TransformAr

Accelerating and upscaling transformational adaptation in Europe: demonstration of water-related innovation packages

Mussel Raft Monitoring (MRM) in Ría de Arousa (Galicia)

Briefing on the development process of the MRM solution and results

This project has received funding from the European Union's Horizon H2020 innovation action programme under grant agreement 101036683.

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Authors	Eva Méndez, Ignacio Gónzalez, Cristian Simoes, Soledad Garrido, Amaya Soto, Lucía Fraga, Silvia Torres
Collaborators	CETMAR: Silvia Piedracoba, Clara Almécija, Marta Vázquez, Pablo Álvarez Mussel producers: Marcos, Andrea,…
Primary Contact and Email	utmar@cetmar.org (Subject: Transformar Mussel Raft Monitoring)
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EXECUTIVE SUMMARY

TRANSFORMAR PROJECT

The TransformAr project, funded by the **European Union's Horizon H2020** innovation action programme, aims to **accelerate transformational adaptation** in vulnerable regions across Europe. Coordinated by the University of Antwerp, TransformAr involves 22 partners from 11 European states. The project focuses on **developing and demonstrating solutions for large-scale adaptive processes**, utilizing open innovation, accessible climate data services, and actionable solutions. Through the implementation of Innovation Packages, TransformAr seeks to enhance communities' social and climate resilience.

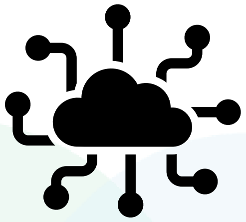
MUSSEL AQUACULTURE IN GALICIA (SPAIN)

Within TransformAr's Work Package 4 (WP4), region-specific portfolios of adaptive solutions are being implemented in Key Community Systems (KCS) from six different countries. **Mussel aquaculture** in Galicia (Spain) has been identified as one of those sensitive KCS, as it plays a vital role in the economic well-being of the region, providing employment opportunities and supporting socio-economic development, while facing significant risks from extreme weather events induced by climate change.

MUSSEL RAFT MONITORING

This report describes the design, installation and testing of an IoT solution for mussel rafts monitoring (MRM) in the Ría de Arousa (Arousa Estuary) in Galicia. This technological solution, developed by the Marine Technologies Unit of CETMAR, aims to provide real-time information through an IoT solution to facilitate decision-making for mussel producers in Galicia, ultimately aiming to transform the sector and help it adapt to the detected environmental changes linked to climate change and other anthropogenic pressures.

The MRM has also potential applications in other blue sectors and regions facing similar challenges. Through the continuous collection of information, this initiative will facilitate changes in practices and the development of adaptation measures, helping to mitigate operational risks and improve the resilience of blue economy activities.



01 Introduction

1.1 Galicia demonstrator

1.2 What is the Mussel Raft Monitoring (MRM)?

1.3 MRM specific objectives

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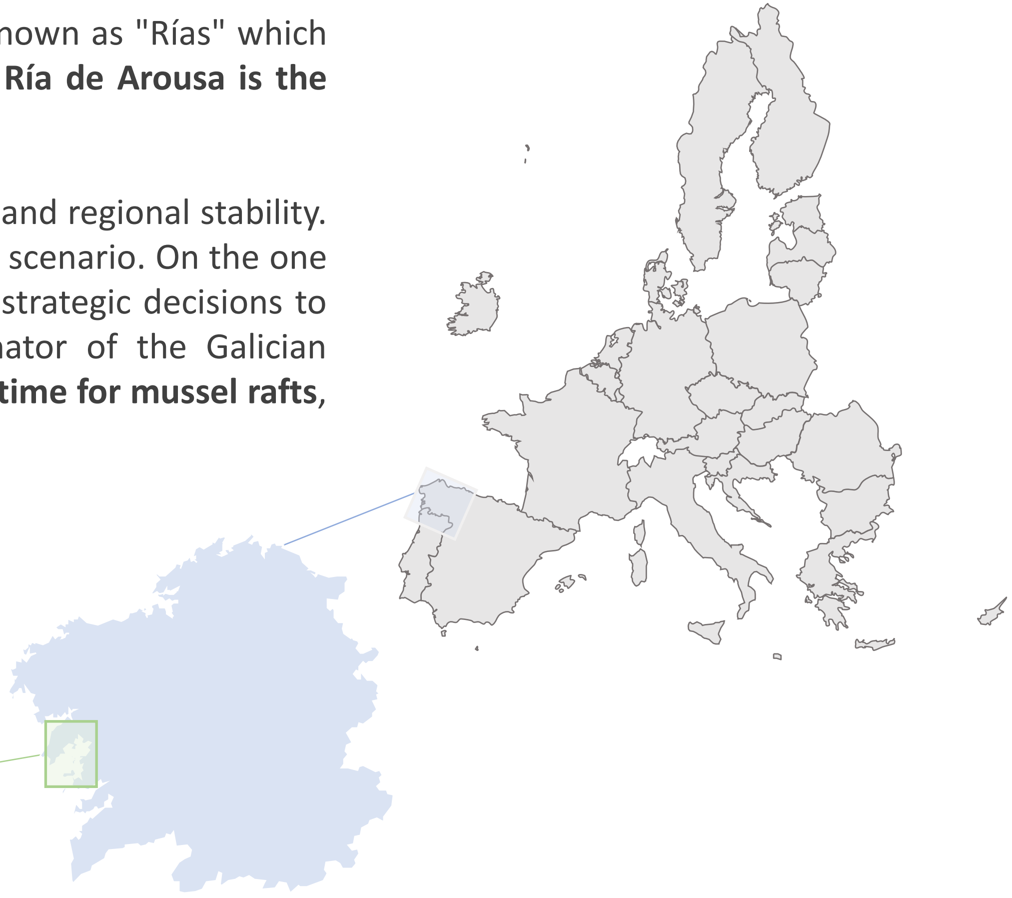
01 INTRODUCTION

1.1 Galicia demonstrator

The region of Galicia, located in the northwest of Spain, is known for its coastal inlets known as "Rías" which present favorable conditions for mussel aquaculture in hanging rafts. In particular, the **Ría de Arousa is the largest and most productive** in Galicia with 70% of the mussel rafts.

This Galician estuary also faces climatic vulnerabilities threatening the productive sector and regional stability. Two solutions are being developed within the framework of TransformAr to adapt to this scenario. On the one hand, the **University of Vigo has developed the Operational Resilience Index** to guide strategic decisions to avoid interruptions in production operations. On the other hand, **CETMAR,** coordinator of the Galician demonstrator in TransformAr, has implemented **monitoring met-ocean variables in real time for mussel rafts**, the subject of this report,



MUSSEL RAFTS

RÍA DE AROUSA

GALICIA

EUROPE

Figure 1. Galicia demonstrator

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01 INTRODUCTION

1.1. Galicia Demonstrator. (CETMAR Background)

CETMAR, together with MeteoGalicia and INTECMAR is part of the ***Observatorio Costeiro da Xunta de Galicia.*** This Coastal Observatory of the Galicia regional Government is located in the NW Iberian Peninsula and it is also part of the cross-border RAIA Observatory. It has been operating for 15 years, by the collaboration of the three public institutions. The observatory includes several networks to gather real-time data on ocean and atmospheric conditions in which CETMAR works actively since 2009. It also maintains numerical forecast systems and develops value-added products and services based on the collected information.

Thanks to the experience in real-time monitoring that CETMAR has acquired over time within the framework of the Xunta de Galicia's Coastal Observatory, CETMAR decided to take on the challenge of implementing real-time monitoring for a mussel farm. This initiative was a natural progression, leveraging their expertise to enhance the precision and efficiency of monitoring operations in these aquatic environments

METEOGALICIA

intecmar INSTITUTO TECNOLOXICO PARA O CONTROL DO MEDIO MARIÑO DE GALICIA

CETMAR CENTRO TECNOLÓGICO DEL MAR

SeaDataNet

EMODnet European Marine Observation and Data Network

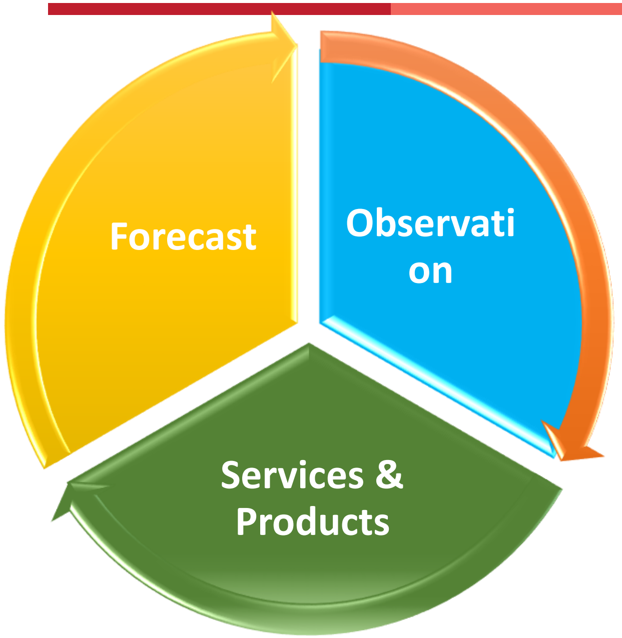
Marine Monitoring

RAIA Observatorio Oceanográfico Marxe Ibérica

www.marnaraia.org

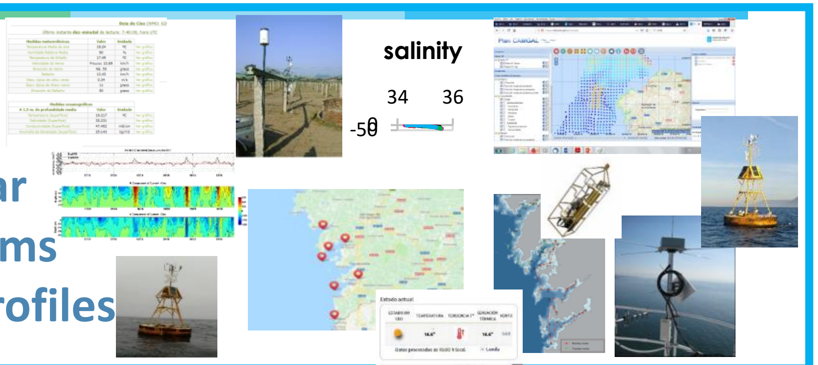
01 INTRODUCTION

1.1. Galicia Demonstrator. (CETMAR Background)



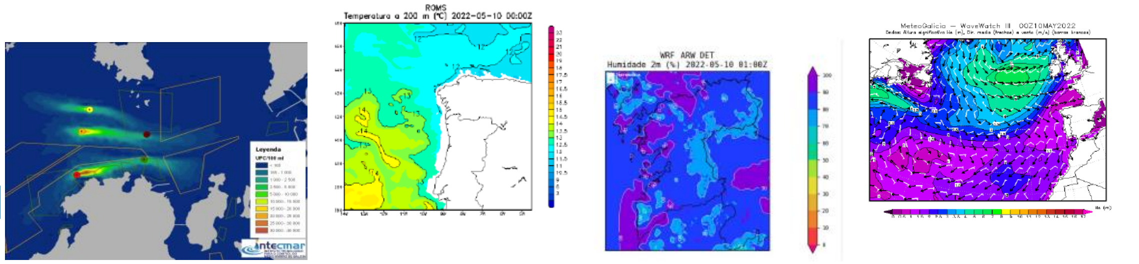
Operational Observing System

- External High Frequency Radar Network
- Coastal Weather Stations and Meteo-Radar
- 6 Automatic ocean-meteorological platforms
- 43 Oceanographic stations: vertical CTD profiles



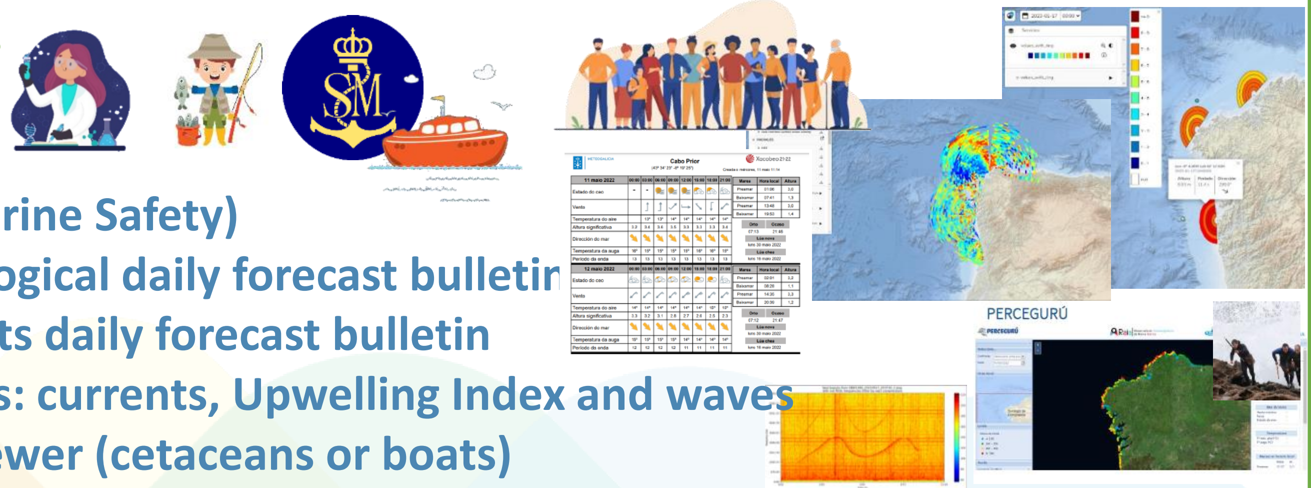
Forecast System

- Hydrodynamic models
- Wave models
- Atmospheric WRF model
- Lagrangian models



Services & Products

- Percegurú APP
- Kitesurf APP
- Plan Camgal (Marine Safety)
- Ocean-meteorological daily forecast bulletin
- Beaches and ports daily forecast bulletin
- HF Radar viewers: currents, Upwelling Index and waves
- Sound events viewer (cetaceans or boats)



EMODnet European Marine Observation and Data Network

SeaDataNet

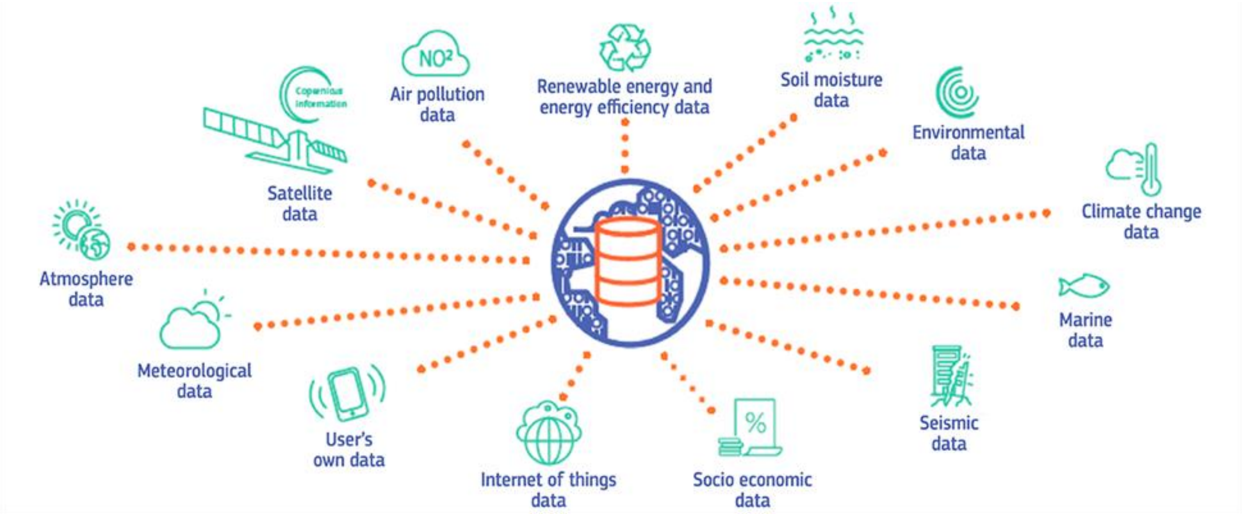
Marine Monitoring

01 INTRODUCTION

1.2 What is the Mussel Raft Monitoring?

Digitalisation of mussel rafts means:

- Real-time monitoring of :
  - Environmental conditions: potential impacts on mussels.
  - Management parameters: control of maintenance operations in the raft (unfolds, rope extraction, surveillance), mussels traceability.
- Near real-time information access



Tranformar MRM Design will contribute to Directive 2019/1024 on open data. (Figure 2: DestinE Data Lake. European Commission. Source:(https://digital-strategy.ec.europa.eu/en/library/destination-earth).

The European Union is strongly promoting the digitalization of various sectors as a key strategy for fostering growth and innovation. Digital transformation is seen as a crucial driver for enhancing productivity, improving competitiveness, and creating new economic opportunities. However, traditional sectors related to the marine environment, such as fishing and aquaculture, remain largely under-digitalized. This digital lag poses significant challenges for these industries in terms of efficiency and sustainability. The EU's Digital Agenda for Europe and the European Green Deal highlight the importance of digital innovation in achieving economic and environmental goals. Specifically, the EU Directive 2018/1972 establishing the European Electronic Communications Code and Directive 2019/1024 on open data and the re-use of public sector information encourage the adoption of advanced digital technologies across all sectors, including marine-related industries, to support their modernization and adaptation to current challenges. Additionally, the European Maritime, Fisheries and Aquaculture Fund (EMFAF) emphasizes the need for technological advancement and digitalization in the blue economy to enhance sustainability and resilience. By embracing digital tools, these sectors can significantly improve their operational resilience, sustainability, and capacity to respond to changing environmental conditions and market demands.

01 INTRODUCTION

1.3 MRM specific objectives

Specific objectives:

- **1 Technological Challenge: Design and install an IoT solution suitable for the marine environment.**
    - To sensorize at least one mussel raft using renewable energy sources for power and mobile communications to reduce costs.
    - To achieve an installation as autonomous as possible, minimizing maintenance requirements.
    - Evaluate the feasibility of the solution from, the capacity to generate FAIR (Findable, Accessible, Interoperable, and Reusable) data perspective, and the cost-benefit of an installation of this nature perspective.
    - To Showcase the efficacy of solutions in bolstering resilience within the mussel sector in Galicia and ascertain their potential for replication.

- **2 Knowledge Challenge: Gather relevant data on the marine environment and other parameters related to the behavior of the mussel raft on a continuous and long-term basis:**
    - To improve the understanding of the conditions of the marine environment and structural parameters, significant for mussel farmers.
    - To evaluate whether having continuous, and real-time data improves the management of a mussel raft or the sector activity as a whole.
    - To improve the understanding of the local oceanographic environment which allow the design of early warnings that will contribute to the effective use of this information in the future.

01 INTRODUCTION

1.3 MRM specific objectives

- **3 Social Challenge: Establish a direct communication channel with the sector to enable co-design of the solution and real adaptation to its needs :**
    - Co-design the solution by integrating scientific perspectives, marine protection considerations, and production management needs.
    - Facilitate access and visualization of data transmitted in real-time and historical data. To implement a Data Web Access to the data to enable the future development of AI-based applications.
    - To evaluate the impact of the solution in mussel producer routine, identify the room for improvement and correct possible errors or inappropriate approaches.
    - Engage with stakeholders and increase the awareness and the perception of risks to address territorial vulnerabilities linked to CC.
    - Promote the social acceptance and interest in replicating the solutions or any of the components developed
    - Propose governance and management measures and actions and contribute to the TransformAr Action Plan

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02 Context and background

2.1. Inception (problem/origin of the idea)

2.2 Introduction (Reference documents)

2.3 Framework

General index

02 CONTEXT AND BACKGROUND

2.1 Inception (problem/origin of the idea)

The main climate-related threats for this culture are negative impacts from **extreme weather events (winds, waves)** on the mussel raft structures, the **availability of mussel seeds** and **harmful algal blooms. However, other risks are also identified: changes in upwelling conditions, high water temperatures, or sustained low salinities over time.**

Mussel aquaculture

- About 40% of European production in more tan 3.000 floating rafts.
- Directly employs more tan 5.000 persons

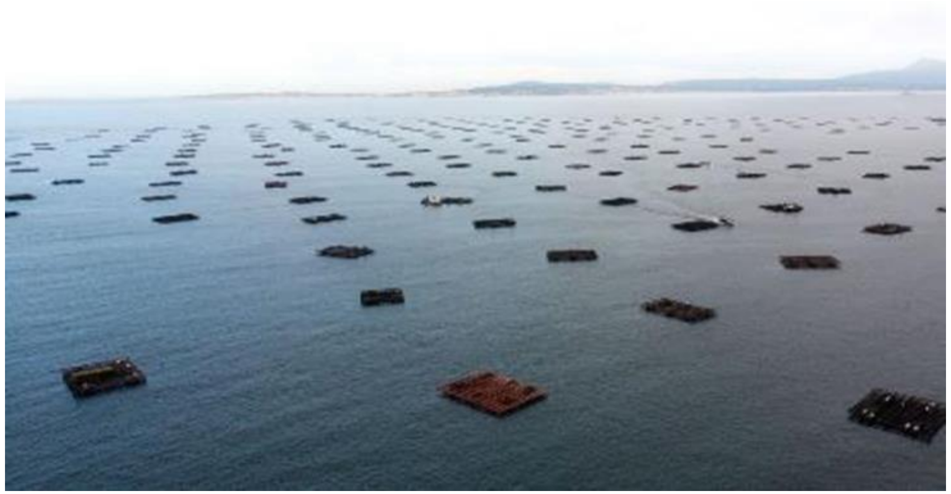

Figure 3. Galicia demonstrator

European Digital Strategy 2020-2030

Digitalization could mean decreasing the carbon footprint and a better and quicker response to extreme events, thus avoiding climate-related damages.

Prompt and open data communication is typically needed to take robust and effective decisions.

TransformAr will test digital and technological solutions for an intelligent mussel production management, based on the real time monitoring of the mussel-rafts.
The behavioral change will be further ensured by involving the relevant actors from the sector, the research community and the public administration in the creation of tools for both cultures.

02 CONTEXT AND BACKGROUND

2.2 Introduction (Reference documents)

The MRM implementation takes as a reference the previous work done in the IR framework by the University of Vigo through literature review and expert consultation. IR Solution has developed two main documents in which CETMAR has actively participated: the contextualization document and the identification of production stages of the mussel aquaculture processes document.


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Índice de resiliencia para la acuicultura del mejillón en Galicia – Delphi 1

Documento de contextualización

Figure 4. Contextualization document

Here

The purpose of this document is to provide an **overview of the context of the mussel sector in Galicia.** The key aspects that make up the environment in which this important aquaculture activity takes place are presented:

- Geographic context
- The climate of the territory
- Demographic context
- Socio-economic context
- Business and R+D+I context
- Institutional framework

Figure 5. Document on the stages of the mussel farming process


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Cadena de valor del mejillón en Galicia

Identificación de procesos

Here

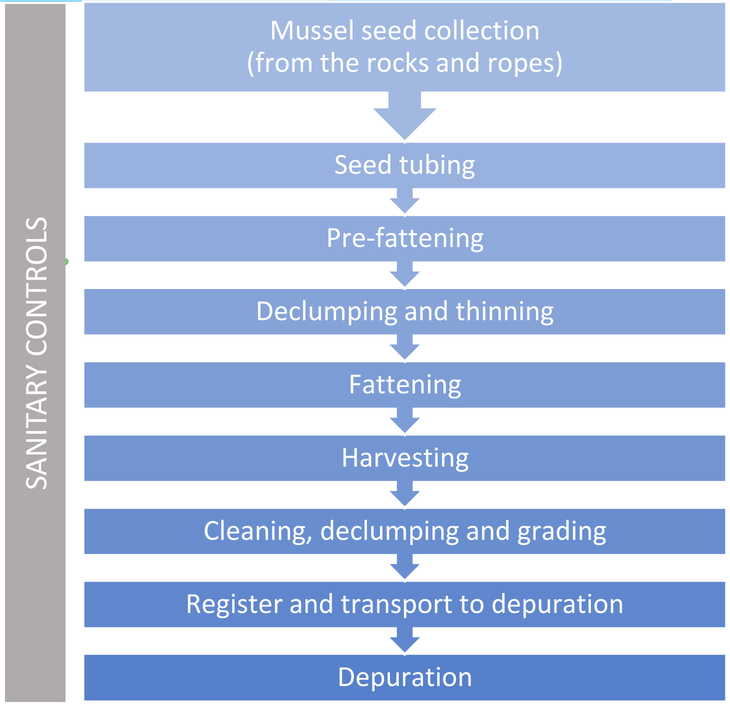

Figure 6. Stages of the mussel farming process

The objective of this report was to identify and validate the main stages of the mussel farming process, from the mussel seed collection to the depuration. After revision by experts, **nine phases of the production process were identified and validated**. In addition, Sanitary Controls have been identified as a cross-cutting activity in all these phases.

The results achieved in the contextualization document of the Galician mussel sector supported the preliminary idea of selecting rafts in the Ría de Arosa.

The Arousa estuary was chosen not only because it is the most productive, but also due to its specific characteristics, since encounters all the identified climate risks. The Ría is affected by storms and extreme events mainly during winter, its high productivity depends on upwelling conditions, and thus on the winds that blow over the Galician shelf. Additionally, the important river discharges cause significant drops in salinity during rainy periods. This choice was further validated during the project, as both a shortage of mussel seeds in the Ría and significant mussels detachments, possibly linked to environmental conditions, were detected.

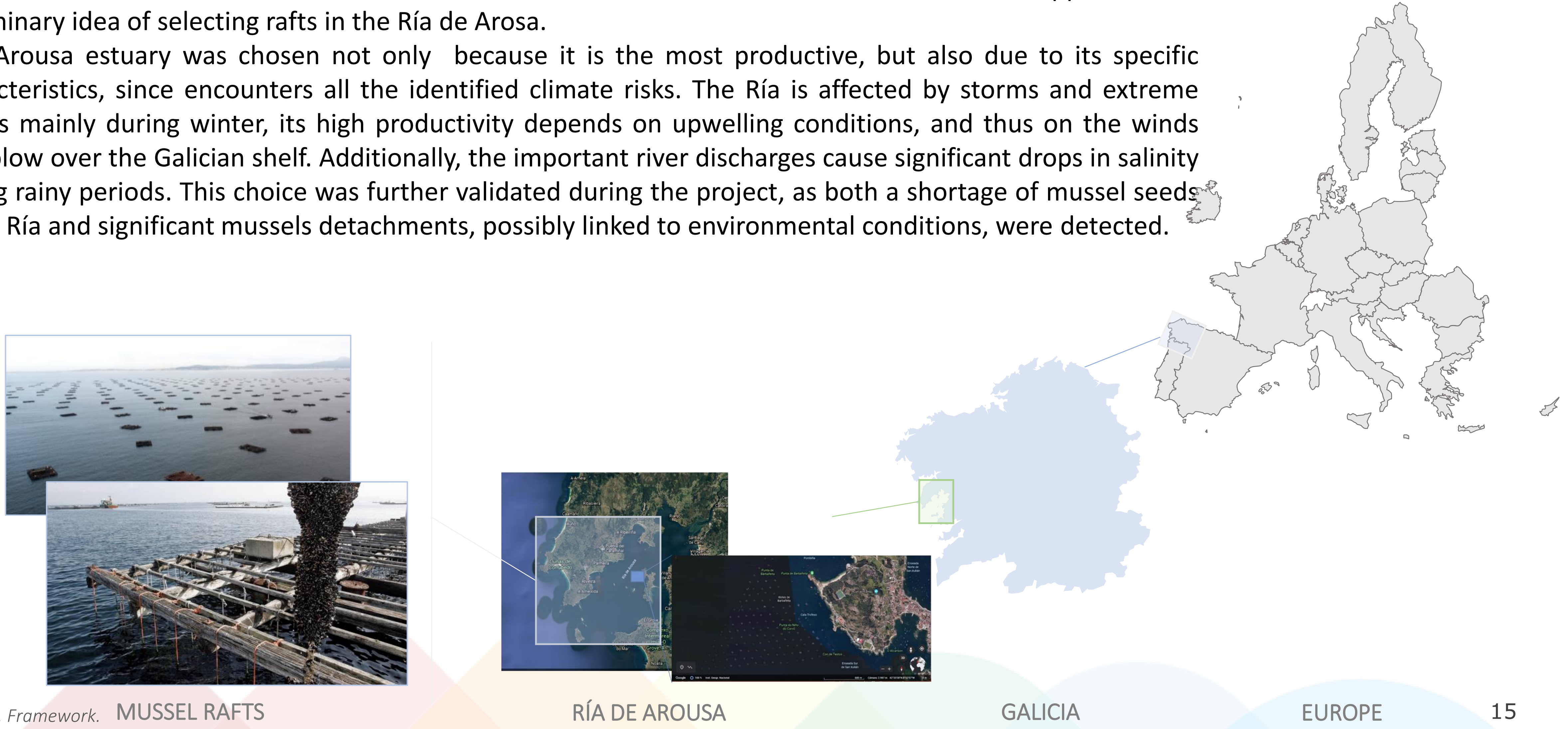

Figure 7. Framework.

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03 Development process

General index

3.1 Requirements

Following the selection of the rafts, a co-design process was proposed to the owners of these rafts, gathering their feedback throughout the entire process and ensuring the implementation of adjustments to meet their requirements.
As a first step, a series of minimum requirements were established, to address both the daily operational requirements of the producers working on the rafts as well as scientific and technological needs :

Producer Requirements:

- The solution must be designed to be integrated into the available infrastructure, without interfering with the daily actions of the workers.
- For its design, both technical and economic aspects were considered, as well as the impact of the implemented solutions, facilitating and promoting its replication and scalability.
- The access and visualization of the data must be affordable for the producers and useful in decision-making for more effective and sustainable management of resources.
- New updates will be always consulted with the owners of the rafts, counting on their collaboration and experience.

Technological Requirements:

- The solution must resist the adverse conditions of the marine environment, achieving a minimum maintenance.
- The autonomy of the installation in normal operation must be at least 15 days without external intervention.
- Monitor the location and movement of the installation (GPS).
- Monitor meteorological data with a minimum frequency of 10 minutes.
- Real-time data transmission. Automatic operation and telematic transmission of data.
- Alarm or warning systems should be in place to provide information on the status of the installation.

Figure 8. Digitalization as a decision-making assistance tool

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03 DEVELOPMENT PROCESS

3.2 Selection of sensors

Figure 9. Rafts situation.

The installation is focused on monitoring the structural condition of the raft and monitoring the environmental condition. Concerning the <u>**structural condition**</u>, the movements of the raft, its exact location, the increase of weight on the mussel ropes and possible vandalism are monitored. The raft is located through a **GPS** device, which will allow the implementation of early warning of mooring failure. The combination of **gyroscope**, **accelerometer,** and **magnetometer** detects the slightest displacements, rotation and orientation of the structure, as well as the abruptness of these changes.

An estimation of the mussel growth rate is measured using **load cells.** They are integrated into a wood or plastic device that allows data collection without breaking the rope to which the mussel are attached. The load cells convert the force exerted by the weight of the mussels into an electrical signal, which the **HX711 module** transforms into amplified digital data, transmitted to the Arduino Pro Mini 328 microcontroller.

Figure 10. Raft

Figure 11. Load cell

<u>Structural State</u>

- GPS
  - Location
- IMU
  - Movement
- Load Cells
  - Production/ Weight
- Bluetooth
  - Vandalism
- Ultrasonic transductor
  - Approach (ships, waves,...)

Since these rafts are anchored in a single point, it is expected that growth across all ropes will not be identical. To study this internal variability, at least three ropes are simultaneously monitored using load cells: one at the bow of the raft, another in the central area, and a third at the stern of the raft.

Figure 12. Vaisala Weather Station

To monitoring the environmental conditions, both meteorological and oceanographic parameters were identified.

Regarding meteorological parameters, **a Vaisala WXT536 weather station was selected to** gather information about rainfall, wind direction and speed, air temperature, and humidity.

Environmental State

- ➢ Turbidity sensor
- ➢ IMU+ Ultrasonic transductor
  - Agitation
- ➢ Vaisala
  - Rain
  - Wind
  - Air Temperature
- ➢ CT
  - Conductivity
  - Temperature
  - Pressure
- ➢ Underwater Temperature Sensors
  - UnderWater Temperature (6 levels)

Regarding oceanographic data, the initial design considered just the installation of a Temperature and conductivity sensor, but during the installation phase, complementary equipment was installed. Although an own design of CTD sensor was considered, finally it was decided to install a **Seabird inductive CTD (SBE37) provided by the Coastal Observatory of the Xunta of Galicia** that assure quality on **conductivity** and **temperature** measurements, as well as the **pressure**, and allows the **salinity** of the water to be calculated. This device has been installed at 2 m depth.

Figure 15. Seabird Inductive CTD and Seapoint turbidimeter before submersion

Figure 13. Ultrasonic sensor

In addition, to monitor temperature in the water column, as indicator of the intensity of stratification and upwelling, a chain of 6 underwater temperature sensors was added to the installation. These allow water temperature measurement in the surface layer (-0.5 m) and at depths of 1, 3, 5, 7, and 10 meters.

Environmental State

- Turbidity sensor
- IMU+ Ultrasonic transductor
  - Agitation
- Vaisala
  - Rain
  - Wind
  - Air Temperature
- CT
  - Conductivity
  - Temperature
  - Pressure
- Underwater Temperature Sensors
  - UnderWater Temperature (6 levels)

DS18B20 underwater temperature sensors, although their accuracy is only ±0.5ºC, are very economical, and using the temperature measured by the SBE37 CTD as a reference, we can calibrate this series of sensors and increase the reliability of the data collected.

A **turbidimeter** was also integrated to give an idea of the surface water transparency.

Figure 14. Temperature sensor

03 DEVELOPMENT PROCESS

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3.3 Installation

The implementation of the solution was design in three phases:

	Calendar	Description
PHASE 1: IN-SITU DATA STORAGE INSTALLATION	May. ´22 - Dec. '23	In progress
1.1 Design monitoring hardware	May '22 – Jun '22	**Design of the in-situ data storage solution done.** Hardware installation design for the raft mussels monitoring finished.
1.2 Installation and monitoring of the in-situ data storage version	Jun '22 – Oct '23	Sensors already installed since May 2022 in one raft in the Ría de Arosa.
1.3 Data Processing	Nov '22 – Dec '23	In progress: Multiparameter data analysis, optimization of data acquisition frequencies and data management
PHASE 2: IoT SOLUTION INSTALLATION. Real time data transmission	Dec. ´22 - Mar. '24	-
2.1 Design monitoring hardware	Dec '22 – Jan. '23	**H**ardware installation design for the raft mussels monitoring and communication protocols for real-time data transmission.
2.2 Installation and monitoring real time version	Feb '23 – Oct '23	Installation of the IoT solution in a raft in the Ría de Arosa (a real time version with telemetry)
2.3 Data Processing	Mar '23 – Mar '24	Multiparameter data analysis, optimization of data acquisition frequencies and data management
PHASE 3: DATA VISUALIZATION	May. ´23 - Jun. '24	-
3.1 Dashboard platform implementation	May '23 – Jun '24	Define and design a dashboard to visualize data in a web platform

Phase 1: **Initial installation (No Real-time transmission)**

Initially, all sensors were installed in a self-contained version without real-time data transmission to assess whether the setup was sufficiently robust and did not interfere with the daily operations on the raft. Data were stored in situ in **SDCard**.

Datasets:

Observational oceanographic dataset: Temperature, salinity, pressure wind, rain, compiled in a ***Quantitative tabular data with minimal metadata*** and referred to *geospatial data.*

Type of expected file: .csv
Size: 7GB/month
Files: 1 file/day

Observational biophysical dataset for the mussel culture*: Attitude, movement, vandalism* compiled in a ***Quantitative tabular data with minimal metadata*** and referred to ***geospatial data.***

Type of expected file: .csv
Size: 7GB/month
Files: 1 file/day

Structural state & production parameters

- GPS.
  - Location
- Load Cells
  - Production/ Weight
- Bluetooth sensor in the ropes
  - Vandalism
- Ultrasonic transductor
  - Ships Approach detection

Environmental state

- IMU + Ultrasonic transductor
  - Wave agitation →movement of the ropes →landslides
- Underwater Temperature Sensors
  - UnderWater Temperature (6 levels)

Phase 2: Real-time monitoring (Data Acquisition and Communication System)

The main components of the installation are a **Campbell CR1000X datalogger**, a **Vaisala WXT530 weather station**, a **Seabird Inductive CTD**, a **Seapoint turbidimeter**, **1 main node (IMU node)**, and **3 sub-nodes (ULC nodes)** with a series of integrated sensors that provide data on the conditions to which the pan is exposed both structurally and environmentally.

- The **Vaisala WXT530** station connects directly to the **datalogger**,
- The **Seabird SBE37 MicroCAT inductive CT** connects via an inductive modem (SIM).
- The **IMU node** consists of an **Arduino Nano 33 BLE Sense** development board, an **Arduino MKR GPS Shield,** and **2 bi-directional UART TTL** to **RS-485 converters**.
- The **ULC node** consists of an **Arduino Pro Mini 328**, a **JSN-SR04T adapter**, an **HX711 amplifier board**, and a **bidirectional UART TTL** to **RS-485 converter**.
- One of the 3 sub-nodes does not need the **JSN-SR04T adapter**, as only two distance sensors will be installed.
- The connection between nodes is made using the RS485 protocol, except in the connection of the MKR GPS Shield component with the Arduino Nano 33 BLE, in which case the protocol used is I2C.

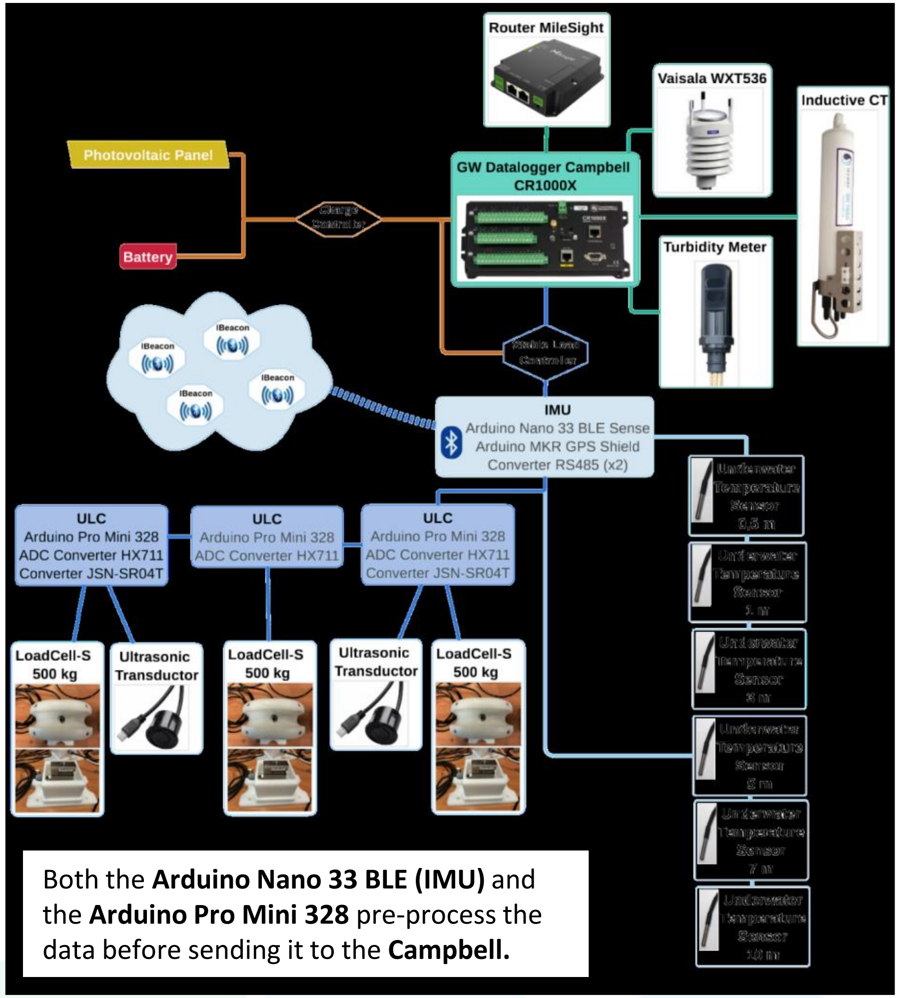

Figure 16. Diagram of the IoT installation components

Phase 2: Real-time monitoring (Data Acquisition and Communication System)

- The data processed by the datalogger is transmitted **in real-time** via the **MileSight UR32 router**.
- This connects to the internet via a **SIM card** and allows data transmission to the center’s server. Using **Campbell Sci's own LoggerNet software**, we can remotely connect to the installation.

This allows one to check its status, download or update the current program, and even change the datalogger configuration and the routes to save the data, among other functions.

Communication Near-Realtime

- ➢ 10 min aggregate values automatic update
- ➢ Store high-frequency values for movement and forcé values (1 second)
- ➢ Visualization dataset in a web platform (in development)

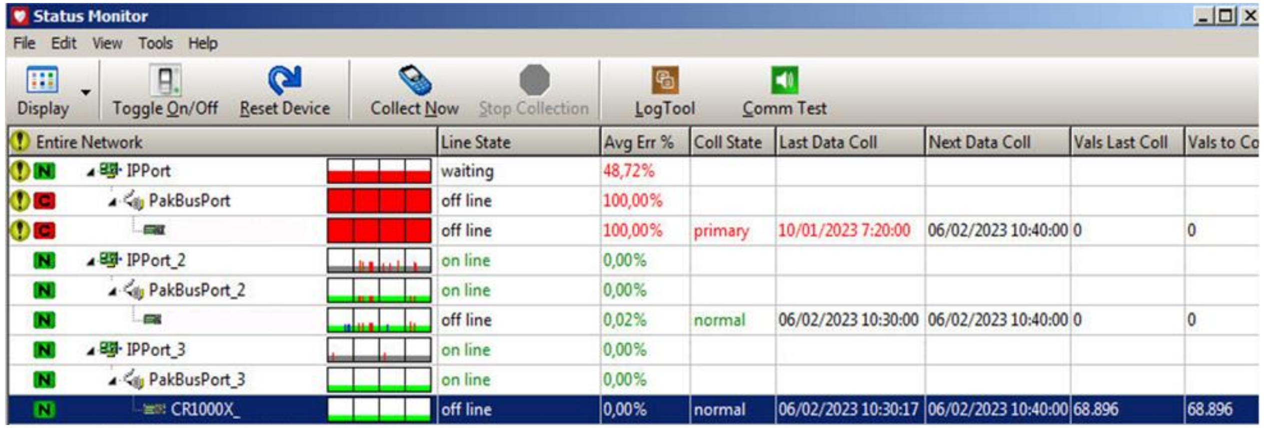

Figure 17. Status Monitor.

03 DEVELOPMENT PROCESS

3.3 Installation

Phase 2: **<u>Real-time installation (sensors)</u>**

Figure 18. Sensors.

<u>Structural State</u>

- ➢ GPS
  - ■ Location
- ➢ IMU
  - ■ Movement
- ➢ Load Cells
  - ■ Production/ Weight
- ➢ Bluetooth
  - ■ Vandalism
- ➢ Ultrasonic transductor
  - ■ Approach (ships, waves,...)

Figure 19. GPS, IMU, Bluetooth and ultrasonic transductor.

<u>Environmental State</u>

- ➢ Turbidity sensor
- ➢ IMU+ Ultrasonic transductor
  - ■ Agitation
- ➢ Vaisala
  - ■ Rain
  - ■ Wind
  - ■ Air Temperature
- ➢ CT
  - ■ Conductivity
  - ■ Temperature
  - ■ Pressure
- ➢ Underwater Temperature Sensors
  - ■ UnderWater Temperature (6 levels)

Photovoltaic system:

- The power supply for the installation comes from a **photovoltaic installation**.
- The installation consists of **2 monocrystalline photovoltaic panels** of **50 W** each, a **75/15 MPPT regulator**, and **2 Varta batteries** of **95Ah** and **800 Amp CCA**.
- The panels feed the batteries, after passing through a charge regulator, and these supply energy to the datalogger, which is connected to the rest of the nodes and the router, allowing it to be powered.
- The weather station, the turbidimeter, and the SIM board through which the **inductive CTD** is connected are powered by **the batteries**.
- The **inductive CTD** device is powered by batteries, so it does not contribute to the consumption demand of the photovoltaic installation.

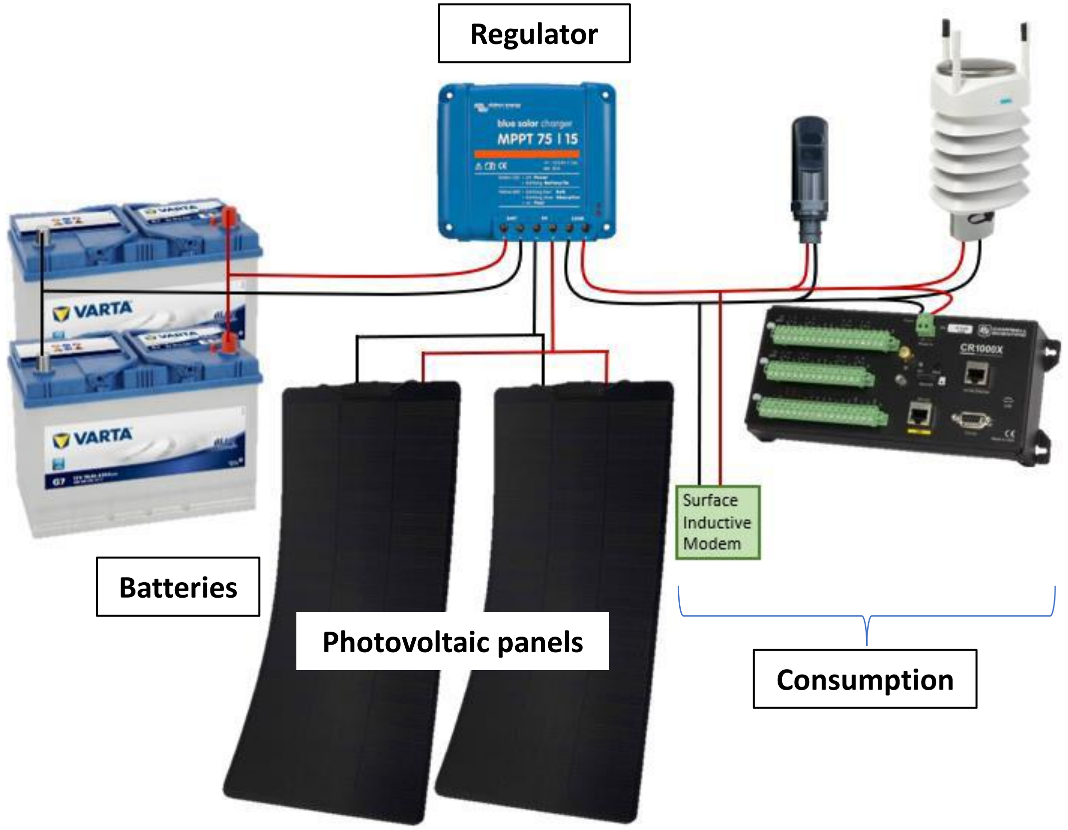

Figure 20. Photovoltaic system diagram.

3.4 Maintenance

The maintenance of this type of solution is a key aspect for its future viability. After the system has been operational for nearly a year and a half, this maintenance should consider the following:

- Routine cleaning of the equipment and solar panels, as well as water sampling for sensor calibration every 20-30 days, as the design allows it to be practically autonomous in terms of data collection and energy. It is expected that in more oligotrophic waters than those in Galicia, these maintenance intervals could be extended.
- Routine weighting of the monitored ropes for the calibration of the load cell data is needed.
- Revision of the wiring and the M12 connectors of the devices to avoid corrosion.

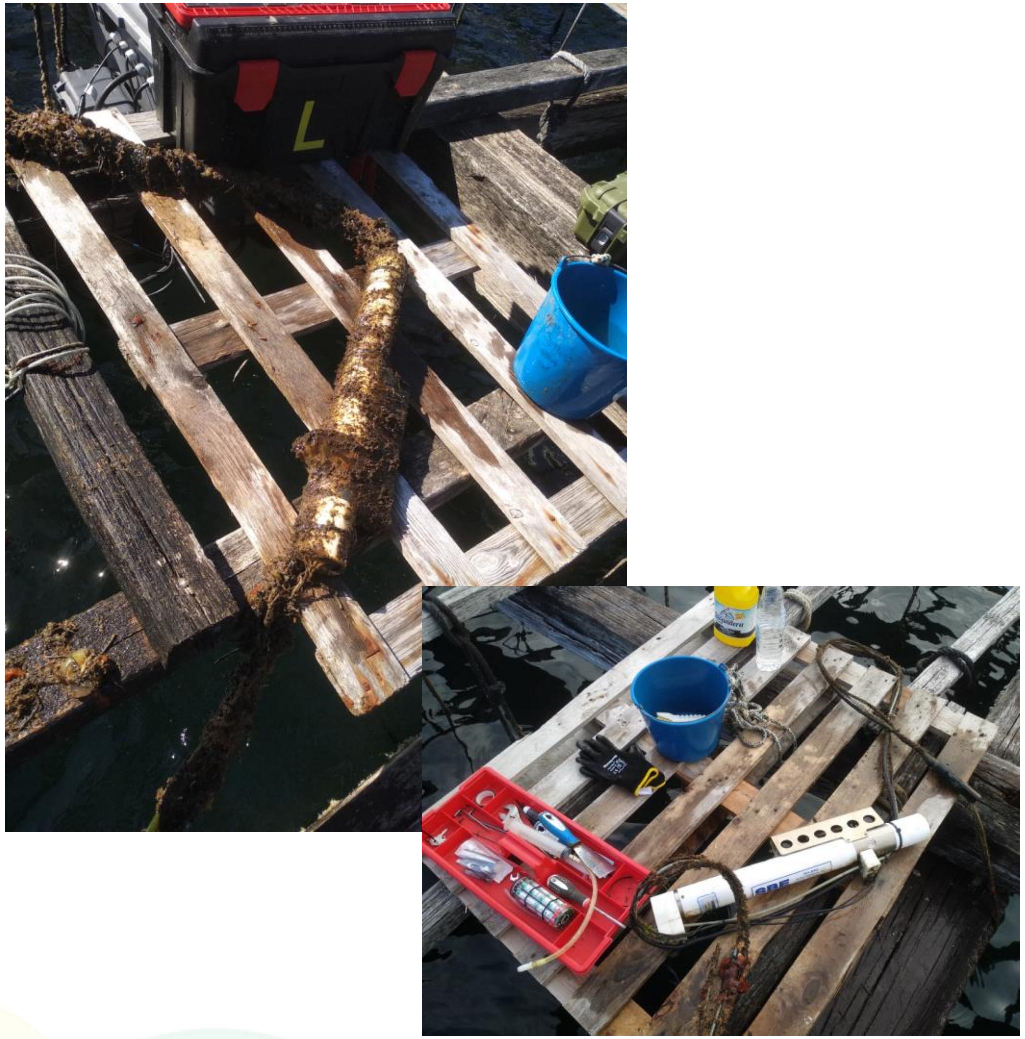

Figure 21. Photos of the installation before and after cleaning. A CTD sensor.

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03 DEVELOPMENT PROCESS

3.4 Maintenance

Regular monthly maintenance visits have been crucial in ensuring the IoT installation on the floating platform remains fully operational. Over the past two years, we have conducted nearly 30 such visits, and we plan to continue this monitoring at least until the end of this year. These visits have been carried out in close collaboration with the platform owners, addressing their concerns and requirements. Through this joint effort, we have identified key areas for potential improvement, such as the detection of possible contaminants in the water and monitoring phytoplankton scarcity. These insights will be invaluable for future implementations and enhancements of the system.

During certain times of the year, scheduling maintenance visits can be challenging due to the limited weather windows available. Despite these difficulties, the collaboration with the platform owners has been exceptional. Their commitment has highlighted the sector's high awareness and acceptance of climate change issues and the importance of these technological developments.

2022	2023	2024
		Jan, 26
		Feb, 24
		March, 13
Apr, 24		April, 9 & 25
May, 27	May, 12	May, 8
Jun, 17	Jun, 14	Jun, 12
Jul, 26 & 27	Jul, 4 & 21	Jul, 12,30
Aug, 30	Aug, 4	
Sep, 30	Sep, 31	
Oct, 30		
Nov, 4	Nov, 17 & 23	
Dec, 1	Dec, 19	

DATA ACQUISITION

Improvements

	Advantages	Disadvantages
Self-contained (upgrade)		- Not having the information in real-time - Periodically replacing the physical memory card with an empty one, thus reducing its autonomy.
Limited real-time	- Increased data storage capacity per unit of time. - Data is stored without the need to be processed. Sent by the datalogger.	- Not having much of the information in real-time (having to wait weeks) to be able to access it. - Periodically replacing the physical memory card with an empty one, thus reducing its autonomy.
Real-time (Current)	- Full real-time availability - Optimizes the amount of data collected and is stored remotely and autonomously on the server. - It avoids having to open the watertight boxes to extract the memory: reducing the risk of flooding and corrosion of the installation's electronic boards as they lose their water-tightness during this manipulation.	-

03 DEVELOPMENT PROCESS

3.5 Monitoring (upgrade)

IMPROVEMENTS

Device	Improvement
Solar Pannel	Replacement of two 50-watt flexible solar panels with one 100-watt rigid solar panel.
Device Nodes	Redesign from a single node per load cell to a single node for all load cells.
Weather Sensor	Use of a new sensor of another brand, with integrated compass
Ultrasonic sensors	Removal of the ultrasonic sensors for water agitation, since they did not provide relevant information.
Temperature sensors (6)	Low-cost temperature sensors are discarded because they are not robust in marine environments. Measurements obtained are very inconsistent over time.
Load Cell	The initial load cells are replaced by stainless steel ones, with a smaller measuring range and more stable measurement.
IMU & Load Cell Data	Change reporting frequency to 1 every 5 seconds
Position and sound Data	Change reporting frequency to 1 every minute

3.6 Shore-based data management and storage

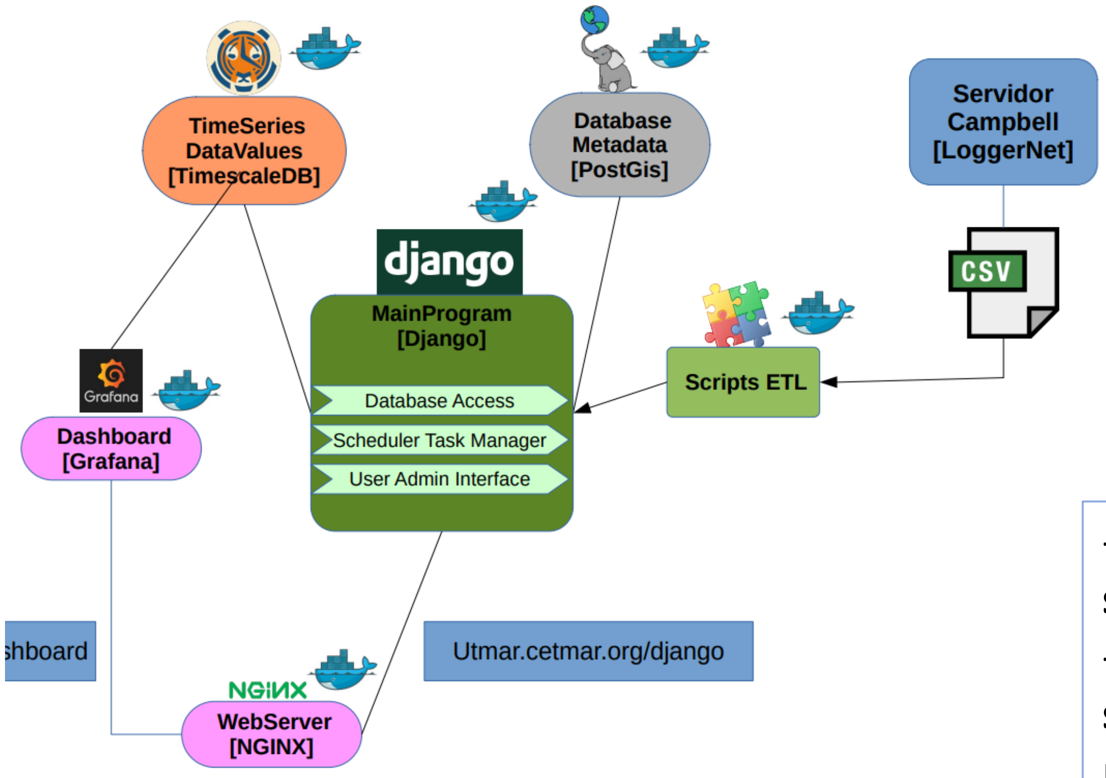


Figure 22. Structure and data flow.

The applications for data management are run independently using containers (Dockers), which allows for greater security of the data and their connections.

1) The Campbell CR1000X datalogger sends data to the central server.

2) Through the LoggerNet software, above, the datalogger stores the configured data tables in 5 different .csv files.

These store the data sorted as follows:

➔ CTD.
➔ IMU and Cell node. Data from High-frequency sensors.
➔ GPS and Temp node. Data from Low-frequency sensors
➔ Weather station.
➔ Turbidimeter.

- Internally, these files can be accessed directly from the **Campbell server** for viewing and analysis.
- The **data** are **collected** at **frequencies of up to 1 data point per second**, so the files become too large after a few days to be easily manipulated and analyzed.
- To solve this problem, a script has been developed that automatically segments these files into smaller ones that a standard computer can manipulate.
- This is one of the **ETL scripts** that **pre-process** and **integrate** the information to be managed later in **Django**.

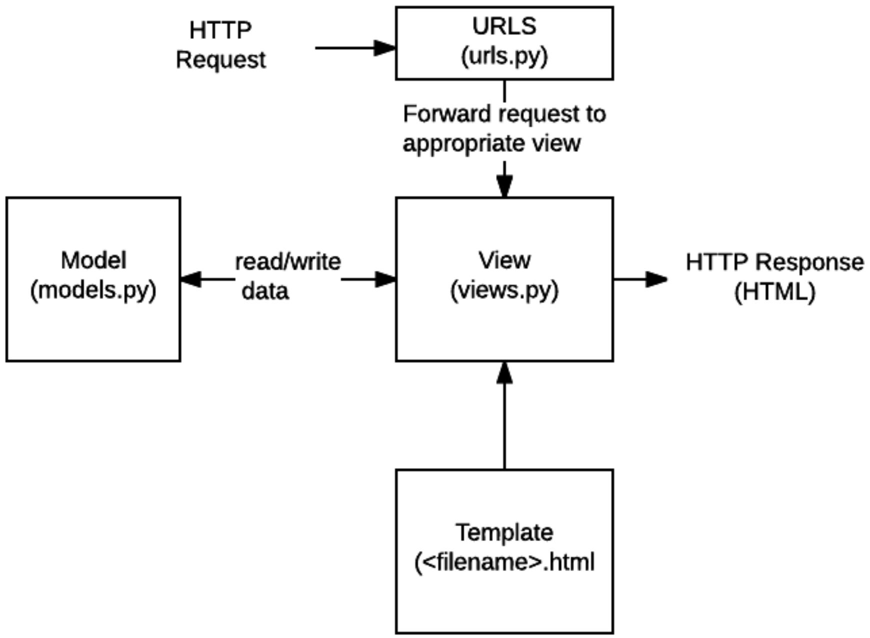


Figure 23. Diagram of the Model - Template - View pattern.

- The main program of this data architecture is developed in **Django**.
- This open-source web development framework facilitates this process and integrates functionalities such as a database management system, user authentication, content administrator, and task manager, among others.
- It is complete, secure, versatile, and scalable.
- It uses the **Model - Template - View pattern**.
- NGINX web server from which requests are made in the form of **URLs**.
- The URL referenced to Django allows us to access its interface, where we can visualize, analyze and manage the data stored internally.
- If the request is to the **dashboard**, access to the data is done through the **Grafana platform**, where permissions are reduced to visualization, and limited by the corresponding user management.
-This way of accessing the data: simplifies and organizes their visualization, and thus enables a secure access route outside the center, so that these data can reach the sector or any interested party, making them available to the public through a web page.

<u>**Regarding data storage**</u>:
- PostgreSQL database is used with the **TimescaleDB extension** for storing values (**DataValue**).
- PostGIS extension for geospatial metadata, providing support for working with this type of data.
- TimescaleDB extension allows for efficient and scalable storage of time series data recorded by **Campbell**. It classifies data in batches according to their origin or type, thus streamlining **SQL queries**.
- This addresses the need for data to be easily accessible to stakeholders from a public platform (**Grafana**).

03 DEVELOPMENT PROCESS

3.6 Shore-based data management and storage

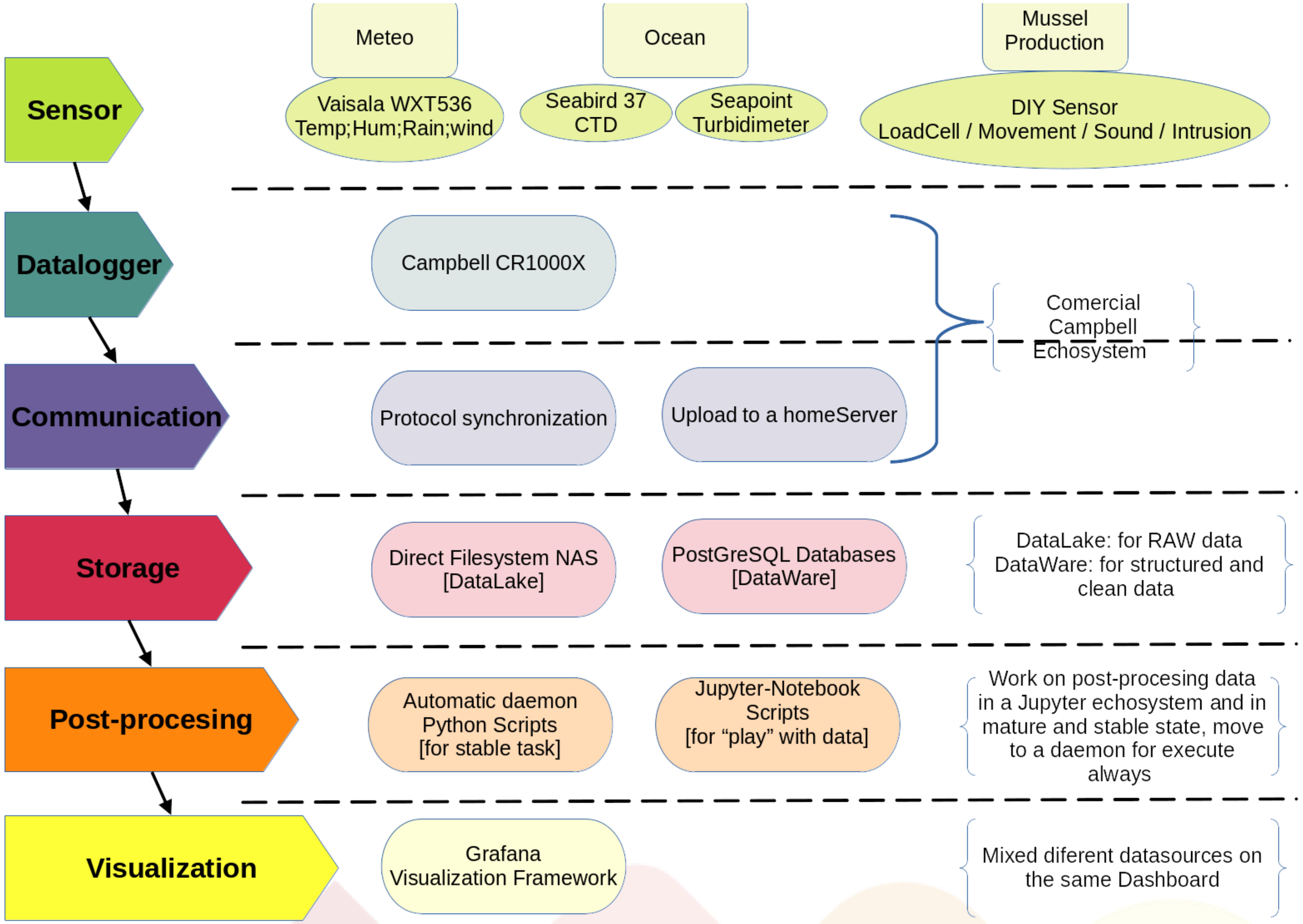


Figure 24. Data flow diagram.

The data flow is as follows:

- Data acquisition: from the **datalogger** in CSV format
- Set of ETL scripts: preprocess and integrate the information to be managed subsequently. Data cleaning tasks are performed by removing outliers by Zscore>2 and in some parameters, performing 24-hour moving averages.
- Data storage: two databases are used, one for storing sensor values (**PostgreSQL** with the TimescaleDB extension) and the other for metadata and data series management (**PostgreSQL** with the GIS extension). for geospatial metadata) The **TimescaleDB** extension allows efficient and scalable storage of time series data recorded by **Campbell**. Classifies data in batches based on its source or type, thereby speeding up SQL queries. This responds to the need for data to be easily accessible to interested parties from a public platform (**Grafana**).
- The visualization of the data collected in real-time is done through a dashboard developed on the **Grafana platform**. This tool facilitates the monitoring and analysis of time series in a friendly and intuitive interface for the user. This framework allows the visualization, download and export of data for both humans and machines (API REST).

03 DEVELOPMENT PROCESS

3.7 Protection of the solution

The solution's design is based on the integration of low-cost commercial components and custom-designed protective parts.
Notably, the protection and placement system for the load cells, developed at CETMAR facilities, has been instrumental in this approach. This device has undergone a lot of development to adapt it to the particularities of a mussel raft. This innovation has led to the application of a "utility model" patent to protect the development, underscoring the uniqueness and value of the design.

Figure 25. Device for in situ weight control of mussel rope.

GOBIERNO DE ESPAÑA — MINISTERIO DE INDUSTRIA, COMERCIO Y TURISMO — Oficina Española de Patentes y Marcas

Justificante de presentación electrónica de solicitud de modelo de utilidad

Este documento es un justificante de que se ha recibido una solicitud española de modelo de utilidad por vía electrónica utilizando la conexión segura de la O.E.P.M. De acuerdo con lo dispuesto en el art. 16.1 del Reglamento de ejecución de la Ley 24/2015 de Patentes, se han asignado a su solicitud un número de expediente y una fecha de recepción de forma automática. La fecha de presentación de la solicitud a la que se refiere el art. 24 de la Ley le será comunicada posteriormente.

Número de solicitud:	U202430299	
Fecha de recepción:	15 febrero 2024, 13:11 (CET)	
Oficina receptora:	OEPM Madrid	
Su referencia:	2024/1104	
Solicitante:	Centro Tecnológico del Mar – Fundación CETMAR	
Número de solicitantes:	1	
País:	ES	
Título:	DISPOSITIVO PARA EL CONTROL DE PESO IN SITU DE UNA CUERDA DE MEJILLONES	
Documentos enviados:	Descripcion.pdf (4 p.)	package-data.xml
	Reivindicaciones.pdf (1 p.)	es-request.xml
	Dibujos.pdf (3 p.)	application-body.xml
	OLF-ARCHIVE.zip	es-fee-sheet.xml
	FEERCPT.pdf (1 p.)	request.pdf
Enviados por:	CN=OEPM	
Fecha y hora de recepción:	15 febrero 2024, 13:11 (CET)	
Codificación del envío:	D2:60:F6:90:46:86:DE:D5:D4:B8:80:2E:22:09:F6:2A:F4:EF:A9:E5	

TransformAr

04 MRM Results

4.1 Results

4.2 Limitations and Research findings

General index

OBJECTIVE 1: **Technological Challenge: Design and install an IoT solution suitable for the marine environment.**

Two mussel rafts have been sensorized during TRANSFORMAR project using renewable energy for power and mobile communications, both of the Ría de Arousa. Main achievements:

- Real-time design and execution have been proven to be feasible. The IoT solution allows for routine operations on the raft to be carried out without needing to change any of the usual procedures, even with the operations involving the sensorized ropes. The use of IP68 watertight compartments for each of the devices that need to be protected from seawater or weather conditions means that they are kept away from corrosion and water. The design of the installation is easily modifiable both in terms of physical connection and adaptation of the programming code, to remove or add devices. Concerning economic viability, a cost corresponding to a pilot case with numerous devices is budgeted, a fairly complete installation, to test the usefulness of the data from each of these devices. When replicating or extrapolating this installation, we would consider which devices should be prioritized, according to the data required and the cost involved.

OBJECTIVE 1: **Technological Challenge: Design and install an IoT solution suitable for the marine environment.**

- The maintenance of the installation has been minimized, assuring autonomy both in terms of energy, data acquisition and transmission. The frequency of data acquisition has been optimized, making it feasible to transmit all the data collected in real-time and store them remotely, avoiding visits to the installation to collect the data in situ. Consequently, an important reduction in maintenance costs is achieved.

- In terms of energy, the installation has achieved an autonomy of 18 days without an external energy source, which is a guarantee against long periods of scarce sunlight that can feed the panels, a frequent and common problem in climates such as Galicia. The low battery and recovered battery warning system eliminate the need to check the battery status if everything is at the correct level, with the corresponding saving of time for the technicians. The possibility of switching off/on part of the installation remotely gives us the power to act on its consumption without the need to be present at the installation.

OBJECTIVE 2: Knowledge Challenge: Gather relevant data on the marine environment and other parameters related to the behavior of the mussel raft on a continuous and long-term basis.

- The systematical monitoring of a raft has allowed to improve the understanding of the Ria de Arousa marine environment, its variability and the key parameters for mussel aquaculture. Time series of more than two years of environmental and structural parameters has been gathered.

Cabodeiro raft - local wind

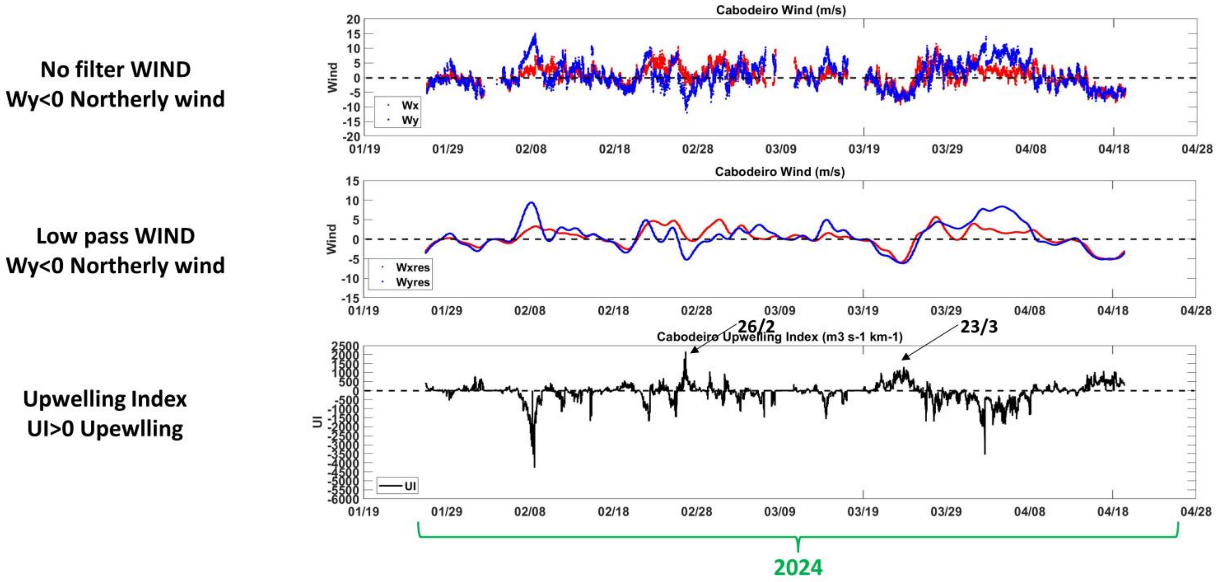


Figure 26. Cabodeiro Raft Local wind Time serie.

Caboderio SST and SSS (from june 2023)

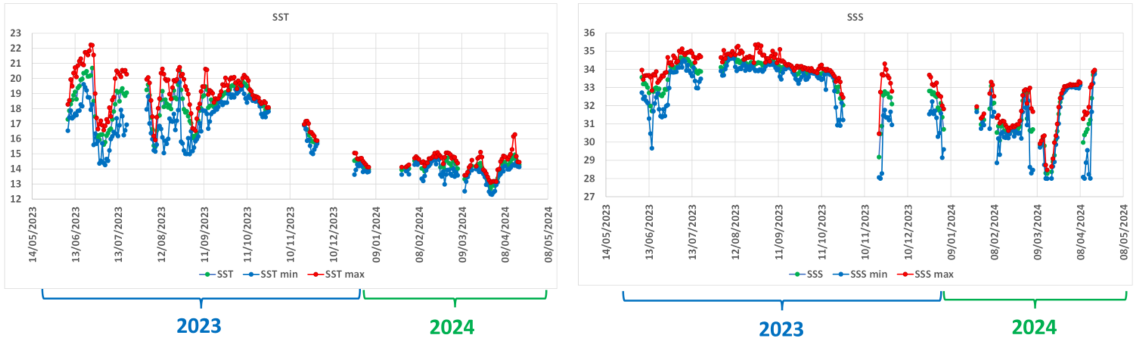


Figure 27. Cabodeiro Raft Surface Temperature and Salinity Time serie.

OBJECTIVE 2: Knowledge Challenge: Gather relevant data on the marine environment and other parameters related to the behavior of the mussel raft on a continuous and long-term basis.

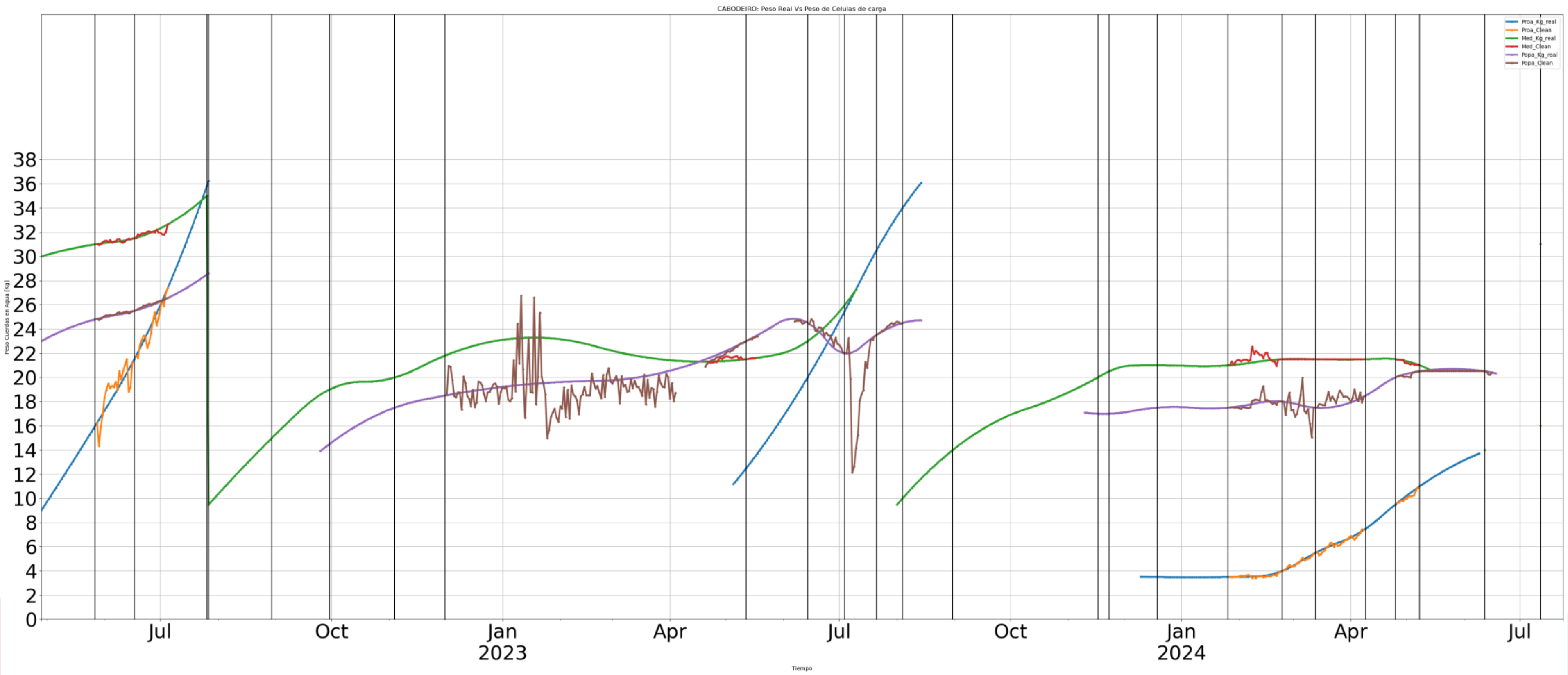
- The GPS, accelerometer and gyroscope data provide insight into the structural behavior of the raft in response to these weather changes and their possible impact on production. The Ultrasonic Distance sensor provide information on agitation and extreme events to which the raft is exposed. The Meteorological station and CTD(temperature and salinity) surface sensor and water temperature at different levels of the water column provide useful information about upwelling conditions. Turbidity sensor was added to the initial design as respond to mussel producer demand to provide information about Water Quality in the area.

- The risk of data loss in the real-time solution decreases compared to no real-time solution since the misplacement of the card is avoided, which would have to be removed in unfavorable conditions just a few centimeters from the sea surface and with constant and unpredictable movements of the raft. Besides, if something fails, it is detected immediately

OBJECTIVE 2: Knowledge Challenge: Gather relevant data on the marine environment and other parameters related to the behavior of the mussel raft on a continuous and long-term basis.

- Sensorization of the raft has allow to follow the increase of weight of the mussels ropes and also to be aware of variability on marine environmental, the movements of the rafts and producer activity on it. Mussel Growth Rate 2023-24

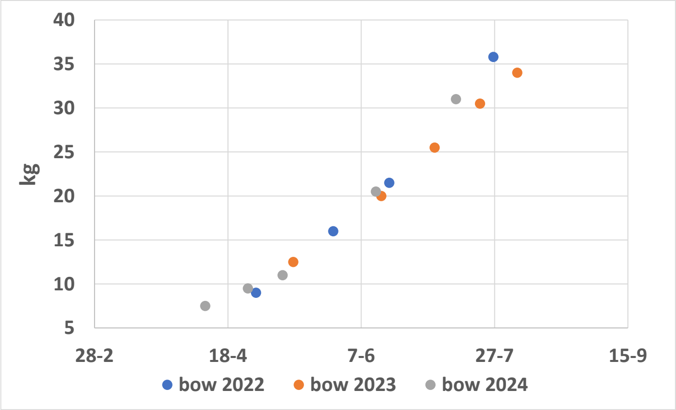
Figure 27. Cabodeiro Raft load cells data 22, 23 and 24.

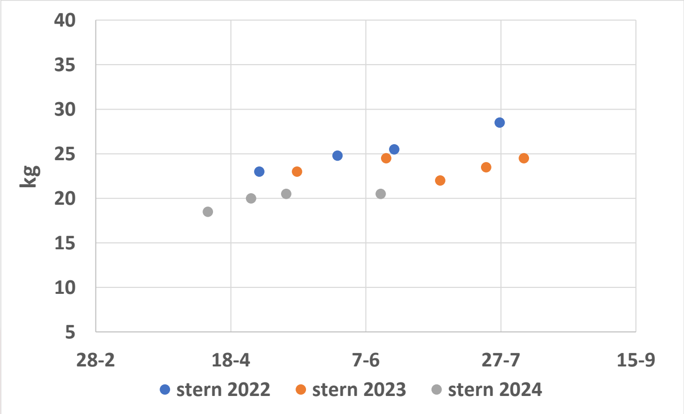


OBJECTIVE 2: Knowledge Challenge: Gather relevant data on the marine environment and other parameters related to the behavior of the mussel raft on a continuous and long-term basis.

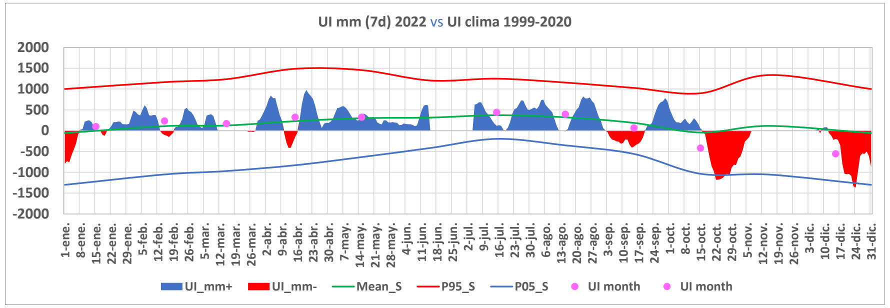
The growth of mussels are clearly link to the position at the raft. Figure 28 shows that position is the key parameter regarding growth rate. The interannual variability during the last three years is clearly less than the position of the rope at the raft. However three years of data are not enough to be able to evaluate the influence of environmental parameters on the mussel growth rate. In fact, the maintenance of the monitoring for a long period is key to be able to evaluate how climate change (i.e changes in the upwelling patterns) could impact on the mussel growth in the future.

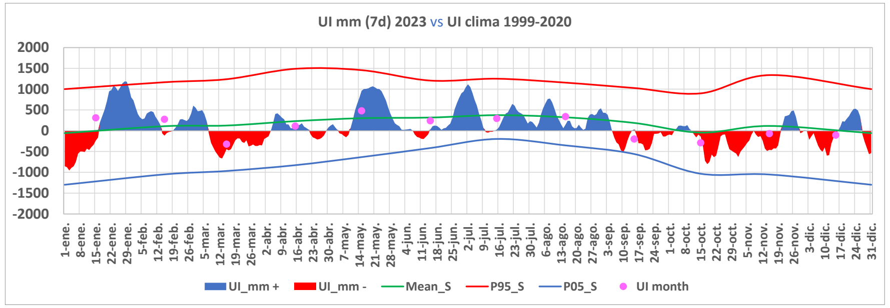
Mussel Rope Weight at bow and stern of Cabodeiro raft during 2022, 2023 2024





Upwelling Index Silleiro





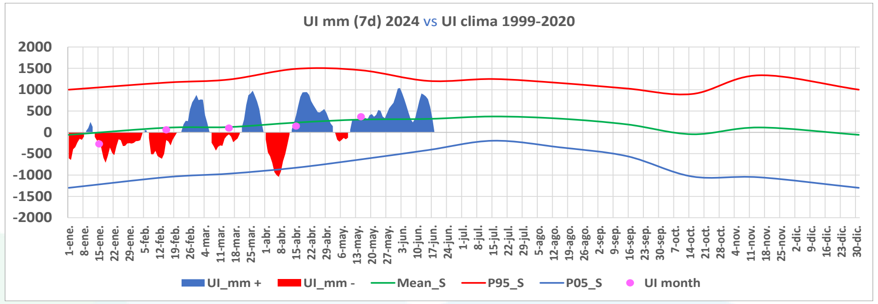


Figure 28. On the right, Cabodeiro Raft ropes weight at bow and stern of the raft in 2022, 2023 and 2024. On the left, upwelling index during these years.

04 MRM RESULTS

4.1 Results: Environmental and structural data

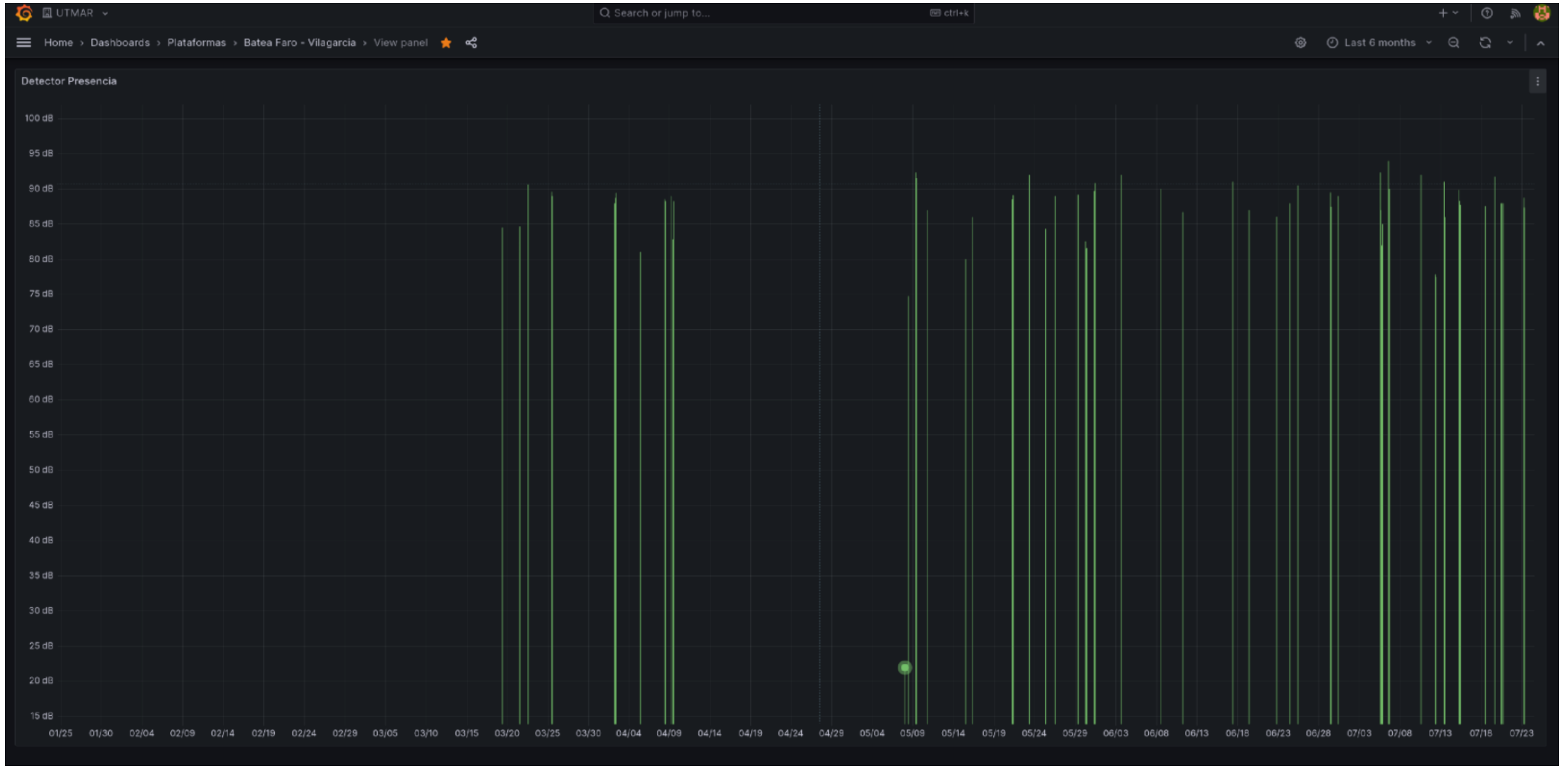


Figure 29. Detections of people in the vicinity of the raft.

Noise sensors, have enabled the detection of people in the vicinity of the mussel farm. These detections have occasionally been linked to the presence of the farm's owners, while at other times, they have identified individuals approaching the farm for nighttime fishing activities. This capability provides valuable insights into human activity patterns around the farm, enhancing our understanding of interactions with the site and contributing to more informed management practices.

Additionally, the Bluetooth sensors placed on some of the ropes of the mussel farms have enabled the detection of when these ropes are removed from the water. This feature is particularly useful for preventing theft, as it allows for real-time monitoring of potential unauthorized activity and provides an added layer of security for the farm's equipment and assets.

OBJECTIVE 3: **Social Challenge: Establish a direct communication channel with the sector to enable co-design of the solution and real adaptation to its needs** .

We have successfully met several key objectives to establish a direct communication channel with the mussel production sector:

- First and foremost, we have thoroughly evaluated the impact of our solution on the routine operations of mussel producers. Through a participatory and collaborative approach, we integrated scientific perspectives, marine protection considerations, and production management needs. This process allowed us to identify areas for improvement and correct potential errors or inappropriate approaches, ensuring that the solution is well-tailored to the sector's demands and enhances operational efficiency.

- Another critical aspect of MRM solution has been actively engaging with stakeholders and raising awareness about the risks associated with climate change. We have worked to increase understanding and perception of territorial vulnerabilities linked to climate change. By involving stakeholders in the co-design process, we have fostered a deeper understanding and preparedness for environmental challenges, which is essential for developing sustainable and effective long-term solutions. In this way, we have also promoted the social acceptance and interest in replicating the solutions or any of the components developed

- Moreover, we have participated in the proposal of governance and management measures and actions to contribute to the TransformAr Action Plan.

OBJECTIVE 3: **Social Challenge: Establish a direct communication channel with the sector to enable co-design of the solution and real adaptation to its needs** .

- Finally, this integrated and collaborative approach has not only improved the daily practices of mussel producers but also strengthened the sector's resilience to emerging challenges. By working closely with the sector and considering its specific needs, we have designed a solution that is both practical and adaptable, laying the foundation for a more secure and efficient future in mussel production.

04 MRM RESULTS

4.1 Results: Visualization and Open Access to data

- Furthermore, MRM solution facilitate access to and visualization of real-time and historical data through the implementation of a web-based data access platform. The visualization of the data through a web page, using simple graphs and clear information, facilitates access to the producers. Besides, the data storage structure lays the groundwork for the future development of AI-based applications. The ability to access and analyze real-time data is crucial for adapting quickly to changing conditions and optimizing production practices based on the most current information available.

Figure 30. Grafana Visualization.

04 MRM RESULTS

4.1 Results: Visualization and Open Access to data

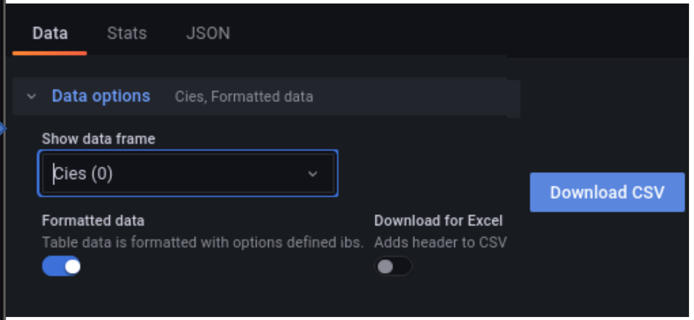
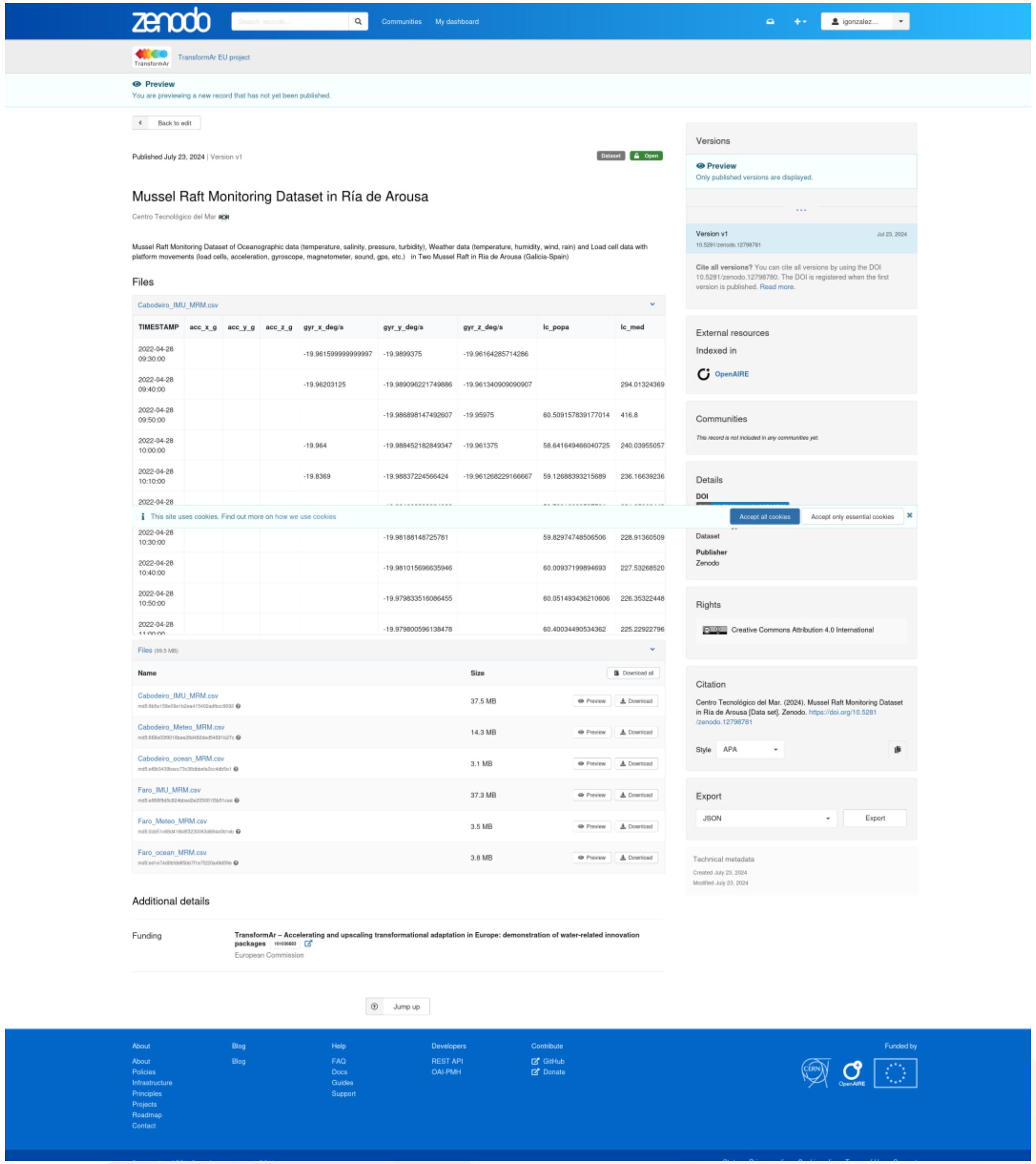


Figure 31. Grafana Data Access Detail

04 MRM RESULTS

4.1 Results: Visualization and Open Access to data



Additionally, all data collected throughout the TRANSFORMAR project is openly shared through the ZENODO repository, in accordance with the project's data management plan. This commitment ensures that the data is accessible to the wider research community and stakeholders, promoting transparency and enabling further analysis and application of the findings. By making this information publicly available, we support ongoing research and collaboration, fostering a more informed and engaged community around the project's objectives and outcomes.

Figure 32. Data uploaded in ZENODO.

Figure 33. Increase of the weight of mussel rope during. Three events detected by Load cells.

LOAD CELLS DATA CHALLENGE

Load cells have a functionality that makes them perfect when the weight to be measured is static and stable. But in the raft, the ropes are always in oscillating movements. This makes the measurements always unstable which force to a careful reanalysis of data. As a consequence, Real-Time measurements must be considered relative, giving indications of the rate of growing but not absolute data.

Looking for absolute data, an algorithm of reanalysis has been implemented. This algorithm is based on in-situ monthly weighting of the sensorized ropes which allow recalibration of the data .

The solution can detect many events linked to producers works in the raft, which have been identified thanks to the collaboration with the producers. An example of this is

1.- Cleaning day of the ropes.

2.- Work on the unfolding of the ropes.

Other events are not easy to identify. For example, the high variability at point 3, could be linked to a decrease of mussels, buy noisy measurements can significantly hinder their detection and analysis

Figure 34. Mussel ropes.

Figure 35. Replacement of mussels by other species.

LOAD CELLS DATA CHALLENGE

Moreover, it is not always easy to detect lost of mussels from the ropes. Sometimes, mussel detachment use to be followed by the substitution of mussels by other species. As it is progressive, there is not a lost of weight of the rope, and the load cell cannot detect it, which continues to show a low increase of the weight or at least a constant weight. Obviously, the load cell cannot detect these events of the ropes and that cannot be detected without extracting the mussel from the rope. An underwater camera could be a solution to detect this changes in the future, but it is out of the scope of the project.

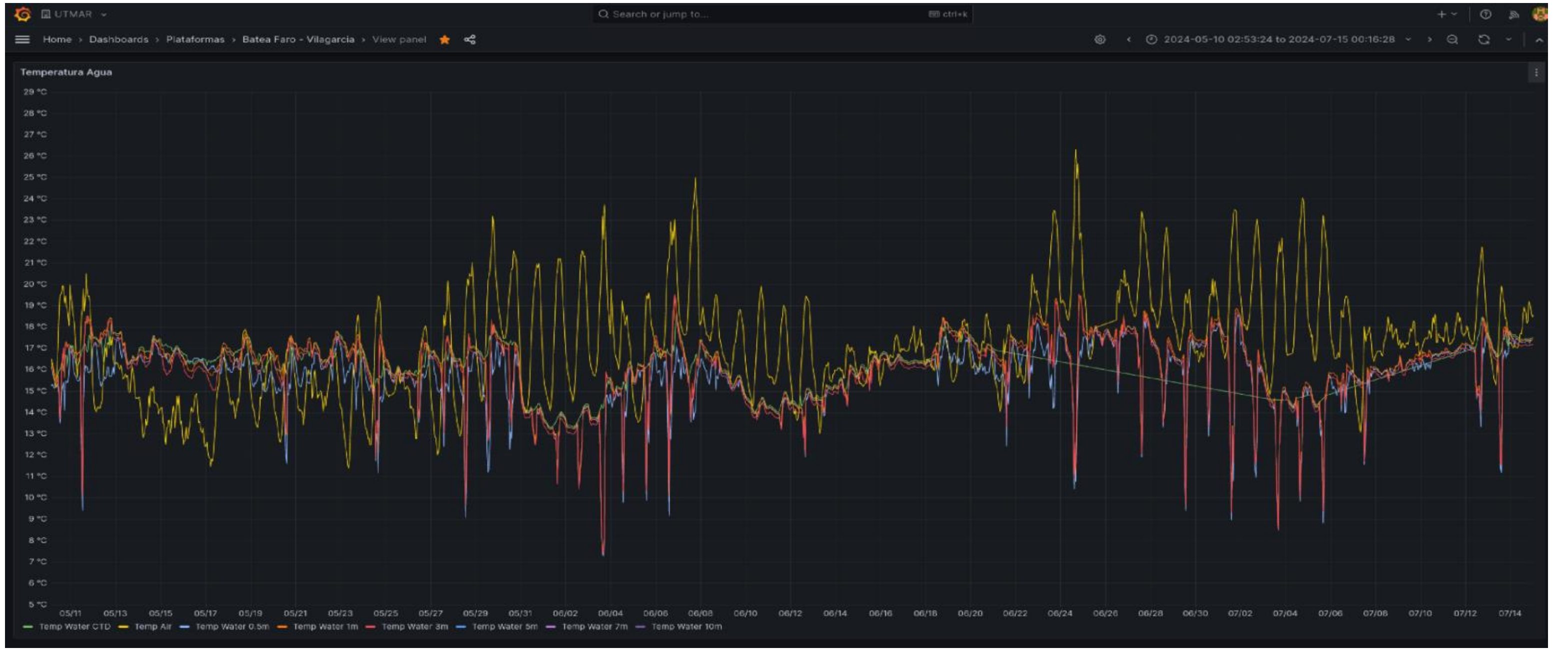


Figure 36. Thermistor string measurements.

LOW-COST THERMISTOR CHALLENGE

The low-cost thermistor string does not have the necessary endurance to be anchored 24 hours during one month in a hostile environment. In addition, the measures have a very large variability compared to the specific commercial CTD. Since commercial ones are to expensive, and further adaptations will be needed to be able to use them reliably, It has been discarded the long-term continuity of use of the thermistor string measurements.

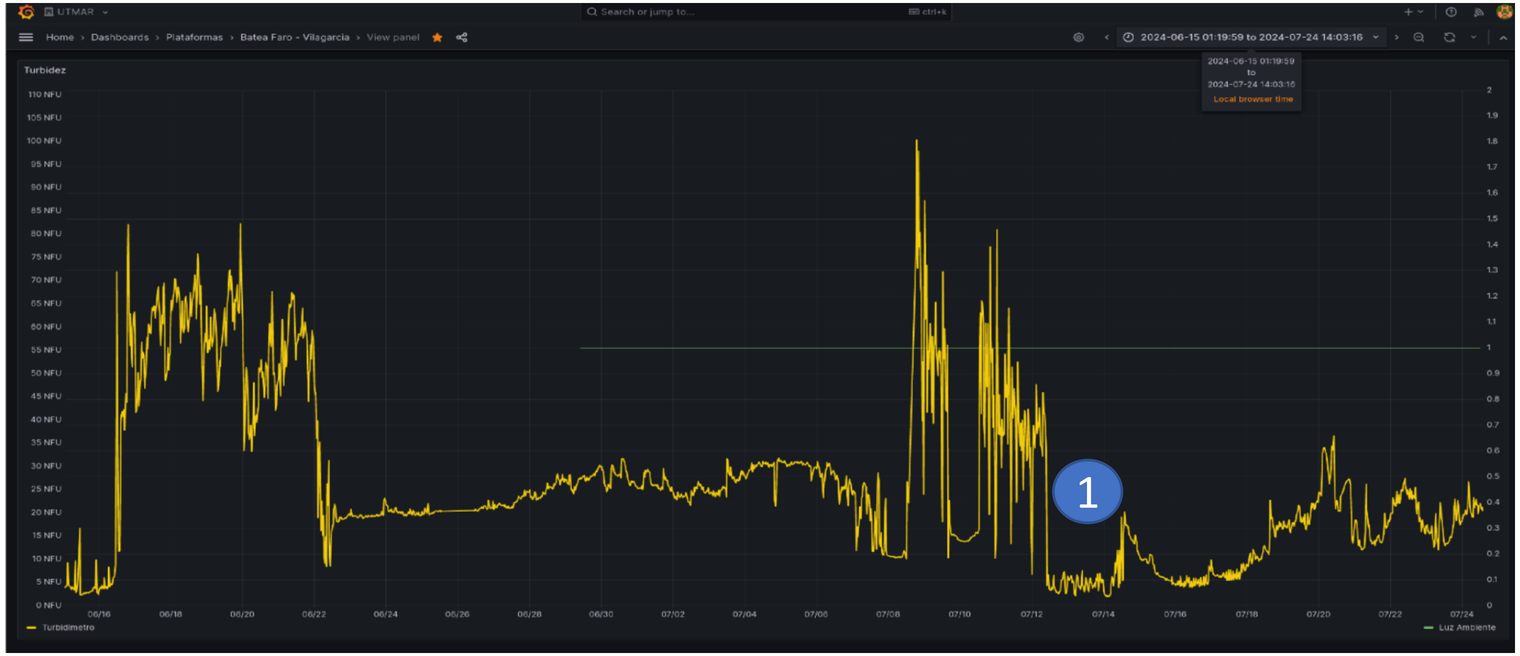


Figure 37. Effect on the measurement of the occurrence of fouling.

FOULING CHALLENGE:

Equipment cleanliness is a basic problem of all oceanographic sensors. Fouling is a problem that always appears in equipment that are for a long lime submerged.
In this example, turbidimeter data changes drastically when fouling covers the sensor. This problem is quite important, and not easy to avoid, in Galicia waters since it is an upwelling area .
Therefore, some measurements cannot be considered as soon as more than 20 days since the last maintenance works (longer time during winter due the lack of primary production).
This cleaning problem also affects the solar panels, which get dirty with "biological residues" and stop working.

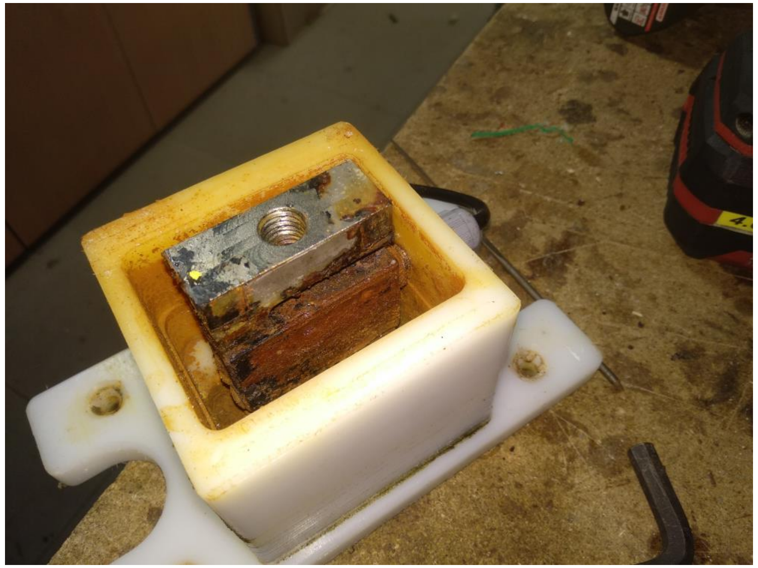


Figure 38. Corrosion of load cells.

CORROSION CHALLENGE:

The environment itself is very hard on equipment. Corrosion is something that always affects all components and all devices must be designed for a harsh environment. And even then, you must keep a very thorough maintenance control.
The initial load cells have been replaced with stainless steel load cells.

TransformAr

05 Communication and Dissemination

5.1 Communication meetings and events

5.2 Involved stakeholders

5.3 Scientific articles

General index

05 COMMUNICATION AND DISSEMINATION

5.1 Communication meetings and events

Several meetings have been organised to communicate and disseminate **the MRM solution to various actors of the quintuple helix in a more general or detailed manner**

N	Event name	Date	Location	Participants
1	TransformAr Workshop for Pathways Co-construction	25/01/2023	Vigo, ES	24
2	TransformAr Workshop for Adaptation solutions	25/09/2023	Vigo, ES	30
3	Step by step towards climate resilience – 2nd REGILIENCE Open Training Session. Presentation "The playbook in action with the Galicia shellfish gatherers and mussel aquaculture farmers"	21/04/2023	Online	45
4	TransformAr presentation in the first Climate Change working group meeting about projects working for the study of the effect of CC impact on aquaculture (Deputy Directorate General of Aquaculture, Fishery Marketing, and Structural Actions)	25/04/2024	Online	29
5	Meeting with key selected stakeholders for the Galician Action Plan	03/05/2024	Vilagarcía de Arousa - Galicia	11
6	DIH-Datalife WS-Mussel digital technical solutions	15/05/2024	Online	23
7	Open Day - Climate Change Adaptation Solutions in the Mussel Sector of Galicia – Results of the TransformAr project	18/09/2024	Oline/ Vilagarcía de Arousa - Galicia	35 (tbc)

05 COMMUNICATION AND DISSEMINATION

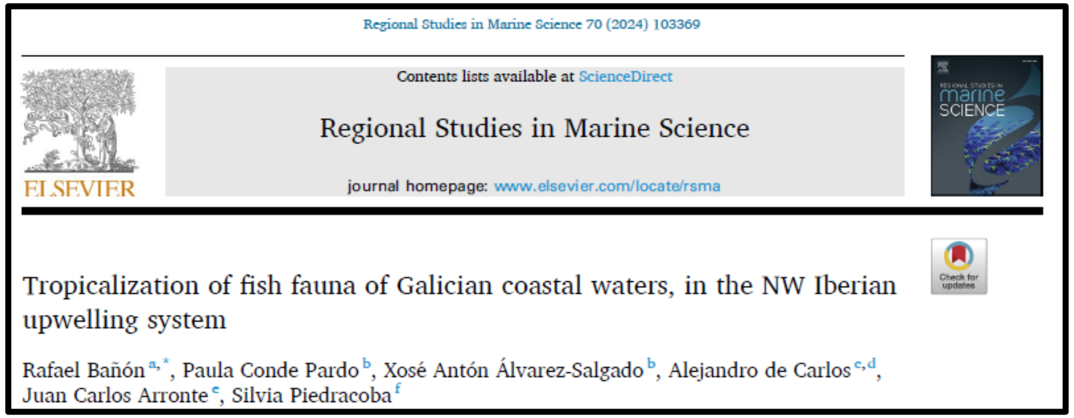
5.2 Involved stakeholders

Stakeholder groups	Experts
Science / Academia	30
Government	26
Society	47
Environment	11
Economy	48
	162

Approximately 162 stakeholders have been directly involved in the communication and dissemination activities obtaining representative numbers of all genders and type of organization.

Moreover, CETMAR's media channels have also widely spread the news and events, reaching a broad audience. Besides publications on the local newspapers, CETMAR's X account has currently 3,681 Followers

5.3 Scientific articles


Regional Studies in Marine Science 70 (2024) 103369

Contents lists available at ScienceDirect

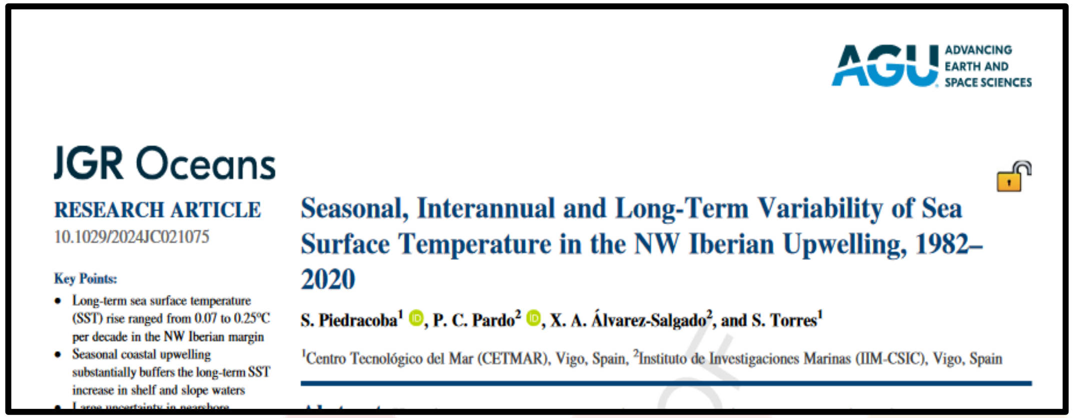
Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

ELSEVIER

Tropicalization of fish fauna of Galician coastal waters, in the NW Iberian upwelling system

Rafael Bañón [a,*], Paula Conde Pardo [b], Xosé Antón Álvarez-Salgado [b], Alejandro de Carlos [c,d], Juan Carlos Arronte [e], Silvia Piedracoba [f]


AGU ADVANCING EARTH AND SPACE SCIENCES

JGR Oceans

RESEARCH ARTICLE

10.1029/2024JC021075

Key Points:

- Long-term sea surface temperature (SST) rise ranged from 0.07 to 0.25°C per decade in the NW Iberian margin
- Seasonal coastal upwelling substantially buffers the long-term SST increase in shelf and slope waters

Seasonal, Interannual and Long-Term Variability of Sea Surface Temperature in the NW Iberian Upwelling, 1982–2020

S. Piedracoba[1], P. C. Pardo[2], X. A. Álvarez-Salgado[2], and S. Torres[1]

[1]Centro Tecnológico del Mar (CETMAR), Vigo, Spain, [2]Instituto de Investigaciones Marinas (IIM-CSIC), Vigo, Spain

Within the Galician demonstrator, CETMAR has also participated in two relevant scientific papers:

- Rafael Bañón, Paula Conde Pardo, Xosé Antón Álvarez-Salgado, Alejandro de Carlos, Juan Carlos Arronte and Silvia Piedracoba (2024). Tropicalization of fish fauna of Galician coastal waters, in the NW Iberian upwelling system Running page head: Non-native marine fishes in Galicia, Regional Studies in Marine Science, Volume 70, 103369, ISSN 2352-4855, https://doi.org/10.1016/j.rsma.2024.103369.

- Silvia Piedracoba, Paula Conde Pardo, Xosé Antón Álvarez-Salgado, and Silvia Torres (2024). Seasonal, Interannual and long-term variability of sea Surface temperature in the NW Iberian upwelling, 1982-2020. Journal of Geophysical Research: Oceans, 129, e2024JC021075. https://doi.org/10.1029/2024JC021075

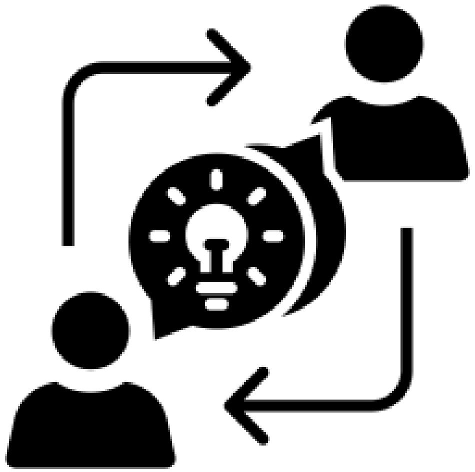
06 Transfer and exploitation

6.1 Transfer meetings and events

6.2 Further interest and transfer perspectives

General index

6.1 Transfer meetings and events



Several meetings have been held for the purpose of knowledge transfer. Four of these meetings, in particular, demonstrated a clear interest in replicating the solution:

- In 2023, one producer expressed interest in increasing the number of monitored rafts.
- In December 2023, a multinational food Company showed interest in the solution.
- In June 2024, another producer showed interest in monitoring one of their own rafts in the outer part of the Ria de Arousa.
- Also in June 2024, the local administration expressed interest in maintaining and improving the MRM solution.

06 TRANSFER AND EXPLOITATION

6.2 Further interest and transfer perspectives

- The implemented solution has generated significant interest among mussel producers, who see it as a valuable tool for monitoring and managing the challenges they face in their industry. The ability to track real-time data on mussel growth and environmental conditions has proven to be a game-changer, providing producers with insights that were previously inaccessible and enabling them to make more informed decisions. Several meetings have been held with mussel farmers' associations, where they have expressed significant interest in the solution, even going as far as requesting offers for monitoring one of their platforms. REPETIDO EN LA DIAPO ANTERIOR

- Furthermore, in the context of the **Observatorio Costeiro da Xunta de Galicia (Coastal Operational Observatory),** the IoT solution for monitoring mussel farms represents a new approach to operational and systematic monitoring, serving as one of the pillars of the observatory. This approach offers a significant advantage in site selection, as existing mussel farms can be repurposed as supporting infrastructure, thereby reducing costs and avoiding the need to install new structures. The data collected not only supports the daily management of the farms but also contributes to other studies, including environmental monitoring of the Rías and research on these unique ecosystems. This integration of technology and infrastructure enhances both the efficiency and scope of monitoring efforts in these areas.

6.3 Further interest and transfer perspectives

- Additionally, this interest extends to the **regional administration** as well, which has recognized the importance of this technology in monitoring the changes currently being observed in the marine environment. The administration sees this solution as a potential contribution of their efforts to understand and respond to these changes, ensuring the sustainability and resilience of the mussel farming sector in the face of ongoing environmental challenges. Discussions have taken place with regional administration representatives to gain a deeper understanding of the solution and to assess the feasibility of continuing this monitoring beyond the TRANSFORMAR project's duration.
- Moreover, **institutions working at the CMEMS-Copernicus level** have also shown interest in collaborating and using this data as a source of FAIR (Findable, Accessible, Interoperable, and Reusable) data. We are exploring the possibility of integrating this monitoring data into Copernicus local services that combine these insights with products offered by Copernicus, further enhancing the value and applicability of the solution on a broader scale.

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07 Impact and conclusions

7.1 Conclusions and indicators

7.3 MRM Further Research Topics

7.3. MRM Long term impact

General index

7.1 Conclusions and indicators

The main impact we have achieved is that mussel producers now view monitoring as a positive ally in addressing the challenges they face, rather than as something purely scientific that hinders their work. They have come to see the value in the information provided, actively requesting new data and presenting us with new challenges. This engagement forms the foundation for achieving real resilience in the industry.

Although significant technological challenges remain, particularly regarding the improvement of data quality from the load cells, this project represents the first step towards obtaining real-time information on mussel growth on the ropes. This data is undoubtedly of the greatest interest to them to take informed decisions and improve resilience within the mussel sector in Galicia.

Furthermore, Its adaptability to different environmental conditions and the valuable insights it provides make it a promising tool for mussel farming across various territories. By implementing this monitoring system in new locations, producers can optimize their operations and enhance the sustainability of their practices, regardless of the specific challenges of their local environments.

07 IMPACT AND CONCLUSIONS

7.1 Conclusions and indicators (Project general indicators)

	Project KPI S	Direct	Indirect	Achieved
1	Population that ~~became~~ enhance resilience	132	9,1 k	✔
3	Farmers/fishermen engaged in demo (20)	30	-	✔
12	Actors involved in the adaptive process (80)	132	-	✔
13	Inclusion of disadvantaged groups	30 fishers + 66 women	More than 8.422 fishers + 2.000 women*	✔
14	Share of population that is vulnerable (5%)	18 (Fisher-women, fish gatherers) = 13,6%	More than 22% (Only taking into account the members of the Galitian association of Seawomen)	✔
16	Policymakers involved (20)	23	-	✔

*Transformar - Galicia has involved in the project the fishing guilds.
According to the Galician Federation of Fishing Guilds, there are currently 12.734 members (4.312 companies and 8.422 workers)
At the same time, the Galician Association of Seawomen “Mulleres Salgadas”, with 2.000 members, has been very active in the demostrator activities, both in the workshops and in the construction of the action plan.

Galician demo - MRM Expected impact -	Achieved
Availability of technically viable and effective digital-technological tools to address territorial vulnerabilities linked to CC (Described in the Objective 1).	✔
Knowledge increase and transfer about regional oceanographic environment (Described in the Objective 2)	✔ ✔
Awareness rising and better perception of CC risks affecting the sector (Described in the Objective 3)	✔
Social acceptance and interest in replicating the solutions or any of the components developed (Described in the Objective 3)	✔
Governance and management measures (Described in the Objective 3)	

07 IMPACT AND CONCLUSIONS

7.1 Conclusions and indicators (specific for the Galicina demo and the MRM monitoring)

Expected impact	Indicators	Solution	Approach	Baseline	Achieved	Expected
Knowledge increase and transfer	Corroboration in local conditions of the correlations described in the literature about environmental impact on the raft (e.g. biomass losses related to 1) persistent temperature changes 2) mussels detachment from the ropes 3) mussels spawning, etc.	MRM	Reports of the workshops, testimonies, key informants and surveys pre- and post-implementation. Log of communication and transfer events, report of transfer workshops, minutes of meetings with 5 helix and bilateral meetings, posters or publications.	0	3 new correlations described (2 showed correlation and 1 not sure yet)	At least 3 new correlations will be described
	Accessible and real time environmental data linking the mussel raft's movement with production information (recorded at high frequency)	MRM		0	Producers have the link to the visor and access to the digital dashboard: at least 1 entry each 15 days https://utmar.cetmar.org/transformar	Access to the digital dashboard: 1 entry each 15 days
	Number of STH or institutions using data	INTERM MRM		0	Data have been just obtained and uploaded on ZENODO (pending for acceptance). By the moment the producers, and the involved partners and administration are using them	90% of engaged STH (124 people and close to 56 organizations)
	N of publications / new outputs of knowledge related to CC adaptation in the shellfish sector	All		0	8 2 scientific papers (CETMAR) + 3 posters and 1 oral presentation (UVIGO) + 3 technical reports in Zenodo (1 for each solution)	4
	N of transfer events / meetings	All		0	14: 4 (GEOMA), 6 (REDE), 4 (CETMAR)	6
Technically viable and effective digital-tech. tools	Increase in the Technology Readiness Level (TRL) scale in the mussel sector (digitalisation and automation)	MRM	Report/video of the solution	TRL4 Validated under laboratory-scientific conditions	TRL6 achieved and TR7 as well	TRL6 Demonstrated in relevant env. (beginning TRL7 System prototype demonstration in operational env.)

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07 IMPACT AND CONCLUSIONS

7.1 Conclusions and indicators (specific for the Galicina demo and the MRM monitoring)

Expected impact	Indicators	Solution	Approach	Baseline	Achieved	Expected
Technically viable and effective digital-tech. tools	Availability of improved technically viable and effective digital-technological tools	INTERM MRM	Reports, videos and links to the dashboard	0	2 new Solutions: INTERM and MRM (2 new technical reports)	2 new solutions
Awareness rising and better perception of CC	Increase in the awareness about the risk affecting shellfish culture and the availability of adaptation measures	All	Reports of the workshops, testimonies, key informants and surveys pre- and post-implementation	Qualitative (less awareness)	More than 11 events with positive answers 72% of the participants in the stakeholders' workshop on the RI reported an increase in their awareness on climate change effects after learning about the RI results.	80% of the STH engaged increase their awareness
Social acceptance and interest in replication	Expensive commercial sensors replacement with COTS	MRM	Report, STH survey	0	2 sensors replaced with COTS: Load cells and Air presure - Temperature string: Fail --> Low Cost not funtional.	At least 2 sensors replaced
	Interest in replicating the solution or any of the components developed	MRM	Expressions of interest for replication or install sensors (Emails, official request forms, meeting minutes)	0	3 (One from the administration, 1 from a Company, and one from a producer)	3
	Participatory engagement	All	Workshops Reports, participation lists of the different project activities (meetings, workshops, etc.)	-	132 (from 60 organisations) 29 Fishers and shelfishers 23 Policy makers 23 from Scientific orgs. 19 from socio-env. orgs. 19 from sectoral orgs.	80 actors 20 Fishers shelfishers 20 Policy makers

07 IMPACT AND CONCLUSIONS

7.1 Conclusions and indicators (specific for the Galicina demo and the MRM monitoring)

Expected impact	Indicators	Solution	Approach	Baseline	Achieved	Expected
Social acceptance and interest in replication	Interest and content with the provided data	INTERM MRM	Entries in the dashboard, satisfaction surveys	N/A	- Producers interested in the data (MRM) - 100% of biologist have interest in the data (INTERM) - Utility model application requested and approved.	80% of the Fishers shelfishers satisfied
Governance and mgmt. measures	Number of innovation helixes represented. (According to the quintuple innovation helix framework)	All	Participation records during consultation processes	0	5 helixes	5 helixes
	Consensus pathways and validated solutions for mussel and clam sector	All	Report	0	Pathways including at least 17 validated proposals/ adaptation solutions	
	Set of recommendations and measures including an appealing document	All	Report	0	Report of the WS and the action plan (1 pathway)	1 set

7.2 MRM Further Research Topics

This is not the end; rather, it marks a continuation with new areas to explore, test, and evaluate for their potential impact. Further research is essential, particularly in improving the understanding of system behavior. Incorporate new sensors to monitorize new parameters , such as current flow and chlorophyll levels, to estimate the natural food availability for the mussels. Besides, it could be interesting to include monitoring nutrient concentrations or chemical and biological contaminants that could impact mussel attachment and growth. These insights will be crucial for refining the monitoring system and enhancing our understanding of the environmental conditions affecting mussel cultivation.

Besides, It's crucial to know exactly when and where specific processes occur and take into account this knowledge to be able to implement automatic detection and early warning systems in the future. Currently, we lack precise information on the variability inside the Rías, with significant changes occurring from one raft to another within just a few days, as a consequence, it will be quite interesting to increase the number of sensorized mussel raft. By enhancing our understanding now, we can develop more precise and timely alerts that will better serve the needs of the industry and help them respond more effectively to critical events.

7.3 MRM Long term impact

In the long term, the impact of this type of solution could be substantial, as it will enable the optimization of mussel production. The future could involve adapting mussel farming to the natural variability of the Galician Rías. This would represent a shift from the current static model, where mussels are "fixed, grown, and harvested," to a dynamic model where "mussels are fixed in some locations, fattened in others, and stored for harvesting in toxin-free areas." Each zone has its unique qualities, and production must be adapted to these characteristics to ensure sustainability.

Currently, farmers are highly attentive to temperature and salinity, but they are seeking more data, such as turbidity (for spawning) and nutrients (for fattening). This additional information will be crucial for optimizing the different stages of mussel production and responding more effectively to environmental conditions, thereby ensuring a more sustainable and resilient industry.

CETMAR

transformar@cetmar.org

0034 986 24 70 47

TransformAr

info@transformar.eu www.transformar.eu TransformarEU

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