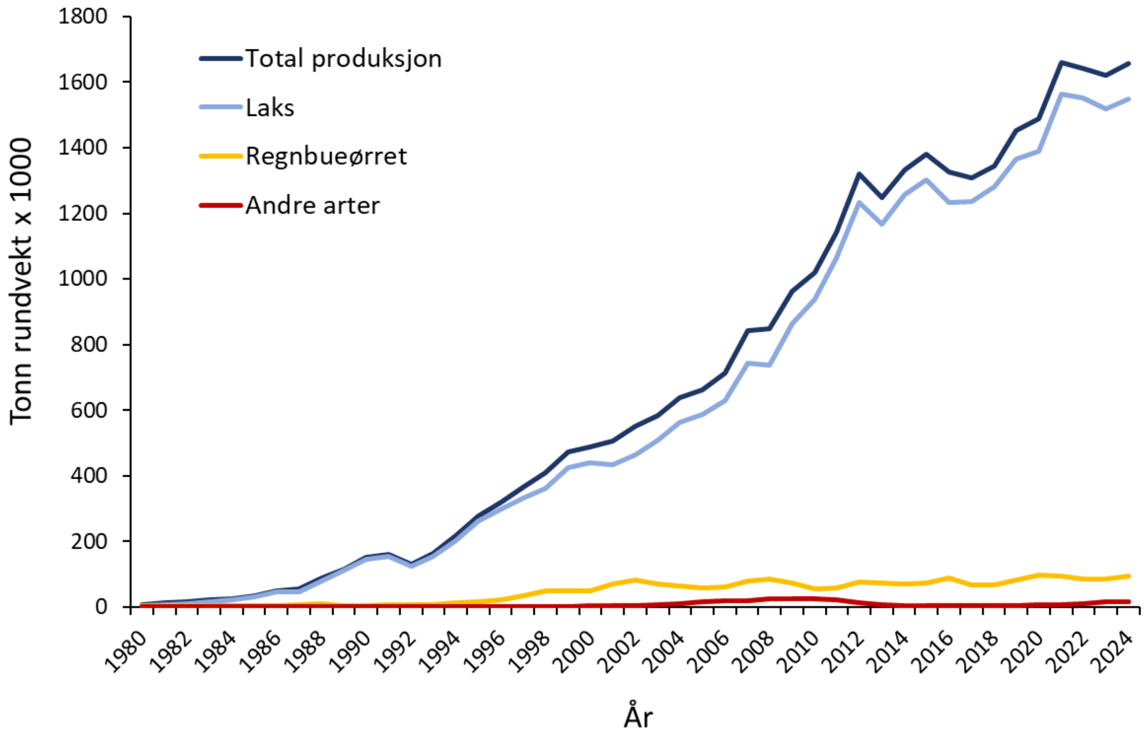

Figure 2: Development of aquaculture production in Norway in the period 1980–2024: total production (dark blue line), Atlantic salmon (Salmo salar) (light blue line), rainbow trout (Oncorhynchus mykiss) (yellow line) and other species including other fish species, shellfish and kelp (red line). Adopted from Figure 1.1. in Grefsrud et al, (2025).

Natural algae growth in coastal waters is among others controlled by the environmental conditions. These include sea surface temperature (SST), salinity, light or photosynthetically active radiation (PAR), and mixed layer depth (MLD) (Karlson et al., 2021). Many of these parameters are directly or indirectly monitored through satellite Earth observation (EO) data. Therefore, EO-based data can also be used as input for HAB forecast models, which is a common approach in many studies worldwide (Cruz et al., 2021; González Vilas et al., 2014; Silva et al., 2023; Silva et al., 2024). Making available sub-seasonal HAB forecasts to shellfish farmers has the potential to empower them with tools to reduce revenue loss and sustain healthy products. For example, they could harvest shellfish prior to forecasted contamination and better plan seasonal supply to the market based on the risks associated with the outbreaks of HABs (FAO et al., 2023). Consequently, such improvements could aid the development of the shellfish farming industry.

4 Current relevant regulatory (policy) and operational framework

Health issues associated with the consumption of shellfish are regulated to safeguard both consumption of naturally grown and aquaculture shellfish. The regulations are diversified for filter-feeding (bivalve molluscs) and none non-filter-feeding species, for natural harvesting and commercial production, as well as for private consumption and commercial sales. There are more comprehensive regulations associated with the commercial production and trade of shellfish; however, the final responsibility for the quality assurance of the products lies with the individual industrial company.

The Norwegian Food Safety Authority (NFSA) has since 2006 been responsible for the implementation of the National Monitoring Programme (Nasjonalt tilsynsprogram) supporting the production and harvesting of shellfish and other molluscs. Presently, this is legally founded on the Norwegian Regulations on public control – animal production, which came into force in April 2020. This Norwegian regulation is founded on the requirements of the Regulation (EC) No 854/2004 (29. April 2004) of the European Parliament and of the Council on the specific rules for the organisation of official controls on products of animal origin intended for human consumption. Further relevant specifications for its implementation are given in Regulation (EU) 2019/627 of 15 March 2019, addressing uniform practical arrangements for the performance of official controls on products of animal origin intended for human consumption. These regulations found the basis to assure uniform European practice (EU and EEA countries) for performing public controls on products of animal origin intended for human consumption. The latter regulation specifically addresses the classification of production and relaying areas for live bivalve molluscs under its *Title V: Specific requirements for official controls concerning live bivalve molluscs from classified production and relaying areas*.

To comply with the above regulations, NFSA have for Norwegian waters:

- *fix the location and boundaries of the production and relaying areas;*
- *classify production and relaying areas from which they authorise the harvesting of live bivalve molluscs as Class A, Class B and Class C areas according to the level of faecal contamination;*
- *fix a review period for sampling data from each production and relaying area in order to determine compliance with the standards.*

The implementation of the monitoring of production and relaying areas and the health quality of the shellfish requires further that:

- *The number of samples, geographical distribution of sampling points and sampling frequency for the programme shall ensure that the results of the analysis are representative of the area in question.*
- *(a) that there is no malpractice with regard to the origin, provenance and destination of live bivalve molluscs;*
- *(b) the microbiological quality of live bivalve molluscs in relation to the classified production and relaying areas;*
- ***(c) for the presence of toxin-producing plankton in production and relaying waters and marine biotoxins in live bivalve molluscs;***
- *(d) for the presence of chemical contaminants in live bivalve molluscs.*

In relation to (c) above, the sampling requirements are further specified:

- *Sampling plans to check for the presence of toxin-producing plankton in the water in classified production and relaying areas and for marine biotoxins in live bivalve molluscs shall take particular account of possible variations in the presence of plankton containing marine biotoxins.*
  This sampling shall comprise:

a) periodic sampling to detect changes in the composition of plankton containing toxins and their geographical distribution. Results suggesting an accumulation of toxins in live bivalve mollusc flesh shall be followed by intensive sampling;

b) periodic toxicity tests using live bivalve molluscs from the affected area most susceptible to contamination.

Accordingly, there is a legal European and national regulatory framework for securing health safety issues for consumers with tailored actual monitoring program during the main growth seasons. This monitoring and its assessments are implemented and used by the authorities and the aquaculture industry to achieve compliance. The National Monitoring Programme is a combination of dietary advice to the public and supervision at commercial shellfish farm locations.

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

Production and harvesting of shellfish are established activities in Norwegian coastal waters; however, for various reasons, at a significantly smaller scale than finfish aquaculture (see *Figure 2*). The main focus of the shellfish aquaculture industry in Norwegian waters is on blue mussels (*Mytilus edulis* - blåskjell), but also scallops (*Pecten maximus*) are harvested from wild stocks, and in more recent years also e.g. Pacific oysters (*Crassostrea gigas*), European flat oysters (*Ostrea edulis*), banded carpet shells (*Polititapes rhomboides*), razor clams (*Solenidae spp*) and green sea urchins (*Strongylocentrotus droebachiensis*), to mention some. The main commercial mussel industry is currently geographically located around two packing plants in Trøndelag (central Norway), with production locations in Trøndelag and on the Helgeland coast. Several produces (licences) are located elsewhere along the coast, primarily in the southwest parts of Norway (**Error! Reference source not found.**). These have with more limited shellfish farming activities. In Trøndelag and the rest of Norway, our early adopter Norgesskjell AS is the main and largest commercial operator for shellfish farming (see EO4SA deliverable D1.1).

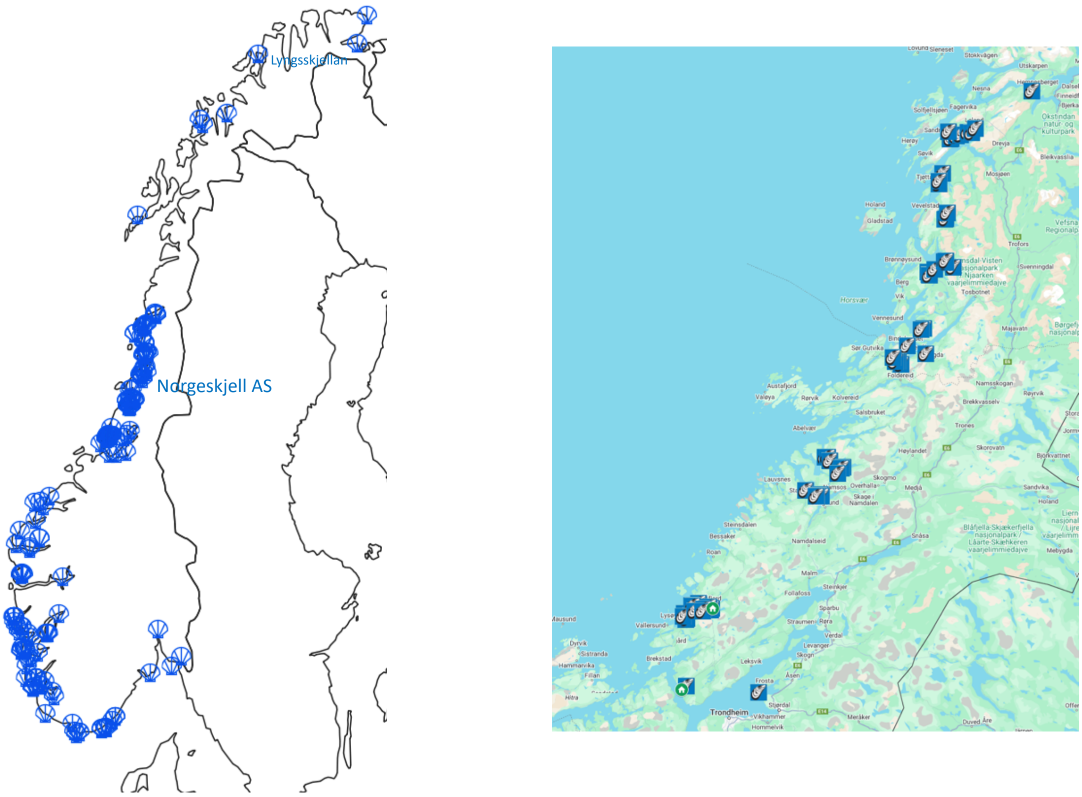

Figure 3: Left: All approved licences (158) for shellfish (i.e. molluscs, crustaceans, echinoderms) production in Norway. Not all may have active production. Source: Fiskeridirektoratet. The production locations two EAs are indicated.
Right: The production and packaging locations of the Early adopter Norgeskjell AS (see Section 6.3). Source: https://norgeskjell.no

The NSFA national monitoring program is based on the in-situ sampling and subsequent analysis of shellfish and water samples. The shellfish samples are analysed for microbiological components, algal toxins, heavy metals, and environmental toxins. In addition, water samples are taken for algae counts. During the main annual algae growth season, weekly sampling is analysed by certified methods and laboratories. The sampling is performed by the shellfish farming industry itself at their own production locations, by the regional NSFA offices or by external research institutes, in compliance with the regulations. Microbiological analyses are used to assess the classification status, both for new production areas and areas that are already classified. Analysis of heavy metals and environmental toxins forms the basis for assessing the degree of pollution in the production areas. The results from algae counts and from algal toxin analyses are used to assess the occurrence of algal toxins along the entire coast and particularly in the production area where the samples are taken. In addition to taking samples in production areas, NFSA also examines the occurrence of toxin-producing algae and algal toxins in some areas along the coast where there is no commercial production of shellfish, but where the public collects shellfish for their own consumption or where such dedicated sampling can provide useful information. Together with the toxin results from the production areas in the inspection program, this sampling provides the basis for the NFSA´s mussel warning. NSFA have made the algae toxin data available for use within the EO4SA project, with the initial condition that it shall not be re-distributed further. NSFA has an open data sharing policy but want to maintain control of the re-distribution of their dataset. In case it will be used in a scientific publication, EO4SA will ask for permission to also publish these data, in accordance with good scientific publishing practice.

Sampling in production areas

The Norwegian Food Safety Authority's branch offices select production areas that are included in the inspection program based on commercial activity. The number of production areas that are included in the inspection program varies from year to year based on activity and the Norwegian Food Safety Authority's financial framework. The Norwegian Food Safety Authority does not inspect all production areas at the same time, and there is therefore a rotation of the areas that are sampled. When a production area participates in the inspection program, sampling is carried out throughout the calendar year.

The production areas covered by the inspection program are inspected as follows:

- Classification and follow-up of classification status: Twelve samples per year for E. coli analyses in shellfish, sampling approximately every four weeks
- Toxin-producing algae: weekly water sampling throughout the year
- Algal toxins in shellfish: 12 samples per year, sampling approximately every four weeks
- Chemical pollutants (heavy metals and some environmental toxins): sampling twice a year
- Sampling continues throughout a calendar year.

Harvest inspections and end-product inspection

The Norwegian Food Safety Authority also carries out random sampling during harvest (harvest inspections) and when the shellfish are on their way to the end consumer (end-product inspection). The purpose of such sampling is to examine whether the shellfish comply with the requirements set out in the regulations, particularly regarding the content of algal toxins and microorganisms.

The monitoring program

For 33 sampling locations along the entire Norwegian coast, NSFA receives and analyses algae and water samples weekly, during the main growth season, typically from March to October. These are the basis for their classification of each production area with respect to permissions for harvesting or not of live molluscs. The list of open and closed areas for harvesting of molluscs is made publicly available every Friday at the NFSA website **Høsteområder for levende muslinger** (Harvesting areas for live molluscs). This Mussel Alert provides information about where mussels may be poisonous and is a service for the public who wish to pick mussels for their own consumption. Harvesting is only permitted in areas that are positively classified. NSFA has the right to close harvesting of shellfish in the different production areas. For the shellfish farm industry, stricter requirements also apply to document the health status of their actual shells stocks brought to the commercial market, by final harvest and end-product inspections.

6 Early adopters and their specific requirements

This Norwegian Use Case has five Early Adopters, of which two are mainly involved in the other Norwegian 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.

Web-site: https://www.fiskeridir.no/English

Use case 2: Forecasting toxic algal blooms (HABs) impacting shellfish farming

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 Use 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.

The Directorate uses others (made by the industry and consultants) and carries out its own monitoring related to aquaculture sites. The data used includes Physical, Chemical and Biological variables.

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 responded that the forecasts of toxic algal blooms (HABs) will be useful to their operations and responsibilities. This includes predictions of abundance /concentration, probability of toxic algae occurrence and the actual algae toxins. Regional risk assessments and advice on mitigation actions. They need daily updates on the present time forecasts with local geographical coverage at the national monitoring sites. The Use Case shall cover the entire Norwegian coastal waters. High spatial resolution is important to be able to implement potential countermeasures against toxic HAB events.

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 Norwegian Institute of Marine Research (research institute)

Early Adopter: the largest national marine research institute and their research scientist (plankton expert).

Website: https://www.hi.no/hi/en

Use case 2: Forecasting toxic algal blooms (HABs) impacting shellfish farming

Response to survey: Institute of Marine Research (IMR) is tasked with coordinating the national monitoring program for HABs affecting the finfish and mussel industry. IMR is responsible for advising and reporting on HABs affecting aquaculture, and the risk assessment of toxin accumulation in shellfish on behalf of the Norwegian Food Safety Authority.

In this respect, IMR is undertaking sampling and monitoring of key ocean physical, chemical and biological variables both at their own locations and analysing samples collected by others. The monitoring is done to identify the occurrence and development of toxic HAB events, to comply with environmental standards and regulations, such as the EU Water Framework Directive and national environmental regulations (see Section 3). Further, the monitoring data are used to support scientific studies. IMR is currently utilising some satellite Earth observation data related to their various monitoring programs, including SST and global chlorophyll-a products that may be relevant to the EO4SA Use Case. In their HAB service, they have earlier used, to some extent, Chl-*a* data, based on global products. In the Use Case will be essential to have access to information on chlorophyll concentration, harmful algae species and algae toxins. Further, it will be useful to have access to additional information about sea surface temperature, sea surface salinity, DOC, and turbidity.

For IMR, it is essential that the forecasts of toxic algal blooms (HABs) include predictions of abundance /concentration, probability of toxic algae occurrence, the actual algae toxins and regional risk assessments. They need weekly updates on the present and future time forecasts with regional geographical coverage at the monitored locations across the entire Norwegian coast.

The forecast must have sufficient information about seasonal risks or monthly risks going forward. Ideally, this should be at the individual locality level, but regional assessments can be useful. They must also be able to distinguish between different algae toxins.

They have their own information framework for the integration of the forecasts. The information shall be delivered as a descriptive text bulletin (weekly updates), included in the existing web map portal and actual data/forecasts for inclusion in own or external existing decision support system. The forecasts should be presented as simple mapping solutions with colour codes for HAB risk, preferably categorised in low-, medium- and high-risk / probabilities.

6.3 Norgeskjell AS (private company)

Early adopter: a private company producing mussels and their CEO.

Website: https://norgeskjell.no

Use case 2: Forecasting toxic algal blooms (HABs) impacting shellfish farming

Quote from the Early Adopter: *"We will assist in the collection of data to the project on the development of forecasting of toxic algae".*

Response to survey: Norgeskjell AS is the largest producer of mussels in Norway. They will assist in the collection of data to project the development of forecasting of toxic algae. The company regularly monitors biological variables at their production sites, including Chl-a, Harmful Algal Blooms, primary production, algae toxins, etc.. Their measurements are primarily used to monitor occurrences of toxic HAB events, to predict optimal harvesting time and to select new areas to locate shellfish sites. Data and actual samples (water and molluscs) are provided to the National Monitoring Program weekly.

The environmental measurements are to be compliant with national and EU regulations for public control on animal production for human consumption (see Section 3). The company has no previous experience in using satellite Earth observation data products.

In their operations, it will be essential to have access to information on sea surface salinity, chlorophyll concentration and algae toxins. Further, it will be useful to have access to additional information about sea surface temperature, DOC, POC, pH and harmful algae species.

For Norgeskjell, it will be essential that the forecasts of toxic algal blooms (HABs) include predictions of abundance /concentration, probability of toxic algae occurrence and the actual algae toxins. Regional risk assessments and advice on mitigation actions will be useful information. They need daily updates on the present time forecasts with regional geographical coverage in the areas where they operate. They have no own information framework for integration of the forecast and prefer to get the information in an EO4SA web-portal, other existing web map portal (TBD) and actual data/forecasts for inclusion in their own or external existing decision support system.

6.4 Lyngsskjellan ENK Mussel- and seaweed production (private company)

Early adopter: a private company producing mussels and their founder and CEO.

Use case 2: Forecasting toxic algal blooms (HABs) impacting shellfish farming

Quote from the Early Adopter: EO4SA may contribute to *"I take water samples on behalf of Mattilsynet each week on my location "Kjempebakken"……. I use it to verify that my mussels can be sold".*

Response to survey: Lyngskjellan take water samples on behalf of the Norwegian Food Safety Authority each week at their production location "Kjempebakken". They sample biological variables (Chl-a, Harmful Algal Blooms, primary production, toxins, etc.). Their sampling is done to optimise their production by monitoring toxic HABs occurrences and to predict optimal harvesting time. The monitoring is done to fulfil obligations with environmental standards or regulations, as well as obligations with food/health standards or regulations, that is needed to verify that the mussels can be sold.

Lyngskjellan has access to some satellite EO data through IMRS´s AlgeStatus https://algestatus.hi.no/. Additional information on sea surface temperature and salinity, dissolved and particulate organic carbon concentration and turbidity (or visibility) will be useful.

Essential for their operations is information about Chlorophyll concentration, harmful algal species and algae toxins. For Lyngskjellan, it will be essential that the EO4SA forecasts of toxic algal blooms (HABs) include predictions of abundance /concentration, probability of toxic algae occurrence and the actual algae toxins. Also, regional risk assessments and advice on mitigation actions, e.g. early harvesting or transfer of the shells to tanks on land with water supply for the depth, will be useful. A use case with weekly updates, regional fjord coverage and present time forecasting is needed to be used in their operations.

Lyngskjellan have no experience in using a dedicated decision support system, so he prefers to get access to the forecasts through a dedicated EO4SA Web-map portal.

6.5 Sparebank 1 Sør-Norge ASA (financial institution)

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

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

Use case 2: Forecasting toxic algal blooms (HABs) impacting shellfish farming

Quote from the Early Adopter: 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 selections 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.

Monitoring of relevant environmental parameters include sea surface temperature, sea lice density, harmful algae species and locations of the cages.

HAB forecasts shall be for the present time and updated at monthly interval and covering 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 map-based bulletin preferably via e-mail.

6.6 Summary of the Early Adopters responses to the questionnaire survey

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 (see Table 1). All except one organization collects their own environmental data of relevance to the Use Case. These data will be used by the EAs within the project for their assessment of the Use Case. One EA use such information collected by others in their assessments. Some of their responses are relevant for both Norwegian Use Cases and some are unique. In Table 2 we extract the Early Adopters (5 in total) requirements of importance for the implementation of this Use Case on Predictions of toxic algal blooms for shellfish aquaculture (some overlap with the other Norwegian Use Case), based on the EO4SA survey. The background information for Table 2 is included in Appendix 1.

Table 2: Summary of each EAs response to the EO4SA 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. Institute of Marine Research	Nor. Directorate of Fisheries	Sparebank 1 Sør-Norge ASA	Norgeskjell AS	Lyngsskjellan ENK
What environmental and other variables do you monitor or monitor through other sources?	Physical (e.g., temperature)	■	■			
	Chemical (e.g., DOC)	■	■			
	Biological (e.g., Chl-a)	■	■		■	■
	Salmon lice		■	■		
	Medication or treatments		■			
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	Red	Red
	SSS	Red	Red	Blue	Orange	Red
	DOC	Red	Red	Blue	Red	Red
	POC	Blue	Red	Blue	Red	Red
	pH	Blue	Red	Blue	Red	Blue
	Turbidity	Red	Red	Blue	Blue	Red
	Chl-a	Orange	Red	Blue	Orange	Orange
	HAB species	Orange	Red	Red	Red	Orange
	Algae toxins	Orange	Red	Blue	Orange	Orange
	Salmon lice density	Blue	Red	Red	Blue	Blue
	Location of cages	Blue	Red	Red	Blue	Blue
Indicate the importance of the following information for the product. Blue for not relevant, red for useful, and orange for essential.	Algae abundance	Orange	Red	Blue	Orange	Orange
	Probability of HAB	Orange	Red	Blue	Orange	Orange
	Toxins	Orange	Red	Blue	Orange	Orange
	Regional risk assessments	Orange	Red	Blue	Red	Orange
	Advice on mitigation	Blue	Red	Blue	Red	Orange
What would be your preferred frequency of updates of the HAB estimations?	Daily		■		■	
	Weekly	■				■
	Monthly			■		
	Bi-monthly					
What is your preferred temporal coverage of the HAB estimations?	Past					
	Present				■	■
	Future	■	■			
What would be your preferred spatial coverage of the HAB estimations?	Local (e.g., local farm)		■			
	Regional (e.g., fjord)	■			■	■
	Entire Norwegian coast					
How would your preference to receive information from EO4SA?	Descriptive text bulleting	■				
	EO4SA web portal				■	■
	Existing web portal	■			■	
	Data for including in own system	■	■		■	
	Direct consultations					

7 Algorithms available – Baseline and innovative

Compliant with the contractor's baseline proposed algorithm and the Early Adopters specific requirements, EO4SA will provide probability of algae toxin abundance reaching above sanitary levels as developed in Silva et. al (2024). This method will be adapted to the Norkyst-800 as input, which will allow the models to provide HAB probability estimates at 800 m spatial resolution, allowing the regional/local estimations of HAB required by the EAs. Furthermore, EO4SA will capitalize also on the method and application in Silva et al. (2023) (Figure 13) but for the forecasting the probability of toxins concentration in the blue mussels reaching hazardous levels. The toxin probability model will use as predictors the Norkyst-800 and the past abundance of harmful algae in each shellfish farms. Toxin will be included in the forecasting model as it was one of the main requirments from the EAs. Finally, the probabilistic models for HABs and toxins will be calibrated by using Support Vector Machines (SVM).

The baseline models will be calibrated for seven day forecasts;. This will enable real-world testing of HAB forecasting in operational settings and facilitate the development of potential mitigation strategies based on the early warnings provided by model predictions. Here the interactions with and additional data from the Early Adopters will be essential.

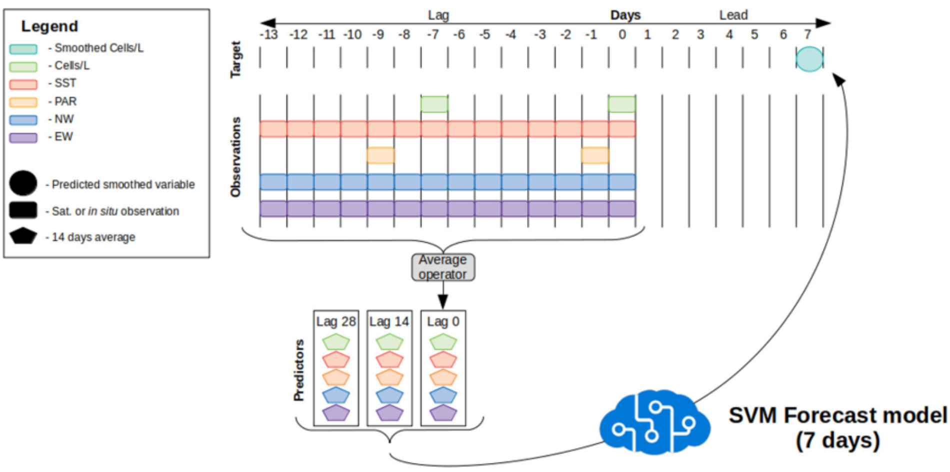

Figure 4. Conceptual model methodology for forecasting D. acuminata abundance in the Lyngen fjord demonstrated in Silva et al. (2023). Note that all observations are based on remote sensing. SVM is for Support Vector Machine, NW is for Northward Wind, and EW is for Eastward wind (Silva et al., 2023).

8 Datasets available

A summary of the available data sets are given in **Error! Reference source not found.**.

The main desired target by the EAs is the probability of HABs and toxin contamination, and therefore we will change from abundance forecast to probability forecast as the output dataset available to them. For both HABs and toxin contamination, the input of the models are the sea surface temperature (SST), sea surface salinity (SSS), and mixed layer depth (MLD) from the Norkyst-800 ocean model. Past algae abundance is an additional input for the probability of toxin contamination. We have concluded to use Norkyst-800 because routinely Level 4 EO will have too many gaps in the inner fjords, due to coarse spatial resolution. Besides, near-real-time EO processed images covered by clouds, which may impact the one-week forecast required by the EA. The input data (used for training), therefore, include Norkyst-800 and past algae and toxin from 2006 to 2019. The one week probability forecast of HAB for four taxa and two group of toxins will be the output data, and the validation period from 2020 to

2026. Note that since the probability of toxin contamination depends on past algae abundance measured on the local farms, the data cannot be provided as a grid but instead as multi points following the farm locations.

8.1 Input data

Variable	Spatial resolution	Temporal resolution	Time-coverage	Spatial coverage	Source
Algae abundance of *Alexandrium* spp., *A. tamarense, D. acuta,* and *D. acumina* (Cells/L)	MultiPoint	Weekly	2006-2019	Norwegian coast	Shellfish farms (NFSA)
Toxin concentration of paralytic shellfish toxins and diarrheic shellfish toxins (µg/kg shellfish feed)	MultiPoint	Weekly	2006-2019	Norwegian coast	Shellfish farms (NFSA)
Sea Surface Temperature (°C)	800 m	Daily	2006-2019	Norwegian coast	Norkyst-800 (MET) (https://doi.org/10.1007/s10236-020-01378-0)
Sea Surface Salinity (PSU)	800 m	Daily	2006-2019	Norwegian coast	Norkyst-800 (MET)
Mixed Layer Depth (m)	800 m	Daily	2006-2019	Norwegian coast	Norkyst-800 (MET)

8.2 Validation Data

Variable	Spatial resolution	Temporal resolution	Time-coverage	Spatial coverage	Source
Algae abundance of *Alexandrium* spp., *A. tamarense, D. acuta,* and *D. acumina* (Cells/L)	MultiPoint	Weekly	2020-2026	Norwegian coast	Shellfish farms (NFSA)
Toxin concentration of paralytic shellfish toxins and diarrheic shellfish toxins (µg/kg shellfish feed)	MultiPoint	Weekly	2020-2026	Norwegian coast	Shellfish farms (NFSA)

8.3 Output Data

Variable	Spatial resolution	Temporal resolution	Time-coverage	Spatial coverage	Source
HAB probability (%)	800 m	Weekly	2025 & 2026	Norwegian coast	HAB forecast model
Toxin contamination probability (%)	MultiPoint	Weekly	2025 & 2026	Norwegian coast	Toxin forecast model

9 Potential limitations of the approach and Conclusions

The Norwegian EA´s have expressed interests 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 same or similar parameters that they already measure using in situ sampling and laboratory analysis. 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, including temperature, salinity, dissolved and particulate organic carbon (DOC/POC), pH, turbidity and chlorophyll-a. Beyond the Use Case, we will guide the EAs to seek such information, where it may be available.

Most EAs identify it as essential that EO4SA Use Case provides predictions of probability of occurrence of HABs and the actual algae toxins – i.e. predictions of both. Initially suggested predictions of toxic algae concentration is of less interest to our EAs. Some EAs find it also useful with regional risk assessments and advice on mitigation actions (one find this information as essential). In the implementation of the prediction model, we will prioritize probability (risk) predictions and eventually provide predictions of algae concentrations. This priority will be made later in the project implementation in consultancy with the EAs when the actual Use case implementation is presented (in WP3).

With respect to the geographical and temporal coverage predictions all EA´s seems to be consistent – local resolution with coverage of sites their own operations. Concerning the frequency of update the EA´s requirements range from daily to monthly. The analysis of past-time data this will primarily be done for Use Case validations and research studies of own interest, since it has not been specifically required by the any of the EAs. This EO4SA Use Case will focus on near real-time and short-term forecasting up to about one week, in consistency with the EA requirements. The geographical coverage will be local, however with EAs with interests along the entire Norwegian coastal waters, so the Use Case will cover the coast from south to north.

Concerning the dissemination of the output of the Use Case the various EAs have different requirements covering integration into own or external systems and to be served by the EO4SA team. Here the project will develop flexible solutions and data formats, including API solutions during the Use Case demonstrations. Automatization of descriptive assessment reports must be further investigated, since this will require regular service operations.

10 References

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APPENDIX 1: Summary of the EAs replies to the questions in the survey

As summarized in Table 2 (above) the following **Error! Reference source not found.** to **Error! Reference source not found.** presents the EA responses to the questions addressed in the EO4SA questionnaire survey (Annex 1 in D1.2-A).

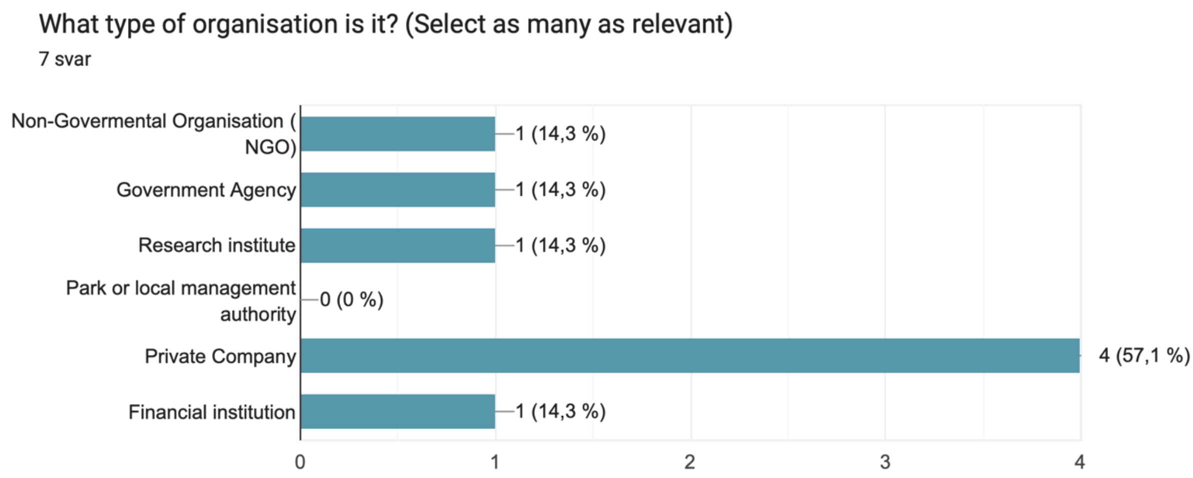

Figure 5: Types of organizations participating in the Norwegian use cases.

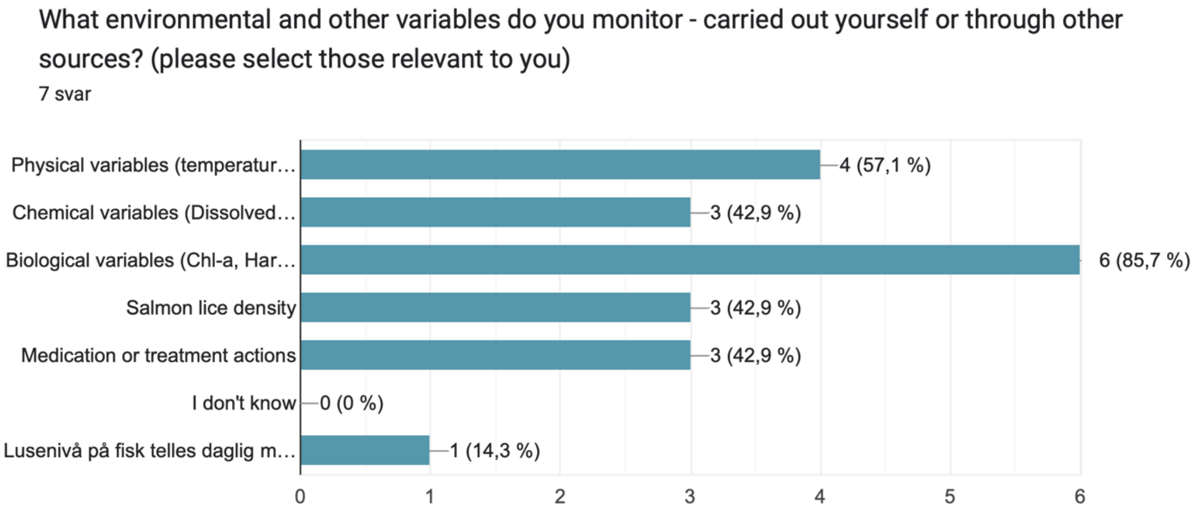

Figure 6: The EA´s have focus on the wide range of environmental data (physical, chemical and biological), as well as sea lice infestation and treatments, with a preference to the biological variables.

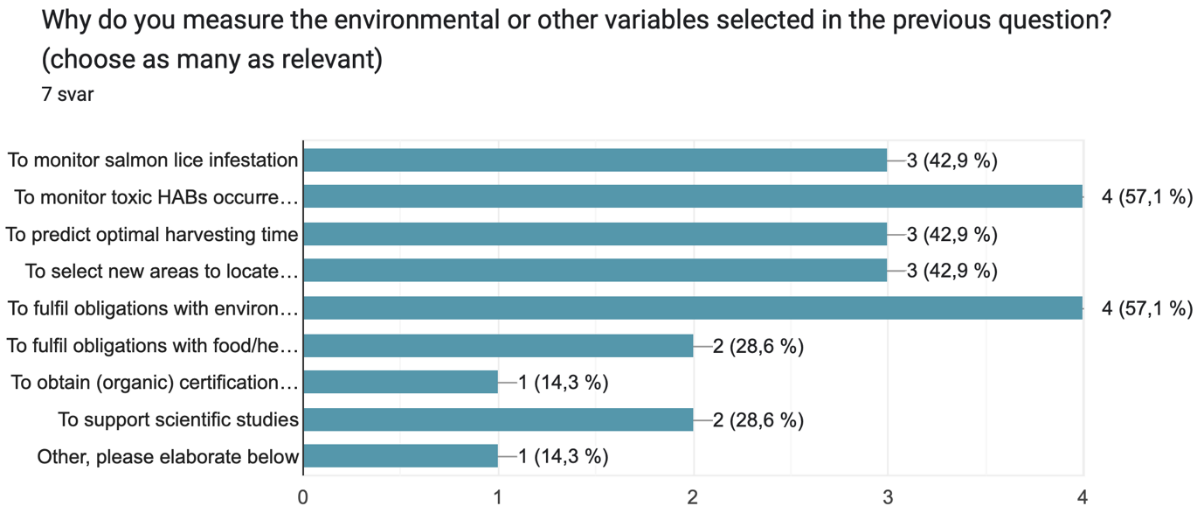

Figure 7: The EA´s need for data and information is triggered by own monitoring needs, optimalization of their operations, planning of new sites, to comply with regulations, and certification as well as to support scientific research studies.

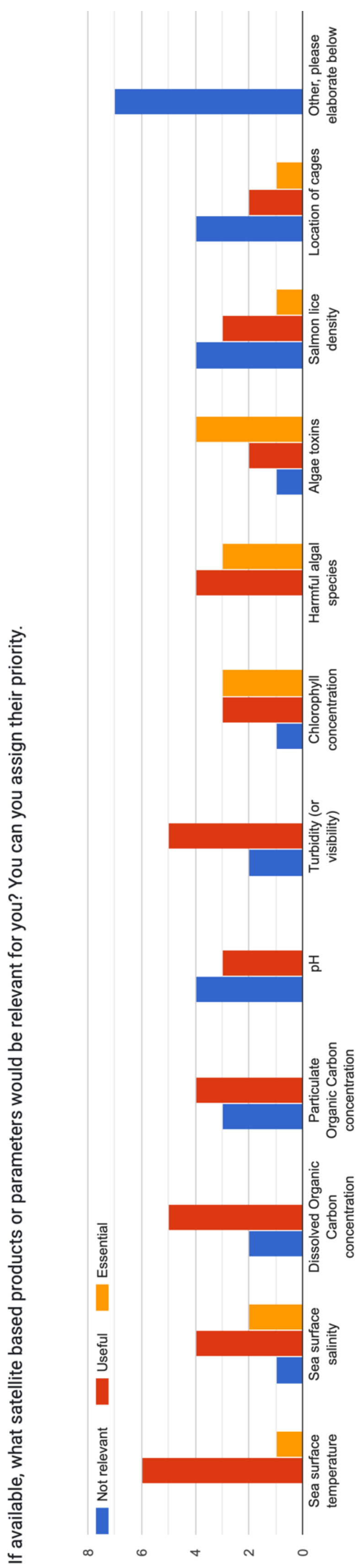

Figure 8: The EA´s have interests in using a wide range of satellite-based products or parameters if they were available in sufficient quality. The focus is on parameters already being measured using in situ methods. Here the responses "not relevant" are associated with EA´s prime interest in the other Use Case.

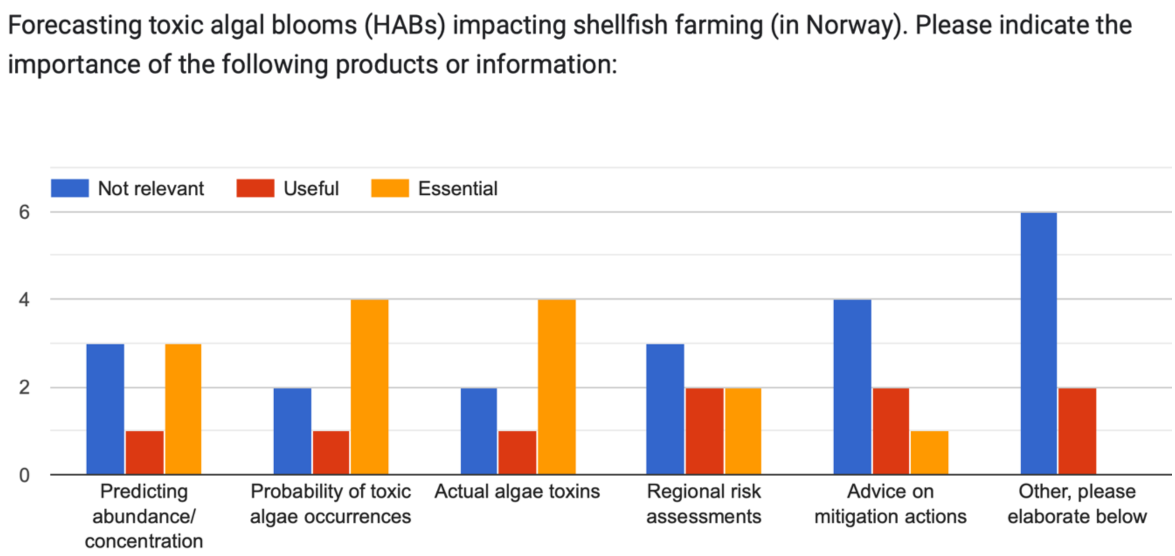

Figure 9: Most EA´s identify as essential to provide predictions of toxic algae concentrations, probability of occurrence and the actual algae toxins. Some EA´s find it also useful with regional risk assessments and advice on mitigation actions (one as essential). Here the responses "not relevant" are associated with EA´s prime interest in the other Use Case.

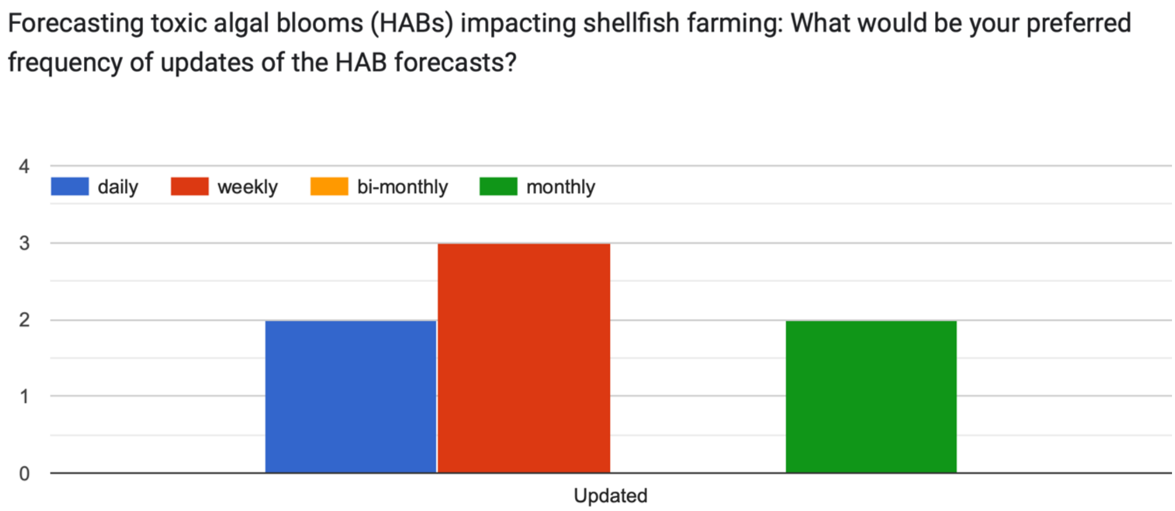

Figure 10: The EA respondents would like to have HAB forecasts updated every week, but also with daily to monthly updates.

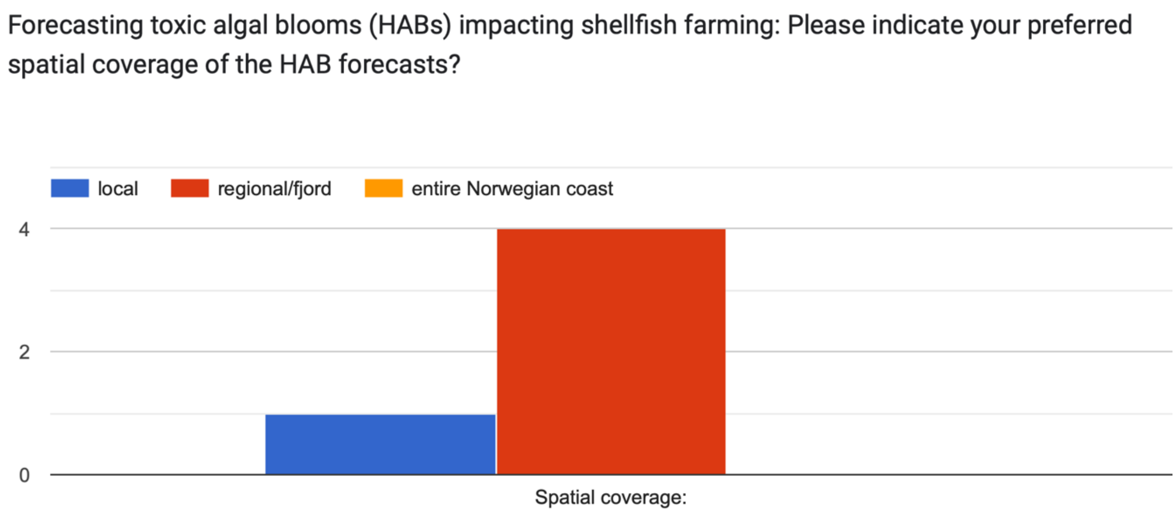

Figure 11: All EA respondents would like to have forecasts covering their relevant area of operations (regional/fjord).

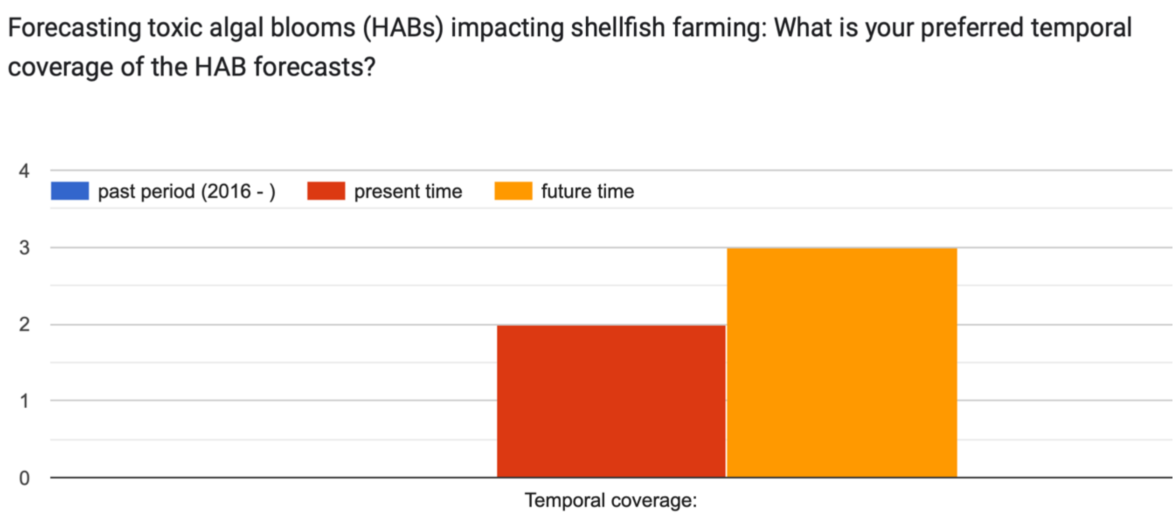

Figure 12: The Early Adopters are primarily interested in forecasting and nowcasting. None have expressed interests in past period data from 2016.

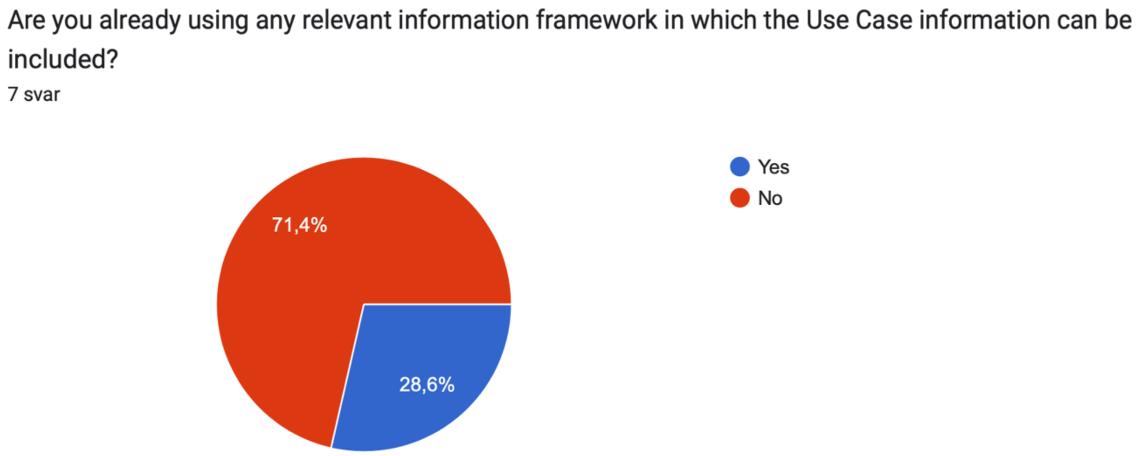

Figure 13: The majority of the Early Adopters are already using some information system (internal or external) in which EO4SA Use cases may be integrated.

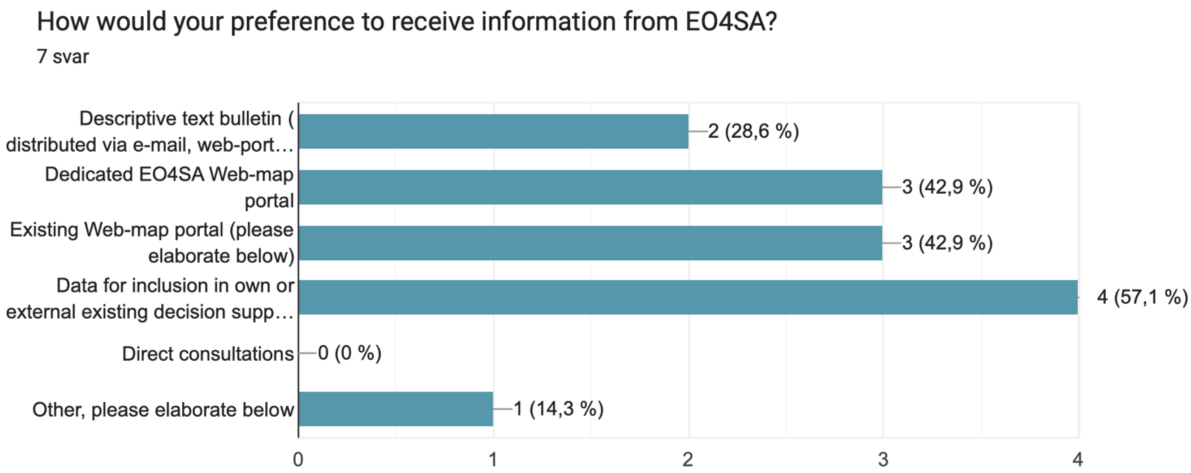

Figure 14: Based on the EA´s responses we conclude that the distribution of the EO4SA Use Cases must provide data for presentation and dissemination via, both project and other decision support systems, including a dedicated EO4SA web-map portal.

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