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Deliverable 4.2

Offshore implementation and process description

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Abstract	The processes and challenges that are involved in offshore installation of the pilot installations, including logistics, transport, installation and associated permitting is described. The requirements of the different stakeholders (government, safety authority,

	offshore wind operator, aquaculture pilot operator) for installing an aquaculture system in a wind farm is outlined. The scope is the requirements for installation (and not earlier phases such as site selection). For the actual installation, a suitable weather window and time of the day with low current speed is needed. Due to this, the actual date and time can only be fixed shortly before. This asks some flexibility from the installation vessels. Guidelines for anchor installation, placing of the longlines and other systems, such as nature inclusive add-ons, are presented. In order to harmonise installation procedures among pilots, other projects and stakeholders, workshops and meetings were organised. An overview is presented of the main challenges encountered at the day of installation at the different pilots and how they were solved.
Keywords	Low-trophic aquaculture, offshore wind farms, co-design, regenerative aquaculture, artificial reefs, design adaptations, testing of design

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Acronyms

AIS	Automatic Identification System
AUV	Automated Underwater Vehicle
BESE	Biodegradable EcoSystem restoration Elements
BMM	Beheerseenheid van het Mathematisch Model van de Noordzee
BMUB	Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety
BSH	Federal Maritime and Hydrographic Agency
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea, 1972
DMA	Danish Maritime Authorities
DP	Dynamic Positioning
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
FOD	Federale Overheidsdienst
GWO	Offshore Wind Safety Training from the Global Wind Organization
HUET	Helicopter Underwater Escape Training
Hs	Significant wave height
HSE	Health and Safety Executive
IMO	International Maritime Law
LTA	Low Trophic Aquaculture
LTAP	Low-Trophic Aquaculture Pilot
LMRA	Last Minute Risk Analysis
LVVN	Ministry of Agriculture, Fisheries, Food Security and Nature
MARPOL	International Convention for the Prevention of Pollution from Ships
ML	Multi Use
MLC	Maritime Labor Convention
MSP	Maritime Spatial Plan
NGO	Non-governmental organisation
NID	Nature inclusive design
NOGEPA	Netherlands Oil and Gas Exploration and Production Association
NSA	North Sea Activity
NVWA	The Netherlands Food and Consumer Product Safety Authority

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OWF	Offshore Wind Farm
OPITO	Offshore Petroleum Industry Training Organisation
OWP	Offshore Wind Platform
PPE	Personal Protective Equipment
PTW	Permission to work
RAMS	Risk Assessments and Method Statements
RDI	The Netherlands Inspection Digital Infrastructure
ROG	Raumordnungsgesetz (Spatial Planning Act)
ROV	Remotely Operated Vehicle
RVO	Netherlands Enterprise Agency
RWS	Department of Waterways and Public Works
SMF	Semi-submersible Mussel Farm
SodM	Dutch State Supervision of Mines
SSM	Occupational Health and Safety Service
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
ULTFARMS	Circular Low Trophic Aquaculture in wind farms and Restoration of Marine Space
WF	Wind farm
WP	Work Package

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Executive Summary

The objective of task 4.2 is to describe the processes and challenges that are involved in offshore installation of the pilot installations. We describe how the logistics, transport, installation and associated permitting and monitoring was done.

The requirements of the different stakeholders (government, safety authority, offshore wind operator, aquaculture pilot operator) for installing an aquaculture system in a wind farm is outlined. The scope is the requirements for installation (and not earlier phases such as site selection).

When all the permits are granted, the actual installation can take place. For that a suitable weather window is needed. HiSea platform is providing such a type of service, using the available metocean forecasts (wind, wind gust, waves, currents, …) and the operation restrictions to define time windows complying with the defined restrictions.

One important parameter for monitoring for example with ROVs or AUVs operations is current speeds, but it may also be crucial for installation operations. An accurate way to predict current speeds is the paid "North Sea Current" application (https://noordzeestroom.ddns.net/nzdb/), which predicts current speeds in the North Sea at any given location.

Due to the need for mostly calm weather, the actual date and time of the installation can only be fixed shortly before. This asks some flexibility from the installation vessels or paying for a ship that will wait in the harbour during bad weather - a very costly approach that is not feasible for restrictive project budgets. Given the size and weight of the aquaculture installation, only offshore ships are able to provide that service. Within the ULTFARMS project it proved to be quite difficult to find ships that were available. One of the reasons is that the installation job is very small compared to other assignments of these companies. Thus, it can happen that a larger, more profitable request comes along which results in cancellation of the aquaculture installation. It was discussed to combine installation of pilots that are close together (e.g. Belgium and The Netherlands), however, the weather window is generally so small that carrying out two installations is not feasible.

Guidelines for anchor installation, placing of the longlines and other systems such as nature inclusive design systems are presented.

In order to harmonise installation procedures among pilots, other projects and stakeholders, workshops and meetings were organised.

Working offshore demands a structured approach to safety, certification, and environmental compliance. Whether operating a wind farm, navigating a vessel, or running an aquaculture pilot, all stakeholders must adhere to strict regulatory frameworks to ensure the safe and sustainable use of the country's maritime space. An overview is presented of the main challenges encountered at the day of installation at the different pilots and how they were solved.

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1. Introduction

1.1 Description of the project

The ULTFARMS project aims to move beyond the current application of Low-Trophic Aquaculture (LTA) systems with novel engineering, technical, ecological and biological processes to optimise production in harsh offshore conditions, low salinities, and their integration within Offshore Wind Farms (OWFs). ULTFARMS will cover the whole value chain expertise for LTA production in OWFs. The project will work with research and industry partners to develop and operate six innovative Low-Trophic Aquaculture Pilots (LTAPs) in six different OWF locations across the North and Baltic Seas.

These six pilots are implemented in the following areas (Table 1):

Table 1: Overview of the six Low Trophic Aquaculture (LTA) pilots of ULTFARMS.

Member state	Name of OWF	LTA production	Type of culture system	Anchor type	Nature-inclusive design system
Belgium	Belwind	Seaweed-Mussels-Oysters	Submersible longline with ropes	Screw anchors	Oyster restoration tables
The Netherlands	Borssele	Mussels	Semi-submersible platform with longlines with buoys and ropes	Plow anchors	No permit for BESE elements underneath SMF, moved to nearshore location
Germany	FINO2	Seaweed	Longline with seaweed net	Concrete block with delta flipper anchors	Algae frames on pilon
Germany	FINO3	Seaweed-Mussels-Oysters	Longline with seaweed net Longline with mussel ropes On bottom table with oyster baskets	Concrete block with delta flipper anchor	No
Denmark	Anholt	Seaweed-Mussels	Longline with buoys and ropes	Plow anchor	No
Denmark	Samsø	Mussels	Tubes and nets	Plow anchor	No

1.2 Objective of task 4.2

After finetuning the findings of Work package (WP)3 – System Design: Mariculture Structures, Renewables, and Sensors. and iterative rounds described in T4.1, the final design from WP3 will be deployed. The findings of "specification and design, numerical modelling and validation, and hardware assembly and installation planning" from task 3.2 are the basis and foundation for proper and safe deployment and will be set into action within this task. To ensure the best and safest way for this practical step, all pilots will harmonize the offshore installation procedure through a close exchange of information including installation companies or suppliers. The deliverable report (D4.2) including the process description will form the basis of training material and manuals to be shared with Work package (WP)8 – Replicability, knowledge and technology transfer (Building Capacity, training and Education).

The objective of task 4.2 is to describe the processes and challenges that are involved in offshore installation of the pilot installations. We describe in general how the logistics, transport, installation and associated permitting and monitoring was done with more pilot-specific details where needed.

In this document, the requirements and processes are described from the perspectives of different stakeholders (government, safety authority, offshore wind operator, aquaculture pilot operator).

Table 2 describes the complete process from preliminary planning to long-term monitoring and optimization. In D4.2 we only focus on the installation phase. Other aspects are dealt with in WP3 System Design: Mariculture Structures, Renewables, and Sensors and WP6 Monitoring and Decision Support System.

Table 2. Phases of installation of aquaculture pilots in the ULTFARMS project.

Phase	Activity	ULTFARMS deliverable[1]
1 Preliminary planning	In the preliminary planning phase, the focus is on getting 'green light' for the aquaculture activity in a certain offshore wind area. The planning includes marine spatial planning approvals, applications for aquaculture-specific licenses, stakeholders consultations and environmental impacts assessments.	These aspects are discussed in UNITED deliverables D1.1, D6.1 and D6.3
2 Technical and site preparations	This phase includes site selection, and infrastructure design	See deliverable D10.3 on site selection and deliverable D3.2 & D3.3 on system design
	A RAMS (Risk Assessment and Method Statement) has to be developed for each activity, to identify hazards and outline mitigation strategies.	This report and D3.2
3 Installation and deployment	In this phase, the following aspects are important:	This report

[1] The deliverables listed in this table and throughout the document are, or will be, publicly available under the 'Results' tab of the CORDIS websites for projects ULTFARMS (https://doi.org/10.3030/101093888) and UNITED (https://doi.org/10.3030/862915).

	Installation logistics (weather, vessel)	
	Worker safety and training	This report
4 Operational launch (start)	The start of the operation requires the start of technical and environmental monitoring and the development of various protocols.	This report
5 Long term monitoring and optimization	Once the aquaculture pilot is running, the pilot site needs to be monitored, maintained, operations refined, and procedures updated. Also regular audits need to take place to ensure compliance with the regulations, and reporting to report findings. Furthermore, routine inspections and upgrades should ensure the structural integrity and efficiency and personnel should be trained to operate the pilot.	ULTFARMS task 4.4

This deliverable has three core chapters:

- Chapter 2: Requirements for installing an aquaculture system in a wind farm, reflecting on the requirements of the different stakeholders (government, safety authority, offshore wind operator, aquaculture pilot operator) for installing an aquaculture system in a wind farm
- Chapter 3: The installation procedure
- Chapter 4: Harmonisation of offshore installation procedures

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2. Requirements for installing an aquaculture system in a wind farm

In the following chapters the requirements of the different stakeholders (government, safety authority, offshore wind operator, aquaculture pilot operator) for installing an aquaculture system in a wind farm are outlined. The scope is the requirements for installation (and not earlier phases such as site selection).

2.1 Government requirements

In this paragraph we describe the requirements from the (national) governments and regulations in place for installation of aquaculture systems with nature inclusive design (NID) elements/systems (see also Deliverable D7.2 "Nature-inclusive designing of offshore multi-use infrastructure" for further details on NID) where applicable.

Duch pilot in Borssele windfarm

The Dutch pilot aims to cultivate blue mussels and also incorporates a NID approach. It is located in the Borssele windfarm. This windfarm is assigned for co-use, such as aquaculture by the Dutch government through a wind park 'area passport' (Figure 1). Part of Borssele is therefore available for aquaculture co-use. To conduct aquaculture in the designated area, a license (NL: beschikking) must be obtained and various parties need to be involved.

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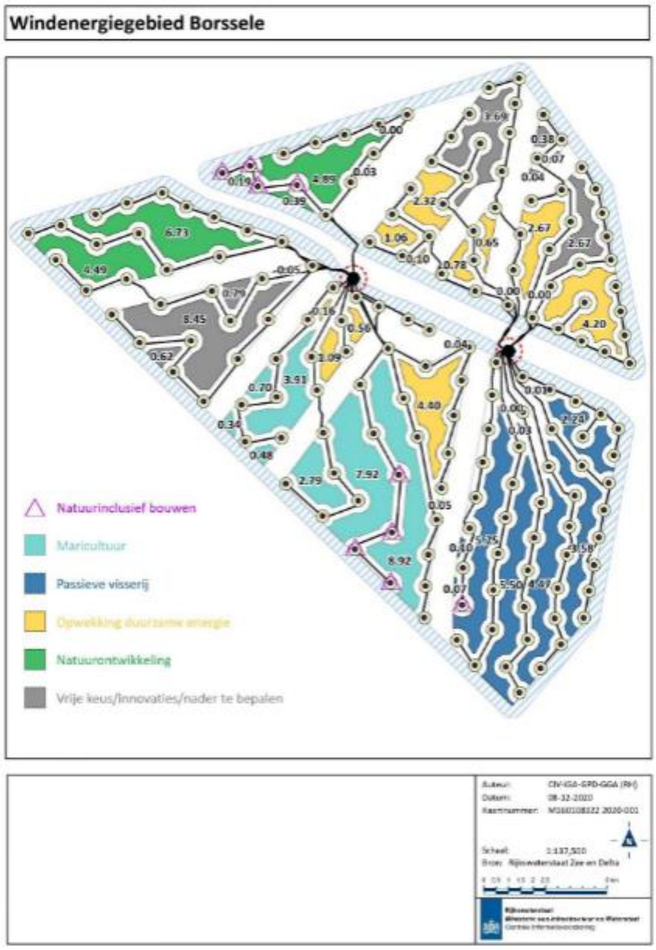

Figure 1. Dutch pilot. Co-use in the Borssele wind farm, purple triangle indicates nature inclusive building, light blue mariculture, dark blue passive fishery, yellow renewable energy, green nature development and grey free choice.

In the Dutch North Sea, the two most important parties to deal with are:

1. Rijkswaterstaat (RWS): the coordinating manager of the Dutch North Sea. RWS is part of the Dutch Ministry of Infrastructure and Water Management and deals with spatial management (including co-use area in wind park), mooring, demarcations (shipping routes, buoys) and the final license (beschikking) under the Water Act (Waterwet). After application, the license process can be digitally followed through the RWS "omgevingsloket" website (https://omgevingswet.overheid.nl/home)
2. Ministry of LVVN (Ministry of Agriculture, Fisheries, Food Security and Nature). This ministry deals with licenses under the Dutch Nature Act. An assessment has to be made of the interaction of the project with Natura 2000 areas such as the Voordelta and the impact of the aquaculture installation on protected species (birds, etc). To assess the ecological impact, a study was conducted by a 3rd party (Waardenburg Ecology). LVVN

also deals with the Visserijwet (Dutch Fishery Act) in relation to mussel harvesting and vessels needed for that.

Other governmental parties involved are:

- Rijksvastgoedbedrijf (Central Government Real Estate Agency for the Netherlands): Is only applicable when project is within 12 nm (OOS project > 12nm).
- RVO (Rijksdienst Voor Ondernemend Nederland, Netherlands Enterprise Agency). Exemption request that our project is not conflicting other fishing activities or disturbing shipping routes and other general support and advise.
- SodM: Staatstoezicht op de mijnen (Dutch State Supervision of Mines (SSM)): (Occupational Health and Safety Service): responsible for safe working conditions ARBO.
- RDI (Rijksinspectie Digitale Infrastructuur): For licenses transmitting AIS
- NVWA (The Netherlands Food and Consumer Product Safety Authority): for sanitary surveys and safe consumption mussels.

Consultation with the windfarm.

Consultation meetings with windfarm operator are important to discuss the co-use and access of vessels in the windfarm. A main discussion point was the approval of vessels entering the windfarm. In general, such vessels need to be approved by the wind farm through a vessel inspection. The windfarm and OOS finally agreed that OOS is responsible for the vessels entering the windfarm being certified and suitable to carry out the job, and not the windfarm. Whenever works are planned, OOS will give a 5 days' notice to the windfarm operations center. To discuss plans, OOS joins the daily toolbox meetings of the windfarms (Teams). All the above has been formalized with the offshore wind park through a so called "proximity agreement".

Useful documents are:

- north-sea-programme-2022-2027.pdf: (https://www.rijksoverheid.nl/documenten/rapporten/2022/03/18/bijlage-programma-noordzee-2022-2027)
- Passport medegebruik (Area Passport Guide): Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2020). *Handreiking gebiedspaspoort Borssele*. https://www.noordzeeloket.nl/publicaties/

German Pilots FINO2 (Baltic Sea) and FINO3 (North Sea)

The German Piot in the North Sea aims to cultivate blue mussels, algae and European oysters, while the German pilot in the Baltic Sea aims to cultivate algae and also has a nature inclusive design system. Both pilots are located in the German Exclusive Economic Zone (EEZ) in Baltic Sea (FINO2) and North Sea (FINO3). In Germany's EEZ, the legal framework governing offshore multi-use activities is established by several key legislations.

- The Federal Regional Planning Act (Raumordnungsgesetz – ROG) provides the foundation for maritime spatial planning in the EEZ, emphasizing the coordination of various maritime uses to ensure sustainable development.
- The Maritime Spatial Plan for the German EEZ, implemented by the Federal Maritime and Hydrographic Agency (BSH), delineates specific zones for activities such as shipping, wind energy production, and environmental protection, aiming to minimize conflicts between different uses. For instance, priority areas are designated for shipping and wind energy, where other activities are restricted unless they are compatible with the primary use.
- Additionally, the Maritime Facilities Act (Seeanlagengesetz) regulates the construction and operation of offshore installations, ensuring that such structures do not impede recognized shipping lanes crucial for international navigation. Any planned offshore activities in the German EEZ require thorough consultation with the Federal Maritime and Hydrographic Agency (BSH) and other relevant authorities to assess potential risks and implement necessary mitigation measures. This collaborative approach ensures that all maritime activities are conducted safely, efficiently, and in harmony with environmental conservation efforts.

Germany's maritime spatial planning has seen significant developments in recent years. The initial Maritime Spatial Plan, established in 2009, was replaced by a new plan that came into force in September 2021. This updated plan encompasses the German Exclusive Economic Zone (EEZ) in both the North Sea and the Baltic Sea, as well as the territorial sea areas under the jurisdiction of the coastal federal states: Lower Saxony, Schleswig-Holstein, and Mecklenburg-Vorpommern (https://maritime-spatial-planning.ec.europa.eu/countries/germany).

Of special interest are of course current and future sites for offshore wind farm development. In November 2023, the Federal Maritime and Hydrographic Agency (BSH) announced the initiation of preliminary site investigations in the North Sea EEZ for offshore wind farm development. These investigations target sites N-13.1, N-13.2, and N-6.8, which are scheduled for tender between 2026 and 2027. The draft investigation framework was open for public comment until January 2024. The preliminary draft of the Site Development Plan was made available for international consultation in early 2024 on the BSH website (https://www.bsh.de/EN/PUBLICATIONS/publications_node.html).

Discussions are being held on how to integrate multi-use in offshore areas. However, the current plans do not mention or account for multi-use. As a result, while other uses within offshore wind farms are neither explicitly prohibited nor approved, this legal ambiguity creates uncertainty. In practice, the decision to allow multi-use often falls to the wind farm concession holder. There are also entry restrictions for offshore wind farms, which may pose practical barriers to implementing multi-use. Additionally, it remains unclear what would happen to successful aquaculture operations once wind farms reach the decommissioning phase.

Danish pilots Samsø and Anholt

The Danish Pilot at Paludan Flak focuses on cultivation of blue mussels while the Danish pilot at Anholt aims to cultivate algae and blue mussels. None of the Danish pilots has a specific NID System. The Danish pilots Paludan Flak (Samsø) and Anholt Offshore Wind Farm (Anholt) are both placed in areas designated for energy production according to the Danish Maritime Spatial Plan (MSP) according to the EU Maritime Spatial Planning Directive. As the Danish MSP also has areas designated for mussel production that are not coinciding with energy production, for the ULTFARMS project we needed to apply for a revision of the DK MSP, which was granted in 2024. The revision only included exemptions in the two ULTFARMS sites and at Kriegers Flak, which is used as test site in the OLAMUR project. The implication is that if future multi-use includes mussel farming in areas outside the present areas designated for mussel production, a new revision of the DK MSP is required.

To get a license for mussel production, a permit from the Danish Agricultural and Fisheries Agency is required. There is a standard protocol to be used that can be downloaded from the agency's website. Currently, there is a temporary ban for new licenses for mussel production sites pending revised legislation. Under normal conditions, the agency once having received the application will follow a public hearing process including other government agencies, NGO's and local stakeholders. A license is temporary and lasts for 10 yr and under normal conditions are of a standard size of 18.8 ha. There are some requirements in relation to management of the area e.g., buoys marking the corners of the site, location of the farm site in relation to protected areas, shipping lanes etc. and financial guarantee for funds to clean up the area in case of bankruptcy. However, there is currently no licensing allowed and no information about the content of the new legislation.

To get a license for growing seaweed, a permit from the Danish Coastal Protection Agency (now part of the Danish Environmental Protection Agency) is required. There is a standard protocol to be used that can be downloaded from the agency's website. The agency once having received the application will follow a public hearing process including other government agencies, NGO's and local stakeholders. A license is temporary and lasts 5-10 years under normal conditions. There are some requirements in relation to management of the area e.g., buoys marking the corners of the site, location of the farm site in relation to protected areas, shipping lanes etc. and financial guarantee for funds to clean up the area in case of bankruptcy. Only native species of seaweed are allowed in the units.

Belgian pilot

The Belgian pilot aims to cultivate algae, European oysters and include also a nature inclusive design approach. For the installation of anchors, aquaculture longlines, and oyster restoration cages in the Belgian part of the North Sea, particularly within the Belgian pilot site of an offshore wind farm, permits and regulatory requirements are necessary to ensure compliance with national and maritime safety regulations

Moreover, environmental compliance is a key aspect. An environmental permit or a marine spatial planning permit is typically needed, especially when installing structures that may impact the seabed or marine ecosystems. This includes adherence to the Marine Strategy Framework Directive (MSFD) and Environmental Impact Assessment (EIA) requirements, depending on the scale of the installation.

Depending on the nature of the anchoring and seabed intervention, a seabed disturbance permit might be required, which involves prior consultation with the Federal Public Service (FPS) Mobility and Transport and the FPS Public Health, Food Chain Safety, and Environment to ensure that activities do not interfere with protected marine habitats or species. As the latter was not the case for the Belgian pilot, we did not have to require this permit for offshore.

Lastly, before the anchor's installation, a seabed survey is advised to assess if there are potentially unexploded items of ordnance present in the area of interest. This survey is usually a non-intrusive unexploded ordnance (UXO) which uses magnetometers to detect ferrous anomalies in the ground (such as munitions, bombs or other).

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Table 3. Overview of required documents from the government for installation of aquaculture pilots in the ULTFARMS project.

Pilot study	Belwind (B) seaweed bivalves	OOS (NL) mussels	FINO2 (G) seaweed	FINO3 (G) seaweed mussels oysters	Anholt (DK) seaweed mussels	Samsø (DK) mussels
Site permit for the aquaculture installation	The WF already has an environmental permit, and the aquaculture (as research purpose) goes under the WF permit	Permit under the 'Waterwet' Area Passport for the wind farm area describing the multi-use requirements (Government)	All permits are given and regulated by Federal Agency for Maritime Navigation and Hydrography (Bundesamt für Seeschifffahrt und Hydrographie, BSH	All permits are given and regulated by Federal Agency for Maritime Navigation and Hydrography (Bundesamt für Seeschifffahrt und Hydrographie, BSH	Coastal Protection Agency license for growing seaweed until 31st of December 2027 Temporary permit for experimental farming of mussels granted by the Danish Fisheries Agency (Now: Danish Agricultural and Fisheries Agency) until July 15th 2027.	Coastal Protection Agency license for growing seaweed until 31st of December 2027 Temporary permit for experimental farming of mussels granted by the Danish Fisheries Agency (Now: Danish Agricultural and Fisheries agency) until July 15th 2027.
Nature Inclusive Design System permit	To deploy habitat restoration structures in an OWF, a permit would likely have to be obtained from the environmental public department in agreement with the offshore wind farm operator.	In the OOS pilot, the area is under the authority of Rijkswaterstaat. For placing installations or objects, a permit under the Waterwet is required.	All permits are given and regulated by Federal Agency for Maritime Navigation and Hydrography (Bundesamt für Seeschifffahrt und Hydrographie, BSH	Not applicable	Not applicable	Not applicable

2.2 Safety authority requirements

The ULTFARMS aquaculture pilots take place in offshore areas where other vessels are sailing around. To prevent collisions and accidents, the national safety authority usually needs to know which activities take place when. In this paragraph we describe this process and what is required to allow for an aquaculture pilot to be transported oversea and installed.

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Dutch pilot

In the Netherlands, activities at sea must be announced to and approved by the **Dutch coastguard**, filling in a "Request for North Sea Activity (NSA)" form[2] and sent to the coastguard. The form contains questions on the risks for other shipping traffic and mitigation measures, the work description, vessel description, and communication (Figure 2). For the installation of the OOS pilot, an NSA was filled out for each seagoing activity, thereafter a number is issued (NSA….) which is to be used in each further communication for this project with Dutch Coastguard.

German pilots

Within the German EEZ different rules apply for safe navigation:

- Adherence to Designated Shipping Routes: Vessels are required to navigate within established shipping lanes as outlined in the maritime spatial plans to ensure safe and efficient passage.
- Compliance with Maritime Spatial Plans: Mariners must be aware of and comply with the spatial designations and regulations set forth in the maritime spatial plans, which aim to balance various maritime activities and environmental protection.
- Coordination with BSH for Specific Activities: For activities such as scientific research, laying of submarine cables, or entering areas near offshore installations, captains should coordinate with the BSH to obtain necessary permissions and guidance.
- Environmental Protection Compliance: Vessels must adhere to environmental regulations, including proper waste management and emission controls, to protect the marine environment within the EEZ.
- Emergency Preparedness:
  - Familiarity with Emergency Procedures: Captains should be well-versed in emergency protocols and maintain up-to-date contact information for the Havariekommando and other relevant authorities.
  - Regular Safety Drills: Conduct routine safety drills to ensure crew readiness in case of emergencies such as collisions, groundings, or pollution incidents.

To enter into a wind farm area for any work the following steps are needed:

Identify the Wind Farm Operator:

- Determine the specific wind farm you intend to enter and identify its operator. A comprehensive list of offshore wind farms in Germany, along with their operators, is available through the Federal Association of Offshore Wind Farm Operators (BWO; bwo-offshorewind.de).

[2] https://kustwacht.nl/en/merchant-shipping/request-nsa/#:~:text=Activities%20and%20work%20on%20the,to%20ccc%40kustwacht.nl%20.

Obtain Contact Information:

- Once the operator is identified, acquire their contact details. This information can often be found on the operator's official website or through maritime directories.

Initiate Communication:

- Reach out to the operator well in advance of your intended entry. Provide details such as your vessel's specifications, the purpose of entry, estimated time of arrival, and duration of stay.

Await Authorization:

- The operator will assess your request and may provide specific instructions or conditions for entry. Ensure you receive explicit authorization before proceeding.

Coordinate with the German Coast Guard:

- Inform the German Coast Guard of your plans, as they oversee maritime safety and security. They can offer guidance and ensure that your activities do not conflict with other maritime operations.

Danish pilots

The permits for seaweed and mussel farming are generally given under the prerequisite of compliance with safe anchoring and seafarer practices. For seafarer, the boat and crew must comply with regulations set by the Danish Maritime Authorities (DMA). There are regulations in relation to boat size, motor power, number of passengers, training of crew that is specific to the given boat(s) used. In addition, for DTU operating the ULTFARMS pilots in Denmark, there are an additional set of compliance requirements regarding safety at sea that exceeds the formal requests of the DMA. In relation to the farm units, there are no special regulations for offshore farming. Proper marking of the area is the only requirement and that is controlled by the Danish Agricultural and Fisheries Agency. They are however not responsible for any wrecking or damage caused by the farm unit.

Belgian pilot

Safety authority requirements for the installation of seaweed cultivation systems and oyster restoration cages within the offshore wind farm were stringent, reflecting the high-risk environment of the North Sea. Compliance with these regulations was critical to ensure the safety of personnel, vessels, and the integrity of the wind farm infrastructure.

The first layer of safety compliance involved obtaining permits from the relevant maritime and offshore authorities. This included securing authorization to operate within the wind farm concession area, which is classified as a restricted zone due

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to the presence of high-voltage cables, turbines, and heavy vessel traffic. The approval process required detailed risk assessments, outlining potential hazards such as equipment failure, vessel collisions, or anchor drag, along with corresponding mitigation measures.

A key requirement was the development and submission of a comprehensive Safety Management Plan, including a risk assessment. This plan covered all operational aspects, including vessel traffic management, emergency response procedures, and protocols for working at sea. It needed to demonstrate how risks would be controlled, with specific reference to the safety of both the crew and the existing wind farm infrastructure. Coordination with the wind farm operator's marine coordination center was mandatory to align activities with ongoing maintenance schedules and avoid conflicts with crew transfer vessel (CTV) routes. Additional information about the risk assessment is given in the section 2.3.2.

Vessel safety compliance was equally rigorous. Each vessel had to pass a thorough vessel vetting (safety inspection), including checks on stability, life-saving appliances, firefighting equipment, and communication systems. These checks ensure that vessels are fit for offshore conditions, especially given the challenging environment of the North Sea.

Dynamic Positioning (DP) systems, particularly for DP2-class vessels, were tested to ensure precise station-keeping capabilities, crucial when operating near sensitive subsea infrastructure. Additionally, vessel insurance had to meet specific offshore requirements, covering potential liabilities related to environmental damage, accidents, or equipment loss.

The vessel and people joining the vessel (crew and externals) have to upload, vessel info, certificates and personal info on the online SOS platform (Offshare) prior to sailout. Via this platform the Marine Coordination Center can expect and allow the voyage plan and the activities.

Environmental safety considerations also fell under regulatory scrutiny. Prior to anchor installation, an Unexploded Ordnance (UXO) survey was mandatory to identify and mitigate the risk of encountering historical munitions on the seabed. The seabed was also scanned to confirm the absence of sensitive habitats or protected species in the installation area. Anchoring techniques had to comply with environmental protection guidelines, favouring screw anchors to minimize seabed disturbance, particularly in ecologically sensitive zones.

Real-time safety monitoring was maintained throughout the operation. A designated Safety Officer was onboard to oversee compliance with procedures, conduct toolbox talks before each shift, and manage incident reporting. Continuous communication with both the marine coordination center and other vessels ensured rapid response capability in case of emergencies. Regular safety drills were conducted to reinforce preparedness, covering scenarios such as man-overboard, medical emergencies, and vessel evacuation.

Additionally, every installed structure has to be decommissioned by the end of the project, and nothing can be left on site/seabed.

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Table 4. Overview of required documents from the windfarm operator for installation of aquaculture pilots in the ULTFARMS project.

Pilot study	Belwind (B) seaweed bivalves	OOS (NL) mussels	FINO2 (G) seaweed	FINO3 (G) seaweed mussels oysters	Anholt (DK) seaweed mussels	Samsø (DK) mussels
Permission from the coastguard	Environmental permit for the marine environment	For each activity permission must be obtained from the Dutch coastguard using a standard procedure: filling in a "Request for North Sea Activity (NSA)" form[3] and sent to the coastguard.	For each activity permission must be obtained from the German coastguard and the operator of the wind park and the operator of the research platform	For each activity permission must be obtained from the German coastguard and the operator of the research platform	None	None

[3]https://kustwacht.nl/en/merchant-shipping/request-nsa/#:~:text=Activities%20and%20work%20on%20the,to%20ccc%40kustwacht.nl%20.

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Netherlands Coastguard

Request for North Sea Activity (NSA)

Contact details applicant
Date | Name
Address | City | Country
Phone number | E-mail

Company details applicant
Name | City | Country
Phone number | E-mail

Client details
Company name | Name point of contact
Phone number | E-mail

Activity description
Type of activity
Start of activity *Local time* | End of activity *Local time* | Crossing traffic lane(s) during during the activity Yes No
Bounded area or exact position *Coordinates must be given in WGS84/ ETRS89 (degrees/minutes/decimals)*

Request for North Sea Activity (NSA)

What are the risks for other shipping traffic?
What measures are being taken to remove the risks for other shipping traffic?
Work description

Vessel description
Name | MMSI
IMO | Call sign
Flag State | Ships type
Phone number | E-mail
Length over all | Width | Draft | Operating speed
Confirming AIS on board | Restricted maneuverability | Requested safe distance other vessels
Supporting-/guardvessel(s) details
Deployed equipment *(in case 'yes') description equipment* Yes No
Communications during work (24/7)
Remarks

Complete this form and send it to ccc@kustwacht.nl

Figure 2. Request for North Sea Activity (Netherlands Coastguard).

2.3 Offshore wind operator's requirements

The ULTFARMS aquaculture pilots take place in offshore wind areas with high safety standards and different operations simultaneously taking place. In this paragraph we describe this process and what is required to allow for an aquaculture pilot to be installed. An overview of required documents is provided in Table 5.

German pilots

As no MU is yet specified in the German Maritime Special Plan, no specific regulations concerning MU exist. However, Offshore operators near and in wind parks in Germany's Exclusive Economic Zone (EEZ) must comply with a range of legal, environmental, and safety requirements. Before constructing or operating an offshore pilot, operators must obtain permits from the Federal Maritime and Hydrographic Agency (BSH). These permits require compliance with maritime spatial planning regulations, construction safety standards, nature conservation, Building, and Nuclear Safety (BMUB). Offshore wind structures must also meet BSH safety and design standards. Additionally, all activities must align with Germany's maritime spatial plan to avoid conflicts with other sea users such as shipping and fisheries.

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Danish pilots

Wind Estate operating the Paludan OWF has no additional demands besides where the farm unit could be placed.

Ørsted has a wide set of requirements in relation to safety of the boats used in the Anholt OWF. All boats used have to be approved by Ørsted using a long list of requirements and an annual physical inspection that is very elaborate and exceeds the standards set by both DMA and DTU by length. In addition, Ørsted has requested a Health, Safety and Environment document from DTU before entering the area. These procedures will increase costs of production and thus affect the economic feasibility of offshore commercial farming.

Both OWF have no restrictions in accessing the areas, as long as the respective safety precautions are met. However, sailing close to the turbines is forbidden and a distance of 200 m has to be kept at Samsø and 100 m at Anholt.

Table 5. Overview of required documents from the wind farm operator for installation of aquaculture pilots in the ULTFARMS project.

Pilot study	Belwind (B) seaweed mussels oysters	OOS (NL) mussels	FINO2 (G) seaweed	FINO3 (G) seaweed mussels oysters	Samsø (DK) mussels	Anholt (DK) seaweed mussels
Risk Assessment and Method Statement (RAMS)	Required also to obtain an insurance	A RAMS is needed for an activity. It is discussed with the offshore windfarm operations manager (weekly meetings).	Needed to get access and conduct works	Needed to get access and conduct works	None	Performed in connection with boat approval.
Ship	Vessel vetting, depending on the activities planned	DP ship	Depending on the activity	Depending on the activity	None	Safety inspection according to Ørsted standards
Personnel safety and certificates	GWO training (only sea survival module), safety training, induction to the windfarm, medial certificate	GWO training, safety training, induction to the windfarm, medial certificate	GWO safety training	GWO safety training	None	HSE according to Ørsted standards
Access permit	An Access Permit (transfer plan) is provided per work day (gives access to Offshore Wind Farm during that day)	An Access Permit is provided per work day (gives access to Offshore Wind Farm during that day) when the RAMS and personnel certificates are approved	Issued by FINO operator if all necessary prerequisites are met (RAM, personnel certificates, shipping certificates)	Issued by FINO operator if all necessary prerequisit es are met (RAM, personnel certificates, shipping certificates)	None	Ørsted to be informed before entering the area.

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Risk Assessments and Method Statements (RAMS)

Usually, an activity can only take place after obtaining a site permit, which allows for access to the windfarm in a certain time window. The site permit is obtained after approval of the RAMS, vessel and crew.

The works and activities should be described in a RAMS that needs to be approved by the offshore wind operator (mainly HSSE department and installation expert).

Usually, there is an operations control center ('traffic control tower or Marine coordination') that coordinates all offshore activities and ensures safety. This control center will need to clear the vessel in the field. As previously mentioned, the vessel needs to be approved to enter the windfarm area (relevant data needs to be in their system).

An example of a RAMS is given below.

Dutch pilot

For the Dutch pilot one RAMS had to be prepared for all activities related to the OOS project. For specific monitoring activities within OOS a RAMS is not officially required. However, it is a good practice to collect all information in a RAMS so that the wind farm owner understands the nature of the activity. An example of a (research) RAMS is given in Box 1.

Box 1. Example of the content of a Risk Assessment and Method Statement (RAMS). The content varies according to the works to be carried out.

Chapter	Subject	
1	Introduction	
		Purpose of this document
		Reference documents
		Scope of work
2	Summary of work to carry out	
3	Crew and responsibility diagram	
		Crew
		Responsibilities
		Work location
		Coordinates
		Vessel information
		Timing of activities
		Scheduling the work
		Alternatives
4	Equipment List	
		Material list
		Personnel list
5	Monopile mooring plan	

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		Sampling location 1
		Sampling location B2
		Sampling D1 & D2
		Sampling amount
6	Method statement	
		Preparations and starting conditions
		Safety instructions
		Method statement – Preparation
		Method Statement – ROV
		Method Statement – AUV
7	Safety Management plan and emergency Procedure	
		Non-alcohol & non-drugs policy
		Preventive measures in place
		PPE policy
		Stop Work Action (SWA) policy
		Situations that may require a Stop Work Action
		Stop Work Action procedure
		Designated person ashore
		Weather
		Emergency contacts
		Roles, responsibilities and tasks in case of emergency
		Reporting of incidents
8	Risk Assessment	
9	Risk Matrix	
Appendix 1		LMRA & Dynamic Risk Assessment on Site
Appendix 2		Operational induction checklist
Appendix 3		Entering of OWF checklist
Appendix 4		RAMS briefing confirmation form
Appendix 5		HSE incident report template
Appendix 6		Hazardous substances

German pilots

A Risk Assessment and Method Statement (RAMS) for entering an offshore pilot or wind farm in the German Exclusive Economic Zone (EEZ) are the same and must comply with national and international maritime safety regulations, including BSH (Federal Maritime and Hydrographic Agency) requirements, HSE (Health and Safety Executive) standards, and industry best practices. It consists of two main sections:

1. Risk Assessment (RA) – Identifies hazards, evaluates risks, and proposes mitigation measures.

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2. Method Statement (MS) – Provides step-by-step procedures to ensure safe operations.

Contents of a RAMS for Entering an Offshore Pilot/Wind Park in the German EEZ

1. General Information

- Project Name & Location: Name of the offshore pilot/wind farm, coordinates, and operator details.
- Purpose of Visit: Inspection, maintenance, research, construction, etc.
- Date & Duration: Expected timeframe of the operation.
- Responsible Parties: Names and contact details of responsible personnel, including vessel crew, technicians, and emergency contacts.
- Regulatory Compliance: Reference to applicable legal frameworks, including:
    - BSH Offshore Regulations
    - Maritime Safety Rules (SOLAS, COLREGs)
    - German Health & Safety Law (ArbSchG, BetrSichV)
    - Pilot or Wind Farm-Specific Safety Rules
    - BIMCO Guidelines for Offshore Operations

Belgian pilot

Permits to enter the offshore wind farm concession area are mandatory. Access to these restricted zones is tightly controlled to prevent conflicts with wind turbine operations and ensure the safety of both aquaculture and energy infrastructure. This typically involves coordination with the wind farm operator and Marine Coordination (MC) to obtain time-bound access authorizations.

The activities planned should be described in detail in the RAMS. This document will be reviewed by someone with a technical background (such as an installation expert) and safety background (HSSE department).

To fully understand how the operations are going to be performed, the vessel vetting (inspection) is complementary to the RAMS review.

Once reviewed and everything is clear, the RAMS can be approved, and activities can be planned offshore.

The RAMS will be included in a work permit (WP) in the transfer plan (TP) in the offshore system of the respective wind farm (WF). The TP also includes a crew list and must be provided and approved by Marine Coordination (MC) the day before the activities.

Personnel safety and certificates

Dutch pilot

To enter an offshore windfarm, depending on the type of work to be done and the work to be executed, employees and visitors must have specific training and certificates which may include:

- Safety at sea
- First aid
- Fire awareness
- Manual handling
- Working at heights

Training generally needs to adhere to specific standards such as OPITO, NOGEPA, STCW, or GWO. In most cases, a medical approval is needed. Operators might also require a wind farm specific induction or online training. Please contact the wind farm operator to learn which certificates you need.

German pilots

As mentioned above, personnel working offshore in the German EEZ must hold specific safety certificates to ensure compliance with international maritime regulations. Seafarers on offshore vessels must complete Basic Safety Training under the Standards of Training, Certification, and Watchkeeping (STCW) convention, which includes firefighting, sea survival, first aid, and personal safety and first aid.

<u>Crew Certifications (for Personnel on Vessels)</u>

- Basic Safety Training (STCW):
    - Purpose: Ensures that all crew members on offshore vessels have the basic skills to respond to emergency situations.
    - Required by: International Maritime Organization (IMO) conventions under the STCW (Standards of Training, Certification, and Watchkeeping) Code.
    - Contents: Firefighting, personal survival techniques, first aid, personal safety, and social responsibilities.
    - Certifying Authority: Issued by the relevant national maritime authority, such as the German Maritime and Hydrographic Agency (BSH).
    - General Maritime Certifications (for All Offshore Workers)
- Maritime Safety Certificate (BSH):
    - Purpose: Certifies that maritime workers comply with national and international maritime safety standards.
    - Required by: Workers in any offshore sector (wind, shipping, aquaculture).

  - Certifying Authority: German Maritime and Hydrographic Agency (BSH).
- Maritime Spatial Planning Compliance:
  - Purpose: Ensures activities do not interfere with designated maritime zones, such as shipping lanes or protected environmental areas.
  - Required for: All maritime activities within the German EEZ.
  - Certifying Authority: Federal Maritime and Hydrographic Agency (BSH).

Belgian pilot

Besides the certifications for specific crew functions (such as captain, deck hand, ...), or specific operations (such as ROV deployment) crew safety training certifications are required.

All personnel are required to undergo certified offshore survival training, such as Basic Safety Training (BST) under STCW regulations or the Global Wind Organisation (GWO) Basic Safety Training. The required module in this case is the sea survival. A valid medical examination is also required.

Danish pilots

Permits for working in the Danish pilots are regulated by the Danish Maritime Authorities for the merchant fleet i.e., the STCW certification and the Maritime Spatial Planning Compliance. As there is no work on the pylons and commercial boats – as used in the Danish pilots – are allowed access to the OWF area, there are no additional demands for safety certificates.

Access Permit

Access permits are issued by the operator of the site. It outlines the approval period and key regulations for conducting work in the safety zone and area. It specifies reporting requirements, safety considerations, and coordination procedures, including communication with Marine Coordination and adherence to navigation guidelines to avoid conflicts.

2.4 Aquaculture pilot owner/operator

This section gives an overview of required documents from the aquaculture pilot owner/operator for installation of aquaculture pilots in the ULTFARMS project. After obtaining the various permits from the government and offshore wind park operator, there are a number of more practical procedures that need to be followed to be able to perform activities at sea. In this paragraph we shortly describe the different procedures that are needed.

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The aquaculture pilot owner or operator will require a copy of the RAMS and personnel safety and certificates. Other requirements are provided in table 6.

German pilots

Aquaculture pilot owners and operators must obtain the necessary licenses and environmental approvals before engaging in activities within the German EEZ. These licenses are issued by local or regional authorities in coordination with the Federal Ministry for Food and Agriculture (BMEL). An Environmental Impact study is often required to assess the potential ecological effects of aquaculture operations, ensuring sustainable practices and minimal impact on marine ecosystems. Additionally, aquaculture activities must comply with Germany's maritime spatial planning regulations to prevent conflicts with offshore wind, shipping, and protected marine areas.

Belgian pilot

To engage with authorities and obtain the necessary licenses for activities in the Belgian North Sea, the timing depends on the nature of the project—whether it involves nearshore or offshore operations, and whether it's scientific research or a potential commercial farm.

For nearshore scientific research at the Westdiep site (nearshore pilot within the H2020 UNITED project), an MPA, an agreement was requested from **FOD (Federale Overheidsdienst) Leefmilieu** and **BMM** (Beheerseenheid van het Mathematisch Model van de Noordzee). Additionally, a written agreement must be obtained from the **kabinet** for each individual research project. If the project plans to upscale to a commercial farm, two key permits are required:

1. Permit (**gebruiksvergunning**): This must be applied for at **FOD Leefmilieu**. The application will be reviewed by an advisory committee chaired by FOD Leefmilieu, which will assess any objections and decide whether to grant the permit.
2. Environmental Permit (**milieuvergunning**): This application is made to **BMM**. They will analyse the environmental impacts of the project, gather objections, and make a decision on whether to grant the permit.

For offshore scientific research, licenses for the wind farm have already been obtained prior to this project, so no additional licenses are required. However, agreement from the wind farm (WF) owners is necessary, and the **kabinet** and **BMM** needs to agree (give permission), like the process for nearshore scientific projects.

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Table 6. Overview of required documents from the aquaculture pilot owner/operator for installation of aquaculture pilots in the ULTFARMS project.

subject	Belwind (B) seaweed mussels oysters	OOS (NL) mussels	FINO2 (G) seaweed	FINO3 (G) seaweed mussels oysters	Anholt (DK) seaweed mussels	Samsø (DK) mussels
Site permit	Internal WF approval by combination of RAMS, vessel vetting and transfer plan	(beschikking) under the Water Act (Waterwet).	BSH	BSH	DMA certificate for boat and site license for aquaculture operation	DMA certificate for boat and site license for aquaculture operation
RAMS	RAMS for all planned activities	A RAMS for all installation activities combined was prepared for the windfarm.	RAMS for planned activities	RAMS for planned activities	RAMS for planned activities	None
Activity at the day of installation	A transfer plan is in place, including the locations to be visited and personnel on board	Activities at sea must be announced to and approved by the **Dutch coastguard**, filling in a "Request for North Sea Activity (NSA)" form	For each activity permission must be obtained from the German coastguard and the operator of the wind park and the operator of the research platform	For each activity permission must be obtained from the German coastguard and the operator of the wind park and the operator of the research platform	Reporting to Ørsted port authorities before and after access to the area.	None

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3. The installation procedure

As outlined in ULTFARMS Deliverable 3.1 ("Co-design of production-related activities"; D3.1) and Deliverable 6.2 ("Description of data flows, manuals and training materials"; D6.2), suitable operational windows are periods in which the maritime conditions allow safe operation by ship, depending on the time and requirements needed to complete the respective tasks. Therefore, a multitude of variables influence the decision process, whether a deployment is to be scheduled and made. The most decisive parameters are the weather window (wave height), ship availability (regulated by market supply and demand), the ship requirements and other operational relevant parameters, especially when working with living organisms (seaweed and bivalves).

3.1 Finding a suitable weather window

When all the permits described in Chapter 2 are granted the actual installation can take place. For that a suitable weather window is needed.

The HiSea platform is providing such a type of service, using the available metocean forecasts (wind, wind gust, waves, currents, …) and the operation restrictions caused by these parameters to define time windows complying with the defined restrictions.

The HiSea platform gathers available data (from observations and modelling) to inform about the suitability of the next hours or days weather to perform specific operations (working on site, navigation from the port to the site, etc.). An example is provided below showing suitable operation windows for FINO3 according to the restrictions in terms of wind and waves.

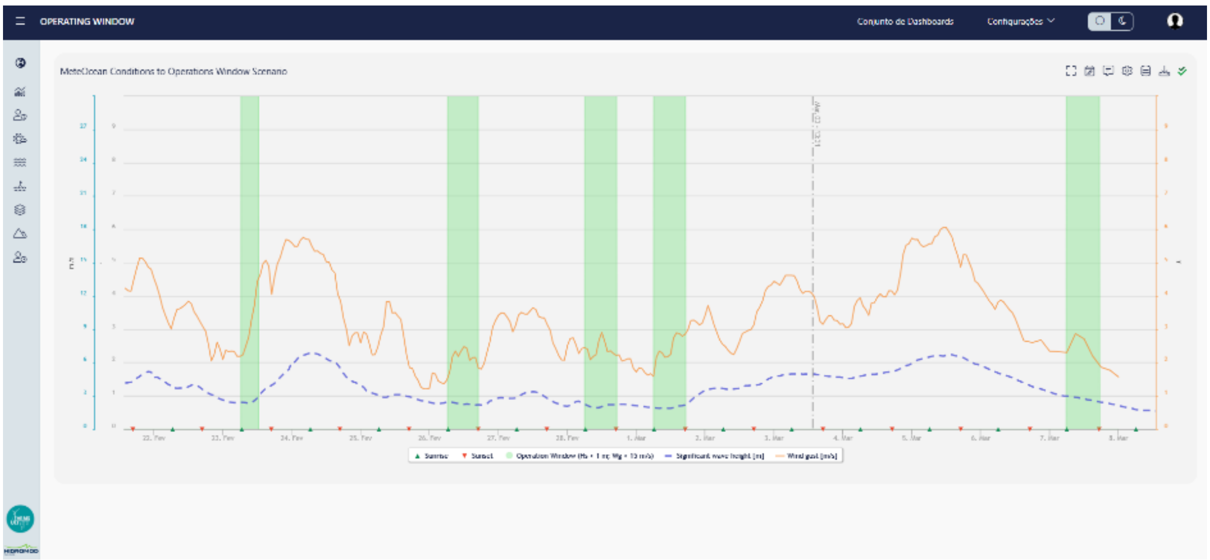

Figure 3. Operation windows compliant with the maximum values of wind and waves defined for safe navigation at FINO3 pilot

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To define these restrictions, and calculate on the fly the correspondent operation windows, the users may use a wizard offered by the HiSea platform allowing to specify the limit values trough an easy-to-use web dialogue:

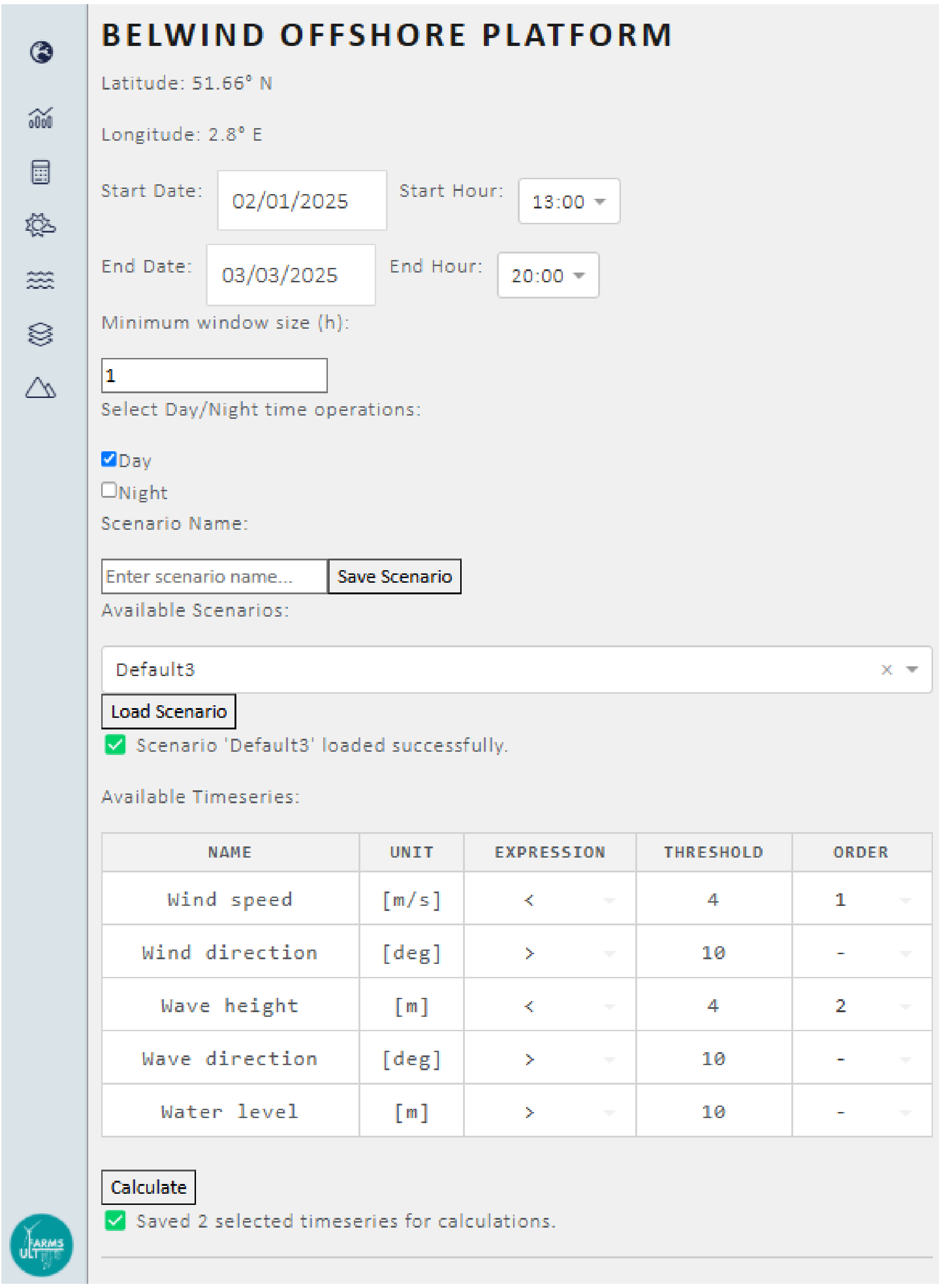

Figure 4. Specification of operation restrictions for Belwind offshore platform on HiSea platform "wizard"

HiSea also offers alert and warning services following the same philosophy and advanced data analytics services to characterize a site or region based on long term datasets provided by the Copernicus online platform (https://dataspace.copernicus.eu/) and other available data sources. The service is designed in a way that may effectively answer to (at least) some of the concerns of the people that must take decisions (ex. planning, licensing or investment) in which these issues are relevant. It provides the capability to combine not only several restrictions and parameters, meeting pre-defined thresholds (most usual scenario), but also the capability to select the frequency that those thresholds must be met (e.g., areas without a protection status observing currents above 10 cm/s 30% of the time and below 1 m/s 80% of the time). There is no limit on the number of restrictions or parameters to consider (it only depends on the data availability). It also includes the analysis of wave climate scenarios allowing to assess potential threats that may be faced in the following years.

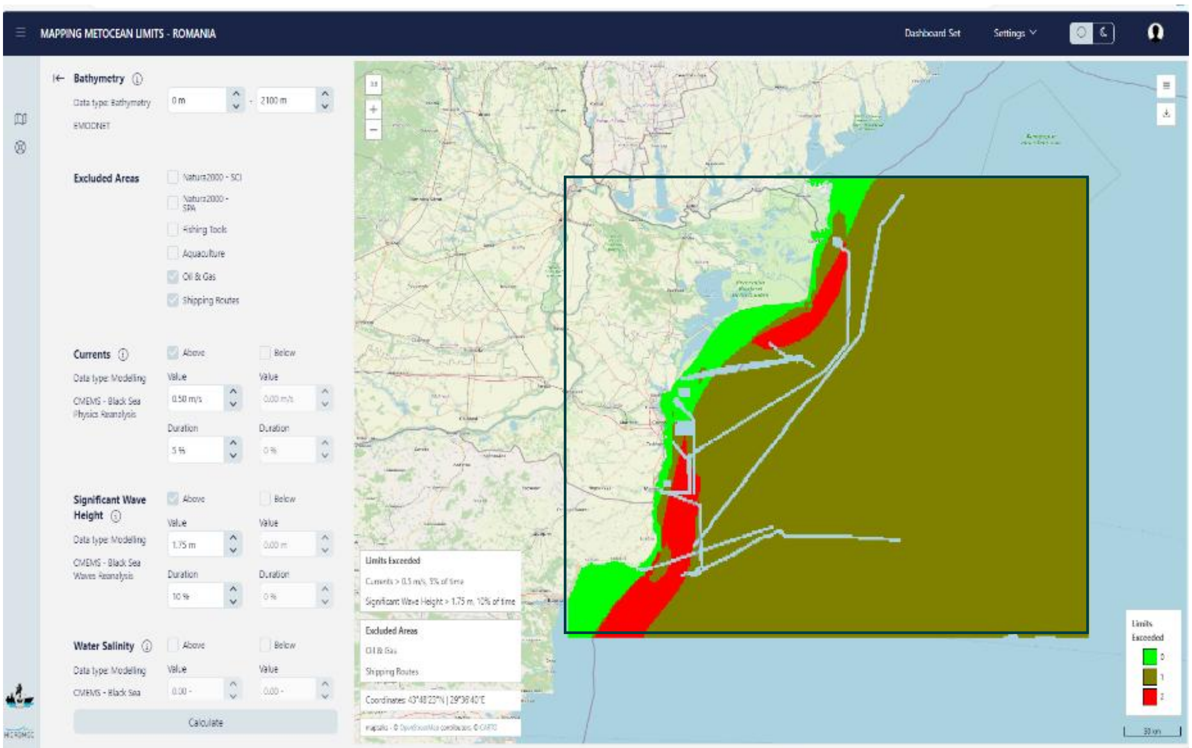

Figure 5. Assessment of compliant user-defined restrictions areas together with other existent restrictions (such as ship lanes, protected areas, etc.) on HiSea platform

Dutch pilot

The suitable weather window depended on the task and the type of vessel needed for the task.

- Weather Considerations:
    - PredictWind (https://www.predictwind.com/), a paid service, was used for weather predictions.

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  - In general wind and waves from south to east are best (max wave height 0.7 m Hs)
  - Northerly winds in Borssele III are unfavourable as they cause prolonged waves and swell.
- Use of RIB: For general inspections and platform access, a RIB with a speed of 25 knots was used, reaching the location Borssele III within an hour from Vlissingen port (distance 22 Nm). A weather window with a maximum significant wave height (Hs) of 0.7 meters was required.
- Use of DP1 Multicat:
  - For longline installation, a DP1 multicat with a 24/7 crew was deployed.
  - A two-day weather window with a maximum wave height of 0.7 m Hs was needed (occasionally max 1.0 m Hs).
  - Due to its slow speed, the vessel departed from Rotterdam port the night before to start work at first daylight. Only daylight operations were allowed in the wind park.
  - After the first day, the vessel anchored just outside the wind park and re-entered at first daylight the following day. Work continued until late afternoon before returning to Rotterdam.

German pilots

The process of finding a suitable weather window is described below in detail for the German pilot within the North Sea and to a lesser extent for the Baltic Sea pilot, due to a similar approach due to differences in scale and operations.

FINO3:

For the FINO3 deployments, operational safety and manoeuvrability are top priorities, which results in a strict wave threshold of a maximum of 1 m in height. This comes due to the operation of long-line systems in the vicinity of a wind park (See chapter 3.3 Finding a suitable vessel). Moreover, the FINO3 location is particularly distant to shore (82 km), which increases the need for accurate and far-reaching weather and wave forecasts.
This comes as a pre-operational time of 12-24 hours is needed (task dependent), prior to deployment from the harbour, with an additional 10-12 hours of shipping time until the arrival at the site. Lastly, the final decision for a sea deployment must be made two to three days in advance (see chapter 3.3 Finding a suitable vessel), which pressures the need for accurate forecasts. Other important factors are the alignment of daylight and good weather as well as to depart or enter with the current and ebbing tides, as otherwise, fuel and shipping time increases.

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For that reason, with the start of the e.g., seaweed (October-March) or blue mussel season (February-April), up to four weather forecasts (see Table 7) are constantly monitored. If certain environmental conditions are projected, the forecasts are checked at least once daily to allow for the earliest possible decision-making. Furthermore, most forecasts are centered around satellite imagery which has noticeable inaccuracies in predicting maximum wave heights (±0.2-0.5m) when compared to the actual data of locally deployed sensors. Therefore, forecasts can only be considered a guidance within the decision-making process. Until accurate medium to long-term predictions is possible, risks of unsuccessful or only partially successful offshore operations remain.

Table 7. German pilot FINO3. Comparison of four weather forecasts for German pilot at the FINO3, as well as the actual data. Two forecasts are publicly accessible, one is being private and the latter one is the demonstration website of "HiSea". The data predictions for that specific day (2023-12-12), were derived two days before the potential deployment. The data presented in "Actual wave height (m)" are the maximum wave height measured by in-situ sensors from the FINO3 location (3D RADAC).

Time	Forecast (m) two days ahead				Maximum wave height (m) 2023-12-12
	Public forecast 1	Public forecast 2	Private forecast	HiSea (Demo)	
5:00 AM	1.1	1.1	1.1		1.1
7:00 AM	1.0	0.9	0.9	0.9	1.1
1:00 PM	0.8	0.6	0.7		0.8
3:00 PM	0.6	0.5	0.9	0.7	0.8
5:00 PM	0.7	0.5	1.3		0.9
9:00 PM	0.8	0.6	1.2	0.7	1.0

Table 7 visualizes the process of evaluating a potential weather window, two days before the attempted but cancelled deployment in December 2023. A small but critical divergence between the forecasts and the actual maximum wave height (m) was observed, which would have led to complications throughout the installation process. In this instance, the actual weather window was significantly shorter by approximately ten hours and the wave height was underestimated. Only the private forecast was more accurate in the prediction of the wave height, although also there persists a substantial mismatch in timing. Despite these challenges faced when working with offshore deployments, four successful ship deployments have been made to FINO3.

However, improving forecasting capabilities remains a crucial requirement to reliably schedule offshore deployments, especially within the autumn and spring seasons.

For the German pilot, such forecast optimizations are ongoing. "HiSea", an online data processing and repository developed by Hidromod, will bundle certain

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forecasts and predict "operational windows" with pilot-specific operational requirements (see ULTFARMS Deliverable 6.2). Furthermore, a process called "downscaling" has started for the German pilot locations, in which satellite-based forecasts are complemented with *in-situ* data and parameters from the offshore research stations e.g., the MARNET program, including FINO1-3 as well as the novel sensor installations through the ULTFARMS project (See section 3.5 BBE Phycoprobe). This will increase our forecasting and alert systems. This approach will be further developed throughout ULTFARMS and updated in upcoming reports such as D6.3 (Month 36), D6.4 (M36) and D6.5 (M41).

Overall, the need for the correct identification of suitable weather windows is driven by their scarcity and randomness. For instance, in the 2023 autumn season, partly influenced by a 150-year storm event, no suitable weather window with a prolonged period was identified. However, in autumn 2024, three suitable weather windows each being several days long and several smaller ones were recognized (See Figure 6 and Figure 7). The alignment of weather windows and ship availability is described in section 3.3.

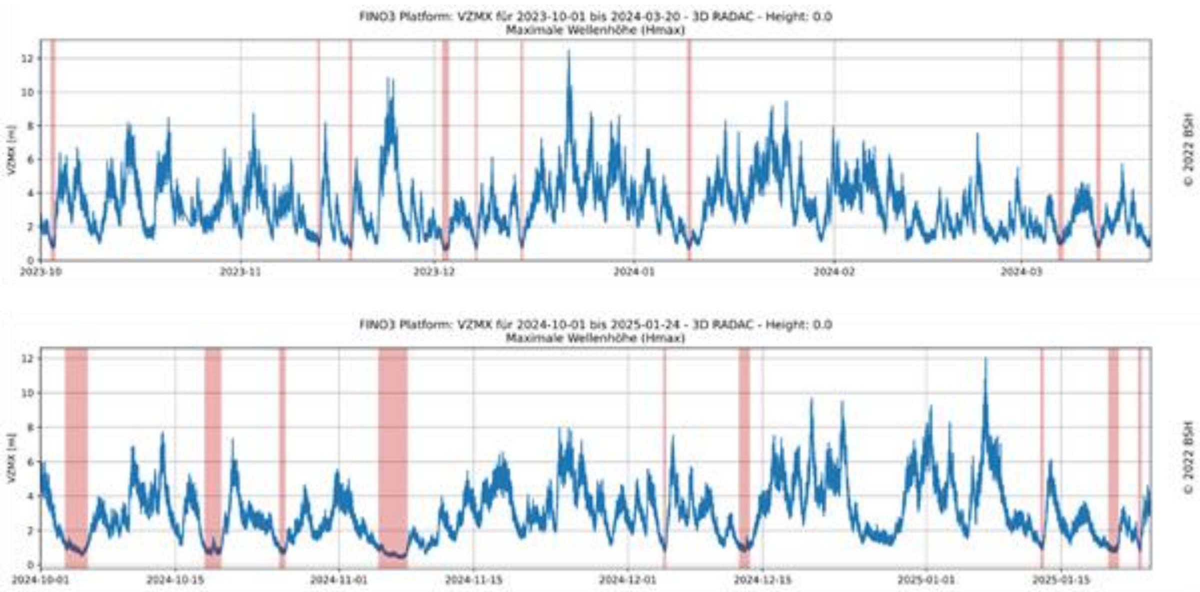

Figure 6. German pilot, FINO3 location. The absolute measured wave height (Vmax, in meters) at the FINO3 location is shown for both autumn seasons, 2023 and 2024. The red bars indicate potential weather windows of a maximum wave height, lower than 1 meter, Figure 7 displays the actual weather windows of both seasons in greater detail. In 2023, only three short weather windows have been observed with a maximum duration of approx. six hours. For the 2024 season, one weather window of 12 hours, three of ~10 hours, and four weather windows shorter than six hours were found (See Figure *7).*

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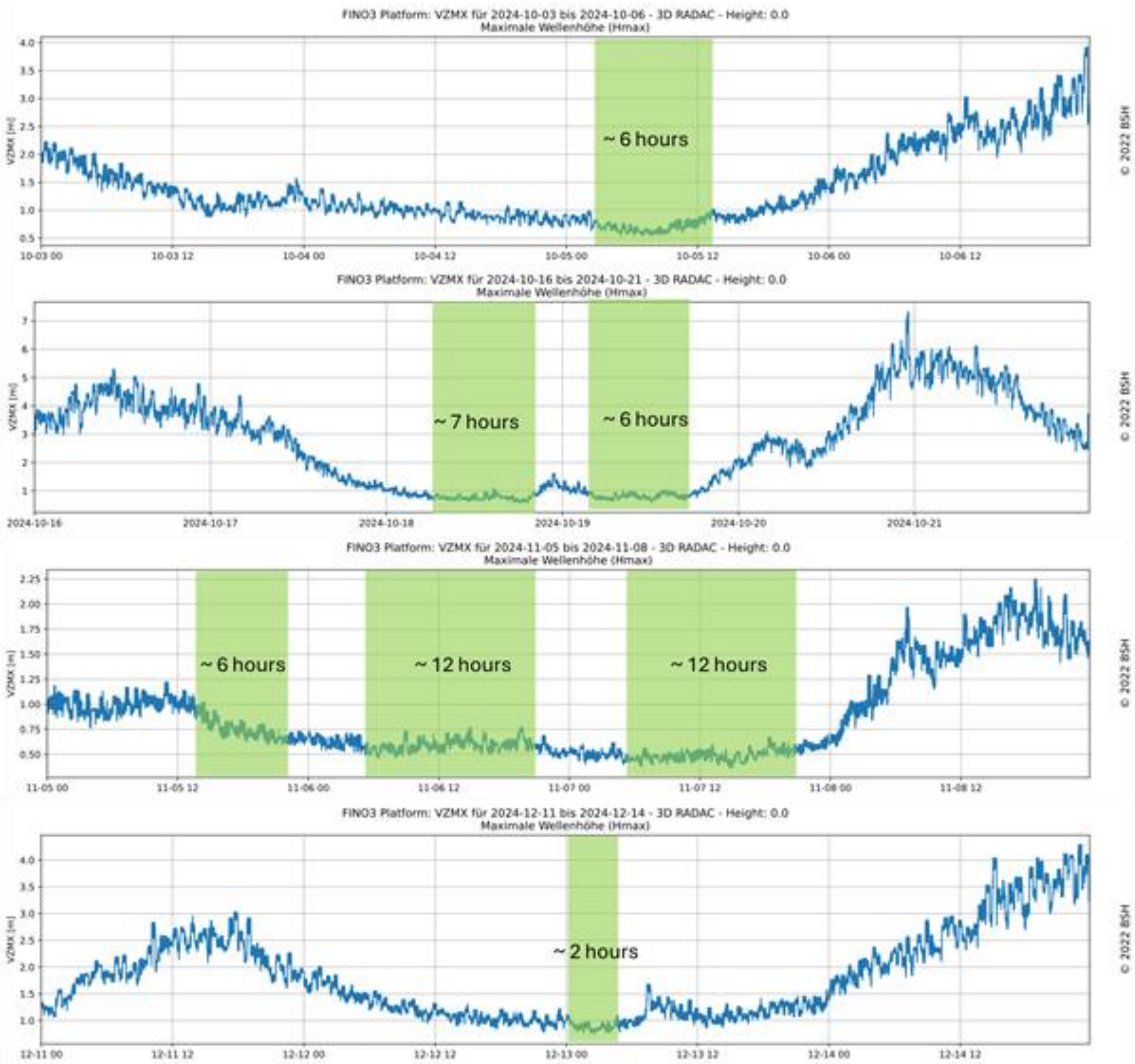

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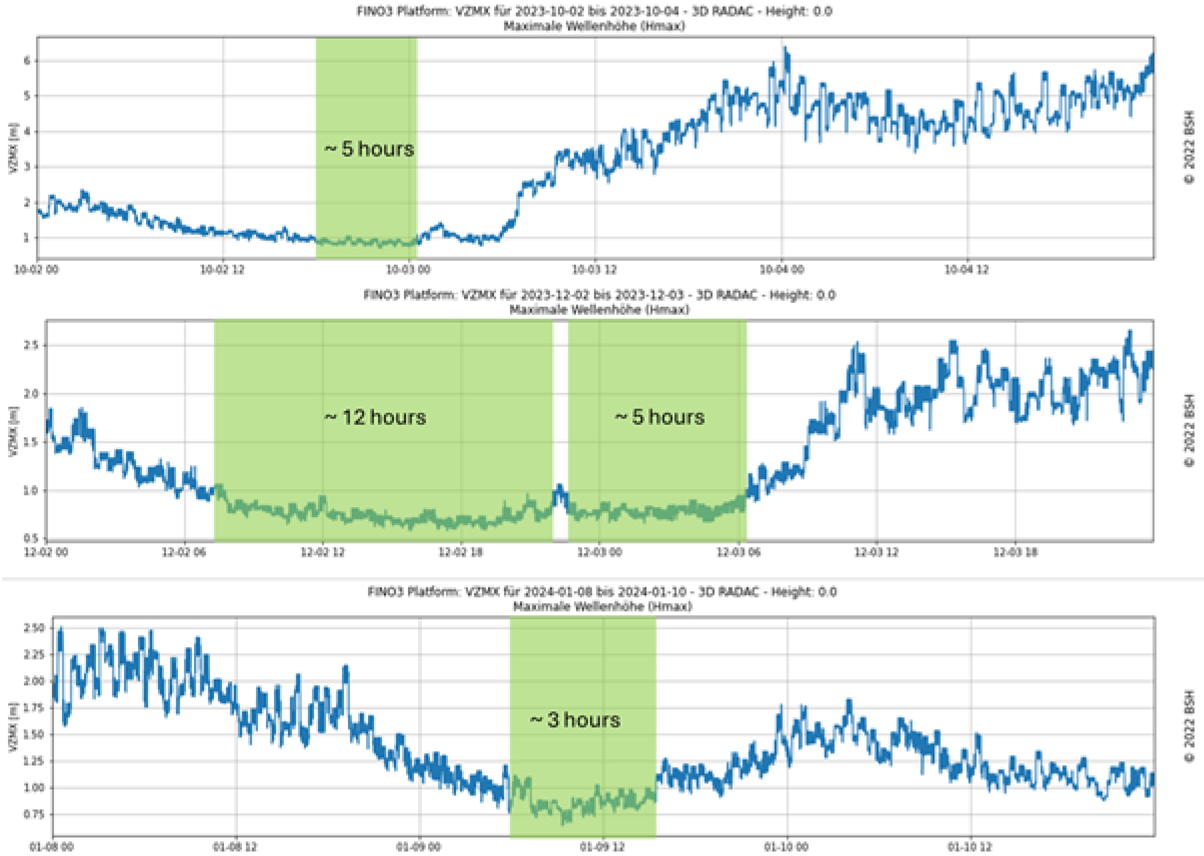

Figure 7. German pilot FINO3. Autumn season 2023, actual maximum wave height (VZMX, m), taken by the stationary 3D-RADAC system. Green = suitable weather window.

FINO2:

For the German pilot at the offshore research platform FINO2, a similar process for the identification of a weather windows applies. While being less sophisticated in complexity and scale, certain installation specific requirements need to be met.

Belgian pilot

The installation day of the ULTFARMS seaweed and oyster cultivation systems within the offshore wind farm presented a series of complex challenges, primarily driven by the harsh and unpredictable nature of the marine environment. Operating offshore inherently comes with elevated risks compared to nearshore installations due to dynamic weather conditions, strong currents, and logistical constraints. One of the foremost difficulties encountered was dealing with adverse weather conditions, including high winds, strong swells, and fluctuating sea states. Even with meticulous planning and the selection of optimal weather windows, sudden changes in weather patterns required rapid, on-the-spot adjustments. Offshore operations are highly sensitive to such variations, as high winds can affect crane operations, and rough seas can limit the manoeuvrability and safety of vessels and crews.

To mitigate these risks, we adhered to strict weather limits for operations in the Belgian part of the North Sea. For most activities, work could only proceed when wave heights were between 0.8 to 1 meter, depending on the specific task. While current speed played a less significant role in some operations, it became critical when vessels without dynamic positioning (DP) systems were involved. In such cases, activities were preferably scheduled during slack tide at low tide to minimize the impact of currents. For the installation of oyster restoration cages, which required diver operations, working at slack tide was essential to ensure both safety and precision.

In contrast, when operating within offshore wind farms for aquaculture purposes, diver access is not permitted, and vessels must be equipped with DP2 systems. This reduces the operational sensitivity to currents, as remote-operated vehicles (ROVs) are used for inspections instead of divers. To address weather-related challenges, we relied heavily on real-time meteorological data and advanced marine forecasting models. This allowed for dynamic rescheduling and provided the flexibility needed to mobilize vessels, equipment, and personnel as soon as conditions improved. Close coordination with maritime authorities and continuous monitoring of weather systems were crucial for maintaining the safety and efficiency of all operations. Despite these precautions, we experienced several weather-related delays, extending our sea missions beyond the initially planned timeline.

Danish pilots

The installation was originally scheduled to include drill anchors for anchoring long-lines and tubes, but it was impossible to arrange for a suitable boat that could drill in the anchors in the available weather windows. It was therefore decided to use a different anchoring system that could be installed by the boat used for all types of farm installation.

Weather windows were determined based on weather forecasts from different open sources and mainly national institutes like Danish Meteorological Institute, Swedish Meteorological and Hydrological Institute and Meteorologisk Institutt (Norway). As appropriate weather windows are few, it is essential for multi-use involving low trophic aquaculture in commercial scale that there is free access to an appropriate vessel both during the installation of the farm systems as well as during maintenance operations and harvest. Competition for vessel capacity during weather windows will jeopardize aquaculture operations and increase risk of loss of production capacity either due to e.g., too late deployment of spat collectors or loss of harvestable biomass. Sharing of vessel capacity can thus become a challenge.

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3.2 Predicting current speeds

Dutch pilot

Current speeds are mostly important for monitoring operations for example with ROVs or AUVs, but may help installation operations as well.

An accurate way to predict current speeds is the paid "North Sea Current" application (https://noordzeestroom.ddns.net/nzdb/), which predicts current speeds in the North Sea at any given location (Figure 8). The app was developed by a private party, originally for scuba diving activities on shipwrecks, for which very accurate current information is crucial. It shows locations of more than 4000 shipwrecks and obstacles. The application allows for cost-effective and safe planning of scuba diving, ROV operations and other fieldwork for which diving windows with low current speeds are required. Existing websites such as www.waterinfo.rws.nl only show currents or tidal information for a few coastal locations. For offshore fieldwork this is not very usable.

The application combines a number of existing databases on currents, shipwreck locations and bathymetry, using multidimensional vector interpolation (spatial dimensions: latitude, longitude; time dimensions: date, time of day; lunar cycle, time of high water at nearest reference harbour). Since 2010 it has proven to be a reliable resource to plan the timing of ROV/AUV fieldwork and scuba diving operations. The North Sea Current Application is updated yearly.

The app shows 'dive windows' with current speeds <0.5 knots in green (Figure 9, Table 8). The coordinates of the pilot location can be added in the top panel, or the wreck symbol can be dragged to the location. The app allows for export (to excel) of predicted timing of current speeds and dive windows for any location for any period. In excel, the data can be filtered on current speeds, or duration of the 'dive window' to select for suitable dates for the fieldwork.

Figure 8. Geographical scope of the North Sea current application.

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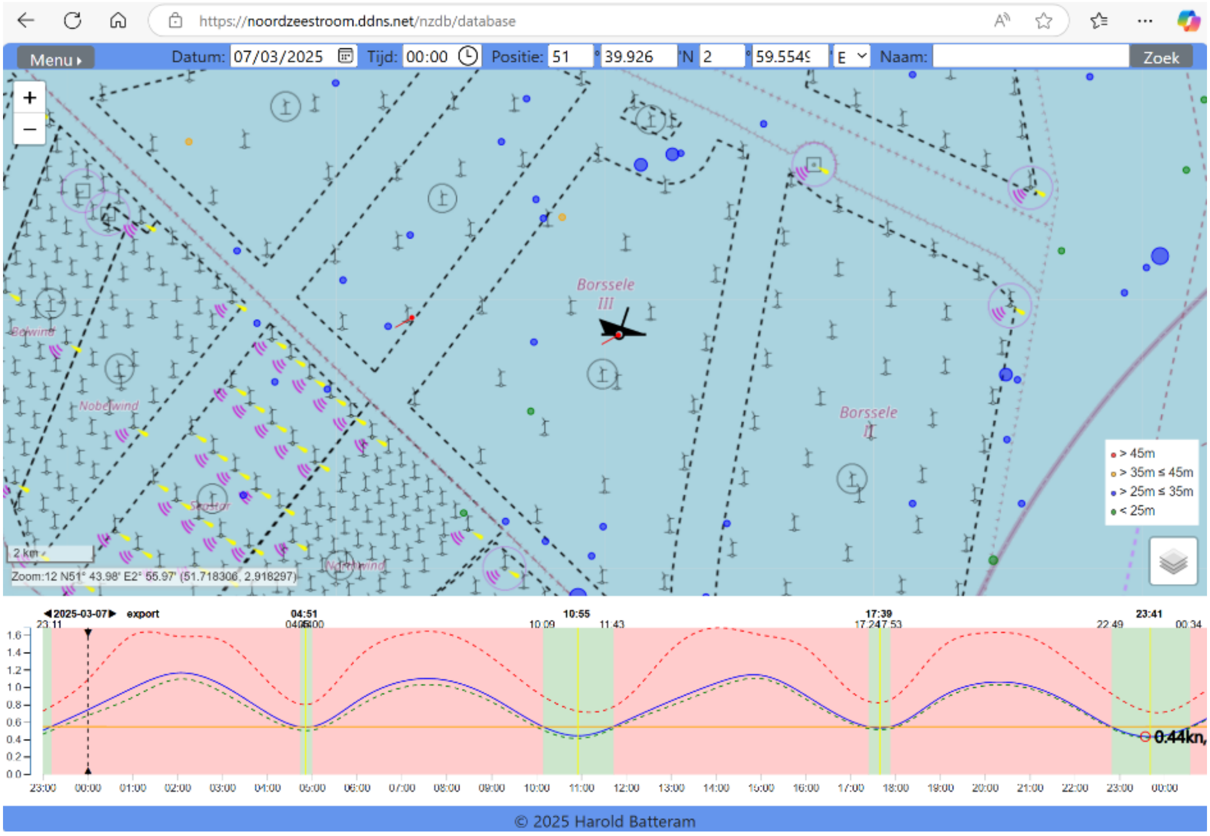

Figure 9. Dutch pilot. North Sea Current application, showing location (top) and current speeds (bottom) of the OOS location for 01-03-2025. The current is below 0.5 knots in the green time windows.

German pilots

The current and wind speed are for most system installations within the German pilot not as essential as the wave height. However, as these factors are interdependent, they are monitored similarly to the wave height as mentioned above. Tidal forces are less prominent within the Baltic Sea.

Danish pilots

Current speed has proven also essential to operations in the offshore farm units and in particular in relation to deployment and maintenance of monitoring equipment. Predictions of currents have been gathered from open sources.

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Table 8. Required wave height, current speeds and wind force per pilot location

Pilot study	Belwind (B) seaweed mussels oysters	OOS (NL) mussels	FINO2 (G) seaweed	FINO3 (G) seaweed mussels oysters	Anholt (DK) seaweed mussels	Samsø (DK) mussels
Wave height	mostly <1.0 m Hs	<1.0 m Hs	1m	1m	1m	1m
Current speed	*	<0.5 m sec	n/a	n/a	<1 knot	<1 knot
Wind force	*	< 5 Bft.	n/a	n/a	<6-8 m/s	<6-8 m/s
Springtide	Try to avoid due to higher currents	Try to avoid due to higher currents	n/a	n/a	n/a	n/a
Weather window	To be aligned with the vessel	Start planning 7 days before and look at developments of the weather				

* depending on the activity

3.3 Finding a suitable vessel

As outlined below the timing of the installation can only be fixed shortly before. This asks some flexibility from the installation vessels. Given the size and weight of the aquaculture installation, only offshore ships are able to provide that service. Within the ULTFARMS project it proved to be quite difficult to find ships that were available. One of the reasons is that the installation job is very small compared to other assignments of these companies. Thus, it can happen that a larger request comes along which results in cancellation of the aquaculture installation. It was discussed to combine installation of pilots that are close together (e.g. Belgium and The Netherlands), however, the weather window is generally so small that carrying out two installations is not feasible.

Dutch pilot

In the Dutch pilot, three different types of vessels were used for installation, depending on the specific installation tasks and their availability. For installation work such as placing anchors, a Multi Cat was used. A Multi Cat is powerful versatile, multi-purpose vessel, designed to work in shallow, as well as deeper waters, with sufficient deck space and a suitable crane. The disadvantage is the slow speed (8–9 knots), resulting in long sailing times, a limited working time and the requirement of a 24/7 crew. As a support vessel, a Harbor Tug is used. This is a smaller vessel. High-speed RIBS (25 knots) are used for inspections and platform access.

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Danish pilots

In the Danish pilots, three different types of boats have been used. For installing and deployment of anchors – and at Anholt also maintaining farm structures – the vessel Frigg was hired from a nearby fish farm with previous experience in mussel farming and equipped with necessary hydraulics and cranes. Frigg is 16-meter single steel hull, single engine fitted with a 52 tm crane, side mount drum winch, capstan winches, side propellers, non-DP. This vessel is used for installation and servicing of the farm. The vessel is owned and operated by a commercial aquaculture company and has previously been used for mussel farming activities in the Great Belt S-SE of the Danish pilots. The vessel has been subject to extensive scrutiny by Ørsted for operations inside the Anholt OWF (see above). Frigg is highly suited for the purpose but is still limited in relation to weather conditions (Figure 10). Disadvantages with this vessel would be the sea speed, which will not exceed 9 knots. This gives a daily transportation time of 5 hours, which are limiting the hours of work that we are able to conduct in the wind farm sites. The vessel is not able to accommodate all crewmembers and passengers on a 24/7 schedule, thus we are operating with a Port-Windfarm-Port turnaround.

This vessel is chartered by contract, at a fixed daily rate. The captain is included in the charter, remaining crewmembers consists of experienced sea ferrying personnel from DTU Aqua. Captain and crewmember have commercial experience in offshore aquaculture farming.

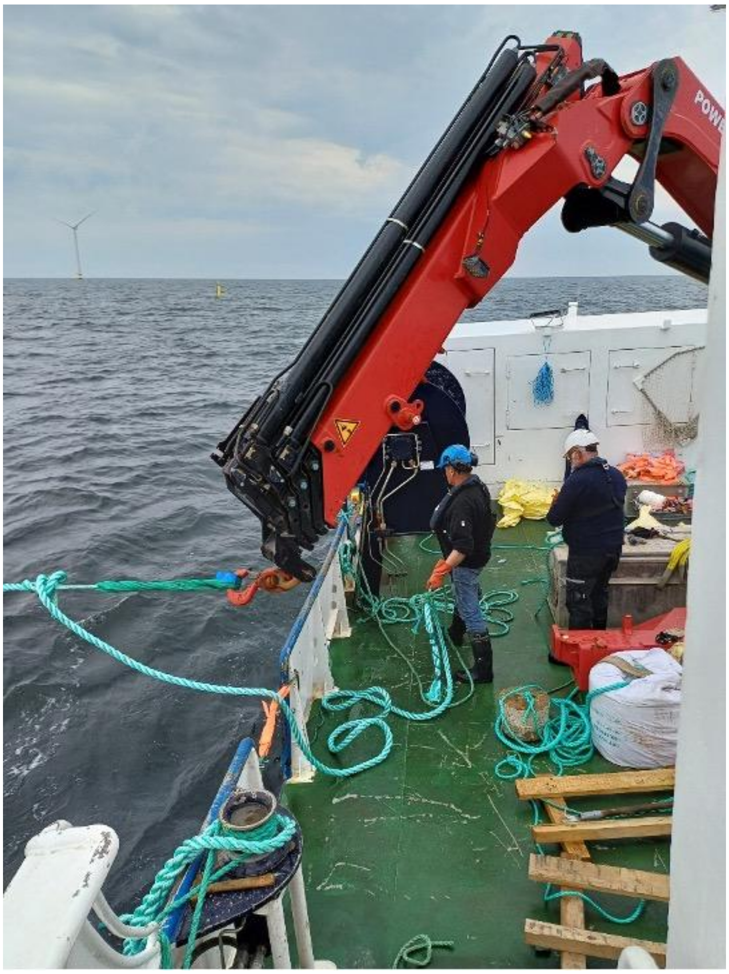

Figure 10. Frigg in operation at Danish pilot.

At Samsø, Blue Biomass has installed tubes and nets after deployment of the anchoring system using their own boats. For monitoring and maintenance of deployed monitoring systems, DTU Aqua has used their own small boat (Figure 11). The smaller vessel is an 8m fiberglass owned and operated by DTU Aqua. This vessel is used for the monitoring of the farm, and servicing of sensors and loggers. Sailing speed of the smaller vessel is 20 knots, depending on weather conditions. This reduces commuting time significantly. The vessel can be trailed behind a larger car, which provides the ability to exploit even narrow weather windows on a short notice. Disadvantages of the vessel are limitations due to weather conditions. Low lifting capacity of the winch and reduced deck space. Crew operating small vessels is DTU employees only.

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Figure 11. Small vessel for monitoring and maintenance.

German pilots

The selection of a suitable vessel always depends strongly on the individual requirements of the work to be carried out and the system to be installed. It is imperative that this is checked for each trip and compared with the scope of work to be carried out.

Safety: in addition, these vessels should be approved for operation outside the 12 nautical mile zone and meet the relevant safety requirements. Depending on the distance to the mainland, sufficient supplies, equipment and provisions should be planned and available to be able to remain at sea for several days. In addition to space for the crew, accommodation should also be available on board for additional and scientific personnel. As a rule, there are usually at least two additional people on board to manage, supervise and check the installation procedure.

Positioning: furthermore, the vessel should preferably be equipped with a Dynamic Positioning System (DP), which keeps the ship in the correct position regardless of the current and wind. This is not a mandatory requirement, as it can also be achieved manually by the captain but increases safety and significantly reduces the time required on site. Overall, good manoeuvrability of the ship is of highest importance and should therefore be ensured for installation.

Crane capacity and deck space: other fixed requirements for a suitable ship are sufficient crane capacity and enough free space on deck. The only case where a crane may not be required is when installing a system completely for the first time, where all components are connected on deck beforehand and deployed at sea by hand or other auxiliaries. However, this is rarely the case, as a crane is already required by loading the ship in the harbour. A crane is also usually required for repair work or maintenance on an existing system in order to lift the components above water or on board. When selecting the vessel, care should be taken to ensure that the crane can lift the individual system components and that the lifting

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capacity is also sufficient for the required jib length. In addition to crane capacity, it is also important that the winch has sufficient capacity. This is required in order to secure, veer or hoist the components when deploying the system. The space on deck should contain all system components and leave additional space for working and any necessary relocation. It also makes sense to select a ship that has free access to the sea on at least one side, but preferably on several sides of the ship. This can be ensured by an open working deck or fold-away rails. In any case, it helps to bring out the sometimes very heavy or bulky components without having to lift them over the railing. This can shorten the needed working time and reduce the likelihood of something like a net or ropes getting stuck.

Additional equipment: further important requirements for a suitable vessel are the various equipment options, which must also be selected individually for the job and therefore be able to be fitted on the vessel. Typical items of equipment are, for example, a dinghy for carrying out minor work directly on the system or just supporting the bigger ship, which is usually difficult to manoeuvre during work. Other useful items are smaller items such as spare ropes and chains as well as additional shackles and other needed material. When lowering anchors or concrete anchor stones, it can also be useful to use a release hook to lower the anchor safely and in a controlled manner. If an anchor or other system components are unexpectedly lost or broken off, it is also good to have a special anchor for searching and picking up chains to find and retrieve the parts on the seabed.

As mentioned before, the choice of the suitable ship should always be evaluated individually before the upcoming trip based on the work to be done and the associated requirements.

Belgian pilot

First and foremost, vessel permits are required to authorize the operation of installation vessels within Belgian territorial waters. These include both general maritime operation permits, and specific certifications related to the type of activity being conducted.

When looking for a suitable vessel for offshore installations, such as deploying anchors, aquaculture longlines, or oyster restoration cages, the process typically begins with consulting the market. Within JDN this is generally done via the Vessel Charter Desk (specific JDN department) as they have the contacts and knowledge of ongoing and future charters (allowing optimisation).

Standard vessel agreements for short to medium term periods (days to weeks) are usually drafted via a BIMCO charter party agreement. This standardized contract framework helps outline the specific requirements for the vessel, including technical specifications, operational needs, and legal obligations. A BIMCO agreement is known by the marine industry and contains a fixed set of agreements which indicates the responsibilities of both the charterer and the vessel owner. The BIMCO outlines the basic grounds from where further final details can be added.

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It avoids complicated discussions and allows to have an agreement in place on short notice.

Once the BIMCO terms are drafted, the next step is to assess availability. Offshore support vessels are often booked well in advance, especially during peak seasons. By circulating the BIMCO to brokers and vessel operators, you can gauge market availability and identify potential candidates that fit the timeline and operational scope.

Price negotiations and availability are intertwined at this stage. While cost is a critical factor, it must be balanced against the vessel's capabilities and suitability for the specific tasks. The BIMCO agreement facilitates transparent negotiations by standardizing terms, reducing ambiguities, and ensuring both parties are aligned on expectations. Specific project details are added to the BIMCO and agreed on between charterer and vessel owner during the negotiation process.

Before finalizing any agreement, it's essential to confirm that the insurance coverage complies with legal and project-specific requirements. This applies to both parties—the vessel owner and the charterer. Insurance should cover risks related to offshore operations, including liability, environmental damage, crew safety, and equipment loss. Ensuring proper insurance safeguards all stakeholders against potential financial and legal liabilities during the project.

Once price, availability, and insurance are aligned, attention shifts to the vessel's technical capabilities. For precision work within offshore wind farms, Dynamic Positioning (DP2) capability is highly recommended, providing redundancy and ensuring the vessel can maintain stable positioning even in adverse conditions. If ROV (Remotely Operated Vehicle) support is needed for subsea inspections, the vessel must have appropriate deployment systems, power supply, and operational space.

Deck space is another crucial factor. The vessel must accommodate all necessary equipment—anchors, cages, longlines, cranes, and winches—while maintaining safe working conditions for the crew. An efficient deck layout can significantly reduce installation time and operational risks.

Consider whether the vessel can stay overnight at sea, which is advantageous for multi-day operations as it reduces transit times and maximizes productive hours. This requires adequate crew accommodations and compliance with offshore anchoring options, particularly given the busy shipping lanes and proximity to wind farms in the North Sea.

Vessel speed and fuel efficiency are important for cost management, particularly if the installation site is far offshore. Faster vessels reduce transit times, but fuel consumption and charter costs must be carefully weighed.

The choice of port of departure and arrival also affects logistics. Proximity to the project site minimizes fuel consumption and transit time, while the port's infrastructure must support vessel operations, equipment loading, and crew changes.

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Finally, after all operational and logistical criteria are satisfied, the process concludes with vessel vetting. This involves a thorough review of the vessel's safety record, certifications, maintenance history, and operational performance. Vetting ensures compliance with both legal regulations and the specific safety standards of the project. Consulting with maritime brokers, local authorities, and industry experts during this phase can provide additional insights and help mitigate risks.

By following this structured approach—starting with BIMCO negotiations, verifying insurance compliance, evaluating technical and logistical criteria, and concluding with thorough vetting—you can secure a vessel that meets all project requirements while ensuring safety, efficiency, and cost-effectiveness.

3.4 Guidelines for anchor installation

Dutch Pilot

For the installation of the OOS mussel platform, a mooring analysis was done and based on the analysis the anchor lines were setup (Figure 12) All anchors were prelaid and pre-tensioned. Anchors (with chain) were placed with a Multicat, pre-tension with a tugboat. Thereafter the platform was connected with the anchor lines one by one. Connecting of the platform was done with a Multicat, tugboat and a small support vessel (Figure 13-15).

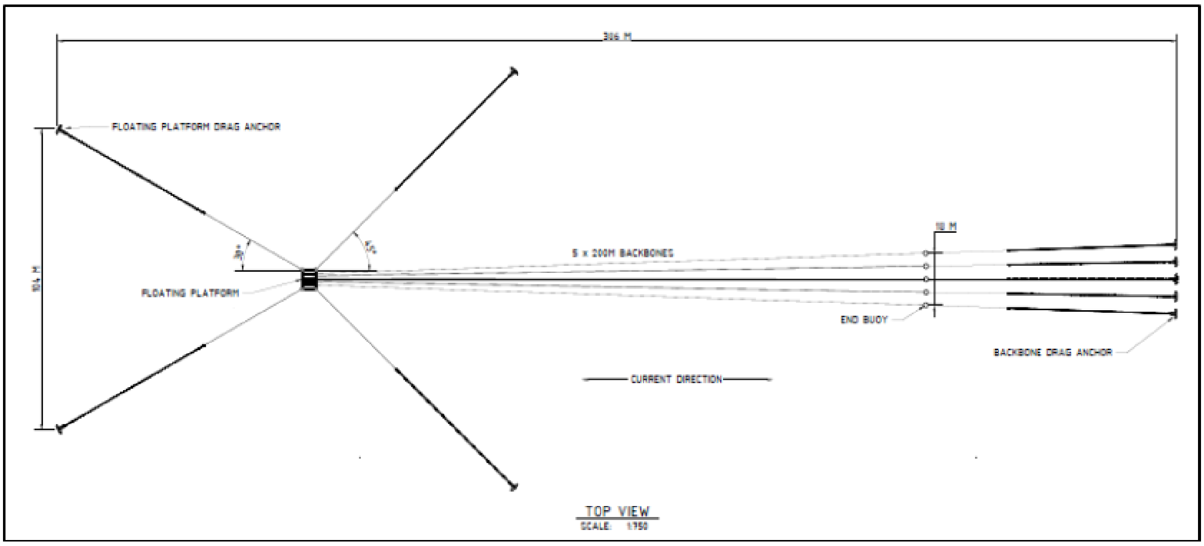

Figure 12. Dutch pilot: Set-up of anchoring system for the OOS mussel system in the Dutch pilot.

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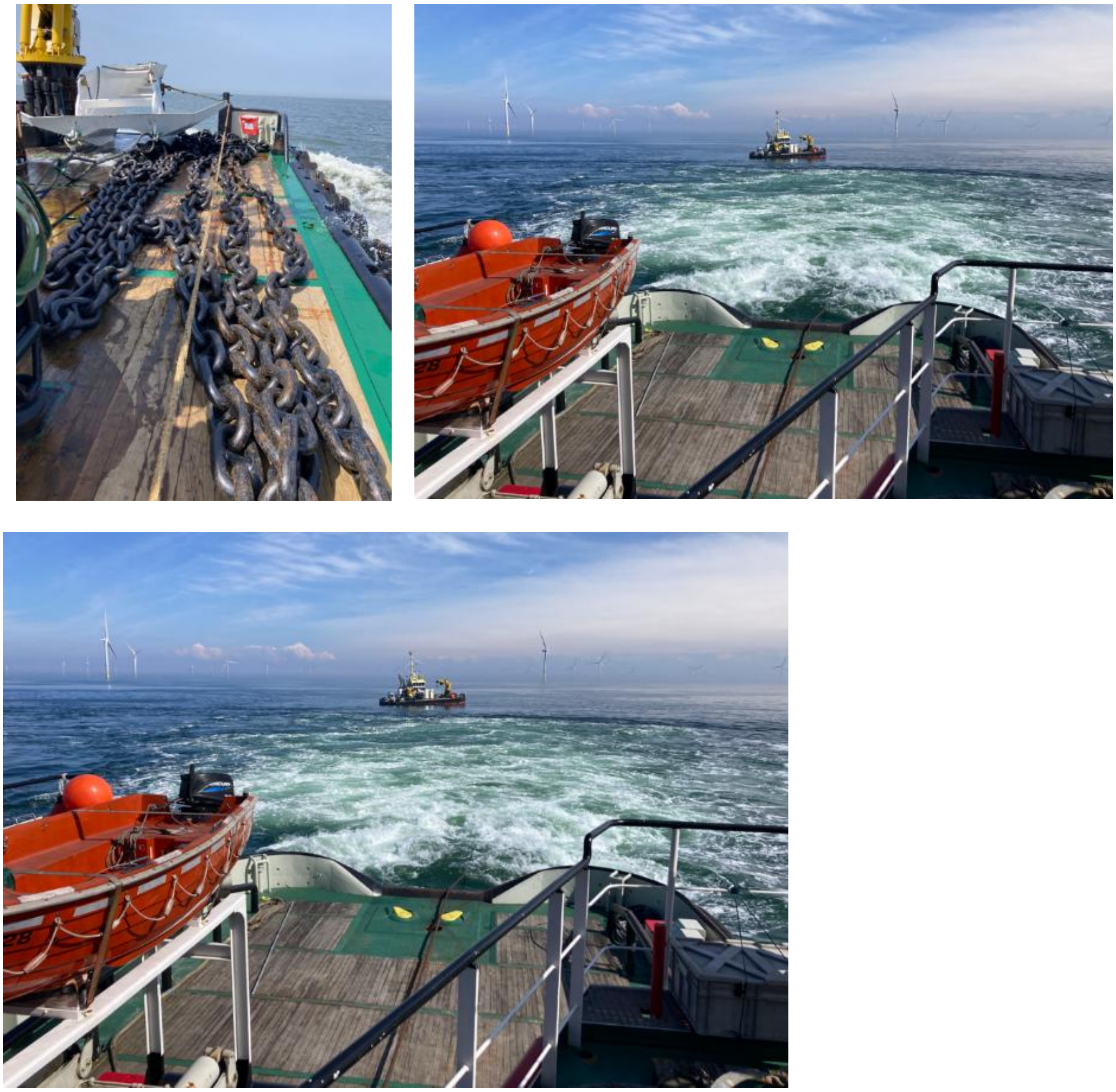

Figure 13. Dutch pilot. Left: anchor with chain before launching. Right: pre-tension of an anchor with tugboat (photos: OOS).

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Figure 14. Dutch pilot. Top: Towing and installing the OOS platform in windfarm Borssele (photo OOS).

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Figure 15. Dutch pilot. Installing end-buoys (photo: OOS).

Danish pilots

Anchors and chains were prepared on land before installation at the farm by DTU Aqua technical staff.

Figure 16. Danish pilot – preparation of anchors and chain on land.

After preparation on land (Figure 16), anchors and chains were loaded on board of the vessel (Frigg) four at the time due to the heavy weight (Figure 17). At the farm site, anchors and chains were installed by crane and pre-tensioned. A buoy was put at the end of each chain and to the surface as markup until lines/tubes were installed (Figure 18).

Figure 17. Danish pilot - Anchors and chain on board Frigg ready for installation on the farm.

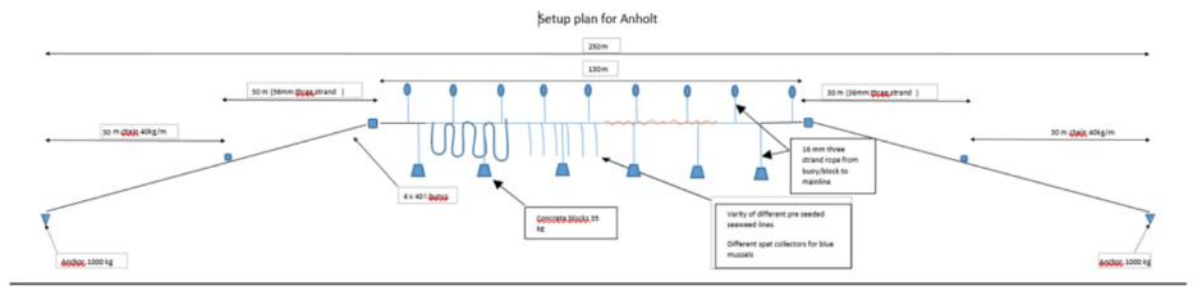

Figure 18. Danish pilot – anchor plan for the Anholt pilot site (Samsø similar).

German pilots (North Sea)

As part of the overall installation of a cultivation system, the positions of the anchors must first be determined depending on the dimensions of the system. In the German pilot in the North Sea, the same anchoring method is used for both the mussel system and the algae cultivation system. This is demonstrated in the following using the algae cultivation system as an example, as shown in Figure 19. The two systems are aligned in parallel with the main current direction in the NW/SE direction.

Figure 19. Overview of the algae cultivation system at the German North Sea pilot.

The system is anchored with two long anchor chains, each of which is held by a concrete block and a delta flipper-anchor, see Figure 19. The concrete block on each side ensures that only horizontal forces are transferred to the delta flipper anchors. The delta flipper anchor transfers the entire holding force to the seabed. A sufficiently long chain is important to compensate for the vertical forces and accelerations resulting from the movement of the swell and therefore of the system.

Before the anchor is deployed, it should be ensured that certain environmental parameters, as described in section 3.1, are observed on site. In addition to a sufficiently low swell, this also includes analysing the current direction and speed. This should be checked regularly by the captain or other crew members at short intervals if the direction of the current changes due to the tide. This is extremely

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important for the deployment of any components so that any components do not get caught in the ship's propeller or rudder.

Once the desired position of the first anchor has been reached, the first anchor can be dropped overboard, typically over the stern of the vessel. As soon as the first anchor, in this case the delta flipper anchor, has been lowered to the planned position, the position of the concrete anchor stone can be approached, and the concrete anchor can also be placed in the previously determined position. Care must be taken to deploy the system with all components, such as the buoys and the net, against the current so that the system does not drift onto the ship, but away from it.

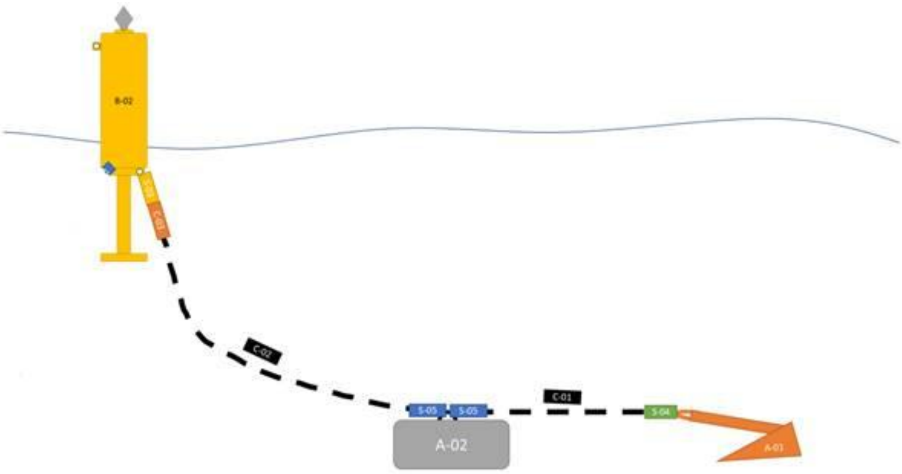

Figure 20. Detailed view of the anchoring method of the of the algae cultivation system at the German North Sea pilot.

In addition to setting the anchors of the cultivation systems, buoys that are marking the pilot site must be set at every pilot site. In order to set these marking buoys, the previously approved coordinates of the national authority must be approached precisely. In the case of the German pilot in the North Sea, the buoys are moored with concrete anchoring stones (see Figure 20, Figure 22). As these are not self-holding anchors, but weighted anchors, care must be taken to ensure that they are sufficiently heavy dimensioned. In the German pilot, the restricted area buoys are therefore anchored with 3 tons of concrete blocks each. Sufficient chain length is also important so that the high load peaks in the storm event are absorbed. The part of the chain that lies on the seabed as a damping weight should be slightly more strongly dimensioned, as increased corrosion abrasion occurs there as a result of friction on the seabed. The rest of the chain can be determined according to the maximum available buoyancy capacity.

The chain is then usually deployed using the crane, which lifts the anchor stone overboard and releases it using a release hook. Due to the heavy weight of the anchor stone and the chain, it is essential to ensure that the chain can run freely

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into the water and does not get caught before releasing. All persons on deck must also be extremely cautious. Sufficient safety distance should be maintained at all times. Once the anchor has been released to the correct position, the buoy connected to it automatically slides overboard.

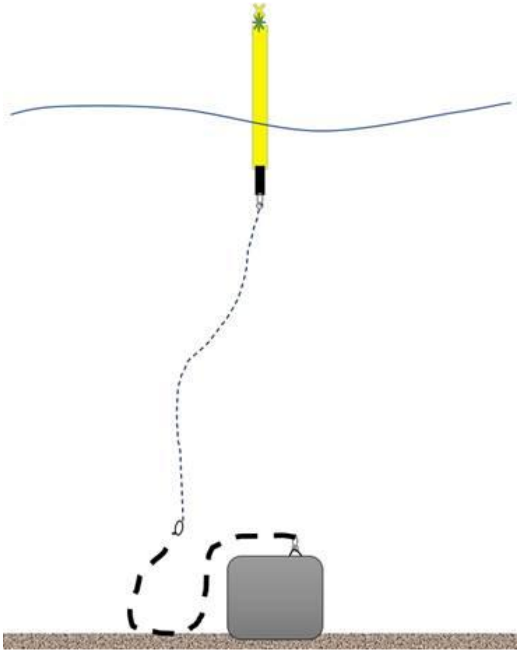

Figure 21. Installation of the algae cultivation system at the German North Sea pilot.

Another important aspect is the decommissioning of the anchors at the end of the project. Ideally, this is done by pulling up on the chain that is connected to the system or buoy. This is done with a winch and is part of the standard procedure for most shipping companies and ships. However, if the system or buoy has been broken off due to mechanical damage or a storm event, the anchor must first be located. To do this, a search anchor is pulled in a specific pattern over the last known position. the pattern should consist of several parallel trips in successively different directions. If the chain of the lost anchor gets caught in the search anchor, it can be picked up and brought on deck.

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Figure 22. Installation of the algae cultivation system at the German North Sea pilot.

Belgian pilot

Before installing the anchors, we had to conduct comprehensive site assessments to ensure both the safety and feasibility of the operation. One of the critical steps in this process was performing detailed seabed surveys, which included high-resolution bathymetric mapping and sub-bottom profiling to scan the seabed for any potential obstacles, such as large boulders, debris, or sensitive habitats that could interfere with anchor placement. This step was essential not only for optimizing anchor performance but also for minimizing environmental impacts.

A particularly crucial part of this pre-installation phase was the Unexploded Ordnance (UXO) survey. Given the history of maritime activities in the North Sea, including past military operations, there's always a risk of encountering UXOs, such as old munitions or bombs buried beneath the seabed. The UXO survey involved deploying specialized equipment, such as magnetometers and side-scan sonars, to detect any anomalies below the seafloor that might indicate the presence of potentially hazardous objects. In areas where anomalies were detected, further investigation with Remotely Operated Vehicles (ROVs) was carried out to confirm whether these posed a real threat.

Once the seabed was confirmed to be free of UXOs and other obstacles, we proceeded with finalizing anchor placement plans. This information was integrated with the anchor load modelling results to ensure both safety and structural stability. The UXO clearance was not just a safety measure but also a legal requirement, as no installation activities could proceed without certification that the site was cleared of such risks.

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In parallel, we coordinated closely with the wind farm operator to cross-reference our site data with existing infrastructure maps, including subsea cable routes and foundation layouts. This helped us refine the anchor positions further, ensuring they were well clear of sensitive areas, particularly the inter-array and export cables that are critical for the wind farm's power transmission.

After confirming the safety of the seabed, the anchor installation process was meticulously planned. We opted for a location within the wind farm's outer perimeter, framed by the last four wind turbine foundations. This strategic positioning minimized the risk of interfering with critical wind farm assets, ensuring that even in the unlikely event of anchor failure, any impact would be confined to non-critical infrastructure, such as the cable of the outermost turbine.

The type of seabed also played a critical role in determining the appropriate anchor installation method. In our case, the seabed composition varied between sandy and muddy substrates, each presenting distinct challenges.

Sandy seabed generally provides better holding capacity for traditional drag anchors due to their compact nature, allowing the anchor to embed securely with less risk of shifting under load. However, sandy conditions also require precise calculations to avoid over-penetration, which can complicate retrieval if adjustments are needed.

In contrast, muddy seabed, while softer and easier for anchors to penetrate, pose challenges related to anchor stability over time. The reduced shear strength of mud can lead to gradual anchor creep, especially under dynamic loads caused by currents and wave action.

Screw anchors offer superior holding power by creating a helical grip within the substrate, reducing the risk of movement. Additionally, the installation process for screw anchors minimizes sediment disturbance, which was a key environmental consideration. The careful selection of anchor types based on seabed characteristics was crucial for ensuring both the structural integrity of our aquaculture systems and the long-term durability of the installations.

The four screw anchors were drilled in the seabed by making use of a drill rig and by staying in position with a 4-point mooring set-up (Figure 23 and 24). The drilling operations were followed via a camera system. Three out of four screw anchors were installed in muddy areas.

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Figure 23. Setup used for screw anchors installation at Belwind: C-Odyssey vessel and drill rig with one of the anchors

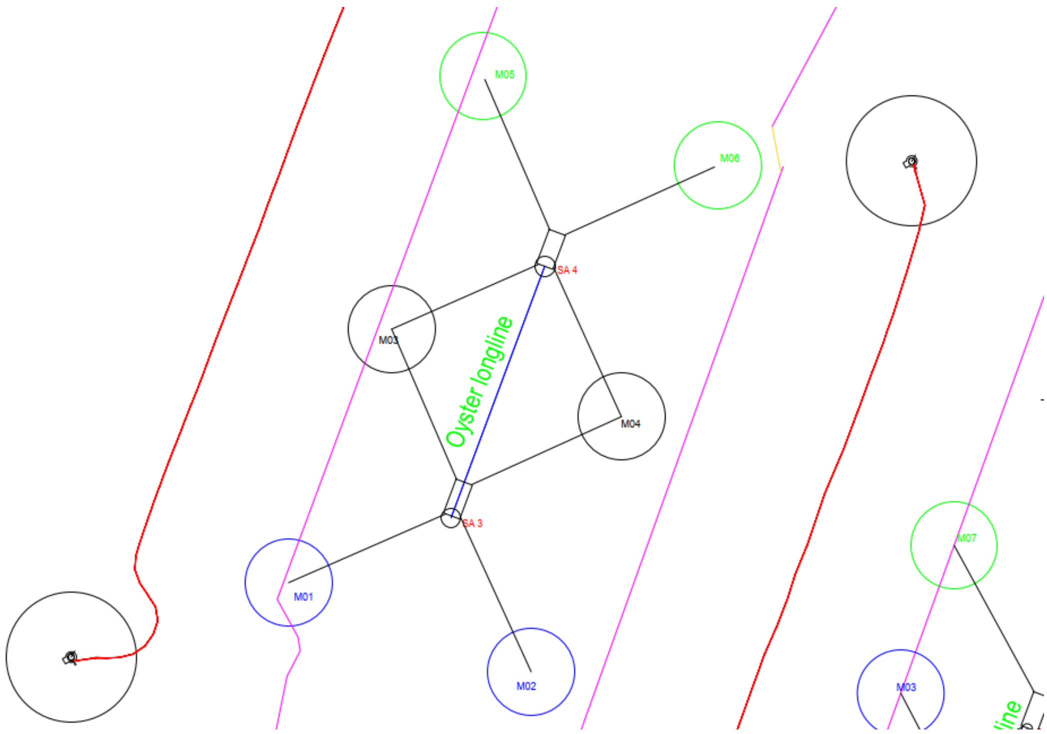

Figure 24. Drilling of four screw anchors of the Belgian pilot with a drill rig and by staying in position with a 4-point mooring set-up.

Adaptation of the screw anchors and its holding power was possible by changing the size of the disc on the anchor. Final decision was made on site and was depending on the soil conditions at that specific location (local variation is possible).

Post-installation, remote camera guided inspections were conducted to verify the exact placement and tension of the anchors, allowing for immediate adjustments if needed. The combination of thorough pre-installation surveys, UXO clearance, real-time monitoring, and post-installation verification contributed to a safe, efficient, and environmentally responsible anchor installation process.

3.5 Guidelines for installation of longlines and other systems

Dutch Pilot

For installing the lines between platform and end buoys a DP1 Multicat was used (Figure 25 and 26). The lines were connected to the end buoys and to the platform with shackles containing load cells.

Figure 25. Dutch pilot. Multicat DP1 installing longlines (photo: OOS).

Figure 26. Dutch pilot: five mussel lines installed (photo OOS).

German pilot (North Sea)

After the first two anchors have been positioned (see chapter 3.4 Guidelines for anchor installation), you can proceed to deploy the rest of the system. The system should be pre-assembled as far as possible onshore and then transported on board in packages. The correct loading order should be followed so that the system does not have to be reloaded at sea during installation. The loading order on board should then be based on the order of deployment. Care must be taken to deploy the system with all components, such as the buoys and the net, against the current so that the system does not drift onto the vessel, but away from it.

The rest of the system can then be deployed piece by piece and held in position with the help of the vessel. To that point of the installation the net with the buoys and other components are already in the water (see Figure 27) and the last both delta flipper anchor and the concrete anchor stone are still on the ship.

After the rest of the system has been deployed except for the last two anchors, the system, in this case the seaweed net, must be pulled into the correct position. The direction of flow must still be taken into account. The system should then be aligned parallel to the main current direction. In the case of the German pilot on

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the FINO 3, this is the NW-SE alignment, as can be seen in Figure 27. Once the correct alignment has been achieved, the next concrete anchor can be placed. The final anchor can then be set. Ideally, this should remain connected to the ship with the help of a line and a release hook. This allows the anchors installed last to be positioned more precisely and the entire system to be pulled tight. Care should be taken not to pull too hard so as not to overstretch the system and thus pull it under water or damage it. Once the system is correctly positioned, the connection to the anchor can be released. After that final step the correct floating position should be checked again before leaving the pilot site.

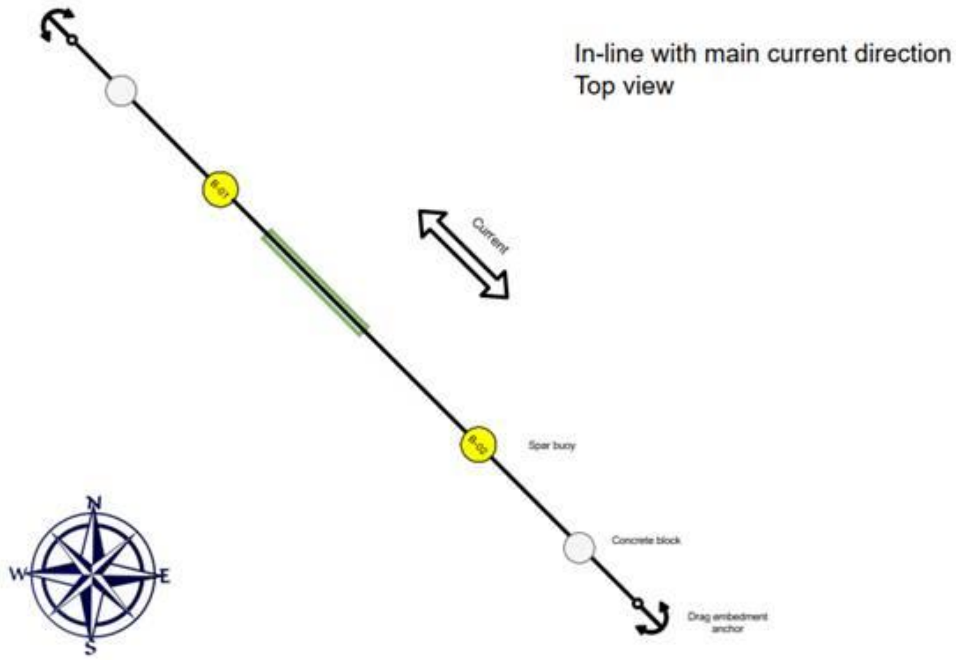

Figure 27. German pilot FINO3. Orientation of the algae cultivation system at the German North Sea pilot.

On-bottom installations:

The European oyster (*Ostrea edulis*) was once a dominant reef-forming species and an important habitat engineer within continental European waters. Within ULTFARMS, two pilots are actively conducting restoration and aquaculture growth trials of the European oyster. As of summer 2024, juvenile oysters have been deployed at the FINO3 (Figure 28). This growth trial within the German North Sea pilot intends to gain insights into the survival rate and the technical feasibility of offshore, on-bottom cultivation. On-bottom systems do have significant advantages in terms of deployment and installation procedures. These setups are mostly static and compact and therefore, do not require sophisticated deployment strategy, which enables their deployments in higher wave heights. Most critical is the scaling of the system for long-term deployments and the acoustic based retrieval system, which enables easy recovery.

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Figure 28. Impression of the deployment process of an on bottom system intended for oyster cultivation near the FINO3 location.

Sensor installations:

The bbe Phycoprobe was constructed as part of the project and tailored to meet the specific installation requirements of the FINO3 platform. In January 2025, the sensor was successfully installed onto the inner side of the Monopile, five meters below the water line, next to flooding holes (Figure 29). Furthermore, site-specific adjustments were needed prior to the installation. Titanium was chosen for most parts and contact components—such as screws, connectors, and coupling elements or where possible, appropriate plastics.

A grid frame was built (BBE Moldaenke GmbH) including the magnetic anchoring as well as a non-conductive coating to prevent corrosion (FuE Zentrum der FH Kiel). These modifications are intended to ensure that the device remains affixed to a specific point on the inner wall. Adjustments to the installation protocol were necessary, to bridge the long distance between the processing unit on top of the

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platform with the processing unit and the actual sensor location, five meters below the waterline (>50m). The Phycoprobe is equipped with a cleaning system that allows it to remain at the measurement site for extremely long service intervals. This system includes a wiper that maintains the cleanliness and functionality of the optical paths, which are essential for fluorescence measurements.

The measurement characteristics were also adapted for the project. The device measures the fluorescence of algae and assigns them to different algal classes. The fluorometric identity of those classes, also called "fingerprint" were used for calibration of the sensor, which was done by regularly providing surface water from the installation site into the laboratory. Furthermore, a robust, long measurement cable connects the device to a computer, which manages communication, device control, data evaluation, and display. Through an Internet connection secured by a VPN tunnel, the data can now be retrieved, and analysed, in real-time or on demand.

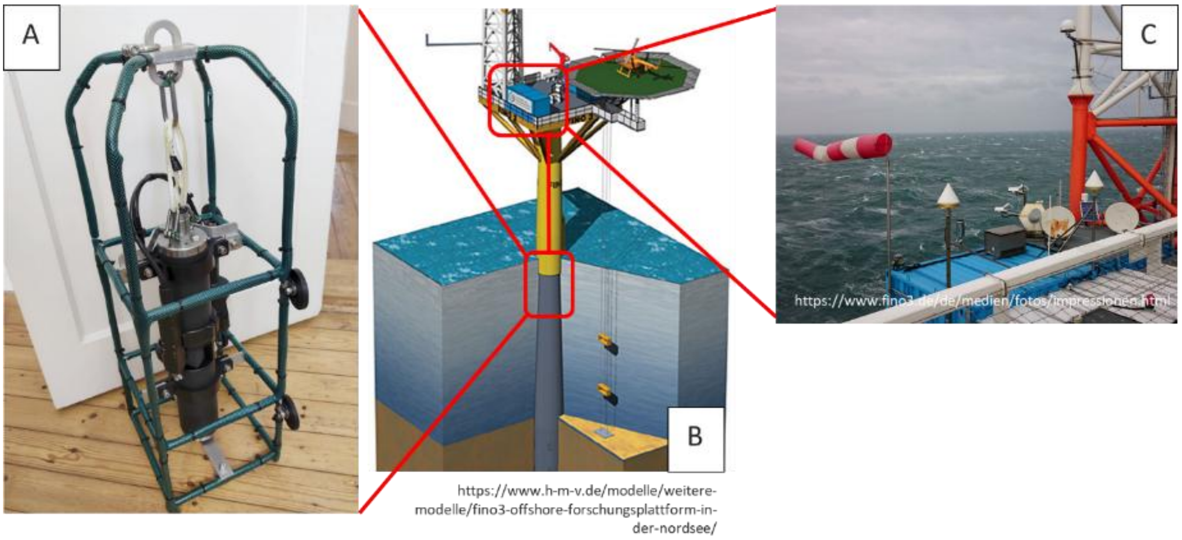

Figure 29. German pilot (A): Phycoprobe prior to deployment (BBE Moldaenke GmbH) with the site-specific installation requirements. (B): FINO3 scheme with the sensor's approximate location, including the processing unit and satellite connection as indicated in (C).

German pilot (Baltic Sea)

In the Baltic Sea, a modular frame solution was selected for algae growth. The installation was carried out using a non-invasive anchoring technique directly on the monopile. The system was installed and maintained by divers and deployed at two different depths. Additionally, a third frame, incorporating a nature-inclusive design solution, was deployed at a third depth (Figure 30). This system will be further explained in the chapter 3.6 Guidelines for installation of the nature-inclusive design system.

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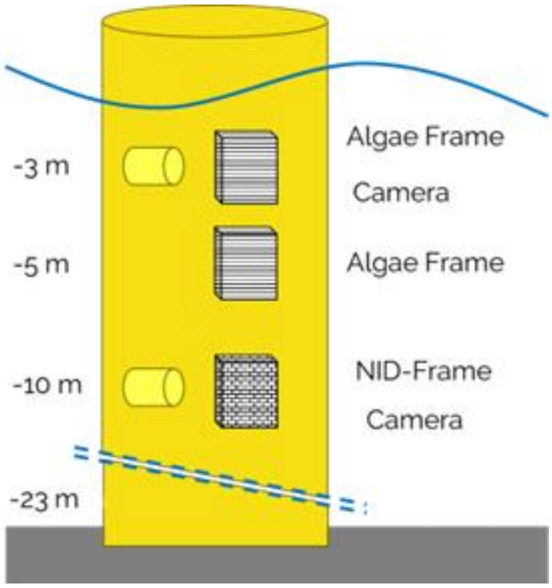

Figure 30. Installation scheme for the German Baltic Sea pilot at the research platform FINO2 within the Krieger´s Flak. Three multipurpose systems (Macroalgae frames and NID installation) have been installed in April 2024 and checked, in May 2024. The installation of the cameras followed (May 2025), as well as the Ulva installation (July 2024). System deinstallation occurred in October 2024.

For the installation, the macroalgae frames were placed within the photic zone of the macroalgae´s tolerance. Although *Ulva* is most often found near the surface, extensive green algae meadows have been found by divers to reach as low as minus five meters along the FINO2 monopile. To therefore test the integrity of the setup in contrast to the wave amplitudes observed (significant wave height of 6.4m), one setup was placed at a depth of minus three, while the other was secured at minus five meters (See Figure 30). Nevertheless, the upper macroalgae frame was adapted with stronger magnets to counteract the possible wave exposure.

Belgian pilot

Both oyster and seaweed longlines were installed in the middle of a selected zone between 4 turbines, along the string direction. In this way, the CTVs could still sail around and do the required maneuvers to transfer crew to the turbines.

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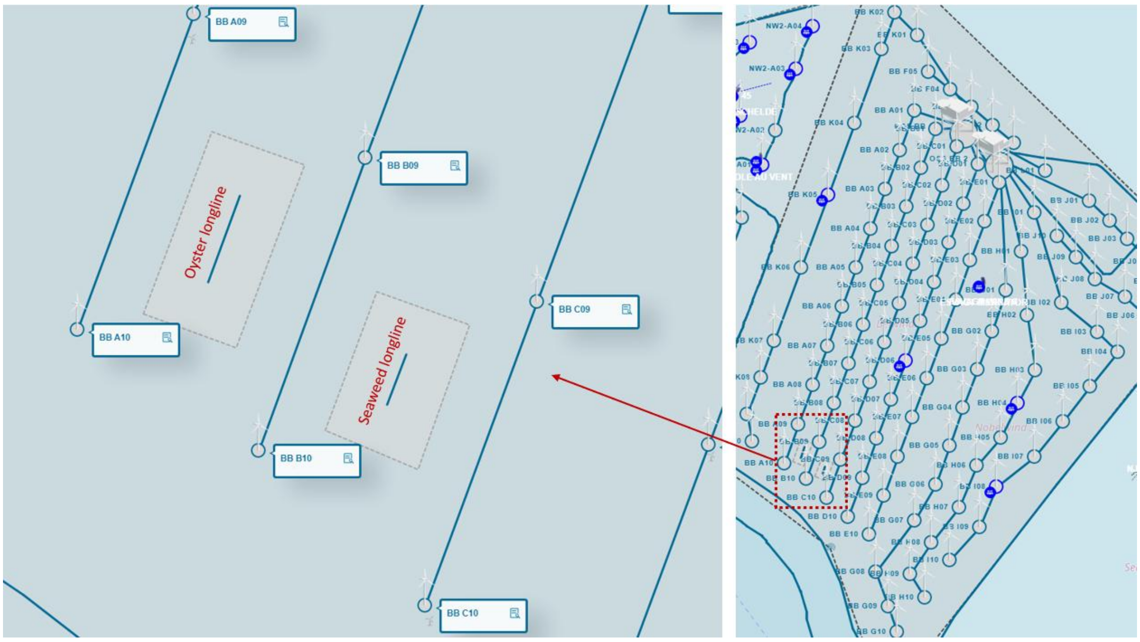

Figure 31. Illustration of longlines location at BWD

The oyster and seaweed longlines were installed on screw anchors (as mentioned in 3.4). The design of both longlines is shown in the figures below.

For the oyster longline, 5 big (grey) buoys were used at the surface and smaller (intermediate yellow) ones at 9m depth below the surface. Between the intermediate buoys, different types of metal structures and baskets containing oysters.

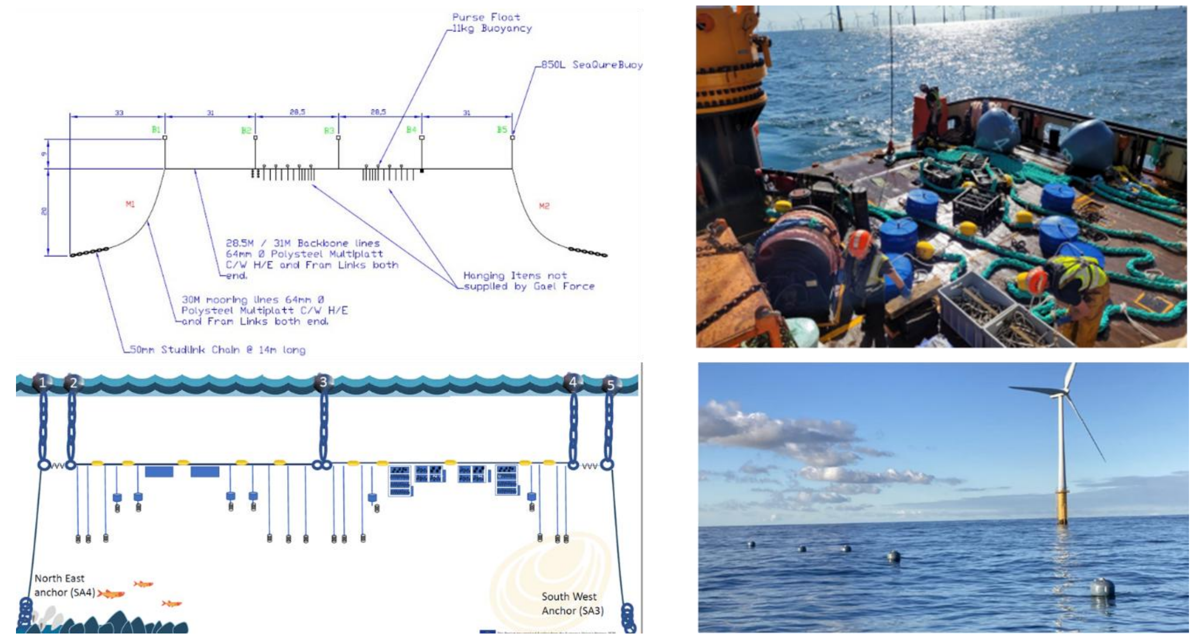

Figure 32. Design oyster longline, deck preparation for installation and longline after offshore installation

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For the seaweed longline, 2 big grey buoys were used as corner surface buoys and intermediate yellow ones (5 medium size and 9 smaller) visible at the surface. After growth of seaweeds, the yellow small buoys were approximately 1.5 to 3 m below the surface.

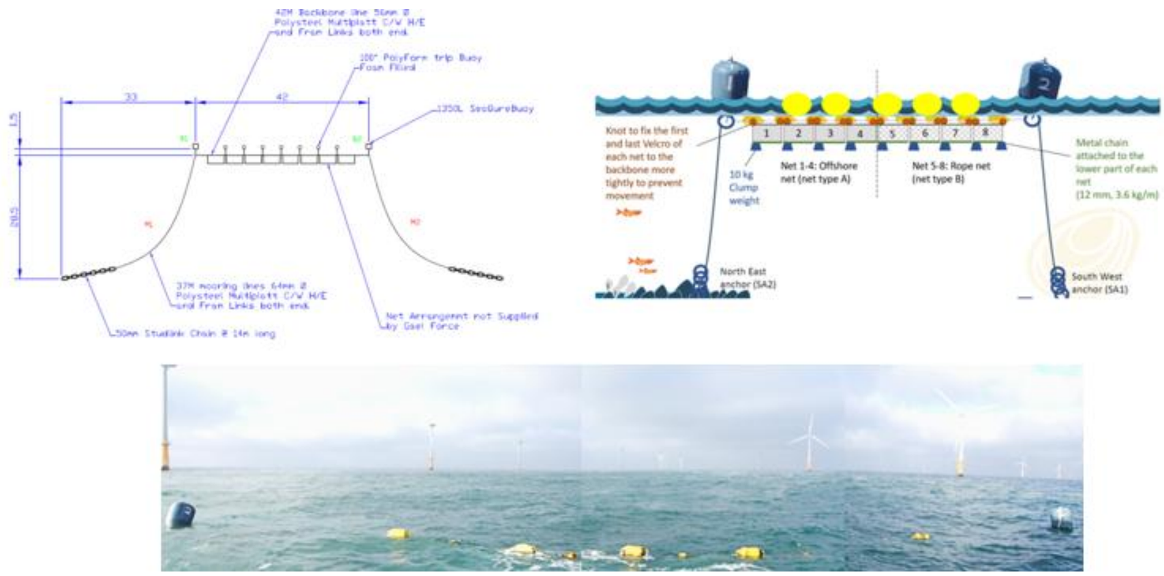

Figure 33. Design of seaweed longline and longline after offshore installation

Two different seaweed net types have been installed. It's important to make sure the nets are well attached to the backbone and each other, to avoid getting loose. A velcro connection further tightened by additional rope was used. Additionally, a metal clump and/or piece of metal was positioned at the bottom side of the net to keep it on the vertical position in the water.

Danish pilots

Anholt: Longlines were installed between the anchor end points. The longlines are 130 m in length and submerged to 5 m using 35 kg concrete blocks at the bottom (every 10-20 m) and 7 l buoys along the longline. Both blocks and buoys were tied to the long line using 16 mm 3-strand PE rope. At each end of the longlines, two 250 L end buoys were installed. At the bottom, the lines were installed with a 1T Danforth anchor and 30 meters of 40Ømm chain (40 kg/m) followed by 30 m 36 mm 3-strand rope in each end. The long line itself is a 36 mm polysteel rope. 3 longlines have been installed for the project.

Samsø: Tubes were installed between the anchor end points (Figure 34). The tubes are 130 m long with a diameter of 315 mm and a wall thickness of 10 mm (Material: PEH). Each tube is anchored with a 1.2T anchor and 45 m of 40Ømm chain (40kg/m) followed by 40 m of 40 mm 3-strand rope in each end. Between the tube and the anchoring rope there is a line of 4 40 l buoys. 2 tubes have been installed for the project.

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Figure 34. Tubes with nets at Samsø.

3.6 Guidelines for installation of the nature-inclusive design system

Dutch pilot

BESE-elements are made of a starch biopolymer derived from potato waste. They function to help reduce local currents and waves, provide stability, shelter and settlement substrate are used for ecosystem restoration. The original plan was to place BESE elements underneath the SMF of OOS in Borssele wind park. However, acquiring a permit for that involved an additional 65kE deposit for removal of the structures at the end of the project. As this was not included in the budget an

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alternative nearshore location was found for the tests of the BESE material. This is reported on in D7.2.

German pilot

Throughout the past decades, a variety of nature inclusive design installations have been proposed with different approaches and ambitions. For the German pilot installation at the FINO2, a systematic review has been conducted, which identified a certain “add on” structure to be most feasible and targeted (see D7.2). The overarching ambition of the NID installation has been thoughtfully planned to support the local juvenile fish populations by providing a biodegradable habitat. The outlined strategy can be found in D7.1 and D7.2.

For the installation, a compact, multipurpose system with the intent to enable flexible add-ons into existing monopiles such as wind parks has been envisioned for the German Baltic Sea pilot location. After the concept, construction (see D3.2 “Design, numerical modelling of a submersible longline” and D3.3 “Design and implementation of mariculture structures”) and nearshore testing phase (see D4.1 “Design, adaptations for deployment in offshore regions”), the prototypes were installed directly onto the FINO2 monopile. This happened in great cooperation of FuE and DNV, as well as the provision of algae material by University of Gothenburg. To test the setup's performances, two frames with a macroalgae installation of *Ulva,* as well as, an NID installation have been successfully mounted, including a monitoring program centring around stationary underwater cameras suitable for long-term deployment. The novel anchoring method of the multipurpose system relies on magnets which are easy to use. Critical is the proper removal of the sessile organisms, however, in this instance, they were loosely attached (Figure 35). Most advantageous is the flexible and harmless attachment method which therefore harmonizes wind park requirements, the anchoring and its development are formulated within the concept phase of D3.2 and D3.3. The NID installation was purposely installed at a depth of minus ten, to serve as a shelter from the waves and to be accessible for juvenile pelagic fish (See Figure 30).

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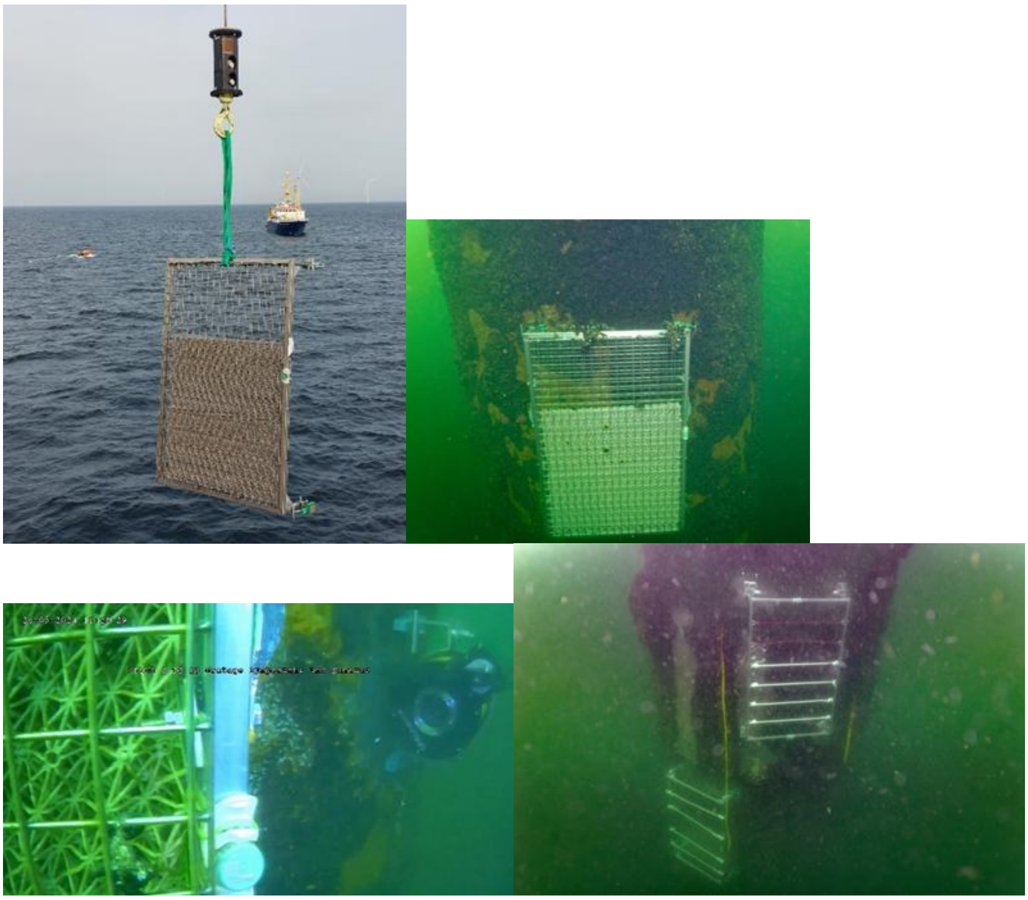

Figure 35. System installations by the use of the novel anchoring technique. A, B: Deployment and installation of the NID-setup, C: Installation of the Macroalgae frames. D: Installation of the monitoring strategy.

Belgian pilot

For the oyster restoration tables (installed on the scour protection), additional precautions were taken when selecting the area for installation, such as: *(i)* avoiding operational zones used by crew transfer vessels (CTVs), especially near the turbine boat landing; *(ii)* close to cables. This not only ensured the safety of both aquaculture and wind farm operations but also helped maintain smooth logistical workflows for all parties involved.

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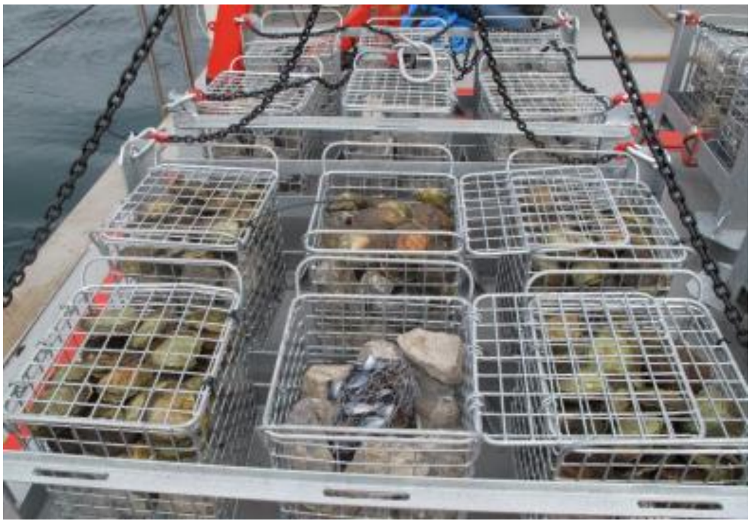

Figure 36. Oyster restoration tables installed at the scour protection of selected turbines.

Danish pilots

No specific nature inclusive design add-ons were installed in the Danish pilots.

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4. Harmonisation of offshore installation procedures

In order to harmonise installation procedures among pilots, other projects and stakeholders, workshops and meetings were organised.

Danish pilot

An Inspirational Workshop on Design & Biology & Monitoring was organised on the DTU premises in Copenhagen, Denmark on the 23rd and 24th of May 2023 which included exchanging information on the physical set-up of the farms, specifically

- Installation
- Mooring – anchor types and design
- Logistics – vessels, liability, permits

In addition, partners interchanged expertise (e.g. on oyster deployment and acoustic releases) at various ULTFARMS meetings. And attempts were made to organise sharing ships, although not yet fruitful.

Dutch pilot

Force calculations were made by Deltares. After that, anchors were designed that could handle the forces. In Norway there is a virtual test center for anchors. During the placement of the anchors at Borssele, it was clear that it was key for the mussel farm owner (OOS) to be present at the site and instruct the technicians how to deploy the anchors, keeping in mind the local currents and previous experiences.

It was discussed to combine installation of pilots that are close together (e.g. Belgium and The Netherlands), however, the weather window is generally so small that carrying out two installations is not feasible.

German pilot

The integration of aquaculture systems with offshore wind platforms presents a unique set of challenges and opportunities. Successful implementation requires careful coordination across multiple disciplines, from engineering and logistics to governance and environmental management. Harmonizing the tasks associated with planning, installation, maintenance, and decommissioning ensures the viability and efficiency of these multi-use offshore projects. Although the German Pilots FINO2 and FINO3 are research platforms, the challenges and tasks faced for OWP are the same, and two key scenarios should be considered for future projects. One where offshore wind and aquaculture are planned from the start, and another where aquaculture is introduced into an existing wind farm.

Planning

Case 1: Simultaneous Planning

When offshore platforms and aquaculture are planned together, efforts can be harmonized from the outset. This allows for:

- Integrated Site Selection: Identifying optimal locations for both platforms and aquaculture installations while considering depth, seabed conditions, and hydrodynamic forces.
- Environmental Synergies: Conducting a unified Environmental Impact Assessment (EIA) to address both wind energy and aquaculture effects, ensuring compliance with ecological regulations.
- Regulatory Coordination: Streamlining permitting processes by integrating aquaculture licensing with offshore wind farm approvals.

Case 2: Retrofitting Aquaculture into an Existing Offshore Project

When adding aquaculture to an existing platform, planning efforts need to account for the constraints of an operational facility:

- Site Adaptation: Identifying locations within the wind farm that minimize interference with turbines, cabling, and maintenance routes.
- Regulatory Adjustments: Updating existing permits to include aquaculture activities and ensuring compliance with additional safety requirements.
- Risk Mitigation: Assessing potential risks such as structural loading, increased marine traffic, and ecosystem interactions before integration.

Installation

Case 1: Simultaneous Installation

When offshore windfarms and aquaculture are installed together, efficiencies can be maximized:

- Coordinated Deployment: Using multi-purpose vessels to install both wind and aquaculture components simultaneously, optimizing resource use and reducing overall project costs.
- Integrated Anchoring: Implementing anchor solutions that support both turbine stability and aquaculture structures, such as hybrid suction anchors or gravity-based systems.
- Load Distribution: Engineering mooring layouts that account for the forces exerted by both wind turbines and aquaculture setups.

Case 2: Retrofitting Aquaculture into an existing offshore project

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Adding aquaculture to an already operational platform or wind farm requires careful adjustments:

- Retrofitting Infrastructure: Assessing whether existing foundations can support aquaculture structures or if separate installations are required.
- Minimizing Disruptions: Scheduling installation activities to avoid conflicts with platform or wind farm maintenance and in the latter case energy production.
- Independent Anchoring: Using dedicated mooring solutions, such as drag anchors or modular gravity anchors, that do not impact platform or wind turbine foundations.

Maintenance

Case 1: Coordinated Maintenance Strategies

To ensure operational efficiency, joint maintenance strategies are essential:

- Integrated Maintenance Strategies: Developing long-term maintenance plans that address both offshore platforms/ wind farm and aquaculture needs, reducing operational downtime.
- Shared Vessel Use: Designing maintenance and service vessels capable of handling both platform/wind turbine servicing and aquaculture activities.
- Regulatory Compliance: Ensuring both industries adhere to safety regulations and liability frameworks through coordinated efforts.

Case 2: Adapted Maintenance Procedures

For aquaculture installations added to existing platforms or wind farms, maintenance strategies need to be adjusted:

- Scheduling Coordination: Aligning aquaculture maintenance schedules with platform or wind farm servicing to minimize conflicts and vessel usage.
- Specialized Equipment: Ensuring vessels used for aquaculture maintenance are compatible with existing safety protocols.
- Risk Management: Addressing potential hazards introduced by aquaculture operations, such as additional navigation challenges.

Decommissioning

Case 1: Joint Decommissioning Plan

When offshore platforms/wind and aquaculture are integrated from the start, decommissioning efforts can be streamlined:

- Simultaneous Removal: Coordinating the dismantling of platforms/wind farm and aquaculture infrastructure to reduce costs and environmental impact.

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- Sustainable Disposal: Recycling or repurposing materials from both industries, such as using decommissioned structures for artificial reefs.
- Regulatory Coordination: Ensuring that decommissioning plans comply with both offshore platform/ energy and aquaculture regulations.

Case 2: Separate Decommissioning Considerations

When aquaculture is added to an existing platform/wind farm, decommissioning requires additional planning:

- Staggered Removal: Assessing whether aquaculture structures can remain operational beyond the lifespan of the platform/wind farm or must be removed simultaneously.
- Post-Project Monitoring: Conducting long-term environmental impact assessments to evaluate site recovery after decommissioning.
- Permit Adjustments: Revising decommissioning permits to reflect additional aquaculture-related structures and their removal process.

Harmonization Efforts in the German Case

In the German case, specific measures were taken to harmonize efforts between offshore operations and aquaculture. To prevent conflicts with regular maintenance activities of the FINO platforms, vessels were booked in a coordinated manner. Synergies were created by leveraging existing diving and vessel activities at FINO2 and FINO3 to conduct both maintenance and monitoring work for aquaculture structures, where applicable.

Furthermore, instead of certifying an independent aquaculture team to enter offshore, the existing certifications and permits of the maintenance crews from FINO2 and FINO3 were utilized. This allowed scientists and technicians from the ULTFARMS team to be integrated into existing operational teams, streamlining certification requirements and reducing administrative burdens. These efforts significantly enhanced operational efficiency and reduced costs while ensuring compliance with safety and regulatory standards.

Workshop Conclusions and Collaborative Efforts

During project discussions and workshops, key insights were gathered on the integration of aquaculture.

- Oyster Deployment & Acoustic Releases: Knowledge-sharing sessions allowed partners to exchange expertise on effective oyster deployment techniques and the potential use of acoustic releases for remote monitoring and management.
- Vessel Sharing Initiatives: Attempts were made to coordinate vessel-sharing efforts between maintenance crews and aquaculture operators. Further discussions and logistical adjustments could enhance feasibility.

- Regulatory and Technical Harmonization: Aligning the legal, safety, and operational requirements of both industries remains an ongoing challenge. Developing standardized procedures for aquaculture integration within offshore wind farms is a key priority for future collaboration.

Belgian pilot

Harmonization of the installation procedure was essential to ensure efficiency, safety, and consistency across all operations, particularly given the complex environment of the offshore wind farm. The process began with the development of a standardized installation protocol, integrating lessons learned from previous deployments and site-specific requirements. This protocol covered every stage, from pre-installation site surveys to post-installation inspections, ensuring that all teams followed the same procedures regardless of the specific task or vessel involved.

A key element of harmonization was the alignment of operational workflows between different contractors, vessel crews, and technical teams. This was achieved through detailed pre-mobilization meetings where all stakeholders reviewed the installation plan, identified potential risks, and clarified roles and responsibilities. Standard Operating Procedures (SOPs) were distributed and discussed, covering anchor placement techniques, the deployment of aquaculture longlines, and oyster restoration cages. This approach minimized miscommunication and ensured that safety protocols, such as exclusion zones around active installation sites and emergency response procedures, were universally understood and applied.

Coordination was further supported by real-time communication channels, including dedicated radio frequencies and a centralized command structure onboard the lead vessel. This allowed for immediate issue resolution and adjustments to the plan as needed, particularly in response to changing weather conditions or unforeseen technical challenges. For example, harmonizing procedures enabled quick adaptation when shifting from sandy to muddy seabed conditions, as all teams were briefed on the specific anchor types and installation methods suitable for each substrate.

Environmental and regulatory compliance also benefited from harmonization. Unified protocols ensured that activities such as UXO surveys, seabed scans, and anchor placement adhered to legal requirements and minimized ecological impact. The use of consistent equipment calibration standards and data recording formats facilitated seamless integration of monitoring results, aiding in both operational oversight and regulatory reporting.

Finally, harmonization extended to post-installation procedures, with standardized checklists for equipment inspection, tension testing of mooring lines, and documentation of installation outcomes. This comprehensive approach not only improved operational efficiency but also enhanced safety, reduced costs through minimized downtime, and ensured the long-term success of the aquaculture systems within the offshore wind farm.

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5. Lessons learned and conclusions

Compliance with maritime spatial planning is essential to avoid conflicts with other sea users, such as wind energy, shipping, and fisheries. Additional requirements may include water quality and health regulations to ensure sustainable marine farming practices.

Working offshore demands a structured approach to safety, certification, and environmental compliance. Whether operating a wind farm, navigating a vessel, or running an aquaculture pilot, all stakeholders must adhere to strict regulatory frameworks to ensure the safe and sustainable use of the country's maritime space.

Below an overview is presented of the main challenges encountered at the day of installation at the different pilots and how they were solved

Dutch pilot

Summary of main challenges for the installation in Borssele III are:

Current**:** The current is a serious factor during installation.
The dominant current direction SSW-NNE is does not last very long: in reality, the current is mainly continuously turning (clockwise). This gives challenges with position keeping.

Installing anchors position**:** required an accurate position within 5 m range. With the turning current it was a challenge to place the anchor on the correct location. At first, the crew of the multicat (Non-DP) lowered the anchor with chain with tuggers, which took relatively long to remain at position. After advice from OOS the anchor was dropped and chain pulled out from deck. This went much faster, and it was easier to maintain the correct position

Installing platform**:** was done with 3 vessels: a tugboat, a Multicat and a support vessel. Anchor lines were connected one by one, this went well. The only remark was that time wise the operation took more than 12 h in total, resulting in more work hours than wanted.

Installing longlines**:** First installing the longlines was tried with a normal support vessel**,** but this vessel was not powerful enough to pull the longlines in position, in particular with the turning current. We hired a DP1 Multicat which worked well to place the 5 longlines and tension them.

Belgian pilot

The installation day of the ULTFARMS seaweed and oyster cultivation systems within the offshore wind farm presented a series of complex challenges, primarily driven by the harsh and unpredictable nature of the marine environment.

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Operating offshore inherently comes with elevated risks compared to nearshore installations due to dynamic weather conditions, strong currents, and logistical constraints. One of the foremost difficulties encountered was dealing with adverse weather conditions, including high winds, strong swells, and fluctuating sea states. Even with meticulous planning and the selection of optimal weather windows, sudden changes in weather patterns required rapid, on-the-spot adjustments. Offshore operations are highly sensitive to such variations, as high winds can affect crane operations, and rough seas can limit the manoeuvrability and safety of vessels and crews. To address this, we relied on real-time meteorological data and advanced marine forecasting models, allowing for dynamic rescheduling and the flexibility to mobilize vessels, equipment, and personnel as soon as conditions improved. This required close coordination with maritime authorities and continuous monitoring of weather systems to ensure the safety of all operations. It also caused our anticipated sea missions to be longer than anticipated for, as we encountered several weather delay days.

Another significant challenge was ensuring the stability and secure anchoring of the aquaculture cultivation structures. The offshore environment subjects mooring systems to immense mechanical stress due to wave action, tidal currents, and the additional load from biofouling over time. During installation, maintaining the precise positioning of anchors and cultivation lines proved difficult, particularly due to current drift and limited visibility underwater. This was mitigated through the deployment of dynamic positioning vessels (DPVs) that could maintain their position accurately without the need for traditional anchoring, reducing environmental disturbance while enhancing operational precision. GPS-guided deployment techniques were employed to improve anchor placement accuracy. Additionally, remotely operated vehicles (ROVs) played a crucial role in underwater inspections, allowing us to verify the correct placement, tension, and integrity of mooring lines in real time. This technology facilitated rapid adjustments when discrepancies were identified, reducing the risk of future structural failures.

For oyster cultivation, unexpected biofouling on pre-installed equipment from earlier pilot trials created significant hurdles. Biofouling organisms, such as barnacles, algae, and mussels, had accumulated extensively, increasing the weight of the cultivation gear and complicating both handling and buoyancy calculations. This added strain required additional manpower during deployment, slowed down operations, and necessitated recalibration of flotation devices to maintain the required buoyancy for optimal oyster growth conditions. To anticipate the extra weight, adjustments were made to the buoyancy aids, with additional floats added to counterbalance the unexpected load. We also abandoned some techniques and materials previously tested. This experience underscored the importance of our nearshore pilot (H2020 UNITED project), routine pre-installation inspections and proactive biofouling management strategies, which will be integral to future installations.

Due to equipment failure of mooring equipment at the target deployment site at Belwind, a decision was made to move the demonstration to an alternate test site,

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the partly exposed site at the Bantry Marine Research Station (BMRS) in Ireland. The design assessment for hardware was based on analysis for the more severely exposed Belwind site. The equipment was installed in November 2024. The deployment has endured several severe storm events during winter 2024 –2025 and repeated submergence has been successfully demonstrated. Overall, the engineering performance of the submersible longline has been good. To date there have been no failures and the calibrated numerical model for the "as installed" structure predicts loads that are far below the breaking strengths of the components employed, even for the most extreme conditions. The pressurised beam has proven to be robust so far with no significant abrasion detected yet. To extrapolate this experience to the Belgian wind farm site and potential future commercial scale-up, it is proposed that some numerical work will be undertaken.

Logistical coordination also presented notable challenges, given the offshore site's remote location and the need to synchronize multiple operations simultaneously. The complexity of managing the deployment of large-scale structures, specialized equipment, and installation crews within tight operational windows required detailed planning and precise execution. Delays or issues with one component could create a cascading effect, disrupting the entire schedule. To mitigate this, we established a centralized command structure that ensured clear lines of communication and decision-making authority. Daily briefings and debriefings were conducted to assess progress, identify potential issues, and adapt plans as necessary. Continuous radio communication between vessels, cranes, and onshore coordination teams enabled real-time problem-solving. In addition, contingency plans were in place to address potential equipment malfunctions, personnel safety concerns, or sudden weather changes, ensuring a swift and coordinated response when needed.

Crew safety was of paramount importance throughout the installation process, given the inherent risks associated with offshore operations. These risks included equipment failure, slips and falls, accidental entanglement in mooring lines, and exposure to harsh environmental conditions. Comprehensive safety protocols were strictly enforced, beginning with thorough pre-deployment safety briefings and risk assessments tailored to the specific tasks at hand. All crew members underwent specialized offshore survival training, which covered emergency evacuation procedures, first aid, and the use of personal protective equipment (PPE). Emergency response plans were developed and rehearsed, with dedicated safety officers on-site to oversee compliance and readiness. Safety drills, including man-overboard simulations, were conducted to ensure that all personnel were prepared to respond effectively to emergencies.

Environmental considerations were another critical aspect of the installation process. The offshore wind farm site hosts diverse marine life, and installation activities carried the potential risk of disturbing sensitive habitats and species. To minimize environmental impacts, an Unexploded Ordnance (UXO) survey was conducted prior to installation to ensure the safety of operations and prevent disturbance to potentially hazardous materials on the seabed. Additionally, screw anchors were chosen over traditional drag anchors due to their reduced impact on the seabed. Screw anchors can be installed with greater precision and minimal sediment disruption, thereby protecting benthic habitats. During the installation, continuous environmental monitoring was conducted, including real-time observations for the presence of marine mammals and seabirds to prevent disturbance. Anchor adjustments were made when necessary to avoid sensitive benthic areas identified through pre-installation habitat mapping, ensuring that the ecological footprint of the installation was minimized.

In conclusion, the challenges faced during the ULTFARMS seaweed and oyster system installation were multifaceted, involving environmental, technical, logistical, and safety-related issues. Successfully overcoming these challenges required a combination of advanced technology, adaptive planning, skilled personnel, and strong communication protocols. The lessons learned from this experience will be invaluable for optimizing future offshore aquaculture installations, enhancing both operational efficiency and environmental sustainability.

German Pilots

The first challenge, which is inevitably related to the nature of the matter, is the logistics during and especially before the offshore installation. Small and infrequent time slots and long journeys increase the financial risk as well as the risk of not being able to keep to the schedule. It is therefore extremely important to plan and go through all processes in detail, especially during installation at the offshore site. This requires a high degree of Co-management, i.e. consultation with various parties, as well as precise organization of the work and everything associated with it. An essential part of this is, of course, the availability of a suitable vessel.

Another aspect that is probably the most challenging and most frequently encountered is the change in conditions at sea. Even the smallest changes in the maximum wave height above the limit make some work impossible. In this case, it is necessary to wait for the right conditions or continue the work at another time. This can lead to additional costs, which should be included in the prior planning of the installation or the entire project.

Danish Pilots

The overall challenge for development of LTA in Danish wind farms are the restrictions imposed by the Danish Maritime Spatial Plan that confines mussel farming to areas that is not coinciding with areas allocated for wind energy production. This is not a challenge for seaweed production that is not confined to specific areas in the Danish EEZ.

In terms of practical implementation, as for the German pilots, the main challenge has been logistics and in particular on a project level where access to suitable boats will depend on market availability as service boats used for wind energy operators were not suited for aquaculture operations. There are boats – like Frigg used in ULTFARMS – that can operate in the Kattegat area and that previously have been used in the same general area for mussel farming operations. For all boats, there is a limited weather window allowing for operations in and around farm units. Hence, farms need to be designed for minimal daily maintenance and the farm unit needs to be equipped with surveillance equipment that can report on malfunctioning or wreckage.

In a commercial scale implementation of mussel and seaweed farming in the Kattegat area, it can be expected, that the operator will have access to a fleet of their own that will allow them to access the farm units when weather allows and using boats with a fit-for-purpose design. In a such scenario, it is key that co-existence with the wind energy operator is as smooth as possible with the least interference between the two operators. This will require planning when placing the farm units in relation to pylons, cables and distance to port.