Deliverable 6.1

Review of the monitoring requirements and strategies for offshore low-trophic aquaculture

ULTFARMS

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Grant Agreement number	101093888
Project title	ULTFARMS - Circular Low Trophic Aquaculture in wind farms and Restoration of Marine Space
Deliverable title	Review of the monitoring requirements and strategies for offshore low-trophic aquaculture
Deliverable number	D6.1
Deliverable version	1
Contractual date of delivery	30 June 2023
Actual date of delivery	30 June 2023
Document status	Final
Document version	Reviewed - final
Online access	Yes
Diffusion	Public
Nature of deliverable	Report
Work Package	6
Partner responsible	RBINS
Contributing Partners	Deltares, FuE, KMF, UGent, DTU
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Abstract	The present document report on task 6.1 of the ULTFARMS project, and proposes a strategy for monitoring of low-trophic aquaculture in the North and Baltic sea, offshore and in a multi-use context. The strategy is divided into two main steps: baseline data collection and post-decision monitoring. The baseline data collection serves to assess the site suitability for aquaculture, to ensure that the best possible solutions are adopted and to provide a baseline scenario for future environmental impacts assessment. Post-decision monitoring is divided into three parts: operation, product and environment. The operation part encompasses monitoring the farm's yield and infrastructure. The product part addresses monitoring variables to ensure food quality and food safety. The environment part monitors the impact of the project on the marine environment. Given the novelty of low-trophic aquaculture in the North and the Baltic seas, and especially in combination with windfarms, existing regulations can be scarce. To remedy this gap, expert judgment and existing literature served to build the monitoring strategy proposed here. Additionally, existing legal requirements are described for the following countries; Belgium, Netherlands, Germany and Denmark, as they are the ones hosting the pilots of ULTFARMS. This monitoring strategy is meant to be used as a tool for offshore low-trophic aquaculture farms when implementing their project. It is a good starting point and should be further elaborated and adapted to fit each specific case.
Keywords	Monitoring, low-trophic aquaculture, offshore windfarms, ocean multi-use

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Acronyms

ADCP	Acoustic Doppler Current Profiler
ADI	Acceptable Daily Intake
ADV	Acoustic Doppler Profiler
ASP	Amnesic Shellfish Poison
ASTs	Amnesic Shellfish Toxins
BMM	Beheerseenheid van het Mathematisch Model van de Noordzee
BSH	Bundasemt für Seeschifffahrt und Hydrographie
DSP	Diarrhetic Shellfish Poison
DTX	Dinophysistoxin
EIA	Environmental Impact Assessment
EU	European Union
FASFC	Federal Agency for the Safety of the Food Chain
FPS	Federal Public Service
HABs	Harmful Algal Blooms
HPLC	High-Performance Liquid Chromatography
LISST	Laser In-Situ Scattering and Transmissometry
LNV	Ministerie van Landbouw, Natuur en Voedselkwaliteit
LTA	Low-Trophic aquaculture
MAH	Market Authorization Holder
MPN	Most-Probable Number
MRCC	Maritiem Reddings- en Coördinatiecentrum
MSFD	Marine Strategy Framework Directive
MWTL	Monitoring Waterstraatkundige Toestand des Lands
NIS	Non-Indigenous Species
NVWA	Nederlandse Voedsel- en Warenautoriteit
OBS	Optical Backscatter point Sensor
OWF	Offshore windfarm
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PSP	Paralytic Shellfish Poison

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PSTs	Paralytic Shellfish Toxins
PTX	Pectenotoxins
SPM	Suspended Particulate Matter
UXO	Unexploded Ordnance
ROV	Remotely Operated Vehicle
RV	Research vessel
RVO	Rijksdienst voor Ondernemend Nederland
TTX	Tetrodoxins
ULTFARMS	CircUlar Low Trophic Aquaculture in wind farms and Restoration of Marine Space
WP	Work package
YTX	Yessotoxins

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Executive Summary

The North and Baltic seas are industrialized, intensively used and heavily degraded seas. With new sectors emerging in the blue economy, solutions for optimal space use and sustainable use of marine resources are necessary. To this end, ULTFARMS investigates the possibility to combine low-trophic aquaculture farms and offshore windfarms. While challenges are numerous: working offshore, working in a multi-use context, etc. The potential for space-use reduction, as well as environmental and socio-economic synergies is high.

The present document reports on task 6.1 of the ULTFARMS project, and proposes a strategy for monitoring low-trophic aquaculture in the North and Baltic sea, offshore and in a multi-use context. The strategy is divided into two main steps: baseline data collection and post-decision monitoring. The baseline data collection serves to assess the site suitability for aquaculture, to ensure that the best possible solutions are adopted and to provide a baseline scenario for future environmental impacts assessment.

Post-decision monitoring is divided into three parts: operation, product and environment. The operation part encompasses monitoring the farm's yield and infrastructure. The product part addresses monitoring variables to ensure food quality and food safety. The environment part monitors the impact of the project on the marine environment.

Given the novelty of low-trophic aquaculture in the North and the Baltic seas, and especially in combination with windfarms, existing regulations can be scarce. To remedy this gap, expert judgment and existing literature served to build the monitoring strategy proposed here.

Additionally, existing legal requirements are described for the following countries; Belgium, Netherlands, Germany and Denmark, as these are the countries hosting the pilots of ULTFARMS.

This monitoring strategy is meant to be used as a tool for offshore low-trophic aquaculture farms when implementing their project. It is a starting point and should be further elaborated and adapted to fit each specific case.

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1. Introduction

Description of the project

ULTFARMS is a Horizon Europe project aiming to develop ocean multi-use in the North and the Baltic seas, specifically by combining offshore windfarms with low-trophic aquaculture and habitat restoration. This combination of activity has the potential to resolve conflicts over marine space use and achievement of some of the Green Deal's goals.

With 2030 Biodiversity goals demanding 30% of the seas protected, including 10% strictly protected, while Renewable energy goals aim for 45% of Europe's energy mix to come from renewable sources, marine space use is under a lot of pressure. Installing low-trophic aquaculture in offshore windfarms might help alleviate some of this pressure, by leaving more space elsewhere to be fully dedicated to marine conservation, while locally supporting habitat restoration.

Low-trophic aquaculture in the North and Baltic seas is in its very early stages but may rise in the future as a local and sustainable food source. Implementing aquaculture farms in offshore windfarms offers potential environmental, economic and social benefits, but also technical challenges, such as designing structures able to withstand harsh conditions (rough sea and climate) and dealing with the distance from shore.

Objective of task 6.1

This deliverable reports on task 6.1 of ULTFARMS: "Review of the monitoring requirements and development of an optimized monitoring strategy for full-scale offshore multi-use aquaculture". The objective of this task is to propose a monitoring strategy for offshore aquaculture farms. Monitoring is essential to ensure that activities are undertaken safely and efficiently, that products are suitable for consumption and that no harm is done to the ecosystem.

The proposed monitoring strategy will support operational activities undertaken under WP 4 – Demonstration: Testing, Deployment, Production and Processing, and will inform and support the biodiversity assessment and modeling in WP 7 – Environmental Sustainability Assessment.

Structure

The monitoring strategy is divided into two major steps: baseline data collection and post-decision monitoring.

The baseline data collection (section 2.1) refers to data that should be collected before installing the farm, to ensure that the area is appropriate for aquaculture. It also serves to create a primary overview of the zone, that can later serve as a baseline scenario for impact assessment of the activities on the environment.

The post-decision monitoring (section 2.2) refers to variables to monitor throughout the life of the project. This section is divided into three sub-sections that inform three different aspects to monitor: operation, product and environment. The operation sub-section refers to the functioning of the aquaculture farm and is further divided into two categories: infrastructure and yield. The product sub-section monitors food quality and food safety of what is farmed. The environmental sub-section addresses variables

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that inform how the environment is impacted by the farm and how the environment in turn impacts the farm's production.

In total four tables are described in this document, one for the baseline data collection and one for each of the three sub-sections of the post-monitoring data collection. Each table is described at the beginning of the section and is followed by a description of the legal requirements in the four countries that host the pilots of ULTFARMS: Belgium, Netherlands, Germany and Denmark.

The making of the present monitoring strategy was based on expert judgment and available legislation and literature.

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2. Monitoring strategy for offshore commercial aquaculture farms

2.1 Baseline data collection

Baseline data collection serves to assess the suitability of the selected site and to provide information for future comparison to assess environmental impact. The proposed monitoring scheme for baseline data collection for offshore aquaculture projects is listed in Table 1 "Baseline data collection for offshore low-trophic aquaculture". The following variables are recommended to be monitored once before the implementation of the aquaculture farm.

Assessment of the seabed is done by mapping the seabed with acoustic methods (Bean et al., 2017), looking at seabed typology, with core penetration tests, and by looking for potential undefined explosive objects and the presence of any other objects on the seafloor, using multibeam technology. This information is necessary for safe anchoring in the area.

Additionally, to fill knowledge gaps about the impact of aquaculture on carbon storage, a first assessment of carbon content in the site sediments should be done before installing anything. This will provide a comparison point for future environmental impact assessments and can be done by taking sediment cores (zu Ermgassen et al., 2021) and analyzing their carbon content.

Ocean's motion must also be investigated, for proper design of the future farm's infrastructure, and estimation of growth and spat falls of cultivated organisms. Swell and waves' period, height and direction can be assessed with water buoys, high-frequency radar (Bean et al., 2017) or using public data. Speed, magnitude and direction of the current can be assessed with an acoustic Doppler current profiler (ACDP) or using public data. The tide can be measured with a tide gauge, the speed and direction of the wind are measured with an anemometer, and depth is assessed with an echosounder.

Characteristics of the water are another essential aspect to explore when implementing an aquaculture farm. Salinity and temperature are important for the growth of algae and shellfish and can be measured with a data logger (zu Ermgassen et al., 2021), a CTD (Conductivity, Temperature and Depth instrument) (Bean et al., 2017), or using public data. Light penetration in the water column is essential for algae growth and can be measured with a Profiling Reflectance Radiometer (PRR), or in situ light sensors (zu Ermgassen et al., 2021).

Plankton and nutrient concentration in seawater is another variable to measure to ensure that shellfish and algae will grow well in the designated site. Both require to collect and analyze water samples (zu Ermgassen et al., 2021). Nutrient concentration can be measured with colorimetric or fluorometric analysis, ion chromatography, flow injection analysis and nutrient autoanalyzer. Measuring phytoplankton can be done through microscopic analysis, (imaging) flow cytometry (Mack et al., 2020), chlorophyll-a analysis, fluorescence-based in situ hybridization (FluoroProbe), remote sensing (satellites or aircraft-mounted sensors), and public data.

Water pH, and concentration of dissolved oxygen and carbon dioxide are important for shellfish and algae growth, and can be measured with the appropriate sensors

(Gao et al., 2021; Shangguan et al., 2022), flow injection analysis (FIA) methods (Mack et al., 2020) or by using public data. Finally, the presence of contaminants in the water must be monitored before implementing the farm, by analyzing water and sediment samples for the presence of toxins and heavy metals (Bean et al., 2017).

The last aspect to monitor before implementing a low-trophic aquaculture farm is the biodiversity of the area, to provide a comparison point for future monitoring of environmental impact. The state and type of benthic community should be assessed with standardized benthic surveys, passive acoustic monitoring, video transects and quadrats, using remote underwater videos (RUV), quadrats and transects by scuba divers, or eDNA metarbarcoding (Bean et al., 2017; Mack et al., 2020; zu Ermgassen et al., 2021). Fish species and population in the designated area can be monitored with passive acoustic monitoring, video transect and quadrats, using remote underwater videos (RUV), transects and quadrats by scuba divers, bait cams and e-DNA Metabarcoding (Bean et al., 2017; Mack et al., 2020; zu Ermgassen et al., 2021). Mammals in the area should be monitored with visual surveys and hydrophone Cpods. Birds can monitored with cameras and visual surveys, or using public environmental reports.

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Table 1. Baseline data collection for offshore low-trophic aquaculture

	Variable	*Reason for monitoring*	*Indicator(s)*	*Legal obligation*	*Methods*
Seabed	Seabed typology	Anchoring	Type of sediment	NL*, DE*	Cone penetration test
	Undefined explosive Objects (UXO)	Anchoring	Presence	DE*, BE	Multibeam
	Other objects on seafloor	Anchoring	Presence	NL, BE, DE*, DK	Multibeam
	Carbon stock	Comparison point for impact assessment	Carbon content in sediment	DE*	Sediment cores
Ocean's motion	Swell	Infrastructure, growth and spat fall	Period, height, direction	BE, DE*	Water buoy, HF radar, public data (e.g. Windy)
	Wave	Infrastructure, growth and spat fall	Period, height, direction	BE, NL*, DE*	Wave buoy, HF radar, public data (e.g. Copernicus, Windfinder, Windy)
	Current	Infrastructure, growth and spat fall	Speed, magnitude, direction	NL*, DE*	ACDP or public data e.g. Windy
	Tide	Infrastructure, growth and spat fall	Water level	NL*, DE*	Tide gauge
	Wind	Infrastructure, growth and spat fall	Speed, direction	DE*	Anemometer
	Depth	Anchoring	Depth	BE, NL*, DE*	Echosounder, CTD
	Salinity	Important for growth of algae and shellfish	Salinity	BE, NL*, DE*	Sensor (e.g. on CTD, datalogger) or public data
	Temperature	Important for growth of algae and shellfish	Temperature	NL*, DE*	Sensor (e.g. on CTD, datalogger) or public data
	Light	Important for growth of algae	Light attenuation	DE*	Profiling Reflectance Radiometer (PRR), in situ light sensors

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Water characteristics	Nutrient	Important for growth of algae	Nitrate, nitrite, phosphate, ammonium	DE*, NL*	Water samples, colorimetric analysis, fluorometric analysis, ion chromatography, flow injection analysis, nutrient autoanalyzers
	Plankton	Important for growth of shellfish	Concentration of seston and/or chlorophyll a Algae classes	BE, NL*, DE*	Water samples, microscopic analysis, clow cytometry, chlorophyl-a analysis, FluoroProbe, remote sensing, public data
	pH	Important for shellfish and seaweed	pH	NL*, DE*	pH sensors, flow injection analysis (FIA), public data
	CO2	Important for growth of algae and shellfish	Dissolved CO2		pCO_2 sensors, public data
	Oxygen	Important for growth of algae and shellfish	Dissolved O2	NL*, DE*	Sensors (e.g. optical dissolved oxygen sensor), public data
	Contaminants	Important for growth of algae and shellfish	Toxins and heavy metals (Hg, Pb, Zn and Cu)	DE*, DK	Water samples, historical sediment samples, lab processing
Biodiversity	Benthic community	Comparison point for impact assessment	Mussels, oysters, starfish, barnacles, algae, biofouling, etc. Invasive vs non-invasive.	DE*, BE, NL*	Standardized benthic surveys, passive acoustic monitoring, video transects and quadrats, quadrat and transects by scuba divers, e-DNA metabarcoding
	Fish	Comparison point for impact assessment	Focus species – site specific	BE, DE*	Passive acoustic monitoring, video transects and quadrats, quadrat and transects by scuba divers, bait cams, e-DNA metabarcoding
	Mammals	Comparison point for impact assessment	Porpoises and Seals in North and Baltic sea	BE, NL*, DE*	Visual surveys, hydrophones Cpods
	Birds	Comparison point for impact assessment	Focus species – site specific	BE, NL*, DE*	Public environmental reports, cameras, visual surveys

**Conditional legal obligations*

Legal obligations regarding baseline data collection

Belgium

Prospective aquaculture operations must apply for a series of permits from the Belgian government to establish and operate their facilities in the Belgian part of the North Sea. Some of the competent authorities include the Federal Minister of the North Sea, the Management Unit Mathematical Model of the North Sea (Hereafter, BMM), and DG Environment (DG Leefmilieu in Dutch).

The law of January 20, 1999, on the protection of the marine environment in the marine areas under the jurisdiction of Belgium, states that a permit from the federal minister responsible for the North Sea is necessary for industrial activities and commercial enterprises. Applicants seeking said permit must first obtain authorization from the office of the Minister of the North Sea to conduct an environmental impact report. This report, written by the applicant and/or a third party must include currently available information on hydrodynamics, sedimentology, water quality, benthic habitat, fisheries, marine mammals, sea birds, potential waste from the aquaculture operation, and planned monitoring activities related to all of these parameters. The final report is then submitted to the BMM and evaluated by a board of experts. The board will respond to the environmental assessment report with their requirements for monitoring among other legal obligations. Therefore, there is no overarching set of monitoring regulations an aquaculture operation must adhere to, but rather, each applicant will be evaluated on a case-by-case basis and receive specific monitoring obligations from the office of the Minister of the North Sea.

In their evaluation, the Minister of the North Sea and the BMM must adhere to the Royal Decree establishing the Marine Spatial Plan (MSP) 2020 – 2026 in the Belgian part of the North Sea which designates which activities are permitted within specified zones of the Belgian part of the North Sea. The MSP designates five zones where commercial and industrial activities have priority over other activities. The MSP also requires the federal government to develop a procedure for the allocation of projects within these zones.

Additional directives must be taken into account depending on the area proposed for the aquaculture operations. This could include monitoring obligations related to Natura 2000 areas, Habitat Directive areas 'Flemish Banks', and Birds Directive Areas. The board of experts must conduct an assessment of the impact on the conservation objectives set for these sites.

The application dossier, the non-technical summary, the environmental impact report and the draft of the appropriate assessment must all be subjected to public consultation by the press, digital availability on the BMM website, and physical availability in the administration offices in Brussels, Ostend, and coastal municipalities. The board may also request an opinion from the Coast Guard. Interested parties can submit views, comments and objections to the board during a specified period.

In addition to the authorization and environmental permit to be obtained from the Minister of the North Sea, the applicant must also obtain a usage permit from DG Environment in accordance with the Royal Decree of July 22, 2020 establishing the procedure for obtaining a usage permit for zones for commercial and industrial activities in sea areas under the jurisdiction of Belgium. The procedure includes an assessment of the project by means of a number of criteria, including multiple uses of space, impact on naturalness, impact on seascape impact on other activities, impact on safety and added value in economic and social terms. The usage permit will be suspended until all other relevant permits are granted.

At the time this report has been written (summer 2023), there is only one operational aquaculture farm in the Belgian part of the North Sea. This farm is located five kilometers off the coast of Nieuwpoort in the Westdiep area and is not situated in an offshore wind farm. Other rules might apply in other locations or circumstances. Nonetheless, this project is operated by Codevco V BV and has been used as an example for this report to illustrate which monitoring parameters the Belgian authorities may legally require of any future aquaculture operations (see Haelters et al., 2020). As stated, the Minister of the North Sea will evaluate each new application on a case-by-case basis. As an example, the baseline monitoring requirements for the Codevco V BV project include a seabed survey to detect depth, undefined explosive objects (UXO), and other significant objects on the seabed, monitoring of wave and swell hydrodynamics, water sampling to determine salinity, plankton and suspended particulate matter. Baseline data required from Codevco V BV will also include soil sampling at the site of the aquaculture farm, a nearby site, and a reference site (more detailed information in the Environmental Monitoring section). These requirements are particular to the aquaculture farm operated by Codevco V BV. Hence in the following pages, the parameters indicated as legally obligated for monitoring activities will not necessarily be the same for the next applicant. They rather serve as an example based on the monitoring obligations stipulated for Codevco V BV in particular.

Netherlands

Aquaculture operators must obtain licenses from competent authorities, such as the Dutch Ministry of Agriculture, Nature, and Food Quality (LNV) and the Netherlands Enterprise Agency (RVO), for operating aquaculture facilities. The licensing process involves the assessment of technical, environmental, and economic aspects of the proposed aquaculture operation. In the case of mussel farming, this mainly takes place in the Wadden Sea and the Oosterschelde. Specific parts of these areas are designated mussel farming zones and are also Natura 2000 areas.

To obtain a license, a Nature 2000 pre-assessment needs to be conducted, according to national (Nature Conservation Act – Wet Natuurbescherming 2021) and European legislations (Bird Directive 2009/147/EC and Habitat Directive 92/43/EEC). The potential effects of aquaculture activities and mitigation measures must be evaluated at the start, focusing on factors such as the carrying capacity of the area, non-indigenous species, additional risks to species (for example by attracting birds), pollution/emissions/nitrogen deposition, disturbances due to mechanical effects (in particular turbidity) and disturbance caused by visual cues, sound, or vibration. After

the pre-assessment, it will be determined whether a full assessment is necessary and/or an exemption from the Nature Conservation Act must be requested.

If the license concerns a larger-scale activity and large-scale effects cannot be ruled out, an Environmental Impact Assessment may be requested. Environmental Impact Assessments (EIAs) are conducted in accordance with national (Besluit milieueffectrapportage 1994) and European regulations (EIA Directive 2011/92/EU), to assess the potential environmental impact of aquaculture activities. Monitoring hydrographical conditions, such as waves, currents, tides, and seabed levels, is necessary for licensing and environmental impact procedures. Rijkswaterstaat's monitoring program (MWTL) and the Netherlands Hydrographical service regularly monitor these variables.

The license application will be assessed based on a series of key criteria (next to the regular criteria from the Water Law 2009), such as safety of the structure, duration, clearing obligations upon expiration of the license, good environmental status (describing the impact of the activity on the environment, and taking into account the guidelines from the Marine Strategy Framework Directive), and the possible effects on archaeological sites. The relevant legislations are the Water Law 2009 and the Heritage Law 2015 at the national level, and the Marine Strategy Framework Directive (Directive 2008/56/EC) at the EU level.

Aquaculture operators must also obtain permits and comply with regulations related to effluent discharge and water quality standards. The Water Framework Directive (2000/60/EC) and the Nitrate Directive (91/676/EEC) provide the legal framework for water quality management in the Netherlands. The Water Framework Directive establishes standards and objectives for water quality and resource management, while the Nitrate Directive addresses the prevention of pollution from agricultural sources, including measures to protect water against nitrate pollution.

The Animal Welfare Act (Wet Dieren) sets regulations for the welfare and protection of animals, including those in aquaculture, covering aspects such as stocking densities, feeding, transport, and handling.

The Dutch Environment and Planning Act (Omgevingswet), although not yet in force, is a comprehensive law governing spatial planning and zoning, including regulations for the location and expansion of aquaculture facilities. It is planned to come into effect on January 1, 2024.

Germany

In general, to be allowed to use marine spaces in Germany, permits have to be obtained. For the use of offshore marine space the German Federal Maritime and Hydrographic Agency (hereafter BSH) is the permitting authority. When moving further near-shore (into the coastal zone) different agencies of the respective federal states with coastline access (Niedersachsen, Schleswig Holstein, Mecklenburg-Vorpommern) are responsible and have to be contacted.

Different monitoring strategies might be necessary. Such as monitoring of physical parameters or monitoring for endangered species. Also, prerequisites might have to be fulfilled before a permit is given. These could pertain to preventing the introduction

of foreign species, physical and chemical substances, prevention of sound and light pollution, prevention of oil spills, and prevention of littering.

Also, an environmental survey determining the potential impact of establishing aquaculture in the designated area and screening for unidentified exploding objects (UXO) might be necessary,

Mussels

According to directive 91/492/EWG, amended in directive 97/61/EG, growing mussels for commercial use as food is only allowed in mussel growing areas (Erzeugungsgebiete) These areas have to be designated (geographic area, distinguishable from the surrounding) by the respective authorities.

Three categories exist for growing and harvesting of live mussels:

(a) Areas for living mussels intended for immediate consumption. Mussels must meet the following requirements:

1. They must have visible signs indicating freshness and viability, including clean shells, a “percussion” response and normal amounts of shell liquid.
2. Less than 300 fecal coliforms or less than 230 E. coli per 100 g of mussel meat and shell fluid must be detected in a 5-tube-3-dilution MPN test or another bacteriological method with equivalent accuracy.
3. Salmonella must not be detected in 25 g of mussel meat.
4. They must not be contaminated with naturally occurring toxic or noxious substances or substances that are exposed to the environment in accordance with the Annex to Directive 79/923/EEC to such an extent that the calculated intake through food exceeds the permissible daily intake for humans (ADI). and the taste of the mussels could be affected. The analytical methods to be used to check the chemical criteria and the limit values to be observed shall be determined by the Commission in accordance with the procedure laid down in Article 12 of Directive 79/923/EEC.
5. The maximum level of radionuclides shall not exceed the levels laid down by the Community for food safety.
6. The total content of water-soluble algal toxins (Paralytic Shellfish Poison - PSP) in the edible parts of the mussel (whole body or individually edible parts) must be determined in the biological analysis - (if necessary in combination with a chemical saxitoxin test method or any other method according to Article 12 of Directive 79/923/EEC) does not exceed 80 micrograms per 100 g mussel meat. If the results are challenged, the biological method should be used as the reference method.
7. The usual biological analysis methods must not give a positive reaction to fat-soluble algal toxins (Diarrhetic Shellfish Poison - DSP) in the edible parts of the mussel (whole body or parts that can be eaten individually).

   7a. The content of "Amnesic Shellfish Poisoning" (ASP) in the edible mussel parts (whole bodies or individually edible parts) must not exceed 20 µg domoic acid per gram of mussel meat in HPLC analysis.

8. In the absence of routine virus testing procedures and virological standards, fecal bacteria must be counted to verify sanitary safety.

(b) Areas to cultivate living mussels that shall only be placed on the market for consumption after processing in a purification center or after being transferred to other bodies of water.

In the case of live mussels from these areas, a maximum of 6,000 fecal coliforms per 100 g of mussel meat or 4,600 E. coli per 100 g of meat may be detected in a 5-tube-3-dilution MPN test in 90% of the samples. After cleaning or moving, all the requirements of mussels from areas of category **a)** must be met.

(c) Areas to cultivate live mussels intended for human consumption, but only after a long period of transplanting (at least two months), whether combined with or without cleaning or after a thorough cleaning, for a period to be determined in accordance with the procedure laid down in Article 12 of Directive 91/492/EG and in accordance with the requirements under letter a), before they are placed on the market. In the case of live mussels from these areas, a maximum of 60,000 fecal coliforms per 100 g of mussel meat may be detected in a 5-tube-3 dilution MPN test.

After determination of the cultivation area type **a)**, **b)** or **c)** the mussels and the producing company are regularly tested. See chapter "production" further down

A sanitary survey, showing all potential sources of contaminants, resulting in a report demarking and validation of all sources has also to be done.

Algae

The cultivation of algae for human use is not as regulated as mussel cultivation in Germany yet. However, several EU directives touch upon algae cultivation (Barbier et al. 2020). These are:

- the Maritime Spatial Planning Directive 2014/89/EU,
- the Marine Strategy Framework Directive 2008/56/EC,
- the Water Framework Directive 2000/60/EC,
- the Alien Species Regulation 2014/1143/EU,
- the Regulation on Aliens Species in Aquaculture 2007/708/EC,
- the Habitats Directive 92/43/EEC.
- the Regulation on Organic Production 2018/848/EU (if applicable)

However, no specific algae monitoring prerequisites exist for setting up the area, such as is the case for mussels. The only permit needed to set up algae cultivation is a permit to do "aquaculture" that is in offshore areas done by the BSH and might include monitoring prerequisites for environmental factors. (see above) When aiming to sell algae for food, it is recommended to use the standard tests for "fresh salad" and monitor bacterial count, e coli count, salmonella detection and also Iodine concentrations in end products. See also chapter "production".

Denmark

Aquaculture operators must obtain licenses from the competent authorities. For both species, a license is valid for 10 years after which, a new application must be submitted. Which competent authority in relation to licensing of LTA species depends on the type of organism.

Mussels

For mussels and other bivalve mollusks, the competent authority is the Danish Fisheries Agency (Fiskeristyrelsen). Permits for the establishment of aquaculture operation of bivalve mollusks are administered according to the Fisheries Act. Specifically, it is administered according to executive order no. 1456 of 24/06/2021 on the farming of mussels and oysters in the water column (BEK nr .1456 af 24/06/2021). In connection with applications, the Danish Fisheries Agency conducts party consultations with several parties defined by the Danish Fisheries Agency and including relevant public authorities, fishing associations and NGOs. In addition, a financial guarantee must be provided if the Danish Fisheries Agency is forced to clean up the area in the event of bankruptcy or suspension of payments. If granted, a permit lasts for 10 years after which it requires a new application to continue the activities.

There are few formal barriers to the establishment of facilities for farming blue mussels and other bivalve mollusks, and these primarily include conservation belts established so that fish that move from streams into the sea must be able to do so freely. It is possible to obtain a farming license in a Natura 2000 area, but this will require a prior impact assessment. Restrictions for placement in relation to shipping lanes, dumping sites, and natural and environmental considerations, etc. will be part of the concrete case processing and emerge through the parties' hearings. There are currently no specific requirements for the location of mussel farms in relation to sensitive habitats such as rocky reefs, kelp forests or eelgrass beds but given the protection of these habitats in Water Framework areas or Natura 2000 sites, it is not likely that an application will pass through the consultation process unnoticed and further documentation of effects may be required.

As part of the Maritime Spatial Planning Directive 2014/89/EU, areas have been designated for mussel farming. Licenses can default not be granted outside these areas and it will require an addendum to the executive order governing the maritime spatial plan.

Since May 2021 there has been a moratorium for new licenses pending further clarification of the cumulative impact of many licenses in the same area.

Macroalgae

Establishing macroalgae cultivation facilities requires permission from the Coastal Authority (Kystdirektoratet), which manages the administrative basis for the Danish Sea territory. Applications can be completed online[1] and must contain a number of information, including information about owners, possibly representatives, permission to publish information, the facility's location, descriptions of the cultivation unit, species and working methods, as well as information about potential environmental

[1] Danish ministry of the Coast. https://kyst.dk/soeterritoriet/anlaeg-og-aktiviteter-paa-soeterritoriet/ansoeg-om-olidsen/

implications. Several necessary appendices must be available (charts/maps with the registered facility, plan and sketch drawing of the facility, dimensioned sectional drawings and overview maps, and declarations of consent from potential owners/users). In connection with applications, the Coastal Authority conducts party consultations with several parties defined by the Coastal Authority and including relevant public authorities, fishing associations and NGOs. In addition, a financial guarantee must be provided if the Coastal Directorate is forced to clean up the area in the event of bankruptcy or suspension of payments.

If the cultivation unit is intended to be built in a Natura 2000 area or in areas with the presence of species that are protected according to the EU's nature management directives (Annex IV species), special considerations must be taken to minimize the impact on the area's animals, plants and nature types, and a consequence - or EIA assessment may be necessary. Restrictions for placement in relation to shipping lanes, dumping sites, and natural and environmental considerations, etc. will be part of the concrete case processing and emerge through the parties' hearings.

2.2 Post-decision monitoring

2.2.1 Operation

Monitoring operational variables throughout the lifespan of an aquaculture farm is essential for preventing damage to the natural environment, maintaining maritime safety standards, and ensuring the economic profitability of the enterprise. The proposed monitoring scheme for operational variables of offshore low-trophic aquaculture is described in Table 2 "Operational monitoring for offshore low-trophic aquaculture". Operational variables to be monitored can be categorized as yield variables related to the crops produced by the aquaculture operation and infrastructure variables related to the structural integrity and functioning of the equipment. Whether or not an aquaculture operation is legally obligated to monitor these variables, it will nevertheless be in the company's best economic interest to do so.

Monitoring yield variables such as seaweed growth, bivalve growth and potential bivalve diseases is important for the economic success of the aquaculture operation as this will indicate the health of the crops and the amount of product to be expected. Seaweed growth can be measured in terms of length, width, and fresh weight. Likewise, indicators for bivalve growth include length, width, and meat weight (wet, dry, and/or ash). Bivalve diseases can be detected by extracting DNA from the animals and/or from the environment (e.g., the water column) to determine the presence of pathogens and parasites such as *Bonamia ostreae*, *Marteilia refringens*, and others. The collection of biological samples is necessary to determine the weight of seaweeds and bivalves as well as the presence of disease. Sampling requires fully or partially removing gear from the water to extract samples of seaweed and individual bivalves. More passive methods such as video monitoring, ROV missions, or multibeam surveys are also possible for measuring the growth of seaweeds and bivalves in situ. However, these visual methods would not be possible for measuring oyster growth if the oysters are contained in grow-out baskets.

Infrastructure variables are also important to include in any monitoring strategy. All structural elements of the aquaculture operation, including longlines, buoy systems, and subsurface structures should be checked regularly to ensure proper functioning and integrity. If any part of the infrastructure becomes disengaged, it can pose a risk to the safety of the operators, other maritime stakeholders, and local wildlife. The loss of gear is also a financial burden for the aquaculture operation in terms of retrieval and replacement. For these reasons, visual surveys, sampling, ROV missions, and regular crew vessel checks are recommended as methods to verify the presence and state of the infrastructure components. Regular monitoring of longlines, buoy systems and subsurface structures will ensure that replacements are made when necessary and loss of gear is avoided. In the summer months, regular inspection of the aquaculture cultivation structures ideally means at least monthly cleaning the fouling from the structures. During the winter time, one or two check-ups of the structures could suffice as less fouling is encountered during this cold period. Beacons ideally are monitored more often (e.g., weekly), that is if the weather conditions during the winter allow. One could consider continuous monitoring via a remote camera system that could transfer data every so many minutes/hours to land e.g., via Wi-Fi.

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Table 2. Operational monitoring for offshore low-trophic aquaculture

	Variable	*Reason for monitoring*	*Indicator(s)*	*Legal obligation*	*Methods*
Yield	Seaweed growth	Economic profitability	Length, width, fresh weight		Sampling, multibeam, video, ROV
	Bivalve growth	Economic profitability	Length, width, weight (wet meat weight, dry meat weight, ash meat weight)		Sampling, multibeam, video, ROV
	Bivalve disease	Economic profitability	DNA from animals directly (*bonamia*, *marteilia*, others)	NL*, DE*	Sampling
Infrastructure	Longlines and buoys	Safety and damage control	Presence and state (e.g. estimate if replacement is needed)	BE, DE*	Visual surveys, ROV, crew vessel passing by, sampling
	Subsurface structures	Safety and damage control	Presence and state (e.g. estimate if replacement is needed)	BE, DE*	Visual surveys, ROV, sampling

**Conditional legal obligations*

Legal obligations regarding operation variables monitoring

Belgium

Based on the aquaculture operation of Codevco V BV, this farm has not been legally required by the Minister of the North Sea to monitor yield-related variables. However, as a matter of sound business practice, the company has its additional protocols for monitoring seaweed and bivalve growth as well as bivalve health.

The Minister of the North Sea and BMM do, however, set specific monitoring requirements for infrastructure to ensure safety for the environment, workers, and other maritime activities. These requirements are as follows:

Lost gear

- Equipment lost during the survey phase must be tracked down and completely removed from the seabed.
- All objects lost during the exploitation phase must be reported to the FPS Health, Food Chain Safety and Environment, the MRCC and the BMM according to a pre-agreed procedure.
- Depending on the type of lost objects, the government may demand that the necessary efforts be made to retrieve them.

Navigational beacons on gear

- The permit holder must inspect the beacons of the sea farm at least weekly unless weather conditions do not permit.
- If hazards to navigation are identified, they must be reported to the department within one hour to inform shipping guidance.
- Signals and lights must be repaired within 24 hours unless weather conditions do not permit.

Marking gear

- The buoys attached to the main lines (breeding installation) must be clearly visible by their color. Suggested colors hence are: yellow, orange or red.
- The buoys of the main lines must be individually identifiable so that their original position can be checked when released and possibly found on a beach.

Additionally, regular gear checks are necessary to detect any possible entanglements involving marine mammals or sea birds. All incidents relating to safety and the environment must be entered into a register by the permit holder.

Netherlands

During the license application phase, the safety of the structure needs to be ensured so that the risk to people and the environment throughout its life-cycle is acceptable. The application should describe how the structure will be secured so that it does not go adrift, and the resistance of the installation to offshore conditions must be demonstrated (for example, with a risk analysis, tests and strength calculations).

There is no specific information regarding a legal requirement to monitor operational variables in the context of seaweed and mussel aquaculture in the Netherlands. However, monitoring operational variables related to seaweed/bivalve growth and infrastructure is generally considered good practice to ensure optimal production, maintain environmental sustainability, and manage potential risks. These variables are generally monitored by aquaculture operators to track growth rates and infrastructure conditions.

There are disease control measures in place to prevent the introduction and spread of diseases among aquatic animals. Some bivalve diseases are subject to a reporting obligation to the Dutch Food and Consumer Product Safety Authority (NVWA). The diseases to be reported are listed in the European Animal Health Regulation (AHR). In addition, the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) has designated additional animal diseases and animal species in national legislation that are subject to notification.

Germany

During an offshore operation, all equipment has to be safely anchored to prevent loss of equipment and also to protect other users of marine space. In the planning phase, all equipment has to be sized and adapted to the local environment. To do this, environmental data such as the water depth, salinity, prevailing wind direction, currents, tides, wind-strength, wave heights and the lice can be obtained from public sources or historic data sets for the respective location. During operation, however, it is a good idea to monitor the current environmental conditions to be able to prepare for harsh weather conditions. It is also advisable (but not legally requested) to monitor the equipment remotely. This can be done by installing video surveillance where feasible or also fit buoys with tracking devices that alert the owner, should they start drifting. This is not only increasing safety by giving the opportunity to alert other users of potential danger by drifting equipment, but in the case of an active tracker, this also helps in retrieving said equipment in the unlikely event of an unforeseen detachment of e.g. buoys or even whole cultivation systems.

Denmark

There are at present no legal requirements for continuous monitoring of bivalve mollusks and macroalgae cultivation units or the surrounding environment except that harvested amounts must be reported. Further, if the cultivation unit is organically certified, there are some specific requirements.

Farming of mussels can be certified as organic production and the mussels are thus sold both as organic food and organic feed ingredient (BEK nr. 2168 af 23/11/2021). There are several rules in the organic regulation to produce organic mussels e.g., demands to the operating ships use of antifouling, traceability of the mussels during the entire production cycle, and animal welfare. There are special requirements for organic aquaculture in the EU's organic regulations including traceability. Harvesting of macroalgae in aquaculture must be notified to and organically checked by the Danish Veterinary and Food Administration.

2.2.2 Product

The proposed monitoring strategy for quality and safety of products from offshore low-trophic aquaculture can be found in Table 3 "Product monitoring for offshore low-trophic aquaculture". To ensure the quality of products of the aquaculture farm, nutritional values must be examined through chemical analyses to assess proteins, lipids and carbohydrates content. Additionally, the size, flesh/shell ratio and dry and wet weight of the products can be estimated from representative samples.

Ensuring food safety is another essential aspect and of utmost importance before selling any product for human consumption. These marine environments provide a rich habitat for these seafood products, but they are also susceptible to various contaminants and toxins that can pose health risks to consumers. As a result, stringent measures have been implemented to monitor and control the safety of mussels and algae harvested from these seas. The table "Product monitoring" and the following paragraphs give an insight into the necessary measurements and practices employed in the pilot countries to guarantee the safety of mussels and algae.

Focus points in all pilots are:

- Monitoring Harmful Algal Blooms (HABs): One of the primary concerns in relation to food safety is the occurrence of harmful algal blooms. These blooms can produce toxins that accumulate in shellfish, such as mussels, through filter feeding. Regular monitoring programs are implemented to detect the presence of harmful algae species and the associated toxins in the water. This early detection allows authorities to take appropriate actions, such as temporary closures of affected areas, to prevent the harvest and sale of contaminated shellfish.
- Biotoxin Testing: Biotoxins produced by certain algae species can accumulate in mussels and pose serious health risks if consumed. Therefore, rigorous testing procedures are conducted to detect the presence of biotoxins, including paralytic shellfish toxins (PSTs), amnesic shellfish toxins (ASTs), and lipophilic toxins. These tests ensure that only mussels with safe toxin levels are permitted for human consumption.
- Microbiological Analysis: Microbial contamination, such as the presence of bacteria like E. coli and Vibrio species, is a significant concern for food safety. Mussels and to a certain degree also algae harvested from the North Sea and Baltic Sea undergo thorough microbiological analysis to assess the levels of pathogenic bacteria. These analyses help determine if the products meet the strict safety standards established by the European Union (EU) and national regulatory bodies.
- Environmental Monitoring: Apart from monitoring the presence of harmful algae species, the water quality and environmental conditions are assessed in the pilots. This monitoring includes factors like temperature, salinity, nutrient levels, and specifically for the food safety aspects pollution indicators (heavy metals). By monitoring the environment, any potential risks or sources of contamination can be identified and mitigated, ensuring the overall safety of the seafood harvested from these areas.

- Regulatory Compliance and Traceability: The EU has established comprehensive legislation and regulations to ensure the safety of seafood products, including mussels and algae. These regulations outline specific quality standards, maximum residue levels, and permissible limits for contaminants. Furthermore, traceability systems are in place to track the origin and journey of mussels and algae from harvest to consumption. This ensures accountability and facilitates swift action in case of any safety concerns or product recalls.

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Table 3. Product monitoring for offshore low-trophic aquaculture

	Variable	*Reason for monitoring*	*Indicator(s)*	*Legal obligation*	*Methods*
Food quality	Nutritional values	Product quality	Proteins, lipids, carbohydrates	DK*, DE, NL	Samples, extractions, chemical analyses
	Size, flesh/shell ratio	Product quality	Size, flesh/shell ratio		Measure and weigh representative samples
	Wet and dry weight of algae	Product quality	Weight		Weigh representative samples
Food safety	Microalgae in water)	Products safe for consumption	Dinoflagellates, Diatoms	DK, DE*, NL, BE	FluoroProbe: chlorophyll in vivo measurement, fluorescence of algae (excitation spectra "fingerprints"); HPLC; mouse bioassay
	Heavy metals from water (in seaweed)	Products safe for consumption	Hg, Pb, Zn and Cu, Iodine	DE*, BE	Tissue samples, extractions, ICPMS (Inductively Coupled Plasma - Mass Spectrometry
	Algal toxins concentration in fresh mussel flesh	Products safe for consumption	ASP-, PSP-, DSP-, Yesso-toxins	DK, DE*, NL, BE	Lab analysis (HPLC)
	Indicator for bacterial contamination	Products safe for consumption	Cultivable bacteria	DK, DE, NL, BE	Cultivation of samples on agar plates in lab, counting of colonies
	Indicator for fecal contamination	Products safe for consumption	*E.coli*	DK, DE, NL, BE	Cultivation of samples on selective agar plates in lab, counting of colonies
	Preventing Salmonella outbreak	Products safe for consumption	Salmonella	DE, NL, BE	Cultivation of samples on selective agar plates in lab, counting of colonies, PCR when indicated
	Micro-algal cell count in Water	Products safe for consumption	Potential toxic microalgae	DE, NL, BE	Filtrating water samples and counting under microscope/binocular
	Contaminants in mussel flesh	Products safe for consumption	list of appr. 30 variable - PCBs, PKA, Heavy metals.... depending on country	DE, NL, BE	Lab analysis of mussel sample

**Conditional legal obligations*

Legal obligations regarding product quality and safety monitoring

Belgium

According to Regulation (EC) 882/2004 of the European Parliament every operator with an activity in the food chain has to be registered with the competent authority. In Belgium, this is the Federal Agency for the Safety of the Food Chain (FASFC). A permit from the FASFC is necessary to sell aquaculture products for human consumption in Belgium. Once this permit is obtained, the aquaculture operation becomes a market authorization holder (MAH) and is legally obliged to adhere to the standards of food safety at the European and State level including all monitoring protocols.

The FASFC is responsible for enforcing the EU Council Directive 91/492/EEC of 15 July 1991 which lays down the health conditions for the production and placing on the market of live bivalve mollusks. The monitoring requirements stipulated for bivalves in this directive include the microbiological quality of the bivalve tissue (presence of *E. coli* or *Salmonella*), presence of biotoxin-producing plankton in the production area water, biotoxins in live bivalves, and presence of chemical contaminants. The maximum authorized level of contaminants such as heavy metals, PCBs and others are in accordance with the procedure outlined in Article 12 of Directive 91/492/EEC.

Monitoring plans are established by the FASFC for sampling at regular intervals to detect the possible presence of harmful bacteria, biotoxin-containing plankton, and other contaminants. Sampling plans must account for likely spatio-temporal variations in fecal contamination or the presence or harmful plankton at each production area. If during routine sampling, an increase of contaminants or biotoxins is detected, then an intensive sampling protocol must be initiated.

Intensive sampling includes increasing the number of sampling points and the number of samples, as well as toxicity tests using the mollusks from the affected area which are most susceptible to contamination. If the result of intensive sampling protocols shows that consumption of the bivalves from the affected area may constitute a hazard to human health, the FASFC must close the production area, until the situation has been restored.

Netherlands

Aquaculture products in the Netherlands must comply with strict food safety standards and the quality of the product needs to be monitored. Aquaculture farms in the Netherlands must have a permit with rules for disease control, traceability and hygiene. The requirements for this are described in European Directive 2006/88/EC. They must also register with the Dutch Food and Consumer Product Safety Authority (NVWA), which is responsible for monitoring and enforcing food safety and quality regulations in the Netherlands, including those related to aquaculture products.

Throughout the year, the NVWA monitors the production areas of live bivalve mollusks, including mussels and oysters.

In terms of microbiological requirements, bivalve mollusks traded for consumption may only come from a designated and classified production area. The indication for the classification is based on the number of colony-forming units (cfu) of *E. coli* per

100 grams of shellfish meat and liquid. The standard for the presence of *E. coli* is currently used as an indicator for the presence of pathogenic micro-organisms and viruses. There are no classified production areas in the Western Scheldt, Eems-Dollard and North Sea outside the 12-mile zone. These are not covered by the current monitoring program, and no live bivalve mollusks for which a classification is required may be marketed from these areas.

Marine biotoxins are toxic substances that live bivalve mollusks ingest, especially when consuming plankton that contains toxins. The total amount of marine biotoxins in the samples must not exceed the following maximum values according to Regulation (EC) No 853/2004 and Regulation (EC) 786/2013:

- paralytic shellfish poison (PSP): 800 µg per kg
- amnesic shellfish poison (ASP): 20 mg domoic acid per kg
- okaidaic acid (OA), dinophysistoxin (DTX) and pectenotoxins (PTX) together: 160 µg okadaic acid equivalent per kg
- yessotoxins(YTX): 3.75 mg yessotoxin equivalent per kg
- azaspiracides (AZA): 160 µg azaspiracide equivalent per kg

The total amount of the toxic substance tetrodotoxin (TTX) in the samples may not exceed 44 micrograms of TTX/kg in shellfish meat.

Besides the toxins in mussel flesh, the water can also contain toxin-forming algae, which can be absorbed into living bivalve mollusks. The Netherlands applies the precautionary standards of:

- 100 cells/liter DSP (diarrhetic shellfish poison) forming algae
- 500,000 cells/liter ASP (amnesic shellfish poison) forming algae
- 1,000 cells/liter PSP (paralytic shellfish poison) forming algae

Live bivalve mollusks in the production areas may not exceed the indicated levels for lead (Pb), cadmium (Cd) and mercury (Hg), polycyclic aromatic hydrocarbons (PAHs) dioxins and polychlorinated biphenyls (PCBs) set in the Regulation (EC) No 1881/2006, Regulation (EC) No 835/2011 and Regulation (EC) No 1259/2011:

- lead (Pb): 1.5 mg/kg fresh weight
- cadmium (Cd): 1.0 mg/kg fresh weight
- Mercury (Hg): 0.5 mg/kg fresh weight
- benzo[a]pyrene: 5.0 µg/kg fresh weight
- sum of benzoa]pyrene, chrysene, benzo[a]anthracene and benzo[b]fluoranthene: 30,0 µg/kg fresh weight
- sum of dioxins: 3.5 pg/g fresh weight
- sum of dioxins and dioxin-like PCBs: 6.5 pg/g fresh weight
- sum of PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180: 75 ng/g fresh weight.

Several EU legislations are relevant to seaweed food safety (fully detailed in Banach et al., 2020). The General Food Law (Regulation (EC) 178/2002) establishes general principles and requirements for food safety at the European and national levels, as well as responsibilities for business operators. Detailed rules on organic seaweed production are described in the Commission Regulation (EC) 2021/1165. The Official Controls Regulation (EU) 2017/625 relates to the official controls and verification of compliance with food and feed law, and rules on plant health. Lastly, given the relative

novelty of seaweed for food purposes, Regulation (EU) 2015/2283 on novel foods is also relevant.

While the food safety and quality regulations for mussels are well established, there does not seem to be specific Dutch legislation for algae and seaweeds for human consumption. However, the standards are already being developed in this area within the Dutch and the European standards committee (NEN & CEN).

Germany

The regulations (EC) No 1881/2006 of 19. Dez.2006, and (EC) No853/2004 lead and govern the maximum allowed concentration of contaminants and also determine how and what should be considered safe and allowed, when handling foodstuff.

Mussels have been mentioned in several directives and regulations, algae however, are not yet as regulated as mussels. Mostly they are considered to fall amongst the standards and maximum allowed concentrations for salad/leafy vegetables or dried herbs.

Mussels are in addition considered an easily spoilable good and hence have strict regulations. Testing of mussels is done during production to ensure the safety of customers. Directives 91/492/EWG, amended in directive 97/61/EG as well as regulation (EC) No 853/2004 apply. These state amongst other prerequisites:

- A public health control system must be established and do the monitoring, note: that this monitoring is done during the production of mussels and not after production to ensure customer safety.
- Monitoring variables are:
    - check the microbiological quality of the live bivalve mollusks in relation to the production and relaying areas;
    - check the possible presence of toxin-producing plankton in production and relaying waters and biotoxins in live bivalve mollusks;
    - check the possible presence of chemical contaminants, the maximum authorized level of which is fixed in the regulation (EC) No 1881/2006 of 19. Dez.2006, and in the regulation (EC) No853/2004

Denmark

Mussels:

Growing mussels and other bivalve mollusks that are to be used for human consumption are governed by rules for control of algae toxins and microbiological contamination (E. coli and Salmonella) as described in the Danish Veterinary and Food Administration (Fødevarestyrelsen) executive order no. 574 of 25/05/2023 on mussels etc. (BEK nr. 574 af 25/05/2023). These rules are in accordance with general EU regulations as is also mentioned for Belgium, Netherlands and Germany. In accordance with the administration of the Danish Veterinary and Food Administration, Danish marine areas are divided into a number of production areas[2], from which

[2] Danish Veterinary and Food Administration. https://www.foedevarestyrelsen.dk/Leksikon/Sider/Kort_over_produktionsomraader_i_Danmark.aspx?Indgang=Kontrol&Indgangsemne=Muslingesurvärgment&

sampling must be carried out in order to meet the criteria for opening the areas with a view to harvesting for human consumption are met. Apart from a few areas, virtually all coastal areas are covered by the regulations of the Danish Veterinary and Food Administration.

Blue mussels are included in the list of marine invertebrates that can be used to produce feed ingredients. Administration of the use of aquatic animals (fish, mollusks, crustaceans) is according to the by-product regulation under category 3 products[3]. For feed ingredients, there are rules for the content of e.g., environmentally harmful substances. In addition, there are rules covering transport, traceability, etc.

Macroalgae:

If a company wants to harvest, market or process macroalgae, e.g. cook, marinate or pack macroalgae in a modified atmosphere, the company must be registered with the Veterinary and Food Authority and comply with the rules in the food area. The company must make a risk analysis for macroalgae and take the necessary measures. Risk analyzes include e.g. microbiology, chemistry, and harmful substances (arsenic, iodine, cadmium and other heavy metals, as well as kainic acid). In addition, it must be confirmed whether the macroalgae species are suitable for human consumption and whether the species are covered by the EU's novel food legislation, which applies to macroalgae species that are not traditionally eaten in Northern Europe.

2.2.3 Environment

This sub-section addresses variables that inform how the environment is impacted by the farm and how the environment in turn impacts the farm's production. The monitoring scheme for environmental impact of offshore low-trophic aquaculture can be found in Table 4 "Environmental monitoring for offshore low-trophic aquaculture". This category is focused on monitoring three variable types: water quality, soil and biodiversity.

In terms of water quality, the variables of interest are nutrient concentrations and plankton abundance. These variables indicate the impact of aquaculture on eutrophication and primary production, the impact of nutrient availability on algal growth and that of plankton availability on shellfish growth. The indicator variables are nitrate, nitrite, phosphate, ammonium, the concentration of seston and/or chlorophyll-a, and the fluorometric determination of the algae classes (i.e., green algae, diatoms, dinoflagellates, cyanobacteria, cryptophytes).

Relevant soil variables are sedimentology and carbon sink. The indicators for sedimentology are particle load and organic content. In terms of carbon sink, carbon stock can be measured as grams of carbon per m^2 along with a measurement of sediment depth. These variables are monitored with sediment samples and sediment cores (zu Ermgassen et al., 2021).

Assessing the uptake of nutrients and carbon by organisms cultivated in aquaculture farms poses challenges due to the diffusion of impact and the limitations and costs associated with monitoring methods. The diffusion of impact occurs as physical processes like currents, tides, and wind facilitate the transport of nutrients over extensive distances, thereby expanding the influence beyond the original source.

[3] Danish Veterinary and Food administration. https://foedevarestyrelsen.dk/siden-findes-ikke

Furthermore, nutrient cycling processes in aquatic ecosystems operate at various temporal and spatial scales, with some transformations occurring rapidly (e.g., organic matter breakdown) and others taking place over longer periods (e.g., sediment nutrient accumulation). Consequently, to estimate the impact of aquaculture on carbon and nutrient levels in the water column, the carbon and nitrogen content present in the tissues of the cultivated organisms can be analyzed, and overall carbon and nitrogen removal estimated at the entire farm scale (Buck et al., 2017).

In terms of biodiversity, the monitoring efforts should focus on the benthic community, fish, mammals, birds and habitat restoration:

For the benthic community, the indicator species include mussels, oysters, starfish, barnacles, algae, and biofouling, as well as the balance between invasive and non-invasive species. The abundance of these species is measured as the mean density of individuals per mm/m^2, and the collection methods include standardized benthic surveys, passive acoustic monitoring, video transects and quadrats (e.g., by scuba divers), or e-DNA metabarcoding (Bean et al., 2017; Mack et al., 2020; zu Ermgassen et al., 2021).

Under the Fish category, the focus species are site-specific and can be monitored using passive acoustic monitoring, camera/video transects and quadrats, bait cams, and e-DNA (Bean et al., 2017; Mack et al., 2020; zu Ermgassen et al., 2021). Under the Mammals category, some important indicator species in the North and Baltic seas are porpoises and seals, to be monitored using visual surveys and hydrophones (C-PODs).

Under the Birds category, a measure of biodiversity can be obtained from public environmental reports, as well as cameras and visual surveys. The indicator species will depend on the location of the aquaculture site.

For the habitat restoration category, the relevant indicators are the presence of oysters on the structures and the seabed, the size and coverage of oyster reefs, and the reef complexity. In the subtidal zone, this is measured with scuba divers, underwater cameras and acoustic methods. In the intertidal zone, GPS mapping and aerial images by drones can be used.

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Table 4. Environmental monitoring for offshore low-trophic aquaculture

	Variable	*Reason for monitoring*	*Indicator(s)*	*Legal obligation*	*Methods*
Water quality	Nutrient	Impact of aquaculture on ecosystem	Nitrate, nitrite, phosphate, ammonium	DE*, NL*	Content in tissues of cultivated organisms
	Plankton	Impact of aquaculture on ecosystem	Concentration of seston and/or chlorophyll a Algae classes	BE, NL*	Water samples, microscopic analysis, clow cytometry, chlorophyl-a analysis, FluoroProbe, remote sensing
Soil	Sedimentology	Impact of aquaculture on ecosystem	Soil, particle load and organic content	DE*, BE, NL*	Soil samples
	Carbon sink	Impact of aquaculture on ecosystem	Carbon stock	DE*	Sediment cores
Biodiversity	Benthic community	Impact of aquaculture on ecosystem	Mussels, oysters, starfish, barnacles, algae, biofouling, etc. Invasive vs non-invasive.	DE*, BE, NL*	Standardized benthic surveys, passive acoustic monitoring, video transects and quadrats - quadrat and transects by scuba divers, e-DNA metabarcoding
	Fish	Impact of aquaculture on ecosystem	Focus species – site specific	BE, DE*	Passive acoustic monitoring, camera/videos transects and quadrats, quadrat and transects by scuba divers, bait cams, e-DNA metabarcoding
	Mammals	Impact of aquaculture on ecosystem	Porpoises and Seals in North and Baltic sea	BE, NL*, DE*	Visual surveys, hydrophones Cpods
	Birds	Impact of aquaculture on ecosystem	Focus species – site specific	BE, NL*, DE*	Public environmental reports, cameras, visual surveys
	Habitat restoration	Impact of aquaculture on ecosystem	Presence oysters Presence of oyster reef Reef complexity		Subtidal: scuba divers, underwater cameras, acoustic methods Intertidal: GPS mapping, aerial imaging by drones

**Conditional legal obligations*

Legal obligations regarding environmental monitoring

Belgium

The Minister of the North Sea and the BMM have stipulated an extensive monitoring plan to investigate what effects the Codevco V BV aquaculture farm will have on the environment and surrounding biodiversity. Monitoring of water quality, sedimentology, and biodiversity is of high priority.

Monitoring of the change in composition and concentration of suspended particulate matter (SPM) and turbidity is required at each stage of the project and is conducted upstream and downstream of the sea farm. In this way, the influence of the sea farm on currents, turbidity and SPM can be determined. To this end, a bottom-mounted acoustic doppler current profiler (ADCP) and a tripod are deployed for extended periods to measure currents, turbulence, SPM concentration and particle size of the suspension material. ADCP measurements can be used to calculate the SPM concentration profile. The tripod is equipped with a variety of sensors, including:

- Acoustic doppler profiler (ADP) for measuring the flow profile close to the bottom;
- Acoustic doppler velocimetry (ADV) for measurement of flow velocity and determination of turbulence;
- Laser In-Situ Scattering and Transmissometry (LISST) for the measurement of the grain size distribution of the material in suspension;
- 3 x Optical backscatter point sensor (OBS) for the measurement of turbidity and SPM concentration at different heights above the bottom;
- Fluorometer for the measurement of fluorescence as a measure of the concentration of chlorophyll.

The tripod is to be placed alternately east and west of the sea farm so that the influence of the sea farm on the advection, composition and concentration of the SPM can be evaluated. Four anchorages will be conducted annually, each for approximately one month. The anchors will be done during the four seasons so that the influence of the tide, the spring tide-dead tide cycle and seasonal variations can be estimated. The effect of meteorological conditions can be determined. The tripod and bottom-mounted ADCP will be purchased at the licensee's expense.

Before or after anchoring or recovery of the tripod, water samples will be taken to determine the SPM concentration and the concentration of organic material. The SPM concentration from water samples is needed for calibration of the OBS sensors and provides insight into any occurring changes in the composition of the suspension material.

In addition, the monitoring of the soil composition will also illuminate possible environmental consequences of bivalve aquaculture. The presence of filter feeders in large numbers would lead to increased deposition of feces, pseudo feces, shells and shell grit, which may impact benthic ecology. To monitor possible effects, soil samples will be taken in the sea farm itself, in a nearby area to the east or west, and in a

reference area. Samples will be taken prior to installation of the aquaculture operation and once a year after installation for the first 9 years of the project, then at years 12, 16, and 20. Soil grain size distribution, amount of organic matter, amount of shell debris, and species composition of infauna will be determined.

The monitoring plan also pays special attention to any possible ecosystem shifts throughout the aquaculture operation's lifespan. The soil samples taken as baseline data and throughout the rest of the project will help determine any shifts in the biodiversity of benthic fauna. Characterization of demersal epifauna will also be conducted before the construction of the farm with 3 beam trawl surveys: in the sea farm, near the sea farm, in a reference area. These surveys will also be conducted annually for the first 9 years of the project. Additionally, scientific divers will conduct standardized fish censuses to monitor the attraction of fish to the artificial hard substrates created by farm infrastructure. These surveys will be conducted prior to construction and after 1, 3, 6, 10, and 20 years.

In accordance with the requirements in the Marine Strategy Framework Directive (MSFD), the occurrence of non-indigenous species (NIS) is also to be monitored. To this end, samples of the accretion can be analyzed. The annual sampling itself can be done in cooperation with the licensee whereby 10 samples can be supplied per year by the licensee.

Marine mammals and sea birds are also a high priority for environmental monitoring. Regular gear checks are necessary to detect entanglements of mammals or sea birds Possible changes in behavior will also be monitored with surveys. To this end, a seabird survey (ship) around the area and in a reference area is carried out 4 times a year (1 per season) for 5 years for the assessment of the presence and density of seabirds. This will help determine changes in attraction or avoidance behavior. To determine the local spatial distribution of porpoises around the project will be used in the period with the highest expected density of porpoises (January-May) across three transects of passive acoustic monitoring devices (F-PODs) anchored at different distances from the project by means of mini tripods. The presence and abundance of grey seals will also be determined with surveys.

In this plan, BMM shares much of the workload of monitoring with Codevco V BV. The RV Belgica is often employed to carry out specific monitoring protocols at no additional expense to Codevco V BV. However, if the RV Belgica is not available, Codevco V BV will be responsible for chartering a vessel to carry out the monitoring at the company's own expense. This is in addition to the costs of the monitoring components and infrastructure required by BMM at the expense of Codecvo V BV. As is true for other sections of this report, it is unclear if these requirements will be the same for any prospective aquaculture operators that will apply for environmental permits in the future.

Netherlands

Before establishing an aquaculture farm, an Environmental Impact Assessment (EIA) is generally required. After implementation, there are requirements aimed at monitoring and mitigating the environmental impacts.

Mussel and seaweed farms are typically required to monitor and maintain acceptable water quality standards. This includes monitoring parameters such as oxygen levels,

nutrient levels, pH, temperature, and the presence of contaminants. Farms must adhere to regulations regarding waste and effluent management. This includes proper treatment and disposal of farm waste to minimize environmental impact. Farms may be required to monitor and report on waste management practices.

As described in the "Baseline data collection" section, aquaculture farms must consider the protection of sensitive habitats and species. Permits for projects in Natura 2000 areas can be granted only if it has been concluded that the project will not lead to the deterioration of the natural features of the area concerned. Special measures may be required to prevent adverse effects on nearby habitats and species (for instance, if inspections show that there are birds and/or seal victims due to the structure).

Monitoring and reporting disease outbreaks and implementing appropriate measures to mitigate their impact are important for maintaining the health of the farmed species and preventing potential negative effects on wild populations. The regulations and monitoring requirements have been described in the previous "Product" section.

Many of the variables that might be impacted by aquaculture farms are part of the regular environmental monitoring in the Netherlands. In terms of water quality, the nutrients and plankton are part of Rijkswaterstaat's monitoring program (MWTL). Monitoring of chlorophyll-a is carried out every two weeks from March to September at six coastal locations, once a month in areas further from the coast (at two locations) and once every two months in remote areas of the Dutch Continental Shelf (also at two locations). In terms of biodiversity, the benthic community is also regularly monitored by Rijkswaterstaat.

Germany

An environmental suitability report might be a prerequisite when establishing a mussel and algae aquaculture. However, even without a whole report, environmental impacts have to be considered and described in the planning phase and can be amended with accompanying monitoring during the operational phase. Special focus is given to effects on endangered species such as sea mammals, but in general possible impacts on all flora and fauna are to be considered. Especially the sealing of the ocean floor by anchoring systems, and net structures in the water column posing an entanglement risk for sea mammals, fish and birds, but also the impact of especially mussel cultivation by increased sedimentation, and increase of local concentration of nutrients by their filtration activity has to be considered. While a theoretical report based on literature and other experiences will be sufficient during the beginning of the project, a monitoring scheme might be necessary during operation, This can include but is not limited to sediment and water sampling to determine nutrient and carbon concentration, sampling of epi-Benthic flora and fauna by divers in so-called "transect-dives" and also the determination of benthic community and counting of species in sediment samples. The data normally has to be reported to authorities that can then decide on actions to minimize the impact of the system.

Denmark

There are at present no legal requirements for monitoring the environmental impact of offshore aquaculture of macroalgae and shellfish.

2.3 Conclusions on legal requirements

In the four considered countries, permits or licenses must be obtained to install an offshore low-trophic aquaculture farm. In Belgium, it is the same procedure as for any activity at sea, since offshore aquaculture is a very new activity, with only one farm implemented and a recent one.

Overall, similar data must be collected across countries to obtain permits and licenses: physical parameters, such as waves, current and state of the seabed must be monitored to ensure safety and feasibility of the foreseen activities, potential sources of pollution and contamination must be reported upon, quality of the water assessed and potential impact on endangered species monitored and avoided. Often, these data will be readily available from public data sources. Because all considered countries also have active and legally binding Maritime Spatial Plans, the areas allocated for offshore aquaculture development will (or should) already be placed in zones that do not heavily impact endangered species such as birds or mammals, or cause harm to sensitive habitats.

As a general rule, yield does not legally have to monitored, although an aquaculture operator is likely to monitor it nonetheless to ensure its profitability. In Belgium, regulation is quite stringent regarding monitoring of structures at sea, while Germany, the Netherlands and Denmark are less demanding. If low-trophic aquaculture projects rise in the future, and especially in a multi-use context, legislation might become more strict as the risk for lost structures at sea rises. Regarding food quality and safety, the safety aspect must be closely monitored in all countries, with Denmark being slightly less stringent.

When it comes to environmental monitoring, with the exception, of Denmark that has no obligation for monitoring of environmental impact of low-trophic aquaculture, Germany, the Netherlands and Belgium require monitoring of impact on birds, mammals and benthic community, as well as impact on sedimentology. The remaining variables differ from one country to another and are context-dependent.

The current heterogeneity in legal requirements of monitoring of low-trophic aquaculture can be attributed to the novelty of this activity in the North Sea and Baltic Sea. If it expands in the future, legal requirements regarding monitoring might become more stringent and homogeneous across northern European countries.

3. Challenges

Working offshore

Offshore low trophic aquaculture presents several challenges that must be addressed for successful implementation. Site selection is critical, considering factors such as water depth, currents, wave energy, and seabed composition. The development of robust and durable infrastructure, capable of withstanding harsh marine conditions, is necessary.

Working in high-energy environments, such as the North and Baltic seas, also means not being able to go at sea at will. There may be days, weeks, or even months when visiting the farm is either not possible or strongly discouraged (Rockman et al., 2017), hence preventing serious work for harvesting, maintenance and monitoring. The technology and system design utilized in high-energy environments must be specifically tailored to accommodate the prevailing conditions and withstand the formidable forces generated by high waves and strong currents (Buck et al., 2018). The monitoring system must also be designed to support harsh conditions, and priority given to automated and remote systems.

Despite the presence of technical challenges associated with cultivating marine organisms in the often harsh open ocean environment, the pursuit of offshore farming holds significant justifications. Open ocean waters possess favorable attributes, such as expansive areas for scalability, extensive carrying and assimilative capacities, minimized conflicts with various user groups, reduced exposure to anthropogenic sources of pollution, the potential to mitigate some adverse environmental effects associated with coastal aquaculture, and optimal environmental conditions conducive to supporting diverse marine species (Holm et al. 2017).

Working in a multi-use context

The expected lifespan of offshore structures depends on the risk of failures caused by damaged mechanisms and mechanical loads. Integrating low-trophic aquaculture in offshore environments can influence these risks and affect the lifespan of each activity. While the potential for damage exists, risk analysis suggests that wind turbines are unlikely to sustain significant structural damage from bivalve structures (Jansen et al., 2016). However, jacket foundations could be at risk of collapse under extreme storm conditions (Jansen et al., 2016). Design considerations should be given to prevent damage between activities, such as using appropriate anchors for mussel cultures. Although a broken longline may not directly damage a turbine, it can hinder maintenance access, impacting performance and potentially causing harm to the wind farm. Vessel anchoring during mussel operations may also pose conflicts, potentially entangling or damaging power cables. On a positive note, aquaculture farms in wind park areas benefit from protection against accidental boat collisions due to restricted access.

Regarding monitoring, the increased risk implies that the farm's infrastructure must be even more closely monitored to ensure that damages and wear are noticed as fast as possible and that reparation is not delayed. While gear and infrastructure must not be lost in all projects at sea, the risk of interfering with the turbines makes it even more necessary in the context of multi-use.

What we want and what we can do

Monitoring activities in the marine environment face numerous challenges due to their vast and ever-changing nature. The remote and inaccessible locations, coupled with harsh environmental conditions, create logistical and technical obstacles. The technology employed must be durable enough to withstand the demanding marine environment, sensitive enough to provide valuable information, and capable of remote operation. Consequently, the most suitable technology tends to be expensive and unaffordable for aquaculture farm operators.

As a result, legally mandated variables are monitored using the most cost-effective technology available, while non-legally required parameters are often overlooked. Moreover, monitoring activities that necessitate the use of boat experience increased costs, as boat operations constitute a significant portion of offshore project expenses.

To overcome these challenges, it is crucial to develop robust monitoring strategies, advance technologies, foster collaboration among stakeholders, and invest in research and infrastructure. Expanding the scope of monitoring in offshore aquaculture farms situated within wind farms requires the development and market availability of reasonably priced technologies. Collaborating with public and research institutes to share the costs of monitoring solutions, as well as leveraging public subsidies, could help address this issue. Monitoring plays a vital role in preventing undesirable impacts, mitigating risks, and bridging knowledge gaps regarding the impacts of combining low-trophic aquaculture and offshore wind farms on the marine environment.

4. Conclusions

This deliverable reported on task 6.1 of ULTFARMS: "Review of the monitoring requirements and development of an optimized monitoring strategy for full-scale offshore multi-use aquaculture". The objective of this task is to propose a monitoring strategy for offshore aquaculture farms.

Offshore low-trophic aquaculture is an emerging sector in the North and Baltic seas, and therefore legislation and methods are still new or in the making. Yet a lack of regulation should not be the reason for neglecting monitoring. Monitoring of activities at sea is essential to ensure the safety of the project, the workers, consumers and the environment.

Challenges may present themselves when working far from shore, and especially in a multi-use context. These challenges require an even more stringent monitoring strategy to ensure the safety of infrastructure and of the environment when no direct human supervision is present, which is bound to happen often when working offshore. To achieve appropriate monitoring, choosing the proper site and the right set-up is essential, and remote solutions must be developed and implemented to ensure swift human intervention should issues arise.

When it comes to product quality and safety, European regulations are already quite developed. They must be respected, as ensuring food safety in mussels and algae is crucial to protect consumers from potential health hazards. Through stringent monitoring, testing, and compliance measures, European authorities work diligently to guarantee the safety of these seafood products. By employing these necessary measurements, Europe aims to maintain high standards of food safety and safeguard public health.

Finally, the combination of offshore wind farms and low-trophic aquaculture as envisioned by ULTFARMS, is meant to respect the natural environment and that enhances conservation and restoration of the marine ecosystem. To this end, strict monitoring of the environmental impact of the farm must be applied and nature-inclusive solutions adopted whenever possible to promote positive environmental impact.

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