Deliverable 10.2

Technical innovation for LTA implementation within OWF

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Abstract	The implementation of low-trophic aquaculture (LTA) within offshore wind farms (OWF) is a new development in multi-use marine spatial planning which requires a site-specific approach to innovative design. There are several challenges, risks and barriers to developing this multi-use activity across the six ULTFARMS pilot projects. Technical and logistical solutions are necessary for

	overcoming these obstacles and upscaling capacity. This internal deliverable aggregates the site-specific solutions in terms of technical and engineering innovations, adapted for local regulations and oceanic conditions. Where applicable, plans for testing these designs under laboratory conditions or in nearshore environments are detailed. The information gathered here will contribute to the project's integrated road map.
Keywords	Low trophic aquaculture, offshore wind farms, technical solutions

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Acronyms

LTA	Low-Trophic Aquaculture
OWF	Offshore Wind Farm
TRL	Technology Readiness Level
NID	Nature Inclusive Design

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Executive Summary

Multi-use maritime spatial planning is becoming an increasingly valuable tool as global demands on marine resources and spatial use continue to grow. This is especially important in areas like the Baltic and North Seas where there is already intensive use of coastal and offshore space. The ULTFARMS project aims to demonstrate ocean multi-use scenarios in which renewable energy development, sustainable food production, and environmental protection can co-exist. Across six different sites in the Baltic and North Seas, ULTFARMS pilots will integrate low-trophic aquaculture (LTA) into offshore wind farms (OWFs) while safeguarding the environment and biodiversity, minimizing carbon footprints, and developing commercial viability.

The implementation of low-trophic aquaculture (LTA) within offshore wind farms (OWF) is a new development in multi-use maritime spatial planning which requires a site-specific approach to innovative design. There are several challenges, risks and barriers to developing this multi-use activity across the six ULTFARMS pilot projects. Technical and logistical solutions are necessary for overcoming these obstacles and upscaling capacity. This internal deliverable aggregates the site-specific solutions in terms of technical and engineering innovations, adapted for local regulations and oceanic conditions. Where applicable, plans for testing these designs under laboratory conditions or in nearshore environments are detailed. The information gathered here will contribute to the project's integrated road map for upscaling LTA in OWFs.

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1. Introduction

1.1 Background

The ULTFARMS project aims to support the integration of Low-Trophic Aquaculture (LTA) into offshore wind farms in the North and Baltic Seas, moving toward multi-use scenarios where energy production, eco-friendly food production and environmental protection can coexist. ULTFARMS builds on knowledge acquired through previous offshore aquaculture and multi-use projects, including MERMAID, Wier and Wind, IMPAQT, HiSea, Coastbusters, BONUS-OPTIMUS, EDULIS, MUSICA and the Horizon 2020 UNITED project. These projects have increased the Technology Readiness Level (TRL) of various aspects of offshore LTA aquaculture. However, there are still significant challenges to be addressed in the upscaling of multi-use scenarios for offshore aquaculture, energy production, and nature restoration.

With six pilot sites spanning four countries and two seas, the ULTFARMS project aims to increase the TRL of offshore LTA with site-specific solutions to technical challenges. This internal deliverable serves to document the design and testing plans for each pilot and explain how these innovations address specific challenges, risks, and barriers relevant to each pilot site.

Table 1.1. Overview of ULTFARMS demonstration pilots.

Pilot	Region	LTA species
Samsø	Danish Baltic Sea	Mussel
Anholt	Danish Baltic Sea	Seaweed & Mussel
FINO2	German Baltic Sea	Seaweed
FINO3	German North Sea	Seaweed, Mussel & oyster
Borssele	Dutch North Sea	Mussel
Belwind	Belgian North Sea	Seaweed, Mussel & oyster

1.2 Scope of deliverable and links to other tasks

This internal deliverable reports on the second task of Work Package 10, "Roadmap to Innovation and Upscaling". This task is meant to aggregate the 6 pilot designs and highlight how each pilot intends to address specific risks, challenges and barriers relevant for their particular site. These challenges, risks and barriers have been identified in Deliverable 10.1 and will be summarized in chapter 2 of this deliverable. In chapter 3, the challenges that are relevant for each pilot will be specified and the corresponding solutions for each of these challenges will be

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addressed, drawing on links with Work Package 3 (T3.1 – 3.4) and Task 4.1 in which designs and plans for testing are developed.

The information gathered here is specific to technical and logistical aspects of the pilot projects. More information on social, economic, and governance factors can be found in deliverables related to work packages 2, 5, and 9, respectively.

The information aggregated in this deliverable will feed into the final task of Work Package 10, T10.5, "An integrated roadmap for upscaling" which will serve as the legacy product of the ULTFARMS project and facilitate transferability and replicability for multi-use scenarios involving LTA, offshore energy production, and nature conservation.

2. Challenges, risks and barriers to LTA in offshore wind farms

This chapter serves to summarize the challenges, risks and barriers to LTA in OWFs identified and discussed in detail in D10.1. The same challenges, risks and barriers are also discussed on a pilot-by-pilot basis in D3.1 in relationship to the co-design of production related activities. In section 3 of this deliverable, each pilot will detail the technical solutions that have been developed to address the challenges identified below.

2.1 Logistical challenges due to distance from shore and location in wind farms

With pilot sites located in offshore windfarms, one of the most obvious logistical challenges is the distance of the farms from shore. This necessitates the use of vessels that can handle long travel distances and offshore conditions. It has been a challenge for pilots in the previous H2020 UNITED project to find and contract appropriate vessels for their operations. Given very specific requirements for the technical and safety related capacities of a vessel (e.g. a crane of a certain capacity or dynamic positioning systems), only a small number may be appropriate for the job, and even fewer may actually be available in the necessary timeframe and weather window. The limited choice of vessels equipped for the work required in an LTA system in offshore conditions means that vessels may have to be contracted from further afield. For example, a vessel may have to travel from Scotland to carry out pilot-related work in the Belgian part of the North Sea which can drastically increase fuel and personnel costs. Additional administrative steps can also lead to delays as vessels must be vetted and approved by the wind farm operators before the sea mission can take place. These logistical challenges can have consequences for the economic sustainability of the farm as the high operating costs and frequent delays make it less feasible to carry out regular maintenance and in-person monitoring of the farm. On-site activities may be limited to those that are strictly necessary such as installations and harvests, while

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regular maintenance activities like gear checks and clearing away biofouling may be cost prohibitive.

Reduced maintenance and monitoring activities due to distance from shore can have consequences. For example, not being able to monitor crop growth and overall health of seaweed and bivalves could cause operators to miss the ideal window for harvesting. Inability to frequently check on farm gear and infrastructure could also lead to otherwise preventable damage.

2.2 High energy environments and extreme weather

In addition to travel distances, the high energy environment offshore can also cause logistical challenges. As mentioned above, the availability of appropriate vessels is a major bottleneck for developing offshore aquaculture. For safety reasons, most vessels can only work with the aquaculture systems at specific tides and in the calmest conditions. This narrows the possible weather windows for sea missions and can lead to significant delays when missions must be postponed or cancelled due to foul weather.

The high energy conditions offshore are also a challenge for the design phase of offshore LTA. Even normal wave energy in these environments can cause considerable wear and tear on infrastructure. Extreme weather events are not uncommon and must be accounted for in modeling scenarios, experimental facility trials, and nearshore testing before deploying equipment at sea. The major risks include loss of biomass and damage or loss of infrastructure components.

Loss of gear due to extreme weather can result in a number of consequences for an LTA operation. For example, if an oyster cultivation structure detaches from the longline, there would be a loss of revenue as the oysters cannot be brought to market. There is also the cost of either retrieving the structure, which may be legally mandated, or replacing it. If the structure has the potential to cause damage to a vessel, wind turbine, cables or other third-party property, there will also be insurance related costs to bear.

2.3 Need for remote and automated monitoring systems

As most currently operating commercial LTA farms are located nearshore, routine checks on gear and crops are part of normal farm operations. Regular monitoring is important in order to catch any possible problems before they develop. This includes monitoring the health and growth of cultivated species as well as environmental conditions such as water quality or presence of harmful algae blooms. It is also important to check on the condition of the infrastructure and gear, for example checking for rust or corrosion, fraying ropes, excessive fouling, or any other damage that may impact the integrity of the system. This is a critical point, as failure to foresee problems can result in economic losses to the farm, damage to third party property, and even negative environmental impacts

With these risks in mind, it is clear that monitoring is a critical part of any farm's operations. And yet, moving offshore makes regular monitoring extremely difficult. As discussed above, the distance from shore and likelihood of increased wave energy makes frequent visits to an offshore LTA system less feasible. Therefore, as monitoring remains a critical activity, there is an opportunity here for innovation in the development of remote, automated, and reliable monitoring systems which can collect data without the need of costly sea missions.

2.4 Potential environmental impacts (positive and negative)

One of the key goals of the ULFARMS project is to create a net-positive environmental impact. There are two challenges in this regard. The first, and possibly most important, is the principle of "first do no harm". In other words, mitigating any potentially negative impacts from industrial multi-use activity. For example, anchoring systems are particularly important to consider in terms of impact mitigation as they can be responsible for disturbing or destroying benthic habitat. Therefore, choosing an anchoring system that will cause the least disruption or alteration to the existing benthic habitat is an important consideration in the design phase of all pilot projects.

In addition to negative impact mitigation, there is potential to achieve a net positive environmental impact through the ecosystem services provided by the cultivation of low-trophic species (Barrett et al., 2022) and restoration of the native European flat oyster. Native oyster restoration is proposed due to the many ecosystem services provided by oysters as a habitat building keystone species before their population decline in Europe (Pogoda et al., 2019). It is worth noting however, that restoration is a challenging task as it requires a deep knowledge of the historical ecology of the location in question. The aim here is not to replace an existing habitat with a new type of habitat, but to provide support in restoring functionality to a degraded habitat.

Another question ULTFARMS aims to answer is if and how a net positive impact can be made by incorporating NID features in the design of offshore LTA infrastructure and the design of future wind farms. For example, providing structural complexity in the design of an anchoring system or scour protection of turbines could increase available shelter for native juvenile fish, effectively providing nursery habitat for fisheries (Hermans et al., 2020). This must be directed by the lessons learned from scenarios implemented in the past and verified with thorough monitoring process (Brancho-Villavicencio et al., 2023).

2.5 Choosing appropriate species for local conditions

The most common species cultivated across the 6 ULTFARMS pilots are the native European flat oyster (*Ostrea edulis*), the blue mussel (*Mytilus edulis*), and the "seaweed," sugar kelp (*Saccharina latissima*). The temperature conditions in the

North and Baltic Seas are conducive to cultivation of these three species. However, the Baltic region has the added challenge of salinity gradients. In some areas of the Baltic, the salinity is too low to successfully cultivate sugar kelp. This is a challenge for the Danish Anholt and Samsø pilots and Fino2 German pilot. Another challenge for all pilots is whether to expand cultivation activities to other seaweed species as other seaweeds are more tolerant as they consist out of a spectrum of locally adapted populations which may hold potential to cope with the salinity gradient. Similarly, brown algae aquaculture for instance is bound to the winter season in continental Europe. Temperature tolerant strains might enable to widen this bottleneck, possibly resulting in winter and summer specific strains. Adaptations to the ongoing change of parameters is of great importance, especially considering climate change.

2.6 Disease and biosecurity

The risk of disease is always a concern for aquaculture operations as high stocking densities can promote transmission between individuals and impact the overall health of the population. This is especially a concern for native oysters which have been decimated in the past by the parasites *Bonamia ostreae, Bonamia exitiosa,* and *Marteilia refringens*. These parasites are well known for causing disease in native oysters and have been responsible for the loss of both wild and cultivated populations (Culloty & Mulcahy, 2007). It is therefore imperative that any aquaculture operation aiming to grow native oysters must take strict biosecurity precautions. For example, any oysters introduced into the marine environment should be certified *Bonamia* and *Marteilia* free using PCR testing. Quarantine periods may also be mandated by state or local authorities along with other precautions. Research efforts are also underway to determine the feasibility of using *Bonamia* resistant, tolerant, or resilient broodstock for restoration purposes (Holbrook et al., 2021).

2.7 Biofouling

The prevalence of fouling organisms poses a risk to the productivity of an LTA farm. Various species of turf algae, tunicates, barnacles, and other sessile organisms that settle on hard substrate also tend to colonize the surfaces of cultivation structures. Biofouling can cause problems for both bivalve and seaweed aquaculture. In the case of oyster aquaculture, overgrowth of fouling organisms can clog the openings of cultivation structures, preventing water flow and essentially suffocating the oysters inside. Fouling can also be a problem for mussel cultivation as biofouling organisms may compete for space with mussel larvae for settlement. Biofouling can be an issue for seaweed cultivation if the seaweed is not harvested by the late spring months. After this period, the season for fouling organisms begins, and there may be significant settlement and even herbivory on the kelp.

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Nearshore LTA operators can manage biofouling overgrowth with regular cleaning. However, given the challenges discussed above, it would not be feasible to plan frequent sea missions for this kind of maintenance in an offshore LTA farm. Therefore, innovative methods are needed for addressing biofouling in this context.

2.8 Non-technical challenges

2.8.1 Legal, regulatory and insurance related considerations

This deliverable is focused on technical and engineering innovations rather than socio-economic and regulatory considerations. However, it is worth stating here that the legal, regulatory, and insurance aspects of integrating LTA into offshore wind farms do, indeed, pose challenges for operators. Offshore LTA is a rather new concept, and consequently, there is very little established policy or protocol related to the process of permitting and insuring a new farm. The pilot projects of ULTFARMS and the previous related projects, UNITED and EDULIS, have been early pioneers in navigating governance, stakeholder relations and insurance services. This information is being used to build a roadmap to make the path smoother for future projects and prospective aquaculturists. Please see UNITED deliverable 6.1 (2021) and ULTFARMS deliverables 9.1 & 9.2 for more information on Legal, governance, and insurance related considerations for LTA in OWF multi-use scenarios.

2.8.2 Commercialization and market challenges

Commercialization challenges can also arise from the lack of robust pre-existing markets for some LTA products. Although shellfish already have a market, seaweed is a relatively new product in Europe. There is currently demand for seaweed as raw material in the cosmetics market, however further development is necessary for other emerging markets for seaweed biomass such as fertilizer, livestock feed, bioplastics, and food for human consumption. Work package 5 of ULTFARMS focuses on commercialization, exploitation and business planning for offshore LTA products. As previously mentioned, this deliverable focuses on technical and engineering innovations, and as such, the market and commercialization risks, challenges and barriers will not be in the focus of the innovative solutions outlined in the following chapter of this deliverable. For more background information, please see UNITED deliverable 3.2 (2021). Commercialization, exploitation, and business planning will be addressed in ULTFARMS work package 5.

3. Innovative solutions for overcoming challenges, risks, and barriers

Each pilot involved in the ULTFARMS project has a unique relationship to the various challenges, risks and barriers discussed in chapter 2 of this deliverable and will therefore need to adapt innovative solutions for their particular environment, cultivated species, and local regulations. This chapter will give an outline for each pilot to identify which challenges, risks, and barriers are most relevant for their site, and identify corresponding solutions they are developing to address these issues. These innovative solutions will be discussed in terms of technical designs and plans for testing in experimental facilities and nearshore environments. This section serves to catalogue the technical solutions that are currently being developed by each pilot project, and it is worth noting that not every challenge, risk or barrier will have a corresponding solution under development at this stage of the project. As the ULFARMS project moves forward, there will certainly be new innovations and design evolutions developed after the submission of this deliverable.

3.1 Danish Pilots

3.1.1 Logistical solutions

Reducing costs by seeking alternative vessels and suppliers

Wind farm owners are apprehensive about any external operations in the area, they demand a high degree of oversight and standards to be fulfilled. This will be a burden for aquaculture operators who operate with different standards. National maritime regulation applies to aquaculture operations and should be the legal basis for operating within a wind park; however, there can be conflict in understanding which (national or wind park owner's) regulations apply to different actors. Vessels must be the right size and must be equipped to handle longlines in offshore conditions. Large vessels can detach moorings and are more difficult to navigate within the farm. Small vessels cannot lift or work on the line. Vessels used by fish farmers may be appropriate for this kind of work, although they are typically slow. It is likely that purpose-built vessels for offshore LTA will be necessary. Offshore vessels and contractors are expensive, they are used to working with the energy sector. Aquaculture operations cannot afford the high operational costs associated with typical offshore work. Some items/equipment for establishing a farm supplied by offshore companies have inflated prices relative to their manufacturing cost. Sourcing equipment from other countries or having equipment manufactured locally from new may reduce costs.

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3.1.2 High energy environments and extreme weather

Adapting existing aquaculture designs for offshore conditions

The offshore physical environment is challenging for maintaining an aquaculture structure. The cultivation design follows years of proven design criteria for coastal farms, and over-dimensioned to account for the higher physical forces. Longlines are situated below Hs (4m), robust buoys have been manufactured and used. Large (4m) screw anchors will be installed to moor the longlines.

3.1.3 Monitoring solutions

Weather in the Danish pilot sites are dominated by conditions unsuitable for working on aquaculture systems offshore limiting operational capacity and site visits. As the weather cannot be changed, an observation station will be established at the farm in place of regular site visits. This will include a rotatable video camera. Other observational tools may be implemented, such as a load cell with telemetry back to land.

3.2 German Pilots

The German offshore pilots are located at the research stations FINO2 within the Baltic Sea and FINO3 in the North Sea. The Seaweed and mussel systems at the North Sea pilot site were installed in 2022 during the previous EU project UNITED. Within the ULTFarms project, we built upon the lessons learned and will improve the system for algae and mussel cultivation in the North Sea, while a novel algae cultivation system will be established in the Baltic Sea. Most of the technical solutions described are based on insights gained from the North Sea pilot. The existence of the two research platforms enables the investigation of multiple oceanographic parameters, based on high-resolution datasets gathered over a period of more than one and a half decades since their installation. This is used for the development of system designs and their implementation, tailored to the respective site. Although both sites are characterized by similar parameters common for offshore locations, their magnitude differs in between the locations. The North Sea pilot is faced with more extremes than the Baltic Sea pilot. With 1.4 times higher significant wave heights and 1.5 times higher maximal wave height. However, the Baltic pilot experiences a 1.5 times shorter wave period (see D.3.1), resulting in a higher wave energy. Nevertheless, most technical solutions found can be transferred between the pilots, as they still share most challenges. These two locations are the most remote offshore locations within the ULTFARMS project. In addition to the offshore location, technical design & cultivation techniques for the FINO2 site are being tested at the nearshore site within the Kiel Bay, focus is given on cultivability and the handling of the materials.

Technical and logistical challenges were identified within the deliverable 3.1, section 3.2, and summarized above. The following solutions are proposed:

3.2.1 Logistical solutions

Operational windows are periods of time, in which the environmental conditions allow safe operation, based on weather predictions, they are, however, depending on the time needed to complete the respective tasks and the equipment that is operating it. The maximum wave height of one meter and the presence of Daylight/Daybreak are the minimum requirements. Another crucial factor is the availability of ships, capable of conducting the necessary offshore tasks. Mussels and algae are bound to natural live cycles. Algae for example have to be installed during cold autumn weather, bringing the risk of stormy weather and unsafe offshore operations, limiting the suitable installation windows to just a few times during the year. Reliable weather forecasts are therefore crucial for planning. Currently, multiple oceanographic and meteorological monitoring stations are already operating within the German EEZ of the North and Baltic Seas. Their gathered data are, however, not reported in one uniform and user-friendly platform and governed by at least six different providers and multiple online platforms. A dashboard-oriented, real-time and user-friendly website will hence be established in HiSea. The HiSea platform will allow for fast, accurate access to weather information to plan trips in advance and aid in deciding on offshore trips (see also D6.2).

3.2.2 High energy environments and extreme weather

The wave and tidal conditions at the German North Sea pilot make it a hostile environment to operate in. Hence, the system design had to be adapted to the high energy conditions. Thanks to the high-resolution data gained by the research platform, common oceanographic parameters are well documented. The main tidal flow follows a northwest and southeast direction with an average current speed of 1.2 m/s at the surface and 0.9 m/s in 12-meter depth. The allocated space is defined by the presence of other stakeholders' actions in that area (e.g., wind parks and logistics).

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Mooring solution for harsh offshore conditions

To ultimately ensure the efficient use of space, a two-point mooring setup was chosen and placed along the main tidal direction, aiming to reduce the overall drag. To further resist the high energy wave conditions of 9.2-meter significant wave height and 17.9-meter maximal wave height and a wave period of 10.7 -13.9 seconds, the strength and composition of all materials chosen were adopted. Special focus was spent on the connections (e.g., in between chains), as they are often the breaking point. The minimum diameter of the shackles used within the algae system, for instance, is in between 25 – 58 mm, depending on the position within the system. The chosen strength of materials intends to account for the speed of corrosion, which is potentially enhanced by the high saline, marine water of at least 35 PSU. The material composition was aimed to solely entail non-precious metals, as a mixture with precious metals may lead to a galvanic chain, which potentially further enhances corrosion speed.

A mooring solution with a minimum holding capacity of 50t per anchor was calculated for the North Sea pilot. A literature survey suggested that Danforth and/or Delta flipper anchors are suitable in the defined conditions of medium-dense to very dense sand deposits with partially gravelly and silty constitutes (https://www.fino3.de/en/location/foundation.html,; API, 2005). Delta flipper anchors pose a folding mechanism which is designed for smooth penetration of various kinds of substrate with no rotation resulting and few decreases in holding capacity with no dragging. According to the proportional relationship between the anchor holding capacity and an anchor´s weight, each individual anchor (two per system) was chosen to weigh 2.5 ton ([2]). An additional concrete ballast weight connected to each anchor was placed. As average concrete has a three times lower density than steel, a weight of six tons was needed to weigh around 3.575 tons as submerged in salt water effectively. This combination of delta flipper anchor and concrete weight was installed in March 2022 and has been proven sufficient to hold the total length of a 320-meter-long seaweed and 265-meter-long mussel system in place.

Envisioned concept for the Baltic pilot

The Baltic Sea pilot is currently within its design phase and is aimed to be implemented by the end of the ULTFARMS project. We aim to transfer the lessons learned from the North Sea pilot and apply them to the Baltic Sea by considering them against the hydrodynamical, geographical and legal limitations at the site near the research platform FINO2. Those site-specific differences will shape the future design.

Most prominent are adaptations to the wave conditions. On the one hand, the significant wave height is much lower with, 6.4 meters and a maximal wave height of 11.9 meters in the Baltic Sea, compared to the North Sea pilot. On the other hand, the wave period is 1.5 times shorter (8.9 seconds) in the Baltic Sea, which translates into a higher wave energy.

We aim to adapt the system by installing a more flexible and shorter setup that can withstand the wave conditions. This also aims to address logistical challenges derived from the limitations of available ships that possess cranes with the necessary lifting force. The envisioned mooring solution with only one point of bottom attachment holds great promise to withstand the forces easier, however it increases the space noticeably, as it can rotate by 360°. Therefore, such a setup could be easier to deploy and maintain outside or on the adjacent area of wind parks, weather stations or other infrastructure, with the potential advantage that scaling up might be much quicker, as it is a single-standing structure.

The first cultivation test of algae was already conducted at the nearshore site with samples of regional algae (Kiel Bay). The basis of the propagation of macro-algae was established by the partner Gothenburg University. Grow out tests and the amplification of biomass were successful, resulting in the establishment of an *Ulva intestinalis* strain from Kiel Bay. This approach served as a template for the establishment of two propagation *Ulva* strains chosen for the remote pilot location at FINO2.
A first structure for the grow out experiments of *Ulva* was successfully designed and installed (Algae Frame). Algae were successfully grown for about three months, until an extraordinary heavy storm hit the platform. Even under these conditions, the design withstood the harsh weather conditions. Although there were heavy losses in biomass, algae could be harvested for processing and first analysis in the laboratory. This is a first step to establish a basis for a design that will withstand the much harsher conditions at the FINO2 offshore location.

3.2.3 Monitoring solutions

Remote and automated monitoring is an essential part of the design in offshore aquaculture (D10.1). To enable real-time monitoring, various sensors can be deployed as different operations, such as offshore fisheries aquaculture, established a wide range of standard oceanographic in situ sensors, placing the TRL in readiness in between 7 to 9. This is invaluable, as real-time or on-demand monitoring systems can lead to the early detection of issues and guide informed decision-making. This is of particular value as the German pilots are in the most distant locations among the project, leading to longer travel times and potentially additional complications within logistics.

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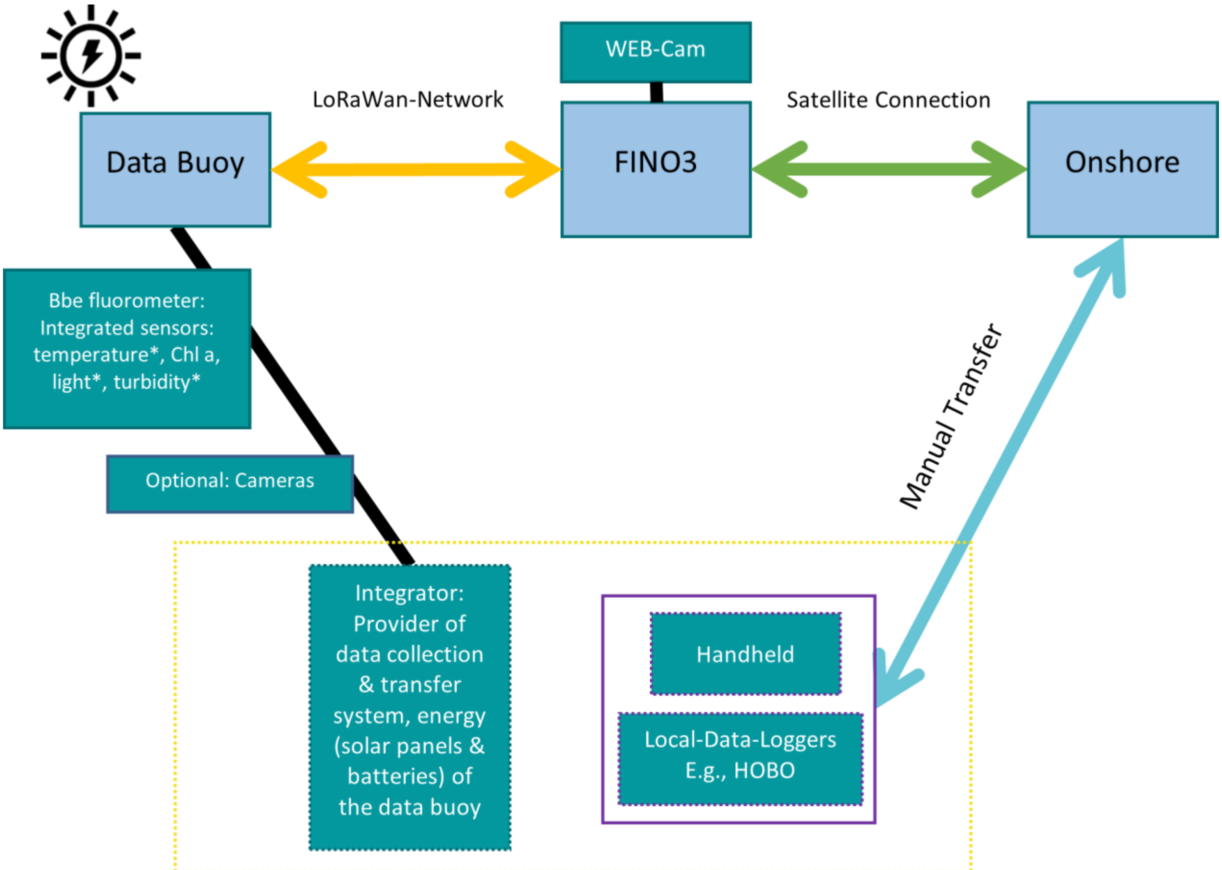

Figure 1. Description of the proposed dataflow to enable remote monitoring at the offshore pilot near the FINO3 research platform. Sensors (e.g., Bbe Fluorometer) will be deployed and connected to a data buoy which acts as a data collection system that sends data to a receiver on the nearby research platform via a LoRaWan-Network. Those data will be sent to onshore servers governed by the FuE center´s technical department, via a satellite connection to be ultimately accessible in real-time or on-demand. Locally, sensors (E.g., HOBO temperature and light sensors) will be installed, which store data on an SD-card, those will be retrieved in between maintenance trips where handheld sensors can be deployed as well.

Most in-situ sensors have been widely tested in the laboratory, as well as riverine or brackish habitats, however, few are established in actual offshore conditions. Additionally, there is currently no established approach for the design and requirements of the data collection and transfer system (view picture; Integrator & data buoy). The R&D center Kiel GmbH in cooperation with BBE Moldaenke aim to synthesize possible data buoy designs developed by different Integrators with the Bbe fluorometer´s requirements (see D6.2). The Bbe fluorometer collects fluorescence spectrum of the present phytoplankton within the water column, intending to discriminate dinoflagellates from diatom. While doing so it is aimed to gather data on temperature, Chl a, turbidity, and light (PAR sensor), however for some parameters, precise specifications are yet to be defined (see Fig. 1). The amount, the frequency and kind of data, as well as the overall need of energy demand will shape the final data buoy´s design. Power is aimed to be provided by

solar panels and batteries, however, the overall usage needs to be balanced between the system´s minimal/optimal requirements and the most efficient usage, as the space for solar panels is limited. For instance, 5 Wh is estimated for the Bbe fluorometer alone, with an additional 15 Wh for the raspberry pi. This energy demand depends on sampling intervals of the in-situ sensors themselves, as well as the response rate of the data collection and transfer system. If the configuration of the data buoy, the power supply as well as the transfer system are capable, the installation of on demand cameras will be aimed. Systems like LoRaWAN (Long Range Wide Area Network) can potentially cover 10 kilometers under ideal condition, which enables the connection of the data buoy with the existing research platforms as they are less than 200 meters away (e.g., FINO3). On the research platforms, a receiver is aimed to be installed for the transfer of the data to a land-based server via a satellite connection, similarly to the previous approach within the project "UNITED".
In addition to the on-demand/real-time monitoring system, sensors with local data storage such as provided by the company HOBO, are aimed to be deployed for parameters of special interest. For instance, the light distribution along the seaweed net. Those sensors run autonomously for several months and will be recovered manually.
As sensors as well as their respective data communication systems are of an especially vulnerable design, each setup will be tested at the nearshore site within the Kiel Bay in cooperation with the ULTFARMS partner KMF (Kieler Meeresfarm), before being deployed at the offshore location.
The proposed on-demand/real-time monitoring system, in combination with the data that are presented by HiSea, as well as the locally deployed sensors are aimed to improve our prediction capabilities of both, biological and physical parameters at the German pilot site.

3.2.3 Creating a net positive environmental impact

The German pilot is unique as it spans over two different locations. Both locations are situated far offshore and share certain conditions such as high energy far remote location. But there are also distinct differences between the two of them. The most pronounced is the difference in salinity, resulting in a difference of species.

Common to North Sea & Baltic Sea

Nature inclusive design can be implemented at both locations, acting as mirror or twins at different sites, testing the same setup. Included in a nature inclusive design can be anchoring and mooring systems spanning from the benthic to the pelagial habitat. Information of benthic designs such as artificial reef systems is plenty. However almost no publications could be found on for example rope design for a more nature inclusive approach. It is also noteworthy to approach in a minimal invasive manner to reduce the impact on the environment.
Also, the creation of structures in the ocean might act as an additional hiding and

breeding place for local fish and sea mammals. Enriching the environment with a habitat for nursing and retreat from fishing vessels that are not permitted in the vicinity.

Specific to the North Sea

The European oyster shall be cultivated in the North Sea pilot. This holds also a big potential for restoration efforts (see also the NORA Project, https://noraeurope.eu/) The oysters themselves have to be *Bonamia* and *Marteila* free and from the same water body to prevent introduction of potential invasive species. Hence not all cultivated oysters are suitable, and a proper provider has to be found. (see also next section)

Specific to the Baltic Sea

In close vicinity to the pilot stony substrates are located. Hence already a benthic fauna and flora might be present that can settle on the new provided substrate, using the exiting bottom substrate as stepping stone for distribution of the benthic communities.

However also negative impacts might arise from the implementation of the pilots in Baltic and North Sea. During installation heave equipment is transported on site by sips. This increases underwater sound pollution and might disturbed water dwelling animals. However, this disturbance is only for a short period of time and in comparison, to the ongoing ship traffic outside the testing area seems to be neglectable small. The same is true for light form ships and waste that might be blown overboard. Both are to be considered comparable minute to the existing effects of normal shipping routes. Also, special focus will be given to prevent any waste spill.

3.2.4 Biological & biosecurity solutions:

For both German pilots' locations, the appropriate selection of species, population and strain is paramount. Due to the current state of readiness among the German pilots, this procedure has the largest impact on suitability, disease, and biosecurity control. Ideally, all organisms deployed at the respective site should originate from the greater local surroundings or at least in a broader connection with the adjacent water body. This raises the chances of sustaining the most adapted organism while limiting concerns related to disease and biosecurity control.

The chosen seaweed, *Saccharina latissima* originated from strains sampled near the closest location towards the North Sea pilot, the furthest offshore island in the German EEZ called Helgoland (by Ute Kiep, AWI?). A stock of this strain has been prepared and grown out by the consortium partner, Hortimare, which supplies the North Sea pilot with sporophyte material for the grow out.

The installed mussel system cultivates the common European blue mussels (*M. edulis*). This genus possesses a larvae distribution strategy, enabling the spread across several kilometers. Therefore, no active introduction of larvae is needed.

The envisioned cultivation of the local European oyster (*O. edulis*) is planned to originate from nurseries and hatcheries within the closed range to the North Sea pilot site. However, the importance of disease control outweighs the selection of the most adapted population or strain, as the spread of the European oysters' most common pathogens, *Marteila refringens* and/or *Bonamia ostreae* must be prevented. Therefore, only pathogen-free hatcheries are suitable candidates for supply. Additionally, it will be aimed to deploy moderately juvenile oysters at around 3 centimeters of length to sustain higher survival rates.

For the Baltic Sea pilot, seaweed cultivation, namely, *Ulva* cultivation, has been chosen, as it is one seaweed that is well-performing in low salinity environment and naturally present along the coastline of the southern Baltic Sea.

The extensive gradient along the west-east axis of the Baltic Sea (high saline – brackish/freshwater) may be of significant influence on the maximum harvest rates of the chosen organism, as further outlined in D10.1.

Mussel cultivation (*M. edulis*, *O. edulis*), for instance, has been predicted to be economically unsustainable for the Baltic Sea pilot, as growth rates would be too low. Seaweed, however, is more tolerant in that regard; for instance, the genus *Ulva* can be found in all aquatic habitats from high saline to freshwater. To select the most ideal species and strain of *Ulva*, a sampling campaign has been launched in close collaboration with the consortium partner of Gothenburg, directed by Dr. Sophie Steinhagen. Samples originated from the closest coastlines next to the Baltic Sea offshore pilot, as well as from the FINO2 platform monopile structure itself.

3.2.5 Biofouling solutions

Biofouling still poses a significant hurdle in aquaculture as it increases the necessary maintenance and limits system applications as well as their lifetime.

At the North Sea pilot, substantial biofouling of low trophic species, has been observed in the past and outgoing projects. This poses a potential problem as:

- The system structure´s drag forces can increase.
- The target organism can be competed by other species.
- The automated monitoring setup, especially the sensors, is prone to being overgrown.

Nevertheless, at the current German pilot level, the second and third constraint appear most crucial.

As observed by this year's sampling campaign of the outgoing UNITED project, which happened in May 2023, the deployed seaweed *Saccharina latissima* and the

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blue mussels *Mytilus edulis*, seemed to grow out relatively unimpaired by biofouling. However, the density of brown algae was potentially reduced.

We aim to address this in close cooperation with Hortimare, by repeating this grow-out experiment but testing different seeding methodologies. Namely a change in sporophyte concentration which will be adjusted to a higher level of 8000 sporophytes per milliliter within the medium that is applied to the net and landman-ropes. Most important is the timing of the target organism of interest and their spatial distribution within the system design. Larvae of the blue mussel can disperse kilometres further and attach to all kinds of materials; therefore, they pose a potential competitor for space with the seaweed. Accordingly, a mismatch of the two species reproductive cycle has been planned, as it is aimed to start the cultivation of the juvenile stages of seaweed in autumn (September-November) and harvest by the time of the swarming period of the larvae of *M. edulis*, in spring (April-June), which adult stages from earlier years are harvested in autumn. This reduces the main dispersion of larvae onto the algae system. Additionally, the two target organisms are cultivated in a separate manner, on both the horizontal and vertical axis, as the mussel system is semi-submerged in a depth of 7-10 meters, and the algae net is floating on the surface. This aims to reduce the competition for space between the two species even further.

To address the overgrowth of structures and especially the sensor system, various antifouling agents have been tested in the previous and outgoing projects. As it is ultimately intended to establish an environmentally friendly aquaculture site that produces human-safe food, no common alloys with heavy metals such as zinc and copper sulfates have been investigated. From those test trials, one agent, showed particular effectiveness at the North Sea pilot. Although this may prove invaluable for the protection of biofouling-sensitive parts of the system or parts of the sensors, other methods must be further investigated that are tailored to the suitability for the actual sensor deployment. For instance, for the deployment of cameras, different types of electronic wipers have been tested, which served the initial purpose but had a lifespan which was unsuitable for the German pilots.

Among many other promising techniques, the use of ultraviolet light has been shown among the most effective antifouling strategies for sensor deployment. Within the monitoring strategy, ultra-violet light is aimed to be tested as a compartment within the phycoprobe of BBE Moldaenke.

3.2.5 Commercialization and market challenges

The enter the market a certain threshold of feasibility has to be reached as the Market prices for mussels and algae are in general low, scalability is of utmost importance to increase production while decreasing costs. A second approach is to enter into a niche market with prices much higher than on the normal market. e.g., production of goods and /or services for the medical or cosmetical market. Production of so-called pharmaceuticals and nutraceuticals form algae and mussels might be a valuable idea. In addition, an, eco-certified might help to

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ensure consumers trust and allow for a higher selling price. Another approach is the building of a brand adding value that is not linked to the direct market prices. Politics can make co usage of space a necessity thereby demanding the implementation of low trophic aquaculture as a prerequisite for erecting wind parks. The introduction of nutrient trading might help in making offshore aquaculture a success story. In the same way as CO_2 is already traded N and P might be the next trading position to increase an environmental benefit of low trophic aquaculture.

3.3 Dutch Pilot

The Borssele windfarm is located 55 km from shore in a high energy environment. The full-scale Submerged Mussel Farm (SMF) with high-density mussel lines poses several challenges, including new management procedures to avoid unnecessary delays, fractionated regulatory frameworks, and sectorial focuses on licensing systems including the preparation of licenses, structural planning, synergies, and energy use. The unique line deployment system to be implemented in this configuration is relatively denser than many existing configurations because the lines start close together near the platform.

The full-scale SMF will not be operational within the timeframe of the ULTFARMS project. In 2024, a pilot SMF farm with a smaller platform and only 5 lines of 200 m will be tested at the Borssele location.

3.3.1 Monitoring solutions

The aim of the SMF platform developed by OOS is to incorporate remote and automated monitoring systems including(1) GPS position of the pilot installation, (2) Load cell and GNSS receiver within the mussel line system (UGENT), (3) Surveillance cameras, (4) CTD, (5) Fluorometer. OOS envisions a real-time transmission of sensor data from the cultivation platform to shore.

The pilot aims to combine various monitoring technologies to assess mussel performance and ecological impact of mussel farming at commercially viable scales. Technical monitoring of water quality provides indicators for toxic phytoplankton that can impact the viability of production and end consumers of the produced mussels. Mussel size and mussel coverage on the lines will be estimated using images from sonar and ROV equipped with a GoPro, using 4K video images. Testing of sonar and ROV is carried out at a mussel farm in the Voordelta that was installed in 2023. Monitoring and automation are critical due to the densely positioned mussel lines and degradation of reef building components.

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3.3.2 Creating a positive environmental impact

Nature inclusive design with biodegradable structures

For nature inclusive design the goal is to apply biodegradable BESE structures underneath the mussel cultivation system in Borssele windfarm to enhance nature on the seabed possibly resulting in a reef (*Sabellaria spinulosa or Lanice conchilega,* blue mussel *Mytilus edulis*, or the native European oyster *Ostrea edulis*) that can enhance and support ecosystem functioning. A first test with BESE elements is envisioned for 2024. The research question is which reef restoration material can be placed underneath aquaculture sites and is attractive for marine life. The BESE will be attached to the platform with the mussel lines. The expectation is that after some time the product will fall on the seafloor and contribute to the formation of biogenic reefs there. A second option is to place the product on the seafloor from the start.

The pilot also aims to increase the share of renewable energy utilized in the full value chain of production of low trophic aquaculture such as direct on-site energy use and to enhance biodiversity through establishing an artificial reef below the mussel farm.

3.4 Belgian Pilot

The Belgian pilot site is located 46 km offshore in the Belwind wind park, operated by Parkwind. The multi-use pilot combines energy production, flat oyster restoration and multispecies low trophic aquaculture (LTA). Some of the major challenges of implementing oyster, seaweed and mussel aquaculture at the offshore Belwind site include logistical challenges related to the long sea routes and hostile physical conditions. Extreme weather is a major risk for loss of biomass and equipment. These difficult sea conditions together with the distance from shore and scarcity of available vessels make remote, automated monitoring systems highly desirable. From a biological perspective, disease risk, biosecurity, and biofouling are also challenges, particularly for oyster aquaculture.

3.4.1 Logistical solutions

Co-planning operations with other pilots

As a participant of the preceding H2020 UNITED project, the Belgian pilot of ULTFARMS can build on lessons learned from the previous years. One of the greatest challenges identified during the operational phase of the UNITED project was sea mission planning. To access the site, the Belgian pilot team must contract a third-party vessel. Due to the nature of working with the longline cultivation

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systems, there are only a limited number of vessels that have the appropriate machinery and configuration to operate in the Belgian pilot. These vessels require calm conditions to carry out work related to installations and harvesting. Therefore, operational limits have been set to waves <1 m, currents of <0.5 m s^{-1} which occur during tidal changes around neap tides as well, and as low wind conditions of preferably <5 m s^{-1} to ensure safe operation within the offshore wind farm. As these conditions can be rare, especially in autumn and winter months, it is difficult to align vessel availability and administrative procedures with a favorable weather window. To complicate the matter, vessel operators may cancel a sea mission if they are offered a longer and more lucrative contract elsewhere.

The Belgian pilot plans to address these challenges by collaborating with other North Sea pilots in sea mission planning. As the German North Sea pilot faces many of the same challenges in sea mission planning as the Belgian pilot, both may benefit from collaboration. If both pilots are able to synchronize activities related to installation, maintenance, harvesting, and decommissioning, it may be possible to contract one vessel for a longer period of time. The ability to offer vessel operators a longer contract may ensure fewer delays as it will be less likely that the vessel company will cancel the contract.

3.4.2 High energy environments and extreme weather

Design optimization utilizing a numerical tool

The metocean conditions within the offshore Belwind site are a challenge for designing resilient offshore aquaculture infrastructure. Various sets of guidelines (e.g., from Det Norske Veritas) have been developed and are available to assist in designing mooring systems suitable for the offshore conditions. The Maritime Technology Division (MTD) of UGent is in charge of performing design assessment and optimization utilizing computer simulations. Based on the Fortran version of the open-source software MoorDyn (Hall, 2015, Hall, 2017), MTD UGent adapted the code to model typical aquaculture mooring systems. Adaptations are done to make the software a stand-alone tool and to include wave and current induced load, seabed horizontal friction model, clump weight, 3-dof buoy and 6-dof rigid body (Pribadi et al., 2019; Pribadi et al., 2022). Using the Adapted-MoorDyn, numerical simulations will be performed to assess the offshore aquaculture mooring system design following the guidelines set by Norwegian Standards (NS9415) and Det Norske Veritas (DNV-OS-301, DNV-RP-C205). This includes simulating the aquaculture system subjected to the 50-year return period of waves and currents for the Belwind site, which translates into a single wave height of up to 11.8 m with a corresponding wave period of 9 s and a surface current of 1.53 m/s. The outputs of the simulations will be used to further refine the design of the aquaculture mooring systems in the Belgian pilot.

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Submersed and submersible longline systems

The high energy environment of the Belgian pilot site is a major challenge to develop reliable infrastructure for low trophic aquaculture. To protect the aquaculture infrastructure and cultivated biomass from the highest energy conditions at the surface, the longline backbone for bivalve cultivation has a submerged design. The longline rests at 10 m depth below the water's surface, with cultivation structures attached and hanging below. This keeps the structure and the biomass safe from the most intense wave energy.

A similar strategy will be used to protect the seaweed cultivation system from wave energy. However, unlike bivalves, seaweeds need light for photosynthesis. If the seaweed cultivation system was kept at the same depth as the bivalve longline, the seaweed yield would be significantly reduced. Therefore, the Belgian pilot partner company, Impact 9, is working to design and test a depth-adjustable or 'submersible' longline system for the cultivation of sugar kelp (*Saccharina latissima*). The submersible longline system will make it possible to keep the seaweed crop close to the surface for optimal light penetration during calm weather. The buoyancy control design will then facilitate the lowering of the longline system to a safer depth when weather conditions are unfavourable.

Impact 9 is currently in testing the submersible longline design in the nearshore environment at Bantry Marine Research Station. Further experiments are planned to take place at the Deltares facilities to test the structural integrity of the submersible longline materials and to subject the longline to certain wave conditions relevant for the Belwind offshore site. The experiments will also focus in obtaining the hydrodynamic coefficients for mussel droppers and seaweed nets to be implemented in the numerical model. This will be done by subjecting the mussel droppers and seaweed nets to a constant flow and later an oscillatory flow (i.e., waves). The outputs are the Morison coefficients (Morison, 1950) of the mussel droppers and seaweed nets with respect to their Reynolds number (for constant flow) and Keulegan-Carpenter number (for oscillatory flow).

3.4.3 Monitoring solutions

The Belwind offshore windfarm site is operated by Parkwind and has real-time video monitoring to track oceanic and weather conditions. The Belgian pilot can also use data from nearby weather buoys for additional environmental data. In addition, the ULTFARMS partner, Hidromod, has developed the HiSea platform which is an open-source, customizable tool for data integration and visualization. This will be an asset to the Belgian pilot moving forward, as the HiSea platform combines multiple data sources and offers services such as modelling, calculations, and customized alerts. Tasks 6.2 and 6.3 also serve to foster close collaborations between Hidromod and the pilots to further adapt the HiSea

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platform to the needs of the particular pilot sites. More detailed information on the HiSea platform can be found in D6.2.

3.4.4 Creating a net positive environmental impact

Restorative aquaculture

In efforts to work toward a net positive environmental impact, the Belgian pilot partners from Gent University and the Royal Belgian Institute of Natural Science (RBINS) have collaborated on a design for restorative aquaculture within an offshore windfarm. The aim of this design is to simultaneously support restoration of the native European flat oyster (*Ostrea edulis*) and promote circularity of larval supply for flat oyster cultivation.

The flat oyster was once a plentiful resource in the Belgian part of the North Sea, until overfishing, disease, and habitat destruction led to its functional extinction in Belgian waters. The natural recovery of O. edulis in these areas is hindered by a lack of hard substrate, particularly oyster shells, which had been removed by generations of bottom trawling. There is also the issue of larval scarcity. Without a resident population of *O. edulis* in the Belgian North Sea the supply of larvae is a limiting factor for natural settlement.

The construction of offshore wind farms presents an interesting opportunity for flat oyster restoration because they provide hard substrate for settlement (turbines and scour protection) as well as protection from bottom trawling. However, the limiting factor in this situation is the supply of *O. edulis* larvae. The aim of the restorative aquaculture design is to address this limitation.

Normally, oysters cultivated for consumption are harvested after 2 years, before they are sexually mature. Therefore, flat oyster aquaculture does not normally serve as a source of larvae. In the Belgian pilot of ULTFARMS we plan to test the feasibility of introducing "broodstock" oysters, capable of reproducing, on restoration tables on the seafloor. The long-term goal of this design is twofold: first the provision of *O. edulis* larvae for settlement onto scour material and natural rocks also introduced with restoration tables, supporting restoration of a native habitat engineer. Second, provision of larvae for aquaculture purposes. In the second case, we will test whether larvae from broodstock oysters will settle on plates which can be harvested to supply spat for further cultivation.

The detailed plan is described below for the first two years of the project.

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Year 1

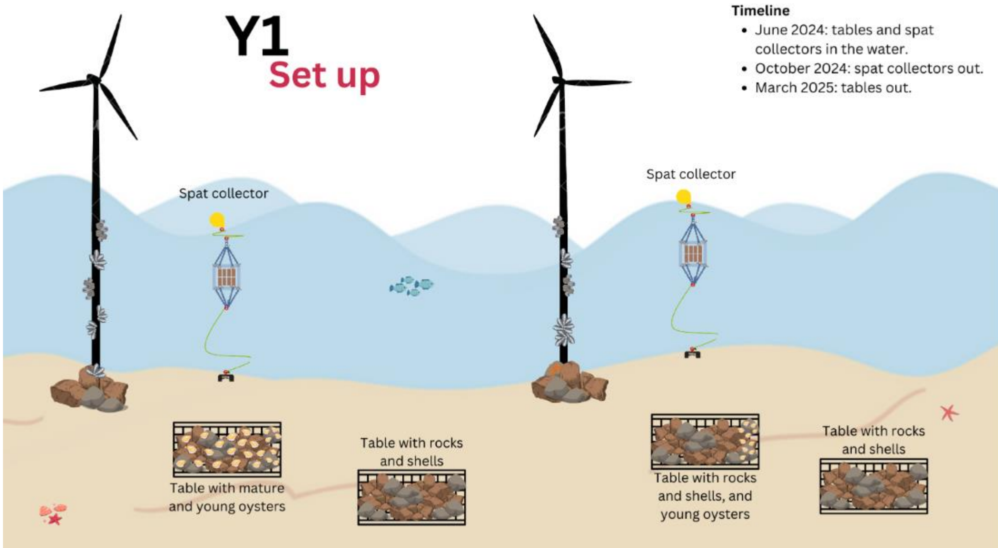

Figure 2. Belgian Pilot Year 1.

In June 2024, the artificial hard substrate garden of RBINS will be deployed (Fig. 2). Four settlement tables will be installed on the sandy bottom between the turbines, one will hold mature and young oysters, one will hold clean rocks and shells and young oysters, and the two remaining ones will hold solely clean rocks and shells. In addition, two moorings, the spat collectors, will be installed at about 10 m under the sea surface. Both the tables and the moorings have successfully been used before for similar purposes. The tables will contain stone mixtures mimicking optimized and existing scour protection layers, with oysters on some of them. The moorings will support settlement plates composed of clay, with different surfaces. Other types of plates may be experimented with (e.g. clay mixed with shell debris), either to assess what is most successful, or to mimic what is most likely to be used in a commercial setting, or to offer better resistance to the high energy environment in which they will have to remain for a few months.

The mature oysters will be specifically bought ready to spawn. June was chosen because it matches the oysters' spawning period. The settlement plates and tables will be deployed at the same time, to maximize the chances of oysters spat settling on the still relatively clean surfaces.

In October 2024, the two moorings will be recovered. The settlement plates will be analyzed for presence of oysters spat. If they are found settled on the plates, it can be assumed that low-trophic aquaculture might enhance its own productivity by having reproduction and nursery at sea.

In March 2025, the tables will be recovered, and the rocks analyzed for presence of oysters spat. If they are found on the rocks, it can be assumed that adding mature oysters on the seafloor may support an active restoration strategy.

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Year 2

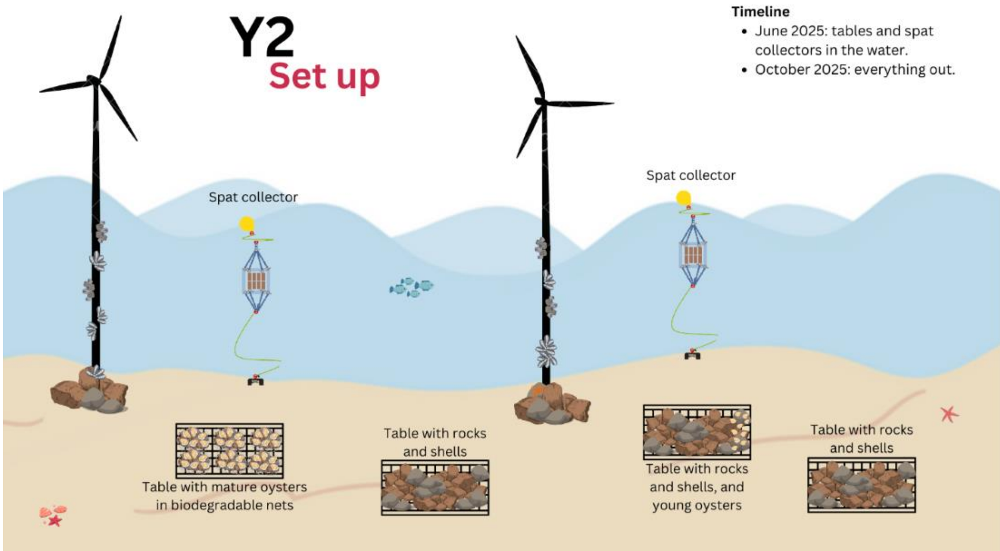

Figure 3. Belgian Pilot Year 2.

During the second year, the first-year scheme will be replicated, with some modifications (Fig. 3). On the parent settlement table, a biodegradable structure holding rocks, oysters and shells together will be installed on the table, to test its performance. While the structure must be biodegradable and harmless for the marine environment, it should stay whole as long as possible so that the artificial reef consolidates on its own and the reintroduced oysters have the best survival chance. On the spat collectors, the type of plates that had the best success the previous year will be re-used and optimized if necessary.

In June 2025, the four tables, one parent and three receiving, and the two spat collectors will be deployed again. Some of the tables will also hold young oysters, again to examine the feasibility of bottom oyster cultivation in the area, and to assess if they attract spat.

In Octobre 2025, everything will be decommissioned and analyzed. The results will inform about:

- The success of spat settlement from reintroduced oysters in an area where no bottom disturbing activities occur.
- The possibility for LTA practitioners to produce their own spat by engaging in active restoration of European flat oysters.
- The survival of reintroduced young and mature oysters at sea.
- The effectiveness of clay plates for oysters spat settlement.

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- The effectiveness of biodegradable nets/socks/etc. for reintroducing artificial oyster reefs.

Gear

The artificial hard substrate garden (AHSG) of EMBRC-BE will be used to achieve the previously described plan (Fig 4; Fig. 5). These structures were used safely and efficiently for other projects by RBINS.

Both tables and moorings will be adapted to suit the specific purpose of this project.

Figure 4. Settlement tables belonging to EMBRC-BE that will be used for restoration purposes in the Belgian pilot of ULTFARMS.

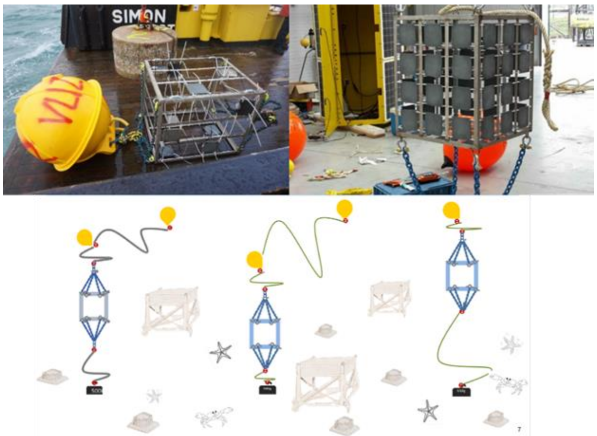

Figure 5. Moorings belonging to EMBRC-BE that will be used for spat collection in the Belgian pilot of ULTFARMS.

3.4.5 Biosecurity

Sourcing certified Bonamia and Marteilia free oysters

One of the major drivers of flat oyster population decline in Europe has been the prevalence of parasitic disease. The most common and destructive of these parasites are *Bonamia ostreae*, *Bonamia exitiosa*, and *Marteilia refringens*. Biosecurity measures are legally mandated in Belgium to avoid the further spread of these parasites. Any import of flat oyster adults, spat, or larvae, must go through

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a certification process. In the Belgian pilot of UNITED, for example, *O. edulis* spat was sourced from a certified *Bonamia/Marteilia* free hatchery in the United Kingdom. The UGent Laboratory of Aquaculture and ARC has also sourced *Bonamia/Marteilia* free spat from Ostrea Aquaculture in Sweden for other projects.

The process of *Bonamia/Marteilia* free hatchery certification involves PCR testing of 5% of the population over the course of a year with at least two sampling times. At a minimum, 300 individuals must be tested in total which may represent a higher proportion of the population if production is low. Protocols stipulate that if any PCR tests yield a positive result for the presence of *Bonamia* or *Marteilia* parasites, further investigation by histology is required. Depending on local regulations, this work can be carried out by a state associated veterinarian who can issue a health certificate. To ensure the lowest possible biosecurity risk, the Belgian pilot will only source native flat oysters from certified *Bonamia/Marteilia* free hatcheries which have followed this protocol (World Organization for Animal Health, 2022).

3.4.6 Biofouling

Physical anti-fouling frames

The Belgian pilot aims to address biofouling on oyster cultivation gear by designing physical antifouling systems. For example, prototypes of antifouling "frames" have been designed and constructed to fit over the outside of lantern baskets. The frames are designed to move in a spinning motion with the current and scrape fouling organisms off the surface of the basket as they spin (Fig. 6).

To test the effectiveness of this method, lantern baskets with and without antifouling frames were sent to Bantry Marine Research Station to be deployed on nearshore longline systems. However, the structural integrity of the frames was not sufficient to withstand storm conditions in the area. Therefore, further development of the design will be necessary to develop an antifouling system suitable for the offshore conditions of the Belgian Pilot.

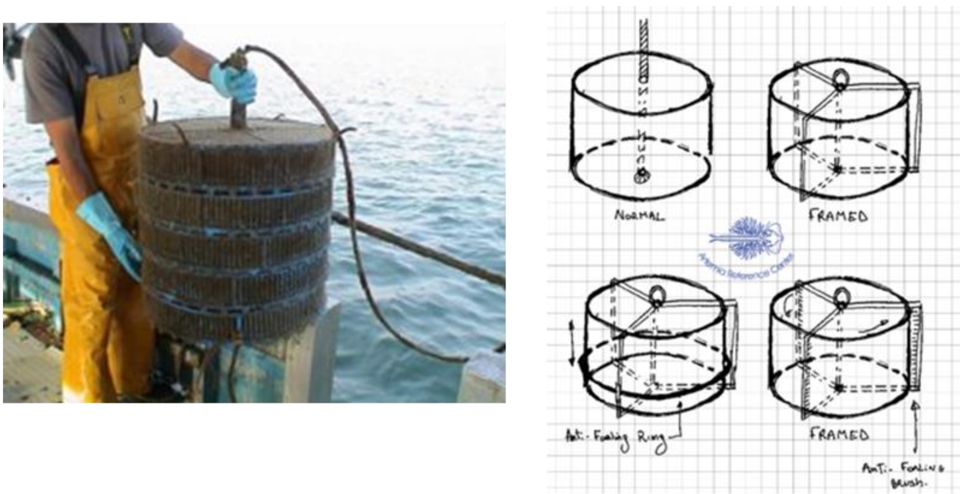

Figure 6. Lantern baskets for oyster cultivation and design for antifouling frames

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4. Commonalities

Although local conditions lead to significant differences between the 6 ULTFARMS pilots, there are also significant areas of overlap and opportunities for collaboration. Logistical challenges related to sea mission planning, for example, are being addressed through inter-pilot and pilot-industry collaborations. This approach will help pilot projects to consolidate costs and ensure more reliable vessel contracts.

All pilot sites are susceptible to foul weather and rough oceanic conditions that can complicate offshore activities related to installation, maintenance, and harvesting. These conditions, along with the high cost of sea missions, make remote monitoring systems an important feature of offshore multi-use projects. Many of the ULTFARMS pilots are using in situ sensors that fit the particular needs of their infrastructure, cultivated species, and local conditions. Moving forward, some pilots aim to establish a communication setup that allows the sending of information via satellite for real-time monitoring capabilities.

One monitoring and decision-making strategy that is available to all pilots is the HiSea Platform which is described in detail in the ULTFARMS Deliverable 6.2. This tool combines data sources such as satellite imagery, weather forecasts, and oceanographic data on one platform. The modular design allows new data sources to be added over time. This is particularly useful for the pilots going forward, as they can collaborate with ULTFARMS partner, Hidromod, in Tasks 6.2 and 6.3 to further adapt the HiSea platform to their needs. The platform can be used to support planning and decision-making processes for offshore fieldwork, make calculations, and process data into reports.

Mitigation of environmental impacts and efforts to create positive impacts through restoration and NID are also shared themes for multiple pilots. Thus far, NID designs differ between pilots. The Dutch pilot aims to use biodegradable materials to support native flat oyster reef restoration, while the Belgian pilot has developed a regenerative aquaculture approach. However, at this early stage in the project, there is still time and a general intention to create more overlap in the restoration and NID measures between pilots.

5. Conclusions

This deliverable reported on task 10.2 of ULTFARMS "Innovations' overcoming of challenges, risks, and barriers." The objective of this task was to catalogue the site-specific solutions developed by each pilot in order to address the technical challenges posed by the multi-use approach of integrating LTA, NID, and nature restoration into offshore wind farms. Where applicable, plans for laboratory and nearshore testing were also detailed. The information aggregated in this document will contribute to Task 10.5, "An integrated roadmap for upscaling."

At the time of submission for this deliverable, ULTFARMS is at its 1-year milestone. It is worth noting that in this early stage of the project, there are still many lessons to be learned ahead. It is likely that pilot designs will be revised when data from experimental facility trials and nearshore testing are taken into account. Moving forward, communication between pilots will be essential for maintaining a collaborative co-design approach. Sharing information on technical successes as well as failures will be critical for contributing to an effective final roadmap for upscaling multi-use scenarios integrating LTA, offshore energy production, and nature conservation.

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