

Marine Biodiversity Restoration

In the Atlantic and Arctic



Pioneering Nature-Based Solutions and Sustainable
Blue Economies for Ocean Restoration by 2030

WP 1: Methodology and Preparation

DELIVERABLE 1.3

High level Project Plan, budget and techno- economics

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Executive Summary

Deliverable 1.3 of the PHAROS project provides a comprehensive high-level project plan, budget allocation, and techno-economic analysis for the four pilot demonstrators, each designed to contribute to marine ecosystem restoration and sustainable aquaculture development. This deliverable builds upon the structured framework outlined in Deliverable 1.1, ensuring the feasibility and strategic progression of implementation efforts while aligning with key ecological and economic objectives.

The four demonstrators encompass a diverse range of innovative marine solutions:

1. **Gran Canaria - Integrated Multi-Trophic Aquaculture (IMTA) and Multiple-Use of Space:** This site combines finfish aquaculture, marine restoration activities, and additional aquaculture productions, aspiring to develop a fully integrated multi-trophic system that optimizes resource use while mitigating environmental impact.
2. **Gran Canaria - Artificial Reefs and Nutrient Remediation for Ecosystem Restoration:** Focused on artificial reef deployment, this demonstrator aims to enhance biodiversity, restore degraded habitats, and remediate excess nutrient loads to improve ecosystem function.
3. **Ireland - Scaled Macroalgae Cultivation:** A network of multiple seaweed aquaculture sites, leveraging coastal environments for macroalgae production to support carbon sequestration, nutrient uptake, and sustainable biomass generation for commercial and ecological benefits.
4. **Iceland - eDNA Monitoring and Invasive Species Management:** This demonstrator pioneers environmental DNA (eDNA) monitoring for early detection and alert systems targeting invasive finfish species, providing a proactive approach to biodiversity protection and fisheries management.

The deliverable outlines critical aspects of each demonstrator, including operational design, site deployment schematization, monitoring strategies, and long-term planning on a high level. A key focus in this work is placed on benchmarking through Key Performance Indicators and relating these to core processes identified of interest. These will again be further enhanced and correlated with planned monitoring and modelling activities in order to measure project success, identify gaps, and refine implementation strategies. By integrating various perspectives, this deliverable sets the foundation for the forthcoming Deliverable 1.4, which will provide detailed site-specific operational and financial blueprints for each demonstrator as well as site layout, operation schedules, and other critical elements to be considered. These detailed plans will be continually updated in order to provide a reflection of the completed activities and act as an easy reference material to document demonstrator activities, successes, and hurdles. This structured approach ensures that PHAROS continues to advance its mission of fostering sustainable ocean resource utilization and marine ecosystem restoration through innovative and scalable solutions.

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Abbreviations and Acronyms

AA	Full Name
AA	Atlantic and Arctic
ALDFG	Abandoned, Lost, and Discarded Fishing Gear
AOM	Atlantic and Outermost Islands
AR	Associated Regions
BMRS	Bantry Marine Research Station
DTO	Digital Twin of the Ocean
DPSIR	Drivers, Pressures, State, Impact, Response
E-DNA	Environmental DNA
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data Network
ESP	Environmental Sample Processor
EU	European Union
H&S	Health & Safety
H2020	Horizon 2020
ICZM	Integrated Coastal Zone Management
IMTA	Integrated Multi-Trophic Aquaculture
ISP	Internal Positive Control
KPI	Key Performance Indicator
LTA	Low Trophic Aquaculture
MBARI	Monterey Bay Aquarium Research Institute
MPA	Marine Protected Area
NBS	Nature-Based Solutions
pCO ₂	Partial Pressure of Carbon Dioxide
PLOCAN	Oceanic Platform of the Canary Islands
qPCR	Quantitative Polymerase Chain Reaction
RPO	Research Performing Organizations
SEA	Strategic Environmental Assessment
SER	Smart Enhanced Reef
SME	Small and Medium Enterprise
TRL	Technology Readiness Level
WP	Work Package

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1 Introduction

1.1 Context and Objectives

The EU's Ocean Mission objectives aim to be achieved through quantified and measurable targets, focusing on three key areas:

1. Protection and restoration of marine ecosystems and biodiversity (Mission Objective 1);
2. Prevention and elimination of pollution of our ocean (Mission Objective 2);
3. Creating a sustainable, carbon-neutral, and circular blue economy (Mission Objective 3) by 2030.

The EU Mission Implementation Plan consists of two near-term phases: the first 'development and piloting' phase by 2025, and the second 'deployment and upscaling' phase from 2026-2030.

The overall aim of PHAROS (<https://pharosproject.eu/>) is to become one of the Lighthouse hubs for the EU Atlantic and Outermost islands, as well as the Arctic. It will support the development and deployment of transformative, innovative solutions to ensure rapid, systematic progress towards achieving the Mission Ocean objectives. PHAROS is envisioned as a critical stepping stone, bridging the gap between Phases 1 and 2 (2026-2030).

PHAROS will feature:

- New and innovative Nature-based Solutions (NBS): Four demonstration projects in the Atlantic and Arctic (AA) basin will be developed and prepared for subsequent replication, contributing to Phase 1.
- Advancement of technologies and solutions: It will extend the Technology Readiness Level (TRL) of leading past H2020 projects and ongoing Mission projects and roll them out across the AA basin, effectively bridging into Phase 2.

PHAROS aims to achieve six objectives within the duration of the project:

4. To engage in citizen and other stakeholder engagement, co-creation and citizen science for community-led biodiversity solutions.
5. To demo the most relevant innovative NBS for ecosystem restoration in four Atlantic and Arctic demo sites to boost coastal resilience through restored and resilient coastal ecosystems.
6. To extend to large areas of the EU Atlantic and Outermost islands and the Arctic, the BLUE4ALL project Marine Protected Area (MPA) Blueprint platform and network for successful co-management of MPA issues, including identification, categorisation, adaptive management practices, governance and corridor integration.
7. To fundamentally change the perception of roles by implementing fisher and citizen Guardians and Cleaners of the sea programs to address ocean pollution.
8. To assist local entrepreneurs and SMEs in the co-creation of multiple demo-based NBS business plans, host investor brokerage events, and co-creation of replication roadmaps for Associated Regions (AR) with systematic biodiversity and ecosystem restoration solutions for the AA basin and beyond, based on project results with innovative business models and sophisticated modelling.
9. To extend the Network of Blue Schools to the AA basin to improve ocean literacy across school communities and support citizen science.

1.2 Scope of the Report

WP1 works with the four demonstrator pilots within the PHAROS project to develop detailed planning instruments for the development and deployment of the demonstrators. These activities align with the overall demonstrator methodology and framework for analysis, which is discussed in detail and outlined in D1.1 of the project. Within D1.3, higher level project plans are developed for each of the four demonstrators, including techno-economic indicators and potentialities. The result of D1.3 will then be used as the basis of D1.4 – Demo Plans, in which detailed information on the specifics of each demonstrator is further elaborated.

1.3 Demonstrators

The PHAROS demos aim to validate innovative NBS across four sites in the AA basin, addressing specific ecological challenges while contributing to ecosystem restoration and biodiversity enhancement. These demos test and refine new NBS approaches, laying the groundwork for replication and scalability in diverse ecosystems. A significant focus is placed on the AOM islands, which host 80% of Europe's biodiversity and are situated within several global biodiversity hotspots, yet are among the most ecologically vulnerable territories.

1.3.1 Demo 1 - Integrated Multi-Trophic Aquaculture and Multiple Use of Space – Gran Canaria

Demo 1 integrates NBS with aquaculture in Gran Canaria, targeting a site nearing oligotrophic desert status and is severely disturbed by anthropogenic stressors. PLOCAN (<https://plocan.eu/>) will deploy a storm-proof, purpose-built infrastructure for long-term deployment of aquaculture activities that can enable Integrated Multi-Trophic Aquaculture (IMTA) as well as restorative production. This infrastructure includes zonalization and buoys to support the underwater framework. To withstand storms, the underwater mooring framework will use ropes, bow shackles, and concrete mooring blocks, along with additional components such as chains and anchors. A standard fish cage will be integrated, equipped with an autonomous feeding system and a floating system of nets with different mesh sizes. The installed mooring framework will be designed not only to support the fish production cage but also to accommodate the cultivation of other species across various trophic levels.

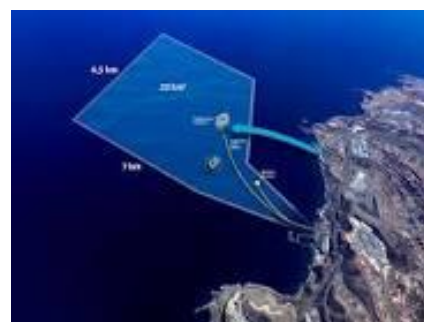


FIGURE 1: DEMONSTRATOR TEST SITE LOCATED OFF THE COAST OF THE PLOCAN OFFICES AND WORKING SITE

Macroalgae production

The macroalgae growth system, a key component of Demo 1, will be integrated into the IMTA system deployed at this site. Real-time monitoring and on-site data collection will support the assessment of ecosystem health, the sustainability of operations, and the effectiveness of macroalgae in carbon cycling. Key performance indicators will include the rate of CO₂ sequestration within macroalgal biomass, nutrient uptake efficiency, and biodiversity shifts within the system. The facility will feature both horizontally and vertically oriented macroalgae production systems, strategically designed to optimize biomass yield while preserving ecosystem balance. These systems will function within a polyculture framework, possibly incorporating multiple macroalgal species to enhance resilience, improve nutrient absorption, and maximize productivity. Positioned to capture emissions from the fish farm at various depths, they will absorb nitrogen, phosphorus, and organic waste from aquatic animals, redistributing these nutrients throughout the water column. By harnessing the natural filtration capabilities of macroalgae, the system will help prevent eutrophication, improve water quality, and enhance the overall health of surrounding marine habitats. The results from this application are to be used as critical supporting information into the survivability and extraction potential of the species utilised in the local environment given the unique water quality and hydrodynamic processes occurring in the Canary Islands.

This trial will generate critical insights into nutrient dispersion patterns in the environment, enabling the optimization of spatial configurations—such as distance and depth of macroalgae deployment—to maximize productivity while minimizing waste accumulation. Additionally, the ability of macroalgae to immobilize and store carbon in biomass and sediment will be analysed to assess its long-term role in carbon cycling. Visual census assessments conducted by scuba divers or camera systems strategically placed to monitor the macroalgae. This monitoring of the Smart Enhanced Reef® will monitor biodiversity changes, tracking the recruitment of fish and invertebrate species attracted to the macroalgal structures. These assessments will help evaluate habitat restoration potential by documenting shifts in species composition and ecosystem interactions. By integrating macroalgae

systems with enhanced ecological monitoring, this initiative aims to establish a scalable, nature inclusive solution for ocean-based operations seeking to mitigate damage from higher trophic level aquaculture and determine the compatibility with low trophic aquaculture as well. Information on the nutrient recycling, and habitat enhancement impacts will be critical for meaningful assessment and analysis. It underscores the vital role of marine vegetation in climate change mitigation and ecosystem restoration.

Fin-Fish Aquaculture

The IMTA system will incorporate fin-fish aquaculture as a central component, utilizing commercially available, off-the-shelf standard cages for fish production. These cages will be strategically positioned at the core of the macroalgae production area, ensuring efficient nutrient cycling within the system. The fish farm will generate organic waste, including nitrogen and phosphorus, which will serve as essential nutrients for macroalgae growth. In turn, the macroalgae will contribute to improved water quality by absorbing these nutrients, reducing excess waste accumulation, and mitigating potential environmental impacts. The deployment and management of these fin-fish aquaculture operations will be led by an experienced team with a proven track record in commercially operating such installations. Their expertise ensures that all activities adhere to industry standards, regulatory compliance, and best practices for sustainable fish farming. By leveraging existing commercial infrastructure and operational knowledge, this initiative will facilitate seamless integration with the broader IMTA system while maintaining high levels of efficiency, biosecurity, and fish welfare.

Utilizing standard fish farming technologies within an IMTA framework also enhances the ease of transferability for successful solutions. If the integration of macroalgae and other activities proves beneficial—either through improved environmental performance, enhanced productivity, or economic viability—these approaches can be readily adopted across other commercial aquaculture sites. Furthermore, if policy and legislative frameworks evolve to encourage or mandate multi-trophic approaches for sustainable seafood production, the tested and validated IMTA model will be well-positioned for large-scale implementation. By combining established fin-fish aquaculture practices with innovative IMTA strategies, this project aims to demonstrate a scalable and commercially viable approach to marine farming. The collaboration with industry leaders ensures that the solutions developed are practical, replicable, and aligned with both business and regulatory expectations, paving the way for broader adoption of sustainable aquaculture models in the future.

Abalone and Circular Processes

The integration of abalone grow-out structures alongside macroalgae production systems will create a synergistic, circular aquaculture approach within the IMTA framework. The grow-out structures will be strategically placed in alternating patterns with the macroalgae cultivation lines, allowing the abalone to benefit from the naturally occurring habitat while feeding on the macroalgae grown on-site. This setup will facilitate a closed-loop system where carbon and nutrient cycling, as well as sustainable seafood production, are interconnected. During the experimental production phase, the trial will assess the feasibility of cultivating high-value abalone within a sea-based IMTA system. Key performance indicators will include abalone growth rates, health metrics, and overall yield, as well as the efficiency of macroalgae utilization as a sustainable feed source. Additionally, the system will evaluate the broader ecological benefits, such as enhanced biodiversity and habitat complexity, which may further support marine life recruitment and ecosystem stability.

By integrating abalone production with macroalgae cultivation, this initiative aims to maximize resource efficiency and minimize waste through circular processes. The macroalgae will serve not only as a biological filter for nutrient absorption but also as a renewable feedstock for the abalone, reducing dependency on external feed inputs. This approach aligns with sustainable aquaculture principles by promoting nutrient recapture, reducing environmental impact, and enhancing farm resilience against fluctuating resource availability. Furthermore, the trial will explore the potential for economic diversification within the IMTA system, demonstrating how macroalgae production can support premium seafood cultivation while simultaneously contributing to carbon and nutrient cycling and ecosystem restoration. The outcomes of this study will provide valuable insights into the viability of integrated abalone farming as a scalable, nature-based solution for sustainable aquaculture and marine resource management.

Sea Cucumber Bioremediation

Beneath the fish production units, specialized cages will house sea cucumbers of the local *Holothuria sanctori* and *Holothuria arguinensis* species, playing a crucial role in bioremediation by utilizing particulate organic matter released during fish production. By naturally processing organic waste, the sea cucumbers contribute to carbon and nutrient cycling within the IMTA system, improving sediment quality and promoting a more balanced marine environment. Researchers will assess key performance indicators, including sediment organic matter content, sea cucumber growth rates, survival, and the nutritional quality of harvested individuals, to evaluate their effectiveness in reducing waste accumulation and enhancing ecosystem health. As part of the broader ecological integration, bespoke Smart Enhanced Reefs® (SER®) will be deployed at the test site to assess their impact on passive reef colonization. Positioned strategically to account for local wind and current patterns, reefs upstream will serve as control sites, while those downstream will evaluate the potential benefits of co-location with IMTA activities. Their placement, layout, and depth will be carefully determined based on nutrient dispersion patterns, hydrodynamics, bionomic factors, and engineering considerations. By monitoring key species, researchers will assess biodiversity shifts, habitat complexity improvements, and the broader ecological impact of integrating artificial reef structures within a multi-trophic aquaculture system.

Comprehensive monitoring and data collection will be conducted to track water quality, nutrient fluxes, species interactions, and overall ecosystem responses. These insights will inform best practices for optimizing the sustainable integration of finfish, macroalgae, sea cucumbers, and reef structures. By combining bioremediation with habitat enhancement, this initiative aims to demonstrate a scalable and ecologically sound approach to multi-trophic aquaculture, reinforcing both environmental resilience and commercial viability.

1.3.2 Demo 2 – Marine Forest and Artificial Reef for Biodiversity Restoration – Gran Canaria

Demo 2 is located in the near-oligotrophic Gran Canaria research area and aims to demonstrate the benefits of combining active reef recolonization and polyculture macroalgae arrangements for biodiversity restoration. The anticipated benefits include providing shelter, food, and breeding grounds for fish, crustaceans, and other marine life through the deployed seaweed structures.



FIGURE 2: MACROALGAE FOREST

Environmental Benefits

The nutrient absorption capacity of macroalgae plays a vital role in enhancing water quality by lowering excess nutrient concentrations in the water column, thereby reducing the risk of harmful algal blooms. The vertical rope systems used for seaweed cultivation, along with Smart Enhanced Reefs® (SER®), will contribute to the formation of a dynamic marine ecosystem, providing essential habitats that support biodiversity. These structures will offer shelter, nursery areas, and feeding grounds for both benthic and pelagic species, fostering ecological resilience while also contributing to coastal stabilization by mitigating erosion from waves and currents. Additionally, the growth of macroalgae supports carbon and nutrient cycling, helping to regulate ocean chemistry and buffer against the impacts of ocean acidification and climate change.

Phase 1: Site Assessment and Species Selection

The initial phase focuses on conducting a comprehensive assessment of the environmental, bionomic, and physical characteristics of the demonstration site to inform the design of Smart Enhanced Reefs®

(SER®) and the selection of suitable macroalgae and invertebrate species. This includes identifying key species such as sponges, ascidians, and polychaetes for incorporation into the marine animal forest. The biological cycles, growth patterns, and ecological roles of these organisms will guide the ecological engineering approach, ensuring that artificial reefs and seaweed forest assemblages are designed to support biodiversity and ecosystem functionality. Polyculture macroalgae species will be attached to ropes deployed at varying depths and locations, with protective netting used to maintain biomass within the controlled study area. This strategic placement will optimize nutrient uptake, habitat formation, and ecosystem interactions, creating a foundation for long-term restoration efforts.

Phase 2: SER® Fabrication and Material Testing

The second phase focuses on the design and fabrication of SER® structures, incorporating multiple factors—including bionomic, physical, and logistical considerations—to tailor their morphology to the specific requirements of Demo 2 and the local environmental conditions. The final design will determine the most suitable fabrication methods, such as 3D printing, casting, or other advanced manufacturing techniques. Material selection will prioritize durability, ecological compatibility, and structural integrity to ensure long-term performance in the marine environment. The fabrication process will be carried out at a central industrial facility, allowing for controlled testing and refinement. Insights gathered from the site assessment phase will guide the final selection of macroalgae species, ensuring optimal integration within the IMTA system and enhancing ecosystem resilience.

Phase 3: Installation and Transplantation

In the final phase, the SER® structures and macroalgae cultivation systems will be deployed at the demonstration site, integrating them into the surrounding ecosystem. This will include the transplantation of marine animal forest species with diverse functional traits and varying tolerances to environmental stressors. The goal is to evaluate their capacity to establish, thrive, and contribute to ecosystem restoration while assessing their interactions with the artificial reefs and macroalgae structures. This phase will provide valuable data on species recruitment, biodiversity enhancement, and overall system stability, offering insights into the long-term viability and scalability of integrated multi-trophic aquaculture and marine habitat restoration efforts.

1.3.3 Demo 3 –Macroalgae Combination in Coastal Setting – Ireland



Figure 3: Macroalgae cultivation sources from BMRS website (<https://www.bmrs.ie/>)

Demo 3 combines Integrated Multi-Trophic Aquaculture (IMTA) and multiple uses of space to evaluate the benefits of integrating polyculture macroalgae with a large salmon farm. The trial will involve two sites:

1. **Bantry Bay:** High-biomass macroalgae species, *Alaria esculenta* (badderlocks), *Saccharina latissima* (sugar kelp), and *Laminaria digitata* (oarweed), will be co-located with a salmon farm.
2. **Roaringwater Bay:** A control site will be established for comparison.
3. **Doneen Bay:** The second control site will be for comparison; this bay is similar to Bantry Bay compared to Roaringwater Bay.

PHAROS will evaluate the biodiversity impact on the Bantry Bay farm located downstream of a salmon farm against the control site.

Environmental Benefits

Demo 3 will investigate the ecological role of macroalgae in enhancing marine biodiversity by establishing new habitats and nursery areas for a wide range of marine species. Macroalgae structures will provide essential refuges for juvenile fish, crustaceans, molluscs, and other invertebrates, offering protection from predation and increasing local species abundance. Additionally, the study will assess how macroalgae cultivation improves water quality by absorbing excess nutrients such as nitrogen and phosphorus from the water column, thereby mitigating nutrient accumulation and reducing the likelihood of eutrophication. By preventing harmful algal blooms that can disrupt marine ecosystems, macroalgae contribute to a healthier and more stable aquatic environment. Beyond nutrient absorption, macroalgae cultivation plays a key role in supporting phytoplankton diversity by balancing nutrient availability, enhancing primary production, and stabilizing the food web. Through their natural filtration processes, macroalgae contribute to oxygenation, improve water clarity, and create conditions that foster broader marine ecosystem resilience. This trial will provide insights into how large-scale macroalgae farming can support conservation efforts while promoting an ecologically sound approach to aquaculture.

Polyculture Systems and Bioremediation

The trial will explore the advantages of cultivating multiple macroalgae species in a polyculture system, optimizing nutrient uptake and minimizing the risks associated with monoculture, such as disease susceptibility and resource competition. Unlike monoculture systems, which can lead to nutrient depletion in specific areas, polyculture fosters resilience by allowing different macroalgae species to absorb nutrients at varying rates, ensuring a more even distribution of resources throughout the system. This balanced approach enhances productivity while improving the overall stability of the ecosystem. In addition to nutrient absorption, macroalgae farming serves as a natural bioremediation tool, actively removing excess organic matter and improving water quality. The complex three-dimensional structure created by macroalgae provides essential microhabitats that support various marine organisms at different trophic levels. These habitats offer feeding grounds, shelter, and spawning sites for commercially and ecologically important species, including juvenile fish, crustaceans, and filter-feeding organisms such as sponges and ascidians. By facilitating the presence of these species, the system enhances natural waste processing and nutrient cycling, further reinforcing the ecological benefits of integrated aquaculture. Macroalgae contribute to sediment stabilization and reduce water turbidity, improving light penetration and supporting the growth of seagrass beds and other benthic habitats. By fostering biodiversity and reinforcing ecosystem stability, macroalgae cultivation aligns with sustainable aquaculture practices while enhancing the resilience of the broader marine environment.

Monitoring and Data Collection

A monitoring framework will be implemented to assess the ecological impact of macroalgae cultivation on biodiversity, water quality, and ecosystem stability. Phytoplankton bioassays will be conducted at multiple locations within the farm site to evaluate changes in nutrient availability and trophic conditions. These assessments will provide valuable data on shifts in primary production and the overall health of the surrounding waters. To track biodiversity and biomass accumulation, monthly monitoring will involve sampling macroalgae growth at different locations and depths, ensuring accurate data on productivity, nutrient uptake, and physiological health. All detected marine organisms within the cultivation areas will be identified and quantified to assess species composition, abundance, and interactions within the system. The presence of juvenile fish and invertebrates using the macroalgae for shelter and foraging will be closely monitored to evaluate the habitat function of the system.

Water samples will be analysed periodically to measure nutrient removal efficiency, with particular focus on nitrogen and phosphorus uptake by macroalgae. Additionally, key water quality indicators such as dissolved oxygen levels and pH will be assessed to determine improvements in overall environmental conditions. To ensure a detailed understanding of macroalgae resilience, individual plants will be examined for growth performance, tissue integrity, and responses to environmental stressors, including temperature fluctuations and salinity changes. By integrating these monitoring efforts, the study will generate essential data on the long-term ecological benefits of macroalgae farming, demonstrating its potential as a scalable and sustainable approach to marine resource management. These findings will inform best practices for aquaculture development while providing scientific support for policies promoting ecosystem-based coastal conservation strategies.

1.3.4 Demo 4 – Invasive Species Reduction – Iceland

Demo 4 aims to detect, monitor, and control invasive pink salmon (*Oncorhynchus gorbuscha*) populations in Iceland, building on the outcomes of the H2020 [ECOTIP](#) project. The focus is on revolutionising invasive species management through advanced detection and intervention measures, contributing to biodiversity protection and restoration in Arctic and European waters.

Invasive Species and Their Impact

Invasive species, such as pink salmon, pose significant threats to biodiversity, the economy, and public health. Nearly 20% of Europe's Red Listed species are endangered due to invasive organisms, a figure expected to rise in the coming years. Pink salmon, native to Alaska and Canada, were artificially introduced to the Atlantic by the Soviet Union in 1956 and have since spread rapidly in the Arctic and Europe. Their high reproductive capacity, ability to adapt to non-native habitats, and the diseases and parasites they introduce endanger indigenous fish species, including Atlantic salmon.

The two main demo 4 sites in Iceland were selected based on registered occurrences and spawning of pink salmon in the rivers Eyjafjarðará and Fnjóská located in northern Iceland in the vicinity of the town of Akureyri, socio-economically significant rivers with local Atlantic salmon populations. Both of these rivers flow into a shared bay, allowing for monitoring across a large estuary.

Advanced Monitoring, Detection and Controlling

The H2020 ECOTIP project completed past and present Arctic biodiversity and its response to external drivers, as well as the effects of expanding commercial activities in the region under expected climate change. Building on their provided basis for evidence-based protection and restoration, PHAROS will focus on the detection, monitoring, and control of invasive pink salmon populations in Iceland, revolutionising how invasive species are managed, employing advanced detection and intervention measures. An Environmental Sample Processor (ESP) deployed at the river will extract eDNA from the water column, allowing subsequent qPCR analysis of target species (pink salmon, Atlantic salmon, Arctic char, European flounder and brown trout; with the potential to archive samples for extensive eDNA metabarcoding analyses). The integration of hydrophones and 2D cameras presents a 'containerised package' for detecting and monitoring invasive species. This can alert scientists to real-time surges in seal populations following pink salmon migration.

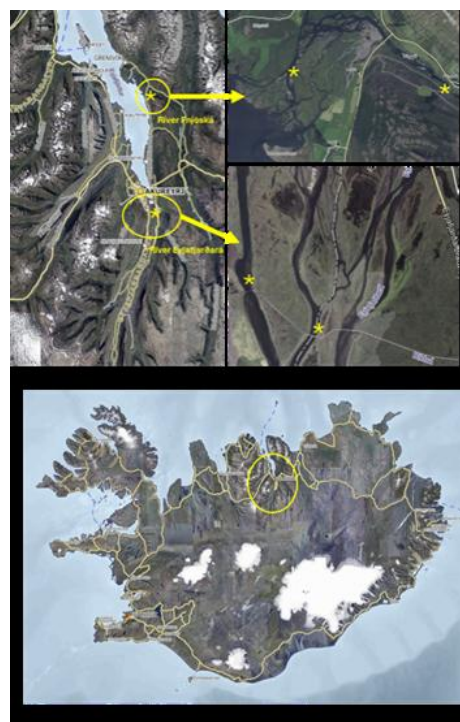


FIGURE 4: LOCATION OF THE KEY ICELANDIC SITES WHERE THE E-DNA BUOY IS BEING CONSIDERED FOR DEPLOYMENT AND MONITORING CAMPAIGNS

Several reduction measures will be used for both adult and juvenile pink salmon, as the species is likely to have different migration times and habitat preferences from the indigenous fish and therefore can be isolated and removed without harming the wild salmonid populations. This will include electrofishing as well as specialised nets and traps already deployed in the local fishery.

Enhanced Coastal Monitoring and Modelling

PHAROS is currently exploring the feasibility of mapping the biodiversity of the Icelandic demo sites' marine ecosystems, along with their historical and present interactions with external drivers, including multiple stressors, using traits as a measure of functional diversity. This initiative is under consideration and further development in collaboration with internal and external experts to assess the extent to which it can be effectively implemented within the scope of WP4 on modelling and digital twins of the ocean. As part of this effort, PHAROS aims to evaluate the potential integration of enhanced coastal monitoring through satellite observations and augmented coastal numerical modelling tools, ensuring a comprehensive and data-driven approach to ecosystem assessment.

2 Project Plan Outlines

In Deliverable D1.1, the overarching national and European policy objectives were linked to the practical objectives and activities of the demonstrators scheduled for execution within the scope of the PHAROS project. The planned activities focus on deploying technical solutions to address the goals of the four project demonstrators, as outlined in Section 1.3.

The project plans described in this document provide a detailed overview of the current status and a general outline of the revised technical solutions for each demonstrator. This includes the initial phases of development, construction, permitting, deployment, operation, and decommissioning. The plans cover the technical solutions to be deployed, the monitoring strategies to be implemented, and the associated cost structures.

The finalised plans, including detailed layouts and designs for all demonstrators, will be comprehensively documented in D1.4. This report will provide the engineering specifications, material selection, system integration strategies, and deployment methodologies necessary to achieve the project's objectives and deliver detailed project plans. The finalised plans will also include the completed Framework for Analysis applications for each of the four core demonstrators.

Management Indicators

Management indicators track progress toward management objectives. Each objective should be linked to one or more indicators, which provide a high-level summary of status or trends. These indicators summarise measurement information and are directly linked to quantified measurements, offering an objective overview of the system. Like other framework levels, management indicators should be clearly stated and broadly understandable to the public.

Management Targets

Management targets define the desired or acceptable status, enabling comparisons of socio-economic, institutional, and environmental status (Figure 5) in relation to management objectives. These targets are established according to the appropriate approach for defining reference levels.

Operational Indicators

Operational indicators are the specific metrics to be measured, each directly linked to a management objective. Multiple operational indicators can be associated with a single management objective. The relationship between the management objective and the measured aspect of the system or pressure must be well understood. Each operational indicator has a clear, unambiguous technical definition of the data collected, providing a quantified and repeatable measure of the system. This technical description does not need to be fully understandable to the public.

Standards

Socio-economic, institutional, or environmental standards serve as reference levels for management. Clearly defined reference levels are necessary to compare operational indicators to the desired or acceptable status. These standards are defined according to the appropriate approach for defining reference levels.

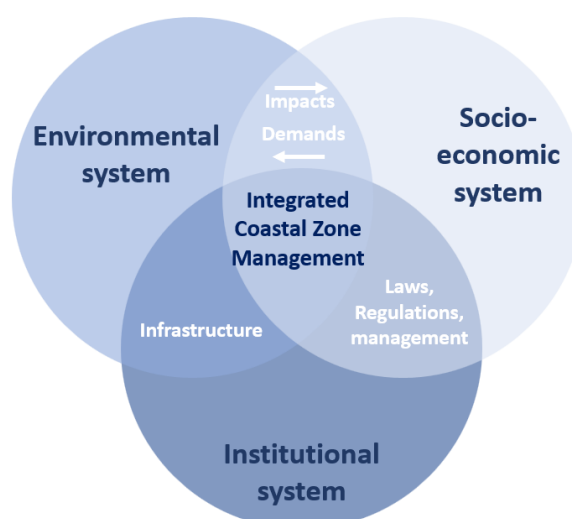


FIGURE 5: INTERRELATIONSHIP BETWEEN SUSTAINABILITY SYSTEMS OF THE BLUE ECONOMY SECTORS. THE INNER PART IDENTIFIES THE SPACE WHERE SUSTAINABLE BLUE ECONOMY SECTORS SHOULD OPERATE (MADE BY AUTHORS).

2.1 Demo 1 – Gran Canaria

2.1.1 Operational Designs

The construction and deployment plans for Demo 1 (along with Demo 2 as it is explained later) are scheduled to be developed in June 2025 in collaboration with a contracted engineering firm. This process will involve finalising the structural and operational design of the Integrated Multi-Trophic Aquaculture (IMTA) system, ensuring that all components are optimised for functionality, efficiency, and environmental sustainability. Key considerations will include the spatial arrangement of fin-fish cages, macroalgae production systems, sea cucumber bioremediation units, and Smart Enhanced Reefs® (SER®), as well as the technical specifications required for successful deployment.

2.1.1.1 Fin-Fish Aquaculture System

The final selection of fin-fish cages for the IMTA system has not yet been determined and will be decided in collaboration with the engineering firm responsible for executing design plans in March 2025. This process will ensure that the selected structures align with both operational and environmental requirements while integrating effectively within the broader IMTA framework. Commercially applied fin-fish cages used in modern aquaculture are standardised, off-the-shelf systems designed to optimise fish health, biosecurity, and production efficiency. These cages are typically circular or square in shape, constructed from high-strength polyethylene or steel, and equipped with reinforced mooring systems to withstand varying environmental conditions. They are available in a range of sizes, generally spanning from 10 to 50 meters in diameter, depending on stocking densities and site-specific oceanographic conditions. The cages are fitted with advanced netting materials designed to minimize escapes, deter predators, and support sustainable farm management practices.

Within the IMTA system, these cages will be positioned at centre of the IMTA system area, allowing for optimal nutrient cycling and water quality management. Fish farming operations will generate organic waste, including nitrogen and phosphorus, which should be in part absorbed by macroalgae, reducing nutrient loads in the surrounding waters in a single use application. This natural filtration process aims to help mitigate environmental impacts while enhancing the overall productivity of the system. The deployment and management of the fin-fish aquaculture component will be overseen by an experienced team with a strong track record in commercial operations. Their expertise will ensure adherence to industry best practices, regulatory compliance, and sustainable fish farming protocols. By leveraging existing commercial infrastructure and operational knowledge, the IMTA system will be designed for seamless integration with current aquaculture standards while maintaining high levels of efficiency, biosecurity, and fish welfare.

Utilizing commercially proven finfish cage technologies also enhances the scalability and transferability of the IMTA approach. Should the integration of macroalgae and other activities demonstrate measurable benefits—such as improved environmental performance, increased productivity, or enhanced economic viability—this model can be readily adapted to other aquaculture operations. Additionally, as regulatory frameworks evolve to encourage or mandate multi-trophic approaches for sustainable seafood production, the IMTA system will be well-positioned for broader commercial implementation. By combining established fin-fish aquaculture practices with ecosystem-based strategies, this initiative seeks to demonstrate a commercially viable and environmentally responsible model for the future of marine farming.

No adaptations of the commercially available system, design, or deployment are considered within PHAROS.

2.1.1.2 Abalone Production Systems

The installation site for the experimental abalone production infrastructure will be selected based on the biological requirements of the species, prevailing environmental conditions, and its potential integration with existing fish farming operations. This strategic placement will ensure optimal growing conditions while enhancing synergies within the broader IMTA system. Key factors influencing site selection will include water temperature, current flow, substrate composition, and proximity to macroalgae cultivation

areas. The abalone grow-out phase will take place in open water within specialized mesh units measuring 80 cm in length and 20 cm in diameter. These units will be incorporated into a structure designed to withstand the operational demands of both fish and macroalgae production while maintaining structural integrity in dynamic marine conditions. Abalones will remain in these enclosures until their final harvest at the conclusion of the experimental period, allowing researchers to monitor their growth, health, and overall performance within the IMTA setting. The selected unit design is engineered to prevent specimen escape, provide protection from predators, facilitate regular inspections, and enable the efficient removal of sick or deceased individuals as needed to maintain optimal sanitary conditions and prevent disease transmission.

These experimental structures will be deployed along the IMTA framework's mooring and macroalgae cultivation lines, ensuring their integration into the overall system. Their strategic placement will allow the abalone to benefit from nutrient cycling processes while contributing to the overall ecosystem balance by grazing on biofouling organisms that may accumulate on aquaculture infrastructure. This approach aims to enhance productivity, minimize environmental impact, and explore the feasibility of abalone farming as a commercially viable component of integrated multi-trophic aquaculture. The abalone seeds will be placed in their designated experimental units at an initial weight of 0.8-1g, where they will remain for approximately 12 months. The abalone seeds will be produced at the aquaculture facilities of the *EcoAqua Institute* in Gran Canaria, following established protocols and according to their life cycle:

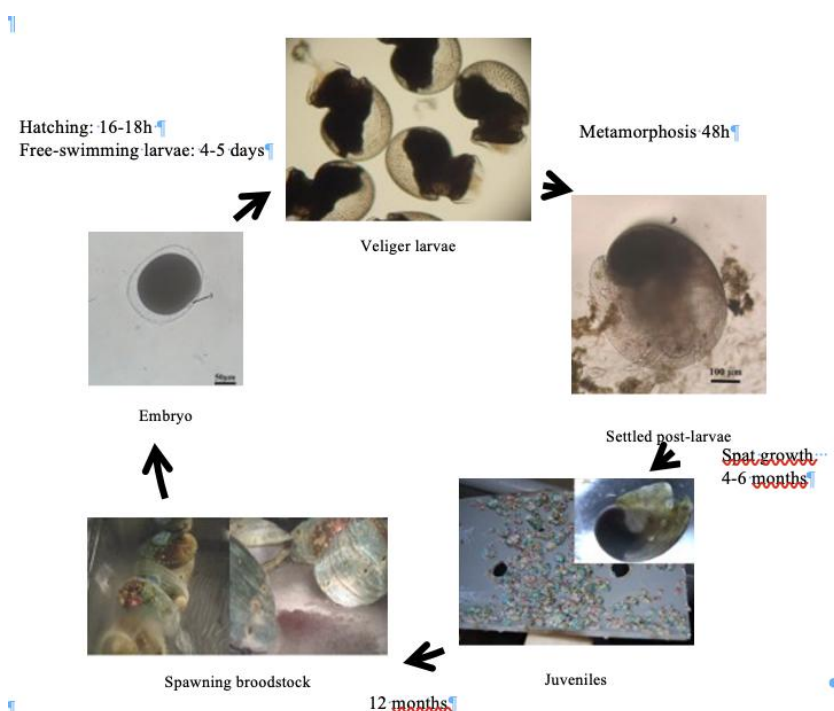


FIGURE 6: *HALIOTIS TUBERCULATA* LIFE CYCLE. SOURCE G. COURTOIS DE VÍÇOSE (2011)

Once they reach the appropriate weight to begin the grow-out process at sea, they will be transferred to the experimental infrastructures at sea, ensuring that physical parameters are maintained to guarantee their good health. Stocking in the experimental infrastructures will be carried out by placing the seeds directly into the mesh units, eliminating potential risks of specimen loss during handling. The grow-out process will take place until the abalones reach an average weight of 12-14g. During this period, the specimens will be fed with macroalgae harvested from ropes cultivated within the same fish farming facility, following a structured feeding management plan. The openings on the sides of the mesh units will facilitate feeding activities using macroalgae grown on ropes. This feeding process promotes uniform growth among all the cultivated specimens. Feeding will be managed based on the average weight of the abalone specimens. A feeding record will be maintained, documenting quantities and dates to ensure full traceability.

Adaption for Demonstrator site

The specification of designs and integration of these custom-made units will be undertaken in March and April of 2025 in coordination with the commercial engineering firms that are producing and providing overall site deployment schemas and designs. As these systems are custom-made for the application in PHAROS, they are specifically designed for use in this application and further customisation is not applicable or envisioned. The experimental mesh units, equipped with an opening and closing system, remain submerged and are suspended from structures using straps or hooks. These experimental units allow the specimens inside to benefit from a good

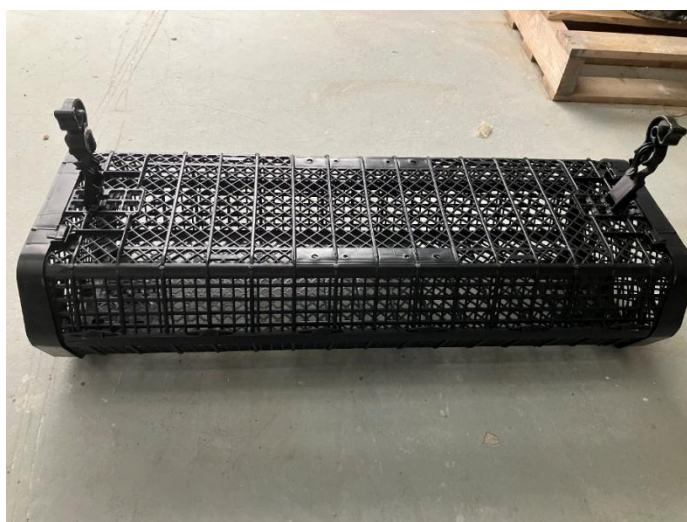


FIGURE 7: EXPERIMENTAL ABALONE MESH UNIT

flow and renewal of water due to currents or tides, which are necessary for their proper development and growth. The experimental units are made of black polyethene mesh. They have openings at both ends and fixation hooks at each extremity to keep them in a horizontal position. Each empty polyethylene box weighs around 2 kg. The volume of each box is approximately 25L. The volumes and surfaces of the units enable the production at densities below 60 specimens per square meter, ensuring good growth rates

2.1.1.3 Macro-Algae Grow-out System

The development of the macroalgae grow-out system is currently in the preparatory phase, with key technical and operational aspects still under evaluation. At this stage, the system has not yet been developed to a level that allows for substantial or additional details beyond what has already been outlined in Section 1.3.1 of this deliverable. Further refinements, including system design, species selection, and integration strategies within the broader IMTA framework, are ongoing and will be informed by continued research, feasibility assessments, and input from project stakeholders. As the concept advances, additional details will be provided in future project updates and technical reports.

2.1.1.4 Smart Enhanced Reefs ®

The SER® are being developed as a fully customised artificial reef structure, specifically designed to align with the environmental conditions and ecological objectives of the demonstration site. Unlike standardised models, these structures are uniquely engineered to meet the precise needs of the project, ensuring optimal functionality within the local marine ecosystem. Their primary purpose is to enhance habitat complexity, support marine life recruitment, and integrate seamlessly within the broader IMTA system. The baseline data required for SER® design has been transferred to the relevant project partners, and the development of site-specific designs is now underway. Underwater Gardens International (UGI) is leading the design process for Demo 1, utilising Reefhopper® and other tools to create structures tailored for deployment at the PLOCAN site. These reefs will provide suitable substrates for the colonisation of marine species, enabling them to complete their life cycles in an environment that replicates the functional structure of natural ecosystems.

The design of the SER® units incorporates multiple factors, including bionomics, physical conditions, and logistical requirements, to ensure their effectiveness in supporting biodiversity and local marine dynamics. The final morphology of each reef structure will determine the most suitable fabrication methodology, such as 3D printing or casting, while engineering considerations will guide material selection and distribution strategies. The SER® structures will be primarily composed of inert materials resembling natural rock, providing a stable foundation for ecosystem development. Although SER® units can be deployed individually, they are typically arranged in clusters to maximise seabed structural complexity and promote ecological resilience. Once installed, these reefs will contribute to both active regeneration efforts, through scientific species transplantation campaigns, and passive regeneration,

through natural colonisation by local marine organisms. Given their bespoke nature, the SER® structures are designed exclusively for this project and will not be adapted for other uses within or beyond the scope of this initiative.

The SER® artificial reefs will not only perform as potential new habitat by themselves, but they will also serve as biomimetic moorings where vertical lines connect to which will grow out macroalgae on the surface. These vertical lines will not only hold the macroalgae on the surface but also suspended artificial reefs all the way down the water column, in an attempt to create a continuous habitat from bottom to surface. In this fashion new available habitat will be created at the seabed, surface and also in the mid-water column. The macroalgae forest near the surface will benefit from the excess of nutrients produced by finfish aquaculture, reducing the amounts of nutrients in the environment that could drive blooms of harmful algae and eutrophication events if the right conditions are met. For these reasons, the macroalgae in Demo 1 will be placed downstream the main current direction from the fish cage to uptake the most many nutrients transported by the currents. The performance of Demo 1 macroalgae forest, downstream the fish cage, will be tested against a control site located right upstream the fish cage, where it is expected to get little to no nutrient outflow from the fish cage. This upstream macroalgae forest on surface along with both suspended and sea bed SER® will be also part of a new habitat environment, now in oligotrophic conditions, which overall conform the demo 2. Bringing the two demos to similar depths will also allow the optimal comparison of both habitats performances. Given this arrangement both Demo 1 and Demo 2 are part of the same IMTA, where Demo 1 is a nutrient rich environment while Demo 2 stands for the natural conditions of a control site.

2.1.1.5 Sea Cucumber Systems

The installation site for the experimental sea cucumber production infrastructure will be selected based on the biological requirements of the species, prevailing environmental conditions, and its potential integration within the existing fish farming system. This strategic placement will ensure optimal habitat conditions while enhancing synergies within the broader IMTA framework. The sea cucumber grow-out phase will be conducted in open water using specialized mesh units, each measuring 100 cm in length and 30 cm in diameter. These units will be positioned beneath the fish production structures at different points within the aquaculture framework, allowing sea cucumbers to utilize organic material settling from the upper trophic levels. Designed to be structurally compatible with both fish and macroalgae production, these enclosures will provide a controlled environment for sea cucumber cultivation, ensuring their retention while preventing escape and offering protection from potential predators.

These experimental structures will be strategically deployed along the mooring points of the IMTA system, optimizing their role in bioremediation and nutrient cycling. Their placement will facilitate natural waste filtration processes while contributing to overall ecosystem balance and productivity. The full description of the sea cucumber production infrastructure, including deployment plans, will be provided in Deliverable D1.4, detailing the final design, integration approach, and long-term monitoring strategies within the IMTA system and how these are integrated with the various elements to be deployed. The sea cucumbers will be placed in their designated experimental units at an initial weight of 5-15 g, where they will remain for approximately 12 months. The sea cucumber life cycle includes six growth stages before maturing into an adult specimen Figure 8.

The grow-out process will take place for approximately 12 months. As holothurians are detritivores organisms that feed on sediments extracting organic matter from them, during this period, the specimens will feed on the particulate organic matter derived from fish production. Consequently, holothurian cultivation does not require specific feeding provisions or the addition of external feed for their production. At regular intervals, sea cucumbers will be monitored to estimate their growth and survival and samples will be taken to the laboratory to analyse their nutritional quality. At the end of the experimental period, the remaining specimens will be harvested from the experimental units following procedures that minimize pain or suffering. The specimens will then be transported to the laboratory for analysis related to nutritional quality, product quality, and various biological parameter assessments.

Adaption for Demonstrator Site

The specimens will be transferred, to the experimental infrastructures at sea, ensuring that physical parameters are maintained to guarantee their good health. Stocking in the experimental infrastructures will be carried out by placing them directly into the mesh units Figure 9, eliminating potential risks of specimen loss during handling. The mesh units, equipped with an opening and closing system, remain submerged and are suspended from structures using straps or hooks. These experimental units allow the specimens inside to benefit from a good flow and renewal of water due to currents or tides, which are necessary for their proper development and growth. The experimental units are made of black polyethylene mesh. They have openings at both ends and fixation hooks at each extremity to keep them in a horizontal position. Each empty polyethylene box weighs around 2 kg. The volume of each box is approximately 25L. The volumes and surfaces of the units enable the production at densities below 60 specimens per square meter, ensuring good growth rates.

2.1.2 Monitoring and Data Gathering

The monitoring program for Demo 1 is designed to assess the ecological and economic viability of co-locating IMTA systems with reef restoration efforts. The primary objectives are to monitor biodiversity

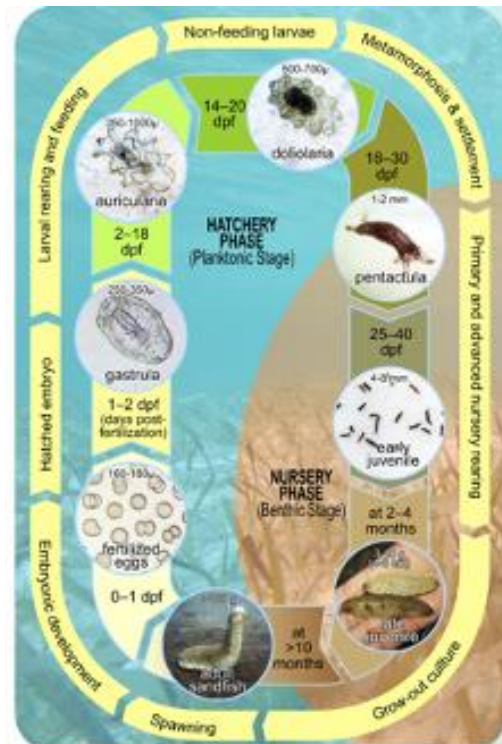


FIGURE 8: HOLOTHURIA LIFE CYCLE. SOURCE SEAFDEC



FIGURE 9: EXPERIMENTAL SEA CUCUMBER MESH UNIT

changes, species growth, water quality, and ecosystem interactions, while also evaluating nutrient cycling, particularly the uptake of nitrogen and phosphorus by macroalgae. Additionally, underwater noise and environmental stressors affecting both the artificial reef and aquaculture setup will be analysed. To achieve these objectives, an extensive monitoring infrastructure will be deployed, integrated within a Digital Twin Ocean (DTO) framework, aligned to the EU DTO initiative through projects such as EDITO, Iliad, Hub Ocean & DITTO.

This system will incorporate multi-parametric sensors to continuously measure wave height, current speed, wind intensity, temperature, salinity, and atmospheric conditions. Additional sensors can be considered according to the needs including, turbidity, pH, pCO₂ and CTD. Species identification, and biodiversity change over the project lifecycle, will be performed through AI-based acoustic monitoring and underwater cameras, providing real-time visualisation of marine life activity. 2D cameras will be deployed on the seabed to monitor habitat and biodiversity change and a 3D camera system is to be deployed in the aquaculture cage to assess fish biomass and growth rates.

The 2D and 3D camera packages form part of the SmartFISHER video monitoring solution from blueOASIS. SmartFISHER comprises a set of pre-trained machine-learning models for marine life detection, species ID, behavioural patterns and size estimation (3D only). The seabed-mounted cameras are to be connected by a tether to the aquaculture power & communication box, shoreside connection or a communication buoy. Their field of view captures activity at each SER reef location. The 3D system would be situated in the aquaculture cage and connected to the local power & communication box. This system will estimate fish biomass based on accurate length measurements using machine vision. A dashboard will serve metrics such as biomass, growth rates, species count, invasive species and system alerts. The solutions SCOUT-S and SCOUT-C promoted by Hydrotwin (www.hydrotwin.pt) will be used for long-term monitoring of underwater soundscape (Figure 10).

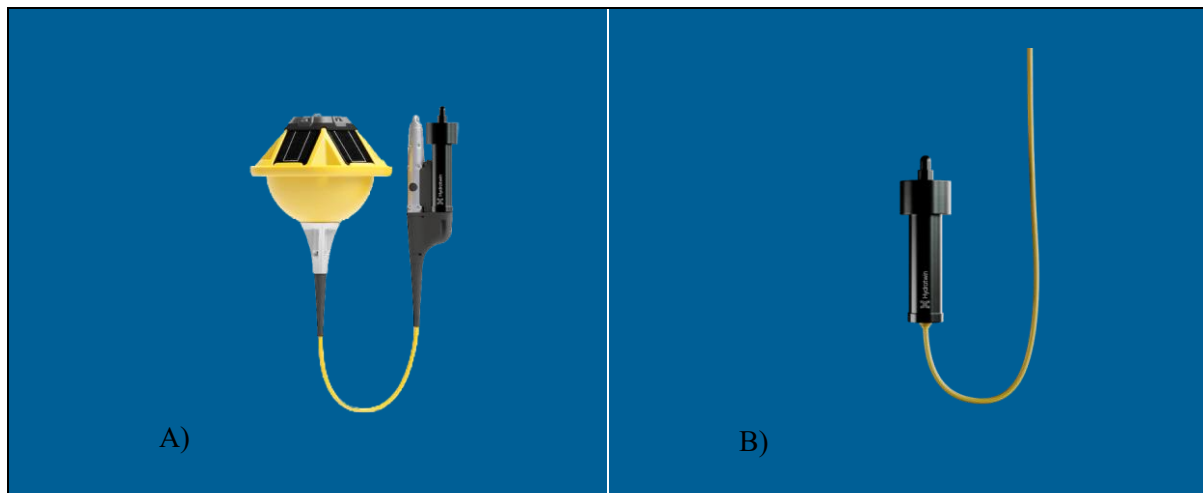


FIGURE 10: ILLUSTRATION OF A) SCOUT-S AND B) SCOUT-C.

These solutions are based on the use of AI, IoT and HPC technologies for real-time monitoring, detection, and classification of underwater sounds, including cetaceans and vessels, with the possibility to expand to other sources as soon as data is available. The data collected will feed into a dashboard for visualization (Figure 11) and high-fidelity noise propagation models, helping assess the impact of anthropogenic activity in the marine environment.

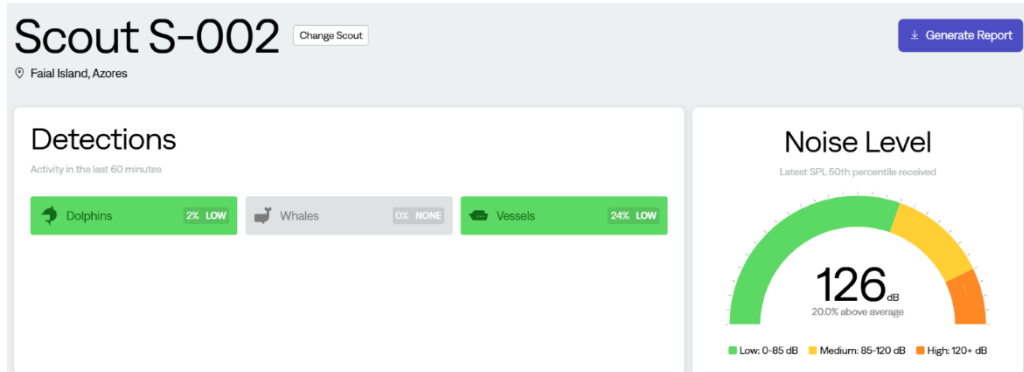


FIGURE 11: ILLUSTRATION OF THE REAL-TIME DASHBOARD FOR ACOUSTIC DATA

Hydrophones (SCOUTs. etc.) will be used to collect data about the environment, with continuous streaming of sound statistics and source detection using AI. RAINDROP will provide the acoustics numerical representation of the environment to complete the DT. It will provide a more comprehensive overview of the soundscape, can be processed to extract metrics and trends, and can be compared with the hydrophone data. Additionally, high-fidelity oceanographic models will be used to simulate wave and current patterns, providing a deeper understanding of environmental dynamics at the demo site. A surrogate modelling approach will be employed, leveraging AI-driven self-improving capabilities that refine predictions based on real-time sensor data. Used numerical tools will be REEF3D::FNPF (<https://www.reef3d.com/reef3dfnfpf/>) and MOHID (<http://mohid.com/pages/home/whatismohid.shtml>) and, for the underwater acoustics propagation, RAINDROP (<https://blueoasis.pt/raindrop/>).

REEF3D::FNPF solves the Laplace equation with fully nonlinear boundary conditions, on a surface and bathymetry allowing for characterization of large-scale phase resolved sea state, accounting for steep waves, nonlinear waves transformation and complex coastlines. Figure 12 shows an example of a REEF3D simulation for the Faial-Pico channel.

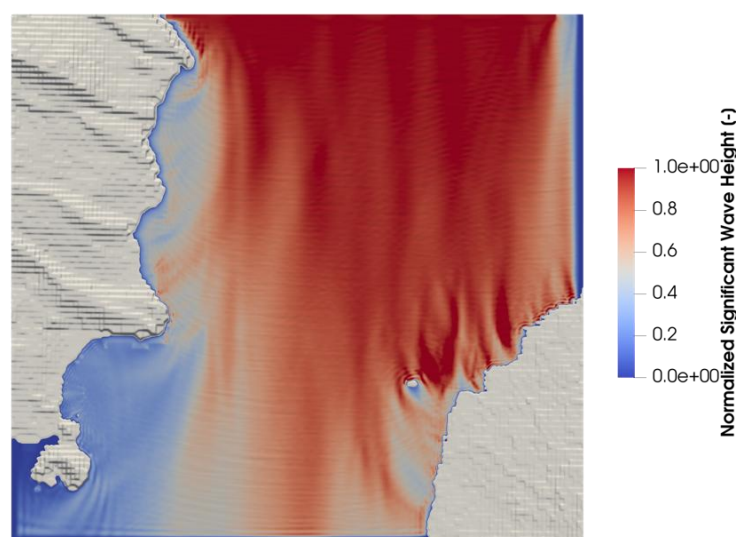


FIGURE 12: SIGNIFICANT WAVE HEIGHT IN THE FAIAL-PICO CHANNEL SIMULATED VIA REEF3D::FNPF

MOHID consists of a three-dimensional baroclinic free surface model that is targeted at simulating coastal hydrodynamics. An example of MOHID outputs is given in Figure 13 for the Azores archipelago, where it is shown the current velocity field in the region.

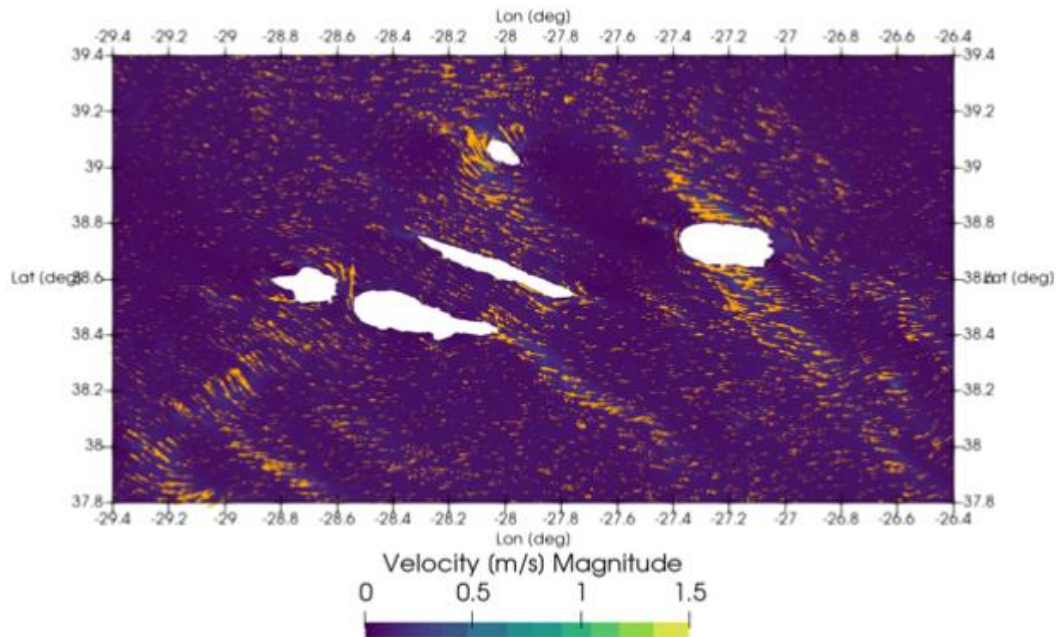


FIGURE 13: CURRENT VELOCITY IN THE FAIAL-PICO CHANNEL SIMULATED VIA MOHID

RAINDROP (Figure 14) is a Python toolbox developed by blueOASIS that streamlines the generation of underwater acoustic maps. It integrates normal-mode acoustic solvers with modules to efficiently process key marine data such as bathymetry, metocean information and AIS. By offering HPC-ready parallelization, the user is able to produce these high-quality maps in real-time, a crucial feature for Digital Twins.

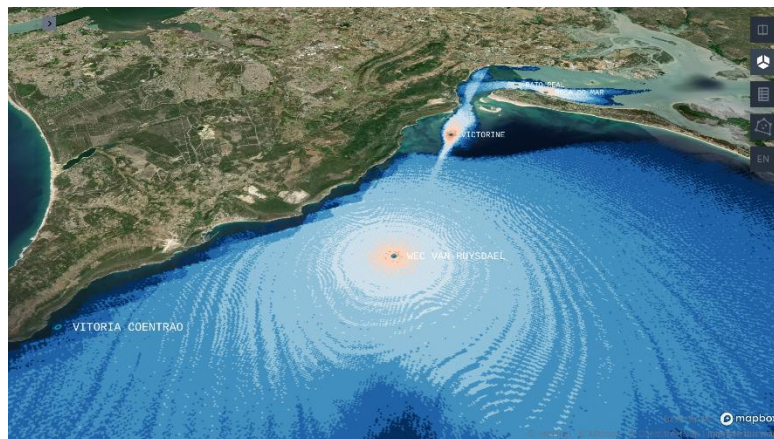


FIGURE 14: EXAMPLE OF AN ACOUSTIC MAP PRODUCED WITH RAINDROP IN SESIMBRA, PORTUGAL

The monitoring program will involve a combination of continuous real-time streaming and monthly manual sampling campaigns to validate automated data collection. Biodiversity assessments will include species tracking through automated AI recognition, diver surveys, and quantitative evaluations of macroalgae and reef growth. Water quality monitoring will focus on key parameters such as nitrate, phosphate, and ammonia levels, with additional assessments of oxygen availability and CO₂ sequestration efficiency.

The expected outcomes include a comprehensive understanding of the interactions between IMTA components—macroalgae, fish, and sea cucumbers—and their role in nutrient recycling and

biodiversity enhancement. The collected data will be integrated into the DTO platform selected, enabling ecosystem forecasting and providing decision-support tools for upscaling similar approaches in other locations.

2.1.2.1 Finfish Production

Standard monitoring equipment required for finfish aquaculture will be utilized to ensure the health, safety, and optimal performance of the finfish cages. This equipment will be implemented following standard commercial aquaculture practices, ensuring compliance with industry regulations and best management strategies. Key monitoring components will include environmental monitoring systems, and fish health assessment tools, all of which will contribute to maintaining ideal rearing conditions and preventing potential risks such as disease outbreaks, water quality deterioration, and structural failures.

Underwater cameras and automated feeding systems will be deployed to observe fish behaviour, identify early signs of stress or disease, and ensure feed efficiency to minimize waste. The position and implementation of the camera are dependent on the power supply. Structural integrity assessments of the finfish cages will be conducted using sonar imaging, mooring tension sensors, and routine diver inspections to detect any potential vulnerabilities in net enclosures, reducing the risk of fish escapes and predator intrusions. The collected data from these monitoring systems will directly contribute to the broader pilot deployment monitoring plan, integrating findings from fin-fish aquaculture with those from macroalgae cultivation, sea cucumber bioremediation, and Smart Enhanced Reef® development. This comprehensive monitoring approach will provide integrated feedback on the overall IMTA system's performance, allowing for adaptive management strategies that enhance both environmental sustainability and operational efficiency as well as key indicators for scaling production and replication in future commercially viable applications. The detailed monitoring framework, along with its implementation strategies, will be further outlined in the pilot deployment monitoring plan, ensuring a cohesive and well-coordinated approach across all aquaculture components.

2.1.2.2 Abalone Production

Regular sampling of abalone will be conducted to assess survival rates and growth performance, ensuring optimal rearing conditions within the IMTA system. Tissue samples will also be collected for biochemical proximate analysis to evaluate product quality and determine the effectiveness of the feeding regime. Additionally, environmental parameter monitoring will be carried out by PLOCAN, providing essential data on water quality and ecosystem conditions to support the sustainable management of the abalone production system.

2.1.2.3 Macro-Algae Production

At the time of this deliverable submission, no specific strategy has been established for the monitoring of macroalgae beyond harvesting and periodic sampling. Future assessments will focus on determining the most effective methodologies for tracking growth dynamics, biomass yield, and overall system performance as the project progresses.

2.1.2.4 Sea Cucumber Production

Regular sampling of sea cucumbers will be conducted to assess survival rates, growth performance, and their effectiveness in utilising particulate organic matter from the environment. Tissue samples will be analysed for biochemical composition to evaluate product quality and nutritional value. Additionally, PLOCAN will oversee environmental parameter monitoring to ensure optimal conditions for sea cucumber cultivation and overall ecosystem stability.

2.1.2.5 Smart Enhanced Reefs®

The monitoring program for the Smart Enhanced Reefs® (SER®) will be designed to assess long-term ecosystem changes surrounding Demo 1, with a focus on biodiversity increases, associated fauna, and carbon immobilization rates. Monitoring efforts will primarily involve fish and benthic species identification through transects, visual census, and photo-quadrat analysis. To account for seasonal variations, surveys will be conducted at least once per season, ensuring a comprehensive assessment of biodiversity and ecosystem dynamics. For consistency and accuracy, a minimum of two divers will perform a double dive at each site during each monitoring campaign. These scuba diving surveys will be complemented by environmental and oceanographic data collected from sensors planned for

installation at the Demo 1 site. Additional monitoring tools, such as underwater cameras or other visual technologies, will further enhance data collection, providing a more detailed understanding of ecosystem changes over time.

2.1.3 Economic Operations and Utilisation of Production

The Demo 1 pilot is expected to generate multiple outputs, including fin fish, macroalgae, sea cucumbers, and other ecosystem services within the site deployment. A preliminary uptake and usage plan will be developed to outline the potential applications of these outputs, ensuring alignment with the licenses and permitting regulations governing site operations. This plan will detail feasible pathways for product utilization, including market applications (the sale of products) or depending on the permit specification, a donation to local initiatives to be utilised most effectively. The full details of this uptake and usage plan will be provided in Deliverable D1.4, incorporating regulatory considerations and operational feasibility assessments.

2.1.4 Site Deployment Schematisation

In the context of Demonstrator 1, which focuses on a fully integrated multi-trophic aquaculture (IMTA) site, concrete design solutions for the deployment of the necessary structures are currently under development. A preliminary siting of the pilot installation within the PLOCAN testing waters has been selected and is illustrated in Figure 15 to the right. The siting plan is being developed with the support of a commercial engineering firm to ensure the effective integration of components within the IMTA framework. Although the conceptual understanding of system integration is well established, the practical aspects of design and spatial layout are undergoing further refinement. This includes the evaluation of site-specific environmental and oceanographic conditions, technical feasibility, and infrastructure needs to ensure optimal deployment and operational efficiency. The finalized siting plan, inclusive of detailed design specifications and spatial configurations, will be delivered as part of Deliverable D1.4.

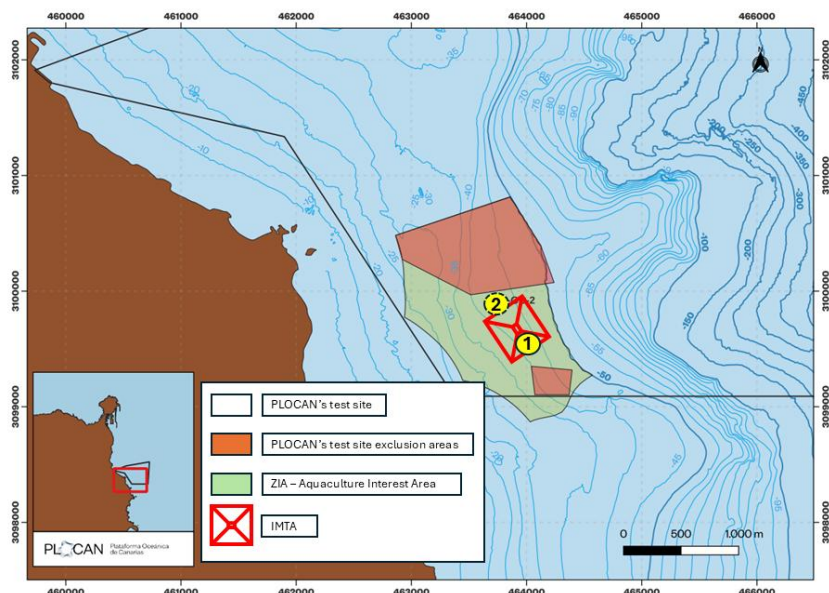


FIGURE 15: SITE LOCATION FOR DEMO 1 AND DEMO 2

2.1.5 Operation and Maintenance Plans

The operation and maintenance plan is dependent on the final configuration of the system and, as stated in Section 2.1.4, is likewise reliant on the contracted engineering firm to deliver the finalized design plans. These plans will provide the necessary structural, logistical, and technical details required to define the operational and maintenance protocols. Until the final design is established, specific O&M procedures cannot be determined. Once completed, the operation and maintenance plan will be developed accordingly and detailed in the appropriate project deliverables (D1.4).

2.1.6 Decommissioning

Once the experimental activities are completed, the experimental infrastructures will be dismantled to be cleaned on land. There is a potential, pending further discussions and extension of permitting, to

maintain the fish aquaculture cages and anchoring system to be used in future and further projects. This is not yet confirmed but is being considered.

2.1.7 *Cost Estimation*

Following the drafting of the preliminary budget and updated deployment plans, cost categories for Demo 1 have now been further specified. All major expenses related to purchasing, development, fabrication, deployment, and operational activities have been aligned with the available budgets as allocated in the Description of Action (DoA). The partnering institutes have confirmed that the planned activities can be carried out within the allotted financial framework. Now that Demo 1 and Demo 2 will be spatially fused in one single demonstrative, keeping the initial objectives of each of them, though, some costs associated with equipment, installation, IT and services will be shared between both demos. That makes it difficult to distinguish for costs which belong exclusively to each demo, making it more advisable to merge both budget estimations too. The single table with costs will be presented at the corresponding section of Demo 2 (2.2.7).

2.1.8 *Planning Timelines*

A preliminary planning timeline for Demo1 is included below. This timeline will be updated and refined as the project progresses, particularly following the completion of site designs and as permitting and deployment conditions become clearer.

Tasks	Description	Leader	Year 1				Year 2				Year 3				Year 4				Year 5			
			3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
T3.1.4	Sea Cucumber	EcoAqua																				
	Design (WP1)	EcoAqua																				
	Procurement	EcoAqua																				
	Stock and Install Cages	EcoAqua																				
T3.1.5	Acquisition and deployment of all monitoring technology	bo, UGI, BEA, EcoAqua, PLOCAN																				
	Design (WP1)	bo, UGI, BEA, EcoAqua, PLOCAN																				
	Nutrient sensors Procurement	PLOCAN																				
	Cameras & Hydrophones Procurement	PLOCAN																				
	Installation of all Monitoring Equipment																					
T3.1	Demo 1 - Gran Canaria IMTA	ULPGC																				
T3.1.1	Aquaculture fish cage	PLOCAN																				
	Design (WP1)	PLOCAN																				
	Procurement	PLOCAN																				
	Mooring blocks and anchors	PLOCAN																				
	Mooring bouys	PLOCAN																				
	Cage Installation	PLOCAN																				
	Installation of PV and telemetry	PLOCAN																				
	Stock fish cage	PLOCAN																				
T3.1.2	SER® reefs	UGI																				
	Design (WP1)	UGI																				
	Procurement	UGI																				
	Install the SER	PLOCAN																				
	Stock and Install seeded lines	BEA																				
T3.1.3	Macroalgae+ Abalone	BEA, ECOAQUA																				
	Design (WP1)	BEA, ECOAQUA																				
	Procurement	BEA, ECOAQUA																				
	Install the lines attached to existing mooring blocks	PLOCAN																				
	Stock and Install seeded lines	BEA																				
T3.5	Trials & Monitoring	bo, HT, all demo leaders																				
	trial 1	bo, UGI, BEA, EcoAqua, PLOCAN																				
	trial 2	bo, UGI, BEA, EcoAqua, PLOCAN																				
	Decommission	bo, UGI, BEA, EcoAqua, PLOCAN																				

FIGURE 16:5-YEAR PLANNING FOR DEMO 1, INCLUDING MILESTONES (MS)

2.2 Demo 2 – Gran Canaria

2.2.1 Operational Designs

2.2.1.1 Smart Enhanced Reefs (SER®)

For Demo 2, Underwater Gardens International will design Smart Enhanced Reefs using reefhopper® and other tools to be deployed at the PLOCAN site, similar to and coupled with the application in Demonstrator. The habitat provided in Demo 2 by the SER® at sea seabed and mid water column, along with the macroalgae forest that will grow out on the top stretch of the vertical lines that will go from the seabed SER® to the surface, will be part of the same IMTA as Demo 1. Demo 2 will be located on the upstream side of the IMTA, where is expected to get little to none outflow nutrients from the fish cage (faeces and feed) and in a manner that will be the natural conditions control site against the SER® and macroalgae forest of Demo 1, nutrient enriched for being located downstream the fish cage where the outflow of nutrients will flow out. The SER® is a structure specifically designed to be placed on the seabed, providing suitable substrates for the colonisation of marine species, allowing them to complete their life cycles in an environment that simulates the functional structure of their natural ecosystems. The design of SER® units will incorporate multiple factors - bionomics, physical and logistics - to address the specific needs of Demo 1 overall design and local conditions. The resultant morphology of the SER® being developed based on these multiple factors will determine the fabrication methodology, such as 3D printing or casting.

Additionally, engineering factors will be considered when designing their final materials and distribution. SER® will be primarily made from inert material that closely resembles natural rock, which serves as the foundation for the reefs. While SER® can be installed individually, it is more common to deploy multiple SER® units at once, distributing them strategically to enhance the structural complexity of the seabed. Once deployed, a SER® will support active regeneration operations through scientific campaigns for species transplantation or passive colonisation, facilitated by the natural colonisation of local species.

Adaptation Requirements for Demonstrator Site

The designs per deployment are entirely customised. The final design and configuration of these elements will be included in D1.4

2.2.2 Monitoring and Data Gathering

2.2.2.1 Monitoring Program Design

For **Demo 2: Macroalgae Forest and Artificial Reef in the Canary Islands**, the monitoring program will focus on tracking macroalgae growth, biodiversity changes, and the overall impact of the artificial reef ecosystem. A key objective is to measure the carbon sequestration potential of macroalgae forests while assessing habitat formation and species colonisation on the SER® reef structures. Additionally, the program will investigate the wave attenuation effects of the reef and macroalgae, evaluating their role in coastal protection.

To achieve these goals, a similar DTO-based monitoring system will be deployed by blueOASIS. Multi-parametric sensors will continuously measure oceanographic conditions, while underwater cameras and AI-driven species identification tools will track biodiversity and habitat formation. Hydrophones, based on SCOUT-S and SCOUT-C solutions, mentioned previously, will record long-term acoustic data, providing insights into marine life interactions and the potential effects of anthropogenic noise.

Macroalgae growth and colonisation studies will be conducted through biometric sampling, while remote sensing via satellite and drone imagery will track the spatial expansion of macroalgae forests. Carbon sequestration efficiency will be estimated through water sampling and CO₂ analysis, allowing for quantification of the ecosystem's role in climate mitigation. Hydrodynamic sensors will assess

changes in wave and current, determining the protective benefits of the reef and macroalgae structures for coastal stability.

Data collection will follow a structured approach, with bi-weekly manual sampling, real-time sensor feeds, and seasonal biodiversity assessments. This comprehensive monitoring effort will allow PHAROS to identify optimal conditions for macroalgae reforestation, evaluate artificial reefs as biodiversity hotspots and carbon sinks, and develop predictive models for ecosystem recovery. All collected data will be integrated into the PHAROS DTO, supporting real-time visualisation and decision-making through the dashboard and selected DTO platform.

By leveraging state-of-the-art digital twin technology, AI-enhanced data analysis, and multi-modal environmental monitoring, PHAROS aims to set a new standard for adaptive ecosystem management and scalable restoration strategies across the Atlantic and Arctic regions.

2.2.2.2 Site-Specific Tailoring

SER[®] monitoring plans are tailored to specific sites depending on the number of SER[®], clusters and depths. Mainly, it will measure biodiversity increase, associated fauna and carbon immobilisation rates. Monitoring will mainly consist of fish and benthic species identification transects, visual census and photo-quadrats.

2.2.2.3 Interoperability and Digital Twins

SER[®] can be interoperable with other monitoring programs and tools. For example, high-resolution underwater cameras can support scuba divers' visual census.

2.2.3 Economic Operations and Utilisation of Production

Not applicable for Demo 2 as no products will result from demonstrations.

2.2.4 Site Deployment Schematisation

The macroalgae cultivation system will be integrated directly with the Smart Enhanced Reef[®] (SER[®]) structures, with the base of the cultivation line anchored to the reef and the upper end connected to the northernmost and upstream side of the main aquaculture frame. This configuration allows the macroalgae to grow along a vertical line suspended in the water column, ensuring consistent exposure to light and efficient nutrient absorption throughout the growing depth. The preliminary preferred depth range for macroalgae cultivation has been identified between 10 and 15 meters. However, current discussions with site planners and permitting authorities indicate a higher likelihood of deployment in deeper waters, in waters as deep as 45m. This adjustment reflects spatial constraints within the test area and the need to optimise layout between various demonstrator components, including fish cages, sea cucumber units, and supporting infrastructure. On the other hand, the joint experiment of bringing both demonstratives to the same IMTA enhances the comparison between two equal demonstratives with the sole difference of the nutrient outflow enrichment from the fish aquaculture cage. The image below provides a rough schematisation of how the system is expected

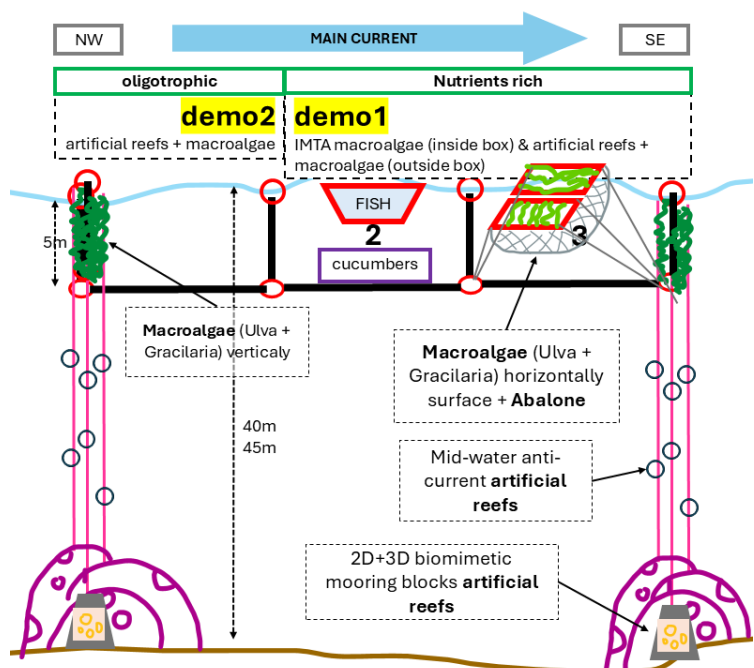


FIGURE 17: SCHEMATIZATION OF THE JOINT DESIGN OF DEMO 1 AND DEMO 2

to look and be deployed in the field. It illustrates the conceptual layout of the macroalgae lines in relation to the SER® structures and the buoy system. However, it is important to note that the exact configuration of the reef system is still under development, and refinements are ongoing based on site conditions, technical requirements, and ecological considerations. As the design and permitting processes are still underway, no final deployment location or depth has been confirmed. The complete and finalised configuration, including structural specifications and placement details, will be presented in Deliverable D1.4.

2.2.5 Operation and Maintenance Plans

The operation and maintenance plan for the demonstration site has been developed to ensure the long-term functionality, safety, and environmental performance of all deployed systems, including the Smart Enhanced Reefs® (SER®). This plan comprises a series of coordinated monitoring and inspection programmes designed to provide ongoing control, tracking, and evaluation of both ecological and structural conditions throughout the duration of the project. An environmental monitoring programme will be implemented starting prior to the deployment of the SER® units and continuing at regular intervals over the course of the project. This programme will apply a range of methods to assess both abiotic and biotic factors. While the use of bO sensors for environmental parameter tracking is still under consideration for Demo 2, biological community monitoring will be a central component. This will focus primarily on measuring changes in biodiversity, the presence and abundance of associated fauna, and rates of carbon immobilisation around the SER® units. To achieve this, field methods will include species identification transects, visual census techniques, and photo-quadrat analysis, enabling a detailed understanding of ecological developments over time. In parallel, a monitoring and maintenance programme for the installed structures will be carried out to ensure the integrity and safety of the surrounding natural environment where the SER® units are located. This includes regular visual and physical inspections to detect any early signs of structural degradation or displacement. Additional assessments will be conducted following extreme weather events or maritime storms to ensure that all components remain secure and fully operational. Together, these monitoring activities form the basis of the operation and maintenance strategy, providing a framework for adaptive management that supports both ecological goals and structural reliability. The outcomes of these efforts will be integrated into the broader project evaluation process and used to inform future improvements and scaling strategies.

2.2.6 Decommissioning Requirements and Plans

The SER® structures have a lifespan of many decades. Functionally, they are intended to remain on the seabed for the duration of the project (about 3 years) to monitor their effectiveness. After this initial period, their development will be evaluated, and if their effectiveness is confirmed, they may be left in place for a longer duration. If the SER® are no longer considered functional, they will be removed from the seabed and repurposed for port-related uses based on their size and weight.

The decommissioning process involves the following steps:

1. Removing the anchors (only if the designs require them) using a team of divers.
2. Refloating the SER with the help of lift bags and divers.
3. Loading the SER onto a vessel using a crane.
4. Transporting the structures to the dock by boat.

2.2.7 Costing Estimation

The costing estimations are being further developed in consultation with the contracted engineering firm, which is developing the final designs for the site and the required specifications to have the demonstrator realised. A first estimate of anticipated costs for the SER®, which is going to be applied in Demo 1 and 2 is provided in the tables below.

TABLE 1: OVERVIEW OF EQUIPMENT, INSTALLATION, IT, AND EXTERNAL SERVICE COSTS FOR DEMO 1 & DEMO 2 IMPLEMENTATION

WP	Cost Category	Item	Partner	Total Cost (€)
WP1	Permitting	EIA	PLOCAN	20,000
WP1	Permitting	Bathymetry study	PLOCAN	10,000
WP3	Consumables	Lab Consumables and Sensor O&M	EcoAqua	15,000
WP3	Consumables	Juvenile Production Consumables and Lab Consumables	PLOCAN	80,000
WP3	Consumables	Fish Stock Fry and Fish Feed	PLOCAN	95,000
WP3	Equipment	Invertebrate Strings, Seeds, Feed	EcoAqua	27,500
WP3	Equipment	Cages for Abalone and Sea Cucumbers	EcoAqua	20,000
WP3	Equipment	Automated Fish Feeder and Support Stand	PLOCAN	40,000
WP3	Infrastructure	Aquaculture Cage Mooring Blocks	PLOCAN	60,000
WP3	Infrastructure	Aquaculture Cage Anchors	PLOCAN	20,000
WP3	Infrastructure	Aquaculture Cage Chains	PLOCAN	20,000
WP3	Infrastructure	Aquaculture Cage 25m Diameter	PLOCAN	70,000
WP3	Infrastructure	Aquaculture Net 25m Diameter	PLOCAN	30,000
WP3	Installation	Aquaculture Cage Installation	PLOCAN	20,000
WP3	Installation	Aquaculture Cage Tow	PLOCAN	20,000
WP3	Installation	Demo1&2	PLOCAN	50,000
WP3	Sensors	Monitoring System for Fish Maintenance	PLOCAN	67,000
WP3	Sensors	Multi-sensors (O ₂ , Temp, Depth, Current) (x2)	PLOCAN	42,000
WP3	Sensors	T, pH, Irradiation Monitoring Equipment	PLOCAN	10,000
WP3	Sensors	Nutrient Sensors (x3)	PLOCAN	75,000
WP3	Construction Contract	Demo 1&2 Reefs Construction and Deployment	UGI	112,000
WP3	Consumables	Lab Reagents and Protective Equipment	BEA	45,000
WP3	Equipment	Buoys for Demo 1&2, Boat Hire and Transport	PLOCAN	100,000
WP3	Equipment	Carboys and Light System	BEA	17,000
WP3	Equipment	Laptop for Demo Management	UGI	3,000
WP3	Infrastructure	Buoys, Stainless Steel, Macroalgae Strings, Net Protection	BEA	50,000
WP3	Maintenance	Biomass Pond and Raceway Tank	BEA	20,000
WP3	Sampling & Analysis	Water Sampling, Nutrient & Biomass Analysis	BEA	105,000
WP3	Transport	Transport to Site and Ropes Harvesting Tools	BEA	30,000
WP4	IT Equipment	Cloud Service	bO	5,000
WP4	Consumables	Workshop Consumables	bO	2,264
WP4	Equipment	Bristlemouth Development Kit	bO	10,000
WP4	Equipment	Floater for Monitoring	bO	10,000
WP4	IT Electronics	Raspberry Pi Module	bO	20
WP4	Infrastructure	Moorings Anchors and Telemetry Buoy	PLOCAN	62,000
WP4	IT Equipment	IT Hardware (High-Performance Computing)	bO	20,000
WP4	Sensors	Hydrophones and 2D Camera for Demo 1&2	PLOCAN	100,000
WP4	Sensors	Hydrophone + Calibration	bO	2,716

WP4	Service Contract	La Terrazas Overwater Cameras	PLOCAN	25,000
			TOTAL	1,510,500 €

TABLE 2: SUMMARY OF DIRECT COSTS BY WORK PACKAGE AND COST CATEGORY FOR DEMO 1 & DEMO 2 IMPLEMENTATION

	Cost Category	Amount (€)
WP1	Permitting	30,000
		30,000
WP3	Consumables	235,000
	Equipment	207,500
	Infrastructure	250,000
	Transport & Installation	120,000
	Maintenance	20,000
	Reef construction & Deployment	112,000
	Sensors	194,000
	Sampling & Analysis	105,000
		1,243,500
WP4	Consumables	2,264
	IT Equipment	25,020
	Sensors & Equipment	122,716
	Infrastructure	62,000
	Service Contract	25,000
		237,000
TOTAL		1,510,500 €

2.2.8 Planning Timelines

For Demo 2, timings for design, production and deployment of SERs should be aligned with the deployment of the overall design for the Demo site. As per the grant agreement, it is expected to be ready by year 3 of the project.

The SER® structures have a lifespan of many decades. Functionally, they are intended to remain on the seabed for the duration of the project (about 3 years) to monitor their effectiveness. After this initial period, their development will be evaluated, and if their effectiveness is confirmed, they may be left in place for a longer duration.

FIGURE 18: 5-YEAR PLANNING FOR DEMO 2, INCLUDING MILESTONES (MS)

2.3 Demo 3 – Irish Coastal Seaweed Production

2.3.1 Operational Designs

Demo 3 will implement a seeded string longline system anchored with mooring blocks to cultivate seaweed in deep-water environments. This configuration was selected as all trial sites are located in deep water, and it is the only system approved by regulatory authorities for such conditions. The design is based on conventional deep-water seaweed farming practices, with key modifications to adapt to site-specific factors. Both the length of the longlines and the weight of the mooring blocks will be tailored according to the size of the cultivation area and the strength of the prevailing currents. These adjustments aim to improve system stability and operational efficiency across the various deployment locations. The target species for cultivation are *Alaria esculenta* and *Saccharina latissima*, selected for their strong suitability to deep-water conditions and their established commercial value. The farming system will comprise longlines suspended at a consistent depth using a series of buoys. Each line will be connected to mooring barrels by extension lines and securely anchored to the seafloor with concrete blocks. To optimise hydrodynamic performance, the longlines will be aligned parallel to the prevailing current, reducing drag and supporting optimal growth. Navigation buoys will be installed at the corners of each site for clear identification and safe access. During deployment, the seeded string will be manually wound around the longlines to initiate the cultivation process.

In parallel to the main system, BMRS—the operator of Demo 3—is conducting additional trials at their Bantry Bay site to evaluate alternative cultivation techniques. These include testing direct seeding by glueing spores directly onto the longlines, which may streamline the initial setup phase. The ULTFARMS project will trial a submersible seaweed line designed to improve resilience in adverse weather conditions. BMRS is also investigating the use of net-based substrates attached to the longlines, an approach that may boost growth performance and improve the efficiency of harvesting operations. These trials and innovations will inform ongoing development of the cultivation system, with the aim of refining deep-water seaweed farming practices for improved sustainability, resilience, and scalability.

2.3.2 Monitoring and Data Gathering

2.3.2.1 Monitoring Program Design

Demo 3 will implement a comprehensive monitoring programme to assess the interactions between the salmon farm and the adjacent seaweed cultivation system. The primary objectives are to evaluate the influence of salmon farming on seaweed growth, to understand how the seaweed farm affects local biodiversity, and to investigate the potential of the seaweed system to act as a bioremediation mechanism for salmon effluent. Seaweed performance will be assessed through systematic sampling along the longlines, where 10 cm blade sections will be collected and analysed. Growth metrics, including blade length, width, fresh weight, moisture content, and dry weight, will be recorded to determine growth rates. Alongside these measurements, the quality of the seaweed biomass will be evaluated through chemical composition analysis. This includes determining ash and protein content, as well as profiling key biochemical compounds such as phenolic compounds, phlorotannins, fucoxanthin and other pigments, and fucoidans. The temporal variability in biomass composition will be monitored throughout the growing season to better understand changes in nutritional and functional properties.

Water quality monitoring will be conducted to evaluate nutrient dynamics and the extent to which the seaweed farm mitigates the effects of nutrient-rich effluent from the salmon cages. Water samples will be collected from three points: upstream of the site, within the farm area, and downstream of the farm. These samples will be analysed for biological oxygen demand, total nitrogen, ammonium, nitrite, nitrate, total phosphorus, and total suspended solids, providing a detailed picture of nutrient flux and potential bioremediation effects. Biodiversity assessment will focus on both mobile and sessile marine species associated with the seaweed farm. Camera systems will be deployed to record the presence of mobile fauna around the longlines and mooring structures. Monthly observations will include visual identification of species found on cultivation equipment, including longlines, extension lines, and

moorings. Additional data will be collected from organisms found attached to the seaweed biomass during growth sampling, further informing species diversity and habitat use patterns. Environmental parameters critical to seaweed growth and overall farm performance will also be monitored. Light intensity and temperature will be recorded using sensors installed at the cultivation site. Supplementary data on wind, wave height, and current velocity will be obtained from publicly available resources provided by the Marine Institute of Ireland, through a nearby wave buoy. This integrated monitoring framework will support a robust assessment of the environmental, biological, and operational dynamics at Demo 3, providing insight into the performance and ecological function of the seaweed farm within a multi-use marine space.

2.3.2.2 Site-Specific Tailoring

As all data except for temperature, light and biodiversity of mobile species is measured in the lab, there is no need to tailor the site for the data gathering. The sensors and camera can be attached to the long lines. The standards and protocols to be used in the monitoring and processing will be detailed in procedural manuals to be shared with Demo 1 & 2 to be undertaken as needed and to ensure sufficient metadata is produced to allow for exposure of the monitoring data to the wide scientific community and bodies of interest.

2.3.2.3 Interoperability and Digital Twins

All data gathered as part of Demo 3 will be offline, hence, incorporation with a digital twin will be challenging. The digital twin can be built after the first growth season and updated with offline data during the subsequent growth seasons.

A Delft-3D hydrodynamic (<https://oss.deltares.nl/web/delft3d>) and bio-geochemical modelling system will be developed for the region of interest to support scenario building, predictive analysis, and strategic planning. This integrated model will simulate key physical and biogeochemical processes, including current dynamics, nutrient transport, sediment interactions, and biological productivity. The system will enable the testing of various environmental and operational scenarios, providing valuable insights into ecosystem responses under different aquaculture configurations, management strategies, and regulatory constraints. One of the core applications of this model will be the assessment of climate change impacts on the region's marine environment. By simulating shifts in temperature, circulation patterns, and nutrient availability, the model will support investigations into how future climate conditions may influence local ecosystem dynamics, water quality, and the productivity of species cultivated within the integrated multi-trophic aquaculture (IMTA) system. This predictive capacity will allow for the identification of potential risks and opportunities, informing long-term planning and adaptive management approaches.

The Delft-3D modelling suite will be implemented within the EDITO Model Lab framework, ensuring full interoperability with the broader architecture of the European Union's Digital Twin of the Ocean (DTO) initiatives. This compatibility allows the model to contribute directly to EU-wide marine digitalisation efforts and ensures that outputs are aligned with established data standards, interfaces, and cross-sectoral modelling tools. Through this alignment, the modelling outputs can be integrated with other datasets and digital tools across current and future EU DTO projects, enhancing their relevance and usability for stakeholders, policymakers, and the scientific community.

2.3.3 Economic Operations and Utilisation of Production

Demo 3 produces two different kelp species, the estimated harvest of *S. latisima* is about 1 tonne and that of *A. esculenta* is between 6 to 10 tonnes. Part of the harvest of *A. esculenta* will be used in research before drying. Most of the seaweed will be dried, after which a small amount of the dried seaweed will be used for research as well. The rest of the dried seaweed will be sold. This revenue stream will be used to recoup some of the additional costs incurred by BMRS. The three aquaculture sites operated by BMRS are also used for other research projects and commercial production. There are just three lines per site (two sites are currently in use for the Pharos project), and the revenue of these lines will not be substantial enough to reinvest into the project.

2.3.4 Site Deployment Schematisation

At the PHAROS demonstration sites in Ireland, seaweed cultivation will be carried out using a longline system, with deployment configurations tailored to the specific conditions and regulatory constraints of each location. The longlines are designed to accommodate deep-water cultivation while ensuring structural integrity and optimal exposure to environmental conditions such as light, nutrients, and water flow. At the Bantry Bay integrated multi-trophic aquaculture (IMTA) site, each

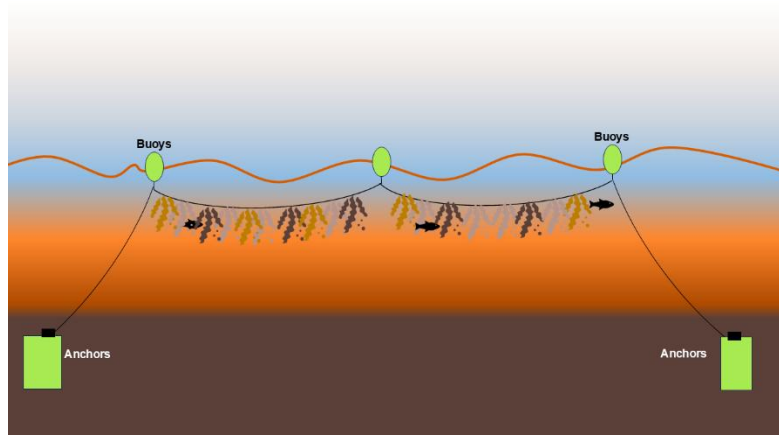


FIGURE 20: ILLUSTRATION OF THE LONG LINE SET UP FOR GROWING SEAWEED IN DEEP

longline will be 110 meters in length, reflecting both the physical layout of the site and the constraints set out in the operating licence. The maximum permitted capacity for this site allows for the deployment of up to 17 longlines. In contrast, the monoculture seaweed farm site at Roaring Water Bay, which operates under a different set of licensing conditions, permits the deployment of longlines up to 220 meters in length, with a total capacity of up to 79 longlines. Additionally, a newly acquired site in Dunmanus Bay has the potential to host a maximum of 50 longlines under its current licence conditions.

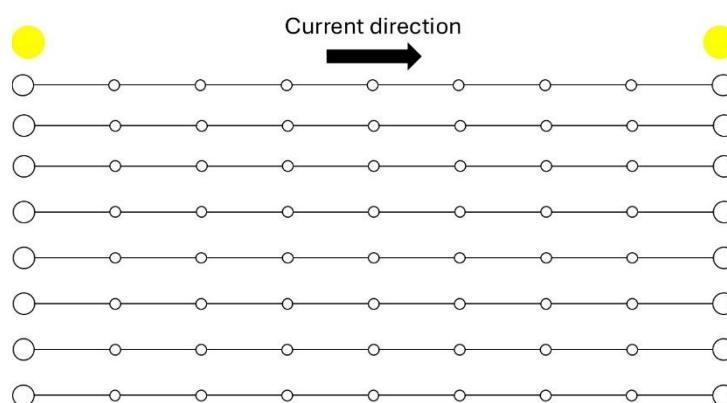


FIGURE 19: TOP SIDE VIEW OF THE SEAWEED FARM WITH LONG LINES

Although these sites have the capacity for large-scale cultivation, BMRS, the operator of Demo 3, plans to deploy a limited number of longlines—specifically three per site—for the purposes of the PHAROS project. This scaled-down deployment allows for focused monitoring, controlled experimentation, and the testing of innovative cultivation techniques within the scope of the project objectives. The deployment strategy across these sites will enable the comparison of seaweed growth performance and environmental interaction under varying site conditions, cultivation intensities, and regulatory frameworks. Figure 20 and Figure 19 provide schematic representations of the generic design and deployment configurations for the longline systems at the IMTA and monoculture sites.

2.3.5 Operation and Maintenance Plans

All sites will be made ready before deployment each year. This means all mooring blocks are put in place with the mooring barrels and extension lines attached. On the day of deployment the seeded string containing little seaweed plants (sporophytes) will be wound around the long lines in situ and the flotation buoys will be attached as well. The site will be checked twice a month, weather permitting, for any damage. During these checks, water samples will be taken as well. Seaweed samples will be taken once a month. At the end of the growing season, the seaweed will be harvested by hoisting the long line out of the water, cutting the seaweed just below the holdfast and depositing it in a 1 Tonne bag. The seaweed is transported to the drying facility by road.

2.3.6 Decommissioning Requirements and Plans

Each site will be decommissioned after each harvest because the long lines will not be in use after the growing season. All the equipment needs to be taken out for cleaning and to prevent biofouling on the long lines. First, the long lines will be disconnected from the extension line and brought to shore. On shore, the flotation buoys are removed, and everything is cleaned. Secondly, the mooring barrels and extension lines are removed, transported to shore and cleaned. After cleaning, everything is stored on the BMRS site for the next season.

2.3.7 Costing Estimation

2.3.7.1 Materials, Equipment, and Construction

The estimated cost for one longline, excluding VAT, is listed in **Table 3: Estimated Equipment and Material Cost per Long Line**. Each site also needs several navigation buoys; the estimated cost per navigation buoy is €2,300. The cost of construction (pre-deployment) and deployment depends on the type of vessel required, depending on the size of the farm.

TABLE 3: ESTIMATED EQUIPMENT AND MATERIAL COST PER LONG LINE

Item	Amount	Total estimated cost (€)
Mooring blocks	2	800
Long line	1	180
Extension line	2	41
Mooring barrel	2	160
Flotation buoy	9	330
Rope from buoy to long line (2m)	9	10
Anchor line	2	140
Shackles	2	70
Chain (12m)	2	410
Total		2,141

Table 4: Estimated Cost for Deployment at the Bantry Bay Site shows the estimated cost for construction and deployment at one site. Taken all together, the estimated cost for the three sites for the Pharos project will be a once-off purchase of €20,000 for equipment and materials and yearly deployment costs of €51,000 for the three sites.

TABLE 4: ESTIMATED COST FOR DEPLOYMENT AT THE BANTRY BAY SITE

Deployment		
Cost category	Amount	Price (€)
Boat hire including skipper and 1 crew	4 days	12,000
Rib hire	4 days	3,000
Additional staff	1 for 2 days and 4 for 2 days	2,000
Total		18,000

2.3.7.2 Transportation and Sea Missions

Each site will be visited twice per month for 4-5 months. Each visit will need a Rigid Inflatable Boat (RIB) and at least 2-4 persons. So, the estimated cost is €1,600 per visit per site. Hence, the total estimated is €48,000 for all three sites with a 5-month growth season.

2.3.7.3 Operations and Processing

The estimated cost for harvesting is expected to be €9,000 per site. The seaweed will be sold ex works to the drying facility based on its wet weight, where it will be dried and processed. Transportation costs will be covered by the drying facility.

2.3.7.4 Decommissioning

The decommissioning cost is estimated to be half the cost of deployment, excluding the cleaning of the materials. So, the cost of decommissioning the farm is estimated at €8,000, and the cost of cleaning is estimated to be around €1,000, which makes the total cost around €9,000 per site.

TABLE 5: OVERVIEW OF EQUIPMENT, INSTALLATION, IT, AND EXTERNAL SERVICE COSTS FOR DEMO 3 IMPLEMENTATION

WP	Cost Category	Item	Partner	Total Cost (€)
WP3	Equipment	Anchor blocks	BMRS	8,000
WP3	Equipment	Buoys, Rope, Chain	BMRS	24,000
WP3	Equipment	Sensors, LED Lights, Socks & Filters	BMRS	10,000
WP3	Equipment	Chemicals, Nutrients, Glassware	BMRS	15,000
WP3	Equipment	Strings and Collectors	BMRS	2,000
WP3	Installation & Services	Installation, O&M, Transport Contract	BMRS	65,000
WP3	Consumables	Miscellaneous Lab Supplies	BMRS	2,000
TOTAL				126,000

TABLE 6: SUMMARY OF DIRECT COSTS BY WORK PACKAGE AND COST CATEGORY FOR DEMO 3 IMPLEMENTATION

	Cost Category	Amount (€)
WP3	Equipment	59,000
WP3	Installation & Services	65,000
WP3	Consumables (Lab supplied)	2,000
TOTAL		126,000

2.3.8 Planning Timelines

2.3.8.1.1 Design And Deployment

BMRS already has the licenses and permissions required to operate its seaweed farms. The design process for these farms took about a month, but the licenses were awarded only after 2-4 years post-application

The seaweed is deployed in October and November on calm days. Here, the string with young “plants” is transferred to the longline (Figure 21, Figure 22, Figure 23). Deployment time depends on the size of the farm, but it is estimated that 4-6 lines can be deployed per day. This means



FIGURE 21: A SUBMERGED LONGLINE



FIGURE 23: DEPLOYING SEEDED STRING ON LONG LINES AT SEA



FIGURE 22: MICROSCOPIC ALARIA PLANTLETS ON THE STRING

that the deployment of each site will take 2-3 days. The sites can be deployed simultaneously, but this is impractical because this means hiring three boats with crew and three times the additional staff. So, BMRS will deploy each site consecutively and hire the boat and staff for a longer period.

Seeded string production

The timing of seaweed cultivation is governed by its biology. Kelp production can only be done by completing the life cycle of the species (see Figure 24), not by vegetative propagation as is the case with other species. The production steps are best illustrated in picture format and include the selection of the best parental individuals between January - March. It is estimated that sporophytes will be collected at low tide during 7 non-consecutive days during this period. The day after collection, the spores are released and transferred to flasks containing growth media. The spore develops into gametophytes after release. Gametophyte cultures are produced in controlled conditions until August. In August, fertilization is induced over an estimated period of 10 days to produce seaweed seeds. After the 10-day period, the seeds are sprayed onto a string which is pre-wound around a pipe or collector. Each collector holds 65m of seeded string. It is estimated that this will take 6 weeks, after which the seeded string will be ready for deployment.

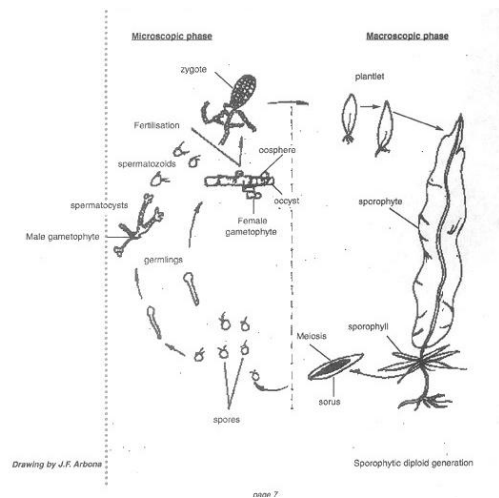


FIGURE 24: THE LIFE CYCLE OF *ALARIA ESCULENTA*



FIGURE 26: PLACING FERTILISED SEED ON STRING WHICH IS WRAPPED AROUND PIPES



FIGURE 28: COLLECTING RIPE SORI FROM THE SHORE



FIGURE 25: BUILDING UP CULTURES OF GAMETOPHYTE



FIGURE 27: RIPE SORI SORTING BACK IN THE LAB

2.3.8.1.2 Operations

Pre-deployments

The pre-deployment of each site is estimated to take two days.

Site visit for research and maintenance

Each site will be visited twice a month for one day per visit (Figure 29). So, for a 5-month growth season, there will be 10 days that the farms will be visited. However, additional visits will be needed after heavy storms to survey the farm. It is estimated that during an average growing season, there will be five heavy storms, which means five additional days of visits to each site.



FIGURE 29: HALFWAY THROUGH THE GROWTH CYCLE (2.5 MONTHS) APPROXIMATELY 6 KG/M

Harvesting

The seaweed will be harvested between April and May, depending on the growth rate (Figure 30). It is estimated that 8-10 long lines can be harvested per day, which means that harvesting each site will take 1-2 days.



FIGURE 30 FINAL HARVEST (AFTER 5 MONTHS) APPROXIMATELY 12KG/M

2.3.8.1.3 Decommissioning

Decommissioning of the farm is estimated to take one or two days per site, with an additional two days required for cleaning all the equipment at each site.

2.3.8.1.4 Future Iterations and Development

BMRS anticipates that the timeline for future iterations will closely follow the timeline outlined below. The 2024/2025 season included two sites: an IMTA site and a monoculture site. For the 2025/2026 season, BMRS plans to add a newly acquired third site in Dunmanus Bay.

Tasks	Description	Leader	Year 1				Year 2				Year 3				Year 4				Year 5			
			3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
T3.3	Demo 3 - Ireland IMTA macroalgae + salmon farm	BMRS	MS1		MS2		MS6				MS9											
	Reef design process	BMRS																				
	Design (WP1)	BMRS																				
	Procurement	BMRS																				
	Mooring blocks and anchors	BMRS																				
	Mooring bouys	BMRS																				
	Ropes & Lines installation	BMRS																				
	Transplant of macroalgae to lines	BMRS																				
	Sampling Chemicals & Nutrientes Procurement	BMRS																				
	Sampling Analysis	BMRS																				
T3.5	Trials	60, HF, all demo leaders																				
	trial 1																					
	trial 2																					
	trial 3																					
	trial 4																					
	Decommissioning	BMRS																				

FIGURE 31: 5-YEAR PLANNING FOR DEMO 3, INCLUDING MILESTONES (MS)

2.4 Demo 4 – Icelandic Invasive Finfish

2.4.1 Operational Designs

Demo 4 will employ eDNA methodology, incorporating both species-specific qPCR and multi-species metabarcoding to monitor the spawning migration of pink salmon into Icelandic river systems. eDNA is expected to offer a more time- and cost-efficient alternative to current methods, such as visual observation, hydrophones, and trapping, while also being less affected by the uneven distribution of pink salmon individuals.

2.4.2 Monitoring and Data Gathering

2.4.2.1 Monitoring Program Design

Demo 4 will monitor the bi-annual spawning migration of pink salmon into Icelandic river systems and implement measures to mitigate their impact on local habitats and native species. Additionally, the demo will assess the effectiveness and potential of the monitoring methodology. To enable real-time monitoring, the demo will deploy a robotic sensor known as an Environmental Sample Processor (ESP). The ESP will perform automated sampling, filtration, and preservation of eDNA samples, as well as process and analyse the samples using qPCR. Deploying the ESP in Icelandic river systems will allow for real-time detection of species presence and potentially their quantities, with results accessible in real-time remotely. This capability will enable early identification of pink salmon migration and facilitate the timely deployment of counter-measures.

The ESP can conduct analysis of up to six assays for each sample. For this demo, validated qPCR assays will target pink salmon, Atlantic salmon, brown trout, Arctic charr, and European flounder, alongside an internal positive control (ISP) for sample verification. The ESP also allows for sample collection for later analysis; these samples will be processed using the same qPCR assays and subjected to metabarcoding in a laboratory setting to provide a broader analysis of species diversity. Manual sampling will be conducted simultaneously to compare with the ESP results. Additional samples will be collected in the estuary to assess the overall species composition through metabarcoding.

To provide comprehensive monitoring, 2D cameras and hydrophones will be installed alongside the ESP in the river. The hydrophones will specifically monitor the presence of seal populations, which are known to follow pink salmon into estuaries. Counter-measures will focus on reducing both adult and juvenile pink salmon populations. This will involve electrofishing, as well as capturing pink salmon using gillnets and specialised traps already used by local fisheries. Since pink salmon are expected to have different timing and habitat preferences from native species, these measures can be implemented without major harm to the indigenous fish populations. The counter-measures will be carried out by DTU staff in collaboration with local stakeholders, with the goal of reducing the pink salmon population by more than 50%.

2.4.2.2 Site-Specific Tailoring

The eDNA sampler, along with the hydrophones and cameras, will be installed at the sites with minimal disruption to the natural environment. Depending on the placement of the sampler along the river, it may be necessary to provide sheltering in the form of a cover or container to protect it from environmental exposure.

2.4.2.3 Interoperability and Digital Twins

As there are no specific digital twins being developed, process based models, or other such applications, there is expected to be a limited degree to which the results and outputs of this demonstrator couple or feed into digital twins. The data produced could be used by future or parallel endeavours to model and inform on the species dynamics, however, the application within PHAROS is more akin to an early warning and alert system in order to activate intervention measures by the local authorities and relevant bodies.

2.4.3 Economic Operations and Utilisation of Production

Identification of products resulting from the operation of the demonstrator (Seaweed, Fish, etc.) with an indication of the end use, potential turnover, and plans for utilisation of project production.

2.4.4 Site Deployment Schematisation

The demo will be conducted in northern Iceland, near Akureyri, in the rivers Eyjafjarðará and Fnjóská. This site was selected due to the recorded pink salmon migration and the rivers' significant socio-economic value as popular Atlantic salmon fishing destinations. The site also offers practical advantages, including easy access for sampling and the availability of electricity and internet connectivity for the ESP. Furthermore, there is strong local interest in the project, creating opportunities for collaboration with local stakeholders and effective communication of findings.

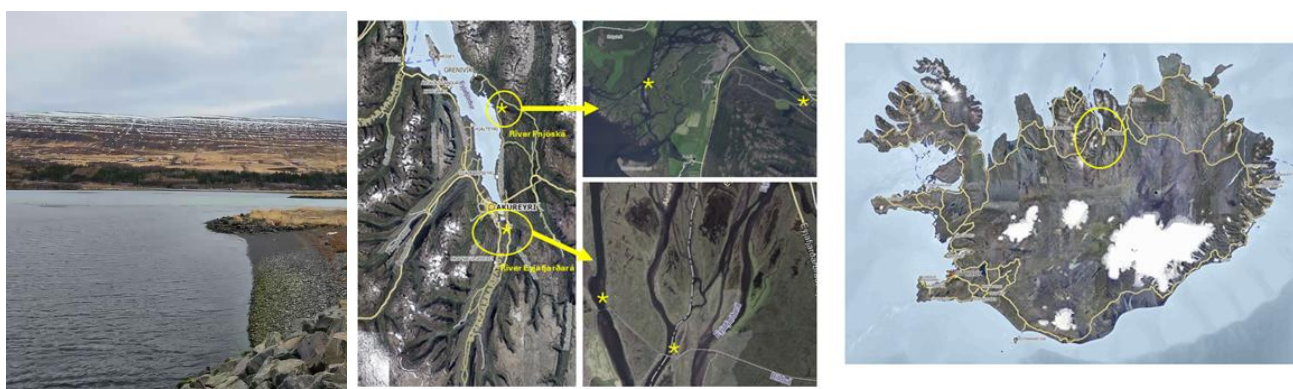


FIGURE 32: SITE SELECTION IN NORTHERN ICELAND (LEFT TO RIGHT) PHOTO OF THE HEAD OF THE FJORD, SATELLITE VIEW OF THE FJORD, SATELLITE VIEWS OF THE CHANNELS, LOCATION OF THE SITE ON ICELAND

2.4.5 Operation and Maintenance Plans

The eDNA sensor will be deployed at strategically selected sites within the designated monitoring area. Location will be chosen based on their ecological relevance, proximity to aquaculture activities, and potential for capturing representative environmental DNA signals across varying conditions. The sensor will remain in continuous operation during the deployment period, with regular maintenance visits scheduled to ensure optimal performance. These site visits will include a full inspection of the sensor's condition and functionality with re-calibration as needed to maintain data accuracy. Particular attention will be paid to the effects of biofouling and the samplers intake, which could interfere with sensor readings or affect the stability of the equipment. Any accumulation of biological material will be manually removed during these visits to ensure consistent sensor exposure and accurate sampling conditions.

This operational plan is designed to support uninterrupted data collection while maintaining the integrity of the deployed equipment. The maintenance schedule and calibration frequency may be adjusted depending on environmental conditions, sensor performance, and emerging technical requirements throughout the deployment phase.

2.4.6 Decommissioning Requirements and Plans

For the Iceland deployment of the eDNA sampler, installation efforts will be kept to a minimum, with the sampler only intended for temporary use. Upon completion of the project, the sampler will be retrieved and returned to the equipment provider. All other deployed sensors and materials will similarly be collected and decommissioned in line with project closure procedures. It is expected, however, that some of the smaller, cost-effective sensors used during the monitoring activities will be fully expended and, due to wear or limited operational lifespan, will not be viable for future redeployment. Despite the temporary nature of the eDNA sampler installation, the alerting system developed as part of the deployment will remain active beyond the project's conclusion. This system has been designed with

future scalability in mind and will continue to operate should a permanent or supplementary eDNA monitoring system be installed at the location in the future. In doing so, the infrastructure established during the project will support ongoing environmental monitoring and provide lasting value to site managers and stakeholders interested in long-term ecosystem assessment.

2.4.7 Costing Estimation

The current project allocations for Demo 4 have been carefully reviewed and validated by the project partners directly involved in its planning and implementation. These allocations reflect a comprehensive understanding of the operational needs of the demonstration and have been confirmed as being both realistic and in line with expected costs for the activities to be carried out over the duration of the project. This validation process included a detailed assessment of technical requirements, site-specific conditions, and logistical considerations to ensure that the budget remains accurate and fit for purpose. The financial planning covers all critical components necessary for the successful execution of Demo 4. This includes costs associated with the initial deployment of infrastructure and equipment, scheduled maintenance voyages to ensure continued functionality, routine cleaning operations to mitigate biofouling, and minor repairs anticipated due to normal wear and tear or environmental exposure. These elements have been planned with flexibility to account for potential variability in conditions and unforeseen operational challenges, while still maintaining a strong alignment with overall project budgeting.

Additionally, the cost estimates take into account the support systems required for monitoring, data collection, and basic infrastructure servicing. This includes vessel use, diver time, sensor recalibration, and periodic inspections of deployed structures. The allocations are based on both previous experience and current market rates, and they remain consistent with expenditures observed in similar marine research and demonstration projects. Overall, the validated cost structure ensures that Demo 4 can be implemented effectively without compromising on quality, safety, or research outcomes, while maintaining fiscal responsibility and alignment with the broader financial framework of the PHAROS project.

TABLE 7: OVERVIEW OF EQUIPMENT, INSTALLATION, IT, AND EXTERNAL SERVICE COSTS FOR DEMO 4 IMPLEMENTATION

WP	Cost Category	Item	Partner	Total Cost (€)
WP3	Equipment	Water sampling equipment	DTU	2,000
WP3	Equipment	CTD sensor equipment	DTU	15,000
WP3	Equipment	Nets	DTU	5,000
WP3	Equipment	Electro fishing gear	DTU	10,000
WP3	Installation	Transport of buoy and sensors	DTU	15,000
WP3	Installation	Installation of buoys and sensors	DTU	30,000
WP3	Installation	Decommissioning of equipment	DTU	30,000
WP3	Installation	Contract for installation	DTU	10,000
WP3	Installation	Telemetry cable 1 km to shore	DTU	30,000
WP3	IT infrastructure	IT hardware (computer, SIM cards, etc.)	DTU	30,000
WP3	Service	eDNA buoy upgrade (service check)	DTU	35,000
WP3	Service	Operation and maintenance	DTU	40,000
WP3	Service	Invasive species control	DTU	73,860
WP4	Equipment	Telemetry buoy with WiFi	DTU	40,000
WP4	Sensors	Hydrophones for Demo 3	DTU	40,000
WP4	Sensors	2D camera for Demo 3	DTU	20,000

TABLE 8: SUMMARY OF DIRECT COSTS BY WORK PACKAGE AND COST CATEGORY FOR DEMO 4 IMPLEMENTATION

	Cost Category	Amount (€)
WP3	Equipment	32,000
WP3	Installation	115,000
WP3	Services	148,860
WP3	IT Equipment	30,000
WP4	Equipment and sensors	100,000
TOTAL		425,860

2.4.8 Planning Timelines

2.4.8.1.1 DESIGN AND DEPLOYMENT

The deployment of the ESP, hydrophones, and cameras will be completed well in advance of the expected pink salmon spawning migration in July, with all systems fully operational by 1st July to ensure sampling is already underway when the salmon begin to migrate into the rivers. The number of days required for deployment will be determined based on dry-testing of the ESP at DTU in Denmark and recommendations from MBARI (Monterey Bay Aquarium Research Institute) researchers, who developed and constructed the ESP.

2.4.8.1.2 OPERATIONS

On-site sampling and maintenance of the ESP, hydrophones, and cameras will be carried out by DTU staff throughout the spawning migration. The duration of the field deployment will depend on the length of the migration period and will be dynamically adjusted based on the presence information provided by the sensor.

2.4.8.1.3 DECOMMISSIONING

Decommissioning of the ESP, hydrophones, and cameras is expected to be completed within one day. If more extensive sheltering of the ESP is required, an additional day may be needed for decommissioning.

			Year 1				Year 2				Year 3				Year 4				Year 5			
Tasks	Description	Leader	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
T3.1.5	hydrophones + cameras procurement	bO, PLOCAN																				
T3.1.5	hydrophones + cameras assembly	bO, PLOCAN																				
T3.4	Demo 4 - Iceland Invasive species identification and reduction	DTU, IZNASU		MS1	MS2				MS6													
T3.4.1	Conduct extensive eDNA analysis of invasive species	DTU																				
	Baseline data collection: Hydrophones + qPCR Metabarcoding	DTU																				
	Map biodiversity and stressors drivers	DTU																				
	Audiovisual monitoring	bO																				
	Water sampling & CTD procurement	DTU																				
	Water sampling & CTD sampling	DTU																				
T3.4.2	Invasive species prevention and reduction trial	DTU							MS7													
	Mooring, anchors procurement / Buoy upgrade	DTU																				
	Mooring, anchors installation / Buoy upgrade	DTU																				
	Environmental Sample Processor ESP Procurement	DTU																				
	ESP transport & installation	DTU																				
	Telemetry cable installation / WIFI setup	DTU																				
	qPCR Metabarcoding real-time Monitoring	DTU																				
	eDNA analysis	DTU																				
T3.4.3	Implement invasive species reduction measures	DTU																				
	Electrofishing + Nets & Traps procurement	DTU																				
	Culling	DTU																				
T3.4.4	Living Lab	DTU, IZNASU																				
	Citizen engagement	DTU																				
	Minka training for Monitoring	DTU																				
	Culling training	DTU																				
T3.5	Trials & Monitoring	bO, HT, all demo leaders				adult								adult								
									fry									fry				
	Decommission																					

FIGURE 33: 5-YEAR PLANNING FOR DEMO 4, INCLUDING MILESTONES (MS)

3 Conclusion

Deliverable 1.3 of the PHAROS project outlines a high-level project plan, budget allocation, and techno-economic analysis for the four pilot demonstrators. The document provides a strategic roadmap for the implementation of the project, aligning technical, economic, and logistical considerations with the overarching national and European policy objectives. The deliverable builds upon the structured framework established in D1.1, ensuring that each demonstrator is positioned to deliver measurable outcomes in marine ecosystem restoration and sustainable aquaculture development.

The four demonstrators address key ecological and economic challenges across different marine environments:

- Demo 1 in Gran Canaria integrates finfish aquaculture with macroalgae production and bioremediation to develop a sustainable Integrated Multi-Trophic Aquaculture (IMTA) system.
- Demo 2 in Gran Canaria focuses on deploying artificial reefs and nutrient remediation systems to restore marine biodiversity and ecosystem health.
- Demo 3 in Ireland tests large-scale macroalgae cultivation to enhance carbon sequestration, nutrient uptake, and biomass production.
- Demo 4 in Iceland introduces eDNA monitoring for early detection and targeted removal of invasive pink salmon, offering a cost-effective and scalable solution for biodiversity protection.

A key focus of this deliverable is the development of robust monitoring strategies to measure project success and refine implementation strategies. The integration of cutting-edge technologies, such as eDNA sampling, hydrophones, and automated monitoring systems, will enable real-time data collection and adaptive management. The findings from these demonstrators will serve as a foundation for scaling the solutions and informing policy recommendations at both the national and European levels.

The next steps involve finalising the detailed design and operational plans for each demonstrator, which will be documented in D1.4. This will include engineering specifications, system integration strategies, deployment methodologies, and site-specific financial models. The structured approach outlined in this deliverable ensures that PHAROS remains on track to achieve its mission of fostering sustainable ocean resource utilisation and marine ecosystem restoration through innovative and scalable solutions.



Pioneering Nature-Based Solutions and Sustainable Blue Economies for Ocean Restoration by 2030. (PHAROS)

IF YOU WOULD LIKE TO KNOW MORE ABOUT
OUR PROJECT ACTIVITIES, OUR TEAM WOULD LOVE
TO SPEAK TO YOU.

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