CS-MACH1

D5.1 - Pilots operation plan

CMCC

May 2026

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List of referenced acronyms

AI	Artificial Intelligence
API	Application Programming Interface
BIO	EMODnet Biology
BioEco	EMODnet Biology & Ecosystems
CORA	Coriolis Ocean Dataset for Reanalysis
CS-MACH1	MArine Citizen science data Horizon
CSV	Comma-Separated Value
DwC-A	Darwin Core Archive
EMODnet	European Marine Observation and Data Network
EO	Earth Observations
EOSC	European Open Science Cloud
EU	European Union
EurOBIS	European node of the Ocean Biodiversity Information System
FAIR	Findable, Accessible, Interoperable and Re-usable
GBIF	Global Biodiversity Information Facility
GNSS	Global Navigation Satellite System
JPI	Joint Programming Initiative
MCS	Marine Citizen Science
MCSI	Marine Citizen Science Initiatives
MCSDN	Marine Citizen Science Data Network
NERC	National Environment Research Council (vocabularies)
NetCDF	Network Common Data Form
NFC	Near Field Communication
ODV	Ocean Data View
OGC	Open Geospatial Consortium
PHYS	EMODnet Physics
POLL	EMODnet Chemistry/Pollution
QA/QC	Quality Assurance/ Quality Control
QF	Quality Flag
SeaDataNet	Pan-European infrastructure for ocean & marine data management
SOOP	Ship Of Opportunity Programme
SOS	Sensor Observation Service
SUP	Stand-Up Paddleboard
WP	Work Package

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I. Executive Summary

This deliverable presents the outcomes of Task 5.1 within Work Package 5 (WP5) of the CS-MACH1 project, focusing on the co-design of use cases and the development of an operational strategy for pilots implementation. The work builds upon a comprehensive review of existing Marine Citizen Science Initiatives (MCSIs), equipped with low-cost technologies, from D2.1 and Networking Workshop registry and participation, activating the Marine Citizen Science Data Network (MCSDN; WP2), and pilot sites proposed by project partners across Europe. Particular attention is given to communities and initiatives whose data can deliver broader benefits for identified stakeholders. The assessment also considers the maturity of data flow procedures, identifies critical gaps, and defines the technical and methodological improvements required to enhance data collection, management and use.

Representative use cases for both Northern and Southern European Seas have been defined to demonstrate the full data value chain, from citizen-based observations to the integration of FAIR-compliant data into European marine data infrastructures. These use cases serve as practical frameworks to test and validate the proposed methodology and tools to enhance interoperability, data harmonization, and scalability across diverse environmental and socio-technical contexts. Use-cases pilot sites will aim to: cover monitoring/observing data gaps; address global challenges at local scale; test the integration towards EMODnet thematics (PHYS-Physical, BIO-BioEco, POLL-Chemistry) or international thematic integrators (e.g. GBIF, SeaDataNet) by implementing multi-source observations.

The deliverable provides a detailed description of the co-design methodology, including pilot selection criteria, MSCIs, technology providers and data managers involvement, and the operational strategy to guide pilot demonstrations, with low-cost sensors' deployments, data collection, validation, and integration. Additionally, training material linked to gaps identified in task 5.1, and to be used for training on-site at pilots, are presented.

Task 5.1 also incorporates additional integrative pilot opportunities and MCSIs identified during the project's implementation phase, leveraging knowledge exchange and networking activities within the consortium and beyond. These contributions enhance the representativeness and scalability of the proposed framework.

The outcomes are expected to contribute to the long-term sustainability and institutional uptake of Marine Citizen Science within European data ecosystems.

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II. Introduction

The CS-MACH1 project aims to strengthen Marine Citizen Science Initiatives (MCSI) by improving the overall capacity of these participatory actions to make data ready for data integration into (and with) key European data systems such as EMODnet, GBIF, EurOBIS, and SeaDataNet. As citizen science becomes increasingly relevant for large-scale and long-term marine monitoring, it offers significant potential to complement traditional scientific observations (Bonney et al., 2009; Garcia-Soto et al., 2017), particularly in terms of spatial and temporal coverage.

However, several challenges continue to limit the full integration of citizen-generated data into formal scientific and policy frameworks. These include inconsistencies in data collection methodologies, storage, limited adherence to standardized metadata practices, variable data quality, and overall insufficient alignment with FAIR (Findable, Accessible, Interoperable, Reusable) principles (Wilkinson et al., 2016). Additionally, issues related to trust, validation, and the automation of data flows remain critical barriers to broader adoption.

Work Package 5 addresses these challenges by implementing real-world demonstrations through co-designed use cases and pilot activities. By combining technological solutions with participatory approaches, WP5 seeks to bridge the gap between citizen science data generation and its effective use within established marine data infrastructures. WP5 also looks at closing the loop by providing the citizen scientists with outcomes of the analysis made possible by the combination of classical scientific marine data collection and citizen science data. The ultimate goal is to enhance the credibility, usability, and impact of Marine Citizen Science in supporting research, environmental management, and policy-making processes.

III. Methodology for Co-design

The co-design process adopted within Task 5.1 follows a participatory and iterative approach, engaging a wide range of stakeholders, including MCSI, technology developers, data management experts, domain scientists, and end-users. This inclusive approach ensures that multiple perspectives are incorporated into the design and implementation of the pilot use cases.

The co-design framework was developed to identify and refine pilot use cases capable of demonstrating the integration of MCSI data into European and international marine data infrastructures. The process combined the analysis of existing initiatives, the assessment of their technical and operational characteristics, and the definition of implementation pathways aimed at improving interoperability, data quality, and FAIRness.

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The methodology is structured around several key phases, beginning with a comprehensive mapping of existing pilots and initiatives to identify relevant activities, data types, and technological solutions.

During this first phase, particular attention was given to initiatives generating observations with potential relevance for infrastructures such as EMODnet, SeaDataNet, EurOBIS, and GBIF. Information was collected regarding monitoring objectives, data types, technologies employed, geographical coverage, community engagement, and existing data management practices. This mapping activity enabled the identification of a representative portfolio of initiatives spanning different thematic domains, including physical oceanography, biodiversity monitoring, and marine pollution. The resulting portfolio was selected to provide a representative range of thematic domains, technologies, data types, geographical contexts, and maturity levels, enabling the project to evaluate integration challenges and solutions under diverse operational conditions. The mapping activity also facilitated the identification of additional initiatives through networking and community-building actions, creating opportunities for the development of integrative use cases that extend beyond the original pilot portfolio (https://cs-mach1.eu/network).

This was followed by an evaluation phase based on scientific relevance, technical feasibility, data management maturity, and gaps needed to be filled by training material for potential integration into European data infrastructures.

The evaluation also considered the integration readiness of each initiative by analysing data collection methodologies, metadata availability and completeness, adoption of standards and controlled vocabularies, quality assurance procedures, accessibility, and alignment with FAIR principles. The objective was to identify both the strengths of existing initiatives and the actions required to facilitate the integration of citizen-generated observations into established data infrastructures.

The assessment of data management maturity in this report is primarily focused on the pilots already implemented through the project, while also considering additional integrative initiatives identified through the networking activities conducted during the first phase of CS-MACH1. These activities expanded the project ecosystem beyond the initial pilots portfolio and provided opportunities to explore synergies among initiatives addressing complementary environmental challenges and data integration needs.

The activities conducted within Task 5.1 are closely aligned with the framework being developed in WP3. While WP3 focuses on defining methodologies, standards, assessment criteria, and technical recommendations required to improve the interoperability and FAIRness of Marine Citizen Science Initiatives data, WP5 provides the operational environment in which these approaches can be tested and validated through real-world pilot implementations. WP3 will provide a deeper assessment

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framework for evaluating data management practices and readiness for integration into key European data initiatives across several dimensions, including data standardisation, metadata completeness, use of controlled vocabularies, accessibility, quality assurance procedures, and alignment with FAIR principles. The pilot initiatives therefore represent practical use cases through which the applicability, scalability, and effectiveness of the WP3 recommendations can be evaluated.

This enabled the mapping of the integration readiness and impact of the initiatives. Pilots maturity was categorised as: high maturity, characterized by structured data management with data ready for being integrated into integrators' products; medium maturity, where data management apply FAIR principles and there are some levels of standardization but further improvements are needed before enabling integration of data into integrators; and low maturity, where data management practices remain fragmented, with limited standardization and reliance on manual processes and which may need training and networking before CS-MACH1 support to data management. This classification provides a structured basis for prioritizing actions and defining implementation pathways.

The maturity assessment performed in Task 5.1 also represents an initial application of the concepts and dimensions further developed within WP3. In particular, the analysis considers aspects such as metadata completeness, adoption of standards and controlled vocabularies, quality assurance procedures, accessibility, and FAIR alignment. The outcomes of the pilot assessment will provide feedback to WP3, helping to refine the assessment framework and ensuring that it remains applicable across the diverse range of Marine Citizen Science initiatives represented within the project.

Based on the results of the assessment, preliminary integration pathways were identified for each pilot initiative. These pathways describe how observations collected through citizen science activities can be transformed into interoperable datasets and progressively integrated into European and international data infrastructures. The pathway definition considered the nature of the observations collected, target repositories and infrastructures, metadata and standardisation requirements, data quality control procedures, and the technological developments required to facilitate data exchange and reuse.

The definition of integration pathways was also informed by the technical approaches and recommendations emerging from WP3. Particular attention was given to the identification of target infrastructures, metadata requirements, interoperability mechanisms, and data quality procedures that could facilitate the transition from locally managed citizen science datasets to interoperable resources suitable for integration into infrastructures such as EMODnet, SeaDataNet, EurOBIS, and GBIF.

In addition to technical readiness, the prioritisation considered the potential impact and scalability of the initiatives, recognising that broad community participation and

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geographical replication can significantly enhance the contribution of Marine Citizen Science Initiatives to environmental monitoring and policy support. Initiatives engaging large and geographically distributed citizen communities (such e.g. the scuba diver communities) or already producing data in different European countries (e.g. bioblitz or biomarathon) may be prioritised over initiatives that are producing high quality data but with their workflow presenting potential limitations in terms of scalability (e.g. using expensive lab equipments).

As a result of CS-MACH1 networking actions, several opportunities for the development of Integrative Use Cases were identified. These use cases aim to combine observations, methodologies, and data flows originating from different Marine Citizen Science Initiatives in order to address common environmental challenges and demonstrate the added value of multi-source observations. Unlike the individual pilot use cases, which focus on specific initiatives and data workflows, the Integrative Use Cases provide an opportunity to explore interoperability across thematic domains, technologies, geographical regions, and data management approaches. They allow the project to assess how heterogeneous citizen-generated observations can be combined within a common data ecosystem and contribute to broader environmental assessments. The Integrative Use Cases, therefore, serve as a cross-cutting validation layer within WP5, complementing the individual pilot demonstrations and providing an operational testbed for the methodologies and recommendations developed in WP3. By facilitating collaboration between initiatives identified through the CS-MACH1 networking activities, these use cases contribute to assessing the scalability, transferability, and long-term sustainability of the project framework.

The assessment and co-design phases also enabled the identification of user needs, operational constraints, and opportunities for innovation. The insights gathered were then used to iteratively refine the use cases, ensuring alignment with both scientific objectives and practical implementation requirements.

The co-design process remains iterative throughout the implementation of WP5. Lessons learned during pilot deployment and testing activities will contribute to the continuous refinement of methodologies, training materials, integration procedures, and technical solutions, ensuring that the proposed framework remains aligned with project objectives and the requirements of the target data infrastructures.

The interaction between WP3 and WP5 is therefore bidirectional. WP3 provides the methodological framework, standards, and recommendations supporting data integration, while WP5 supplies practical implementation experiences and validation cases through both individual pilots and Integrative Use Cases. The lessons learned from pilot deployment and cross-pilot integration activities will contribute to the refinement of the WP3 framework and support the development of sustainable

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pathways for the long-term uptake of citizen-generated marine observations within European data ecosystems.

IV. Use Cases Review and Analysis

The pilots' review identified a geographically well-distributed portfolio of MSCIs across Europe, spanning Southern and Northern European Seas as well as integrative cross-basin efforts, with initiatives covering a broad spectrum of thematic domains, including physical oceanography (e.g., temperature, sea level, meteorology), biodiversity monitoring (e.g., invasive species, species presence and abundance, benthic habitats), and marine pollution (e.g., microplastics, turbidity, water colour). A key strength emerging from the analysis is the high level of community engagement combined with innovative, low-cost data collection approaches, enabling scalable observations across spatial and temporal gradients that are otherwise difficult to monitor through traditional infrastructures.
At the same time, the analysis highlights substantial heterogeneity in data collection protocols, sensor technologies, metadata standards, and data management practices across the entire data lifecycle.

The pilots employ a wide range of complementary technologies and methodologies (https://cs-mach1.eu/pilot-studies), including:

- In situ low-cost sensors;
- Mobile and digital platforms;
- Autonomous and semi-autonomous systems
- Optical and imaging methods

The data management maturity and integration readiness assessment confirms this variability with gaps or inconsistencies in metadata, limited use of controlled vocabularies, and uneven compliance with FAIR principles, as well as differences in data validation and quality control mechanisms, which affect the reliability and comparability of datasets.
These findings underscore the need for harmonized protocols, improved metadata practices, and the adoption of common standards aligned with FAIR principles, which are the key actions implemented by WP3. Furthermore, the analysis provides a foundation for the selection and refinement of pilot use cases, guiding the development of targeted solutions to improve data integration, interoperability, and overall system performance.

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A. Southern European Seas

The Southern European pilots are characterized by high diversity in methodologies, strong reliance on mobile applications and low-cost sensors, and significant engagement in biodiversity and pollution monitoring.

A.1: ENVLOGGER: collects in situ temperature data using low-cost loggers with periodic retrieval.

Identified Pathway: Providing in situ temperature, the EnvLogger based citizen science initiatives target integration into EMODnet Physics via CSV/NetCDF conversion, FAIR metadata model for the observation, the sensor and the deployment, supported by e.g. SeaDataNet vocabularies (P01/P06/L22) in the metadata, automatic outliners (QC/QF) detection.

Figure 1. Envlogger being used by a surfer of OutBe's community

Status to date: The EnvLogger, produced by ElectricBlue, is a miniaturised temperature logger designed for use in aquatic and terrestrial environments. Its technical specifications (including a precision of 0.1 °C, accuracy of 0.2 °C, programmable sampling intervals, long-life battery and waterproof acrylic housing (Pereira et al 2026) make it particularly suited to distributed citizen science

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deployments.

Its usability is further enhanced by NFC data transfer, allowing citizens to download data directly to smartphones without specialised equipment, and by CSV export formats that integrate easily into existing research workflows. The robustness of the casing, ease of attachment with cable ties, and contactless readout ensure the device is practical for use on boats, moorings or recreational equipment. The EnvLogger has also been adopted in ecological monitoring studies, further demonstrating its suitability for a wide range of field deployments and CS applications.
Examples are the field activities in Liguria, conducted within the framework of RAISE (Robotics and AI for Socioeconomics Empowerment) with the projects TACS (Technologically Assisted Citizen Science) and Be.Ci.S (Be a Citizen Scientists).
Both projects explored different EnvLogger based monitoring protocols ranging from the use of the logger in combination with floating loads (SUP, kayak), the use of the logger in fixed positions and at different depths (smart rope) and the use of the loggers while diving or surfing.

The activities confirmed strong community engagement and straightforward building a culture of stewardship and participation among coastal sports communities.
While data validation has been tested through comparisons with the CORA climatological dataset from Copernicus Marine Service, the different approaches have different levels of integration readiness: EnvLogger is not tracking the position that is applied when the data is downloaded, hence it works better for fixed positions (bounded areas) monitoring.

Concerning the quality of the data and phenomena detection, all the approaches properly worked, and measurements closely tracked seasonal sea temperature patterns (showing Ligurian coastal water to reflect a warmer and longer 2025 summer if compared to reference CORA climatological dataset from Copernicus Marine Service). Notably, although the sensor can sample at very high frequency, it's important to apply statistical processing to remove spikes and out-of-water data.
The projects provided direct evidence that low-cost citizen science devices can reproduce trends captured by global reference datasets.

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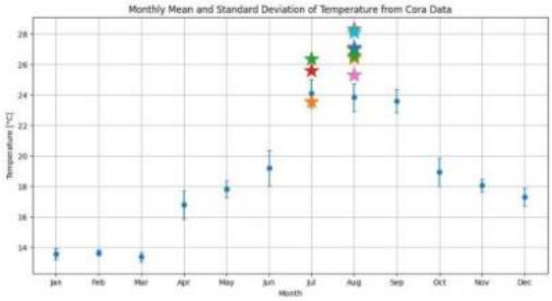

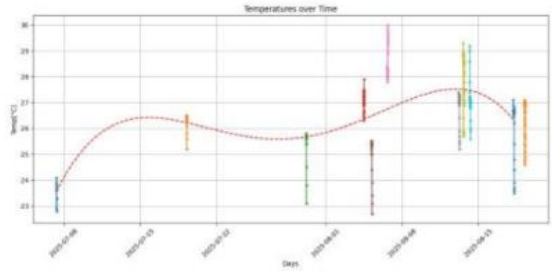

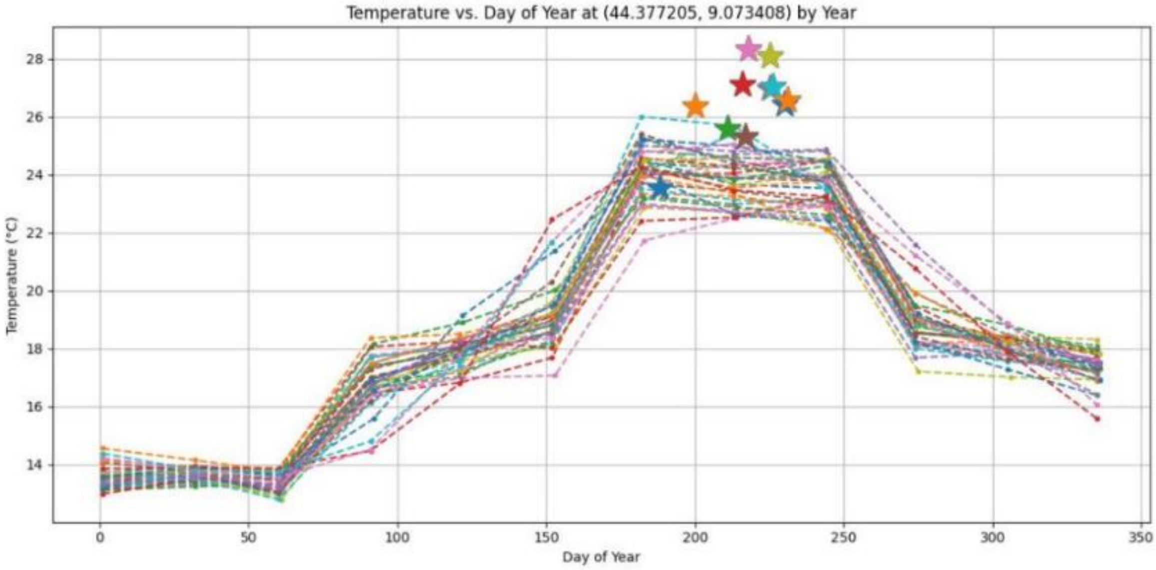

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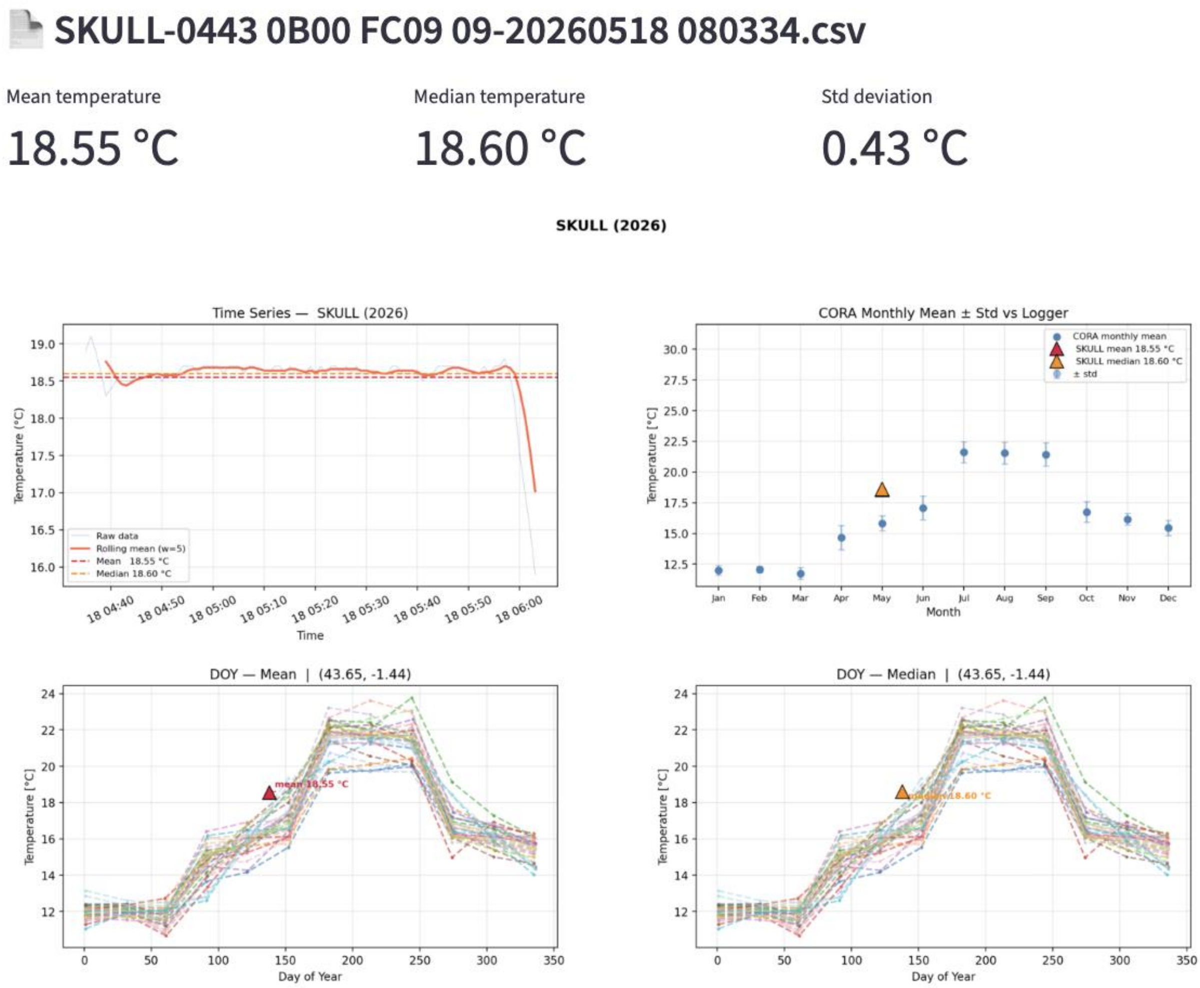

Figure 2. Example of water temperature data collected by of EnvLogger Opportunity Diving, processing (data is smoothed with over a 5 min rolling window, then mean and median are extracted and plotted vs the closest point data from the CORA - Coriolis Ocean Dataset for Reanalysis - doi: 10.17882/46219). The dive lasted about 1h. Final temperature drop reflects the device cleaning with fresh water. Figure and analysis done by the CS-MACH1 app: https://cs-mach1-envlogger-scuba-v-20260518.streamlit.app/

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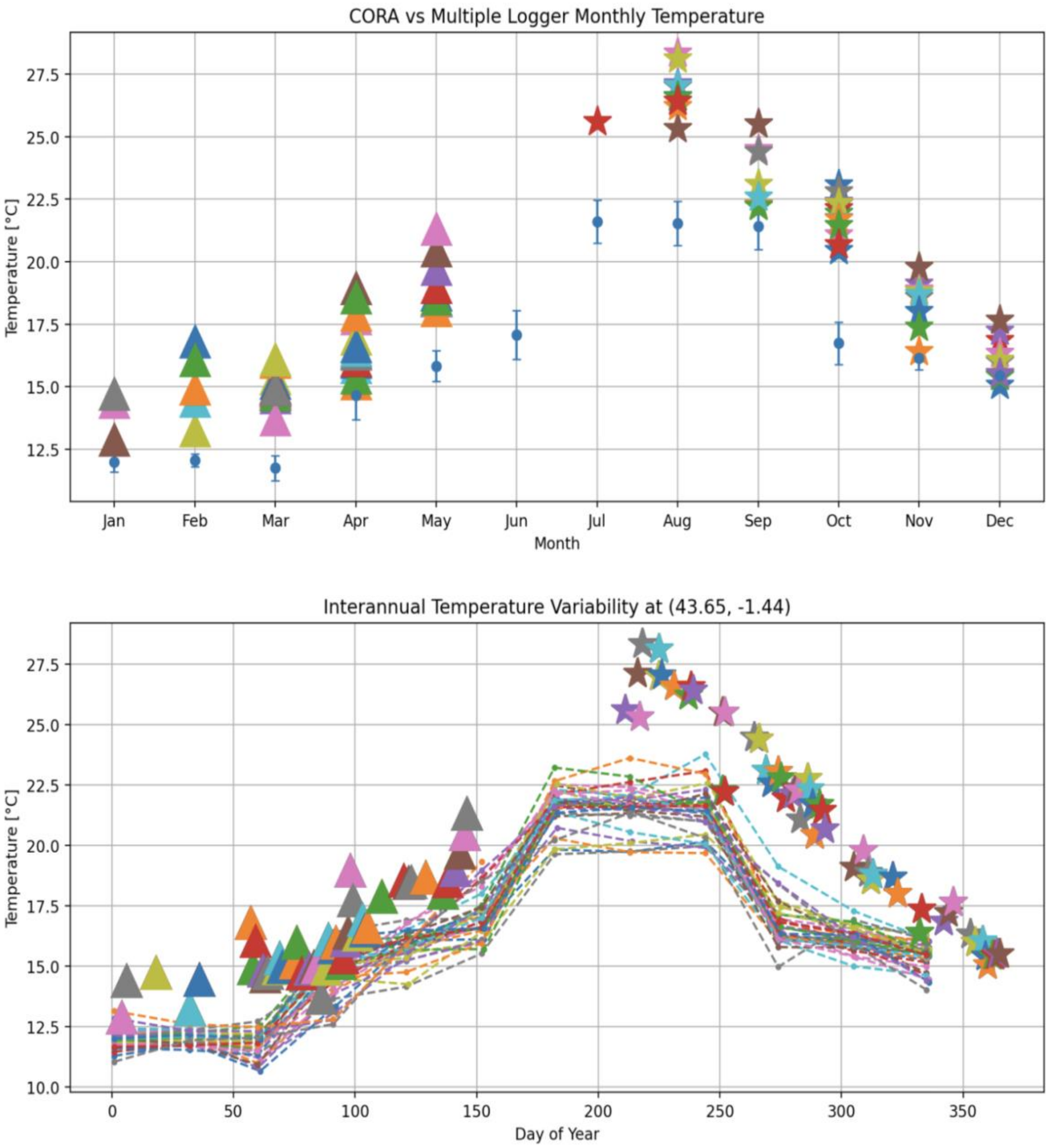

Figure 3. 107 days of EnvLogger Opportunity Diving temperature data (plotted against CORA) showing that shallow water warms more than open ocean. Stars represent 2025 data, triangles represent 2026 data, squares represent 2027 data.

Such low-cost devices can contribute meaningfully to coastal monitoring, but to fully exploit this potential there are key “data” actions to be addressed:

- Improvement of the metadata model in line with the EMODnet/SeaDataNet requirements and use NERC vocabularies
- Development of an easy-to-use data processing and committing/sharing tool
- Development of a CS-MACH1 hosting/grouping stack for easier integration into e.g. EMODnet Physics

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- Immediate feedback loop to the citizen.

A.2 ANDROMEDA: supports beach-based microplastic sampling by allowing users to photograph collected particles; artificial intelligence/image-analysis tools then help characterise the samples and extract information such as size, colour and roughness.

Identified pathway: EMODnet Chemistry following the litter data pathway in D3.1. ANDROMEDA can contribute to EMODnet Chemistry through the production of standardised microplastic sampling metadata and harmonised pollution descriptors. Its structured sampling protocol, geo-enabled app workflow, image-based particle characterisation and centralised data repository provide a basis for converting citizen-science observations into interoperable datasets suitable for wider marine litter and pollution data aggregation.

Status to date: ANDROMEDA was a JPI Oceans-funded project focused on improving methods for collecting, analysing, identifying and monitoring micro- and nanoplastics in marine environments. The project brought together 15 international partners and aimed to advance cost-effective in-situ sampling, low-cost laboratory analysis, and refined techniques for quantifying small and challenging particles such as microfibres, tyre-wear particles and paint flakes.

A key citizen-science component was the ANDROMEDA smartphone app, developed by the Oceanography Malta Research Group, University of Malta. The app supports beach-based microplastic sampling by allowing users to photograph collected particles; artificial intelligence/image-analysis tools then help characterise the samples and extract information such as size, colour and roughness. The resulting images and derived data are stored in a University of Malta repository.
The app-supported protocol guides participants through standardised beach sampling using a quadrat, sieve, trowel, ruler, photo template and collection jar. Participants sample a defined sand area, sieve material to retain larger particles, place suspected microplastics on the ANDROMEDA photo template, photograph them using the app, and collect the particles for appropriate disposal or further analysis. Seasonal or recurring citizen-science campaigns therefore create structured observations from beaches while also raising public awareness of microplastic pollution.

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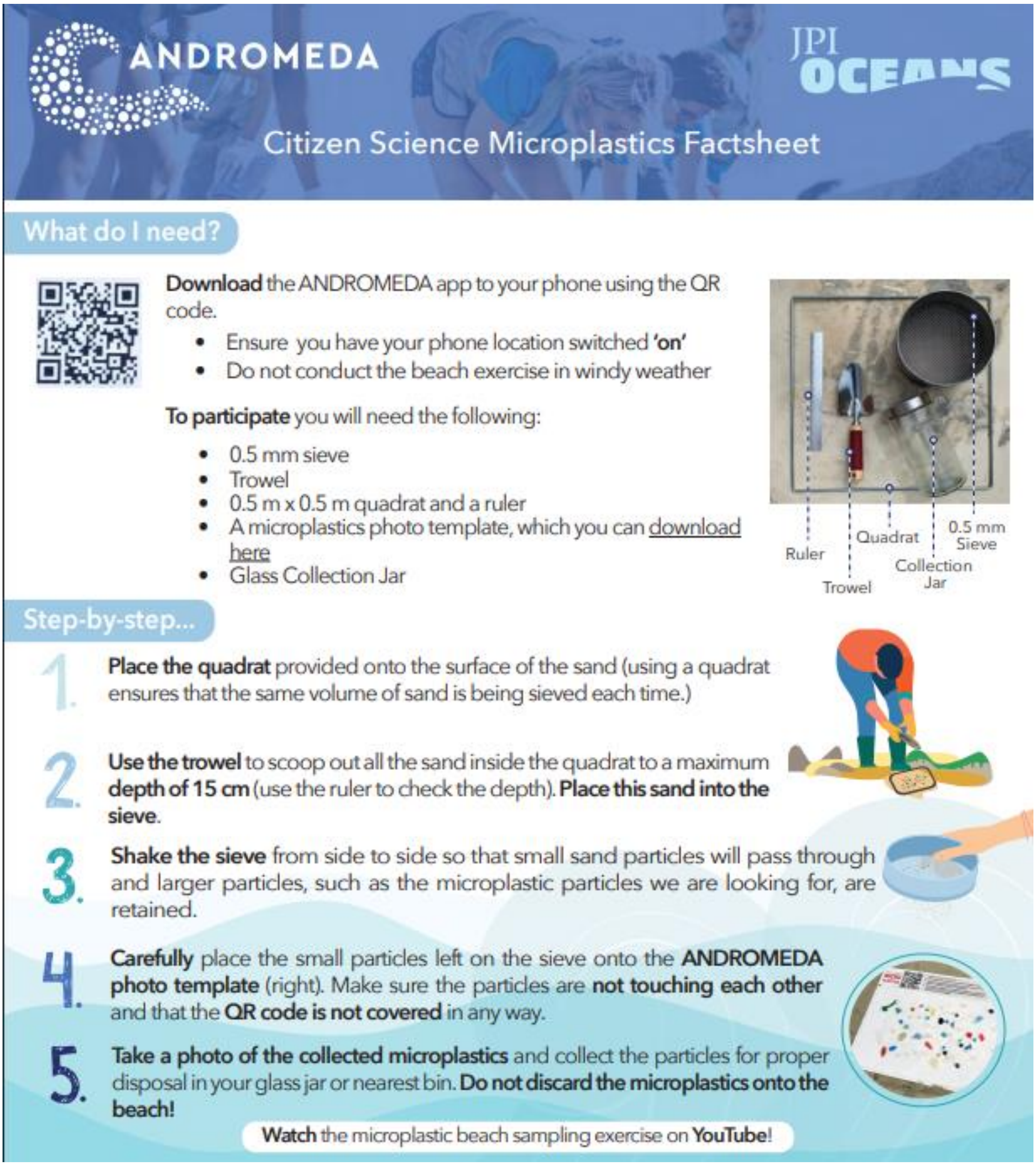

ANDROMEDA

JPI OCEANS

Citizen Science Microplastics Factsheet

What do I need?

Download the ANDROMEDA app to your phone using the QR code.

- Ensure you have your phone location switched **'on'**
- Do not conduct the beach exercise in windy weather

To participate you will need the following:

- 0.5 mm sieve
- Trowel
- 0.5 m x 0.5 m quadrat and a ruler
- A microplastics photo template, which you can download here
- Glass Collection Jar

Step-by-step...

1. **Place the quadrat** provided onto the surface of the sand (using a quadrat ensures that the same volume of sand is being sieved each time.)
2. **Use the trowel** to scoop out all the sand inside the quadrat to a maximum **depth of 15 cm** (use the ruler to check the depth). **Place this sand into the sieve.**
3. **Shake the sieve** from side to side so that small sand particles will pass through and larger particles, such as the microplastic particles we are looking for, are retained.
4. **Carefully** place the small particles left on the sieve onto the **ANDROMEDA photo template** (right). Make sure the particles are **not touching each other** and that the **QR code is not covered** in any way.
5. **Take a photo of the collected microplastics** and collect the particles for proper disposal in your glass jar or nearest bin. **Do not discard the microplastics onto the beach!**

Watch the microplastic beach sampling exercise on **YouTube**!

Figure 4. Factsheet and instructions for Citizen Science to the proper use of the ANDROMEDA sampling campaign

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A.3: Maccaferri Futura: operates met-ocean multi-parameter sensor systems with boat-based telemetry onboard a raceboat, providing near-operational datasets.

Identified pathway: operating met-ocean multi-parameter sensor systems and operating a telemetry system the initiative targets integration into EMODnet Physics.

Status to date: Maccaferri Futura operates a Class40 sailing platform equipped with the scientifically validated SailingBox/SOOP (Ship Of Opportunity Programme) system, enabling the continuous acquisition and transmission of near real-time met-ocean observations during offshore navigation campaigns. The initiative combines offshore racing, onboard environmental research and sustainability outreach, using telemetry-enabled multi-parameter sensors to collect operational oceanographic datasets. Meccaferri Futura is already providing operational data to EMODnet and it is available under EMODnet Ingestion "as is".
The Sailing Box was chosen also for its potential compatibility with boat and navigation info collected via NMNA 2000 and integration with Navico Connect PLC was established also with the support of Corvina.

Figure 5. The Sailing Box low-cost device (left) installed onboard the Class40 Maccaferri Futura gathering seawater data, and the Navico OP Box (right) gathering navigational data and sharing all via Starlink connection

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Figure 6. Maccaferri Futura class40 Racing boat racing while collecting data in Fastnet Race 2025 in Cowes (UK).

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Characteristics of SOOP Sailing Box

Category	Specification / Parameter	Details
Device Performance	**Data Output Rate**	≈ 10–15 kB every 2 seconds
	Power Consumption	20 W (12 V)
	Pump Flow Rate	3–6 L/min
	Data Link	EMOBUS connection
	GPS	Not included (boat GNSS used instead)
	Dry Weight	8.5 kg (with pipes and fittings)
	Integration	Fully compatible with Navico PLC + Corvina dashboard
	Installation Chain	Water inlet → pump → debubbler → Sailing Box → outlet
Scientific Parameters Collected	**Surface Temperature**	Unit: °C · Range: 0–40 - shared with EMODnet
	Salinity	Unit: PSU · Range: 0–40 · shared with EMODnet
	pH	Unit: pH · Range: 5–9 · shared with EMODnet
	Dissolved Oxygen	Unit: mg/L · Range: 0–8 · shared with EMODnet
	Flow Rate (QC)	Unit: L/min · Range: 0–10 · Display: Internal diagnostics only
Boat parameters homogenised with thanks to Navico PLC	**Wind Speed & Direction**	Unit: knots · shared with EMODnet with delay
	Atmospheric Pressure	Unit: mbar · Range: 900–1100 · shared with EMODnet with delay
	Bathymetry	Unit: m · Range: 2–∞ · shared with EMODnet with delay
	Geolocation (Lat/Lon)	Derived from boat GNSS · shared with EMODnet with delay

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Figure 7. Maccaferri Futura onboard installation of the Sailing Box and data transfer via Navico OP Box to Corvina dashboard and EMODnet Physics.

More specifically the telemetry implements automatic dissemination of observations via a connector (API) to the EMODnet Ingestion ERDDAP.
The required next step is the full operational integration into EMODent Physics which needs the following “data” actions:

- Improvement of the metadata model in line with the EMODnet/SeaDataNet requirements and use of NERC vocabularies (P01/L22).

A.4: Meteotracker: MeteoTracker is a citizen-powered environmental monitoring platform that transforms moving vehicles and vessels into mobile weather stations.

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Using low-cost devices to collect real-time atmospheric and geolocated data such as air temperature, humidity, pressure and weather conditions, MeteoTracker helps improve local forecasting, climate observation and environmental research. In offshore sailing and ocean science projects, it enables boats, kayaks and stand-up paddleboards to contribute valuable at-sea meteorological observations that complement oceanographic datasets and support broader Earth system monitoring efforts. MeteoTracker data are typically shared through APIs and interoperable web services, allowing third-party platforms and scientific infrastructures to access both real-time and archived environmental observations.

Figure 8. Meteotracker ultra-compact portable weather station for moving vessels and platforms

Identified pathway: Meteorological data at sea level are targeted by EMODnet Physics.

Status to date: The MeteoTracker platform is a citizen science and professional environmental monitoring system designed for mobile and hyperlocal meteorological observations. The initiative combines portable multi-parameter meteorological sensors, mobile applications, cloud infrastructure, APIs and dashboard services to collect and disseminate georeferenced atmospheric observations in near real time. The system supports measurements of temperature, humidity, pressure, altitude,

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solar radiation indicators and derived atmospheric variables, with automatic geolocation and timestamping integrated into the acquisition workflow.

The MeteoTracker ecosystem has already demonstrated scientific applicability through multiple research and citizen science projects, including urban heat mapping, climate monitoring and participatory environmental campaigns. The platform has been validated in scientific studies comparing citizen-generated observations with official meteorological networks, demonstrating that properly processed mobile citizen science datasets can provide reliable and operationally useful environmental observations.

Its technological framework — including cloud-connected telemetry, APIs, CSV export, georeferenced datasets and collective data management tools — makes MeteoTracker particularly suitable for integration pathways aligned with EMODnet Physics and broader FAIR data-sharing practices. The platform already supports interoperable dissemination workflows and collaborative data collection approaches that are consistent with the growing role of citizen science initiatives within EMODnet and European marine and environmental observing systems.

One specific application of interest is the offshore sailing and ocean science projects; it enables boats, kayaks and stand-up paddleboards to contribute valuable at-sea meteorological observations that complement oceanographic datasets.

Although the system is already offering APIs for real-time data integration, the platform is not using marine standards and conventions.

To fully exploit this pilot the following “data” actions to be addressed:

- Improvement of the metadata model in line with the EMODnet/SeaDataNet requirements and use NERC vocabularies
- Development of an easy-to-use data processing (according to the marine integrators needs) and committing/sharing tool
- Development of a CS-MACH1 hosting/grouping stack for easier integration into (e.g.) EMODnet Physics.

A.5: Spot the Alien: geo-referenced observations of alien species occurring in Maltese waters, primarily through photographs and videos uploaded online

Identified pathway: Integration into GBIF through the generation of species occurrence records that can be structured according to biodiversity data standards such as Darwin Core.

Citizen observations → Online submission → Expert validation → Dataset standardisation → GBIF publication

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Status to date: Spot the Alien and Spot the Alien Fish are Maltese citizen-science campaigns launched in 2017 by the Oceanography Malta Research Group to support the reporting and monitoring of marine non-indigenous species (NIS), commonly referred to as alien or invasive species. The campaigns encourage fishers, divers and the general public to submit geo-referenced observations of alien species occurring in Maltese waters, primarily through photographs and videos uploaded online. While Spot the Alien Fish focuses specifically on alien fish species, Spot the Alien targets all other marine non-indigenous species.

The campaigns rely on crowdsourced biodiversity observations contributed by citizen scientists using social media reporting means and visual evidence, including underwater photography. Submitted sightings support long-term biodiversity monitoring and help scientists track the spread, abundance and ecological impacts of invasive marine species around the Maltese Islands. The campaigns also contribute significantly to public awareness and education regarding marine biodiversity change, invasive species risks and marine ecosystem management.

To facilitate participation, the initiative distributes bilingual educational posters and outreach material to fishers, diving operators and marine stakeholders. Campaign activities are regularly promoted through science festivals, Blue Schools initiatives, public exhibitions and dedicated online portals. Reported observations have contributed to peer-reviewed scientific publications and support Malta's national and international obligations related to invasive species monitoring.

Contributors submit records through social media platforms by uploading photographs and videos of suspected alien species together with the following information:

- Name, surname and email address of the observer
- Location and date of the sighting
- Number of individual species which were sighted
- Method of sighting (fishing, SCUBA diving, kayaking, etc.)
- Other details about the sighting (depth, habitat, etc.)

Submitted observations undergo a scientific validation process coordinated by the Oceanography Malta Research Group. Once validated, the record is included in the dataset for future standardisation.

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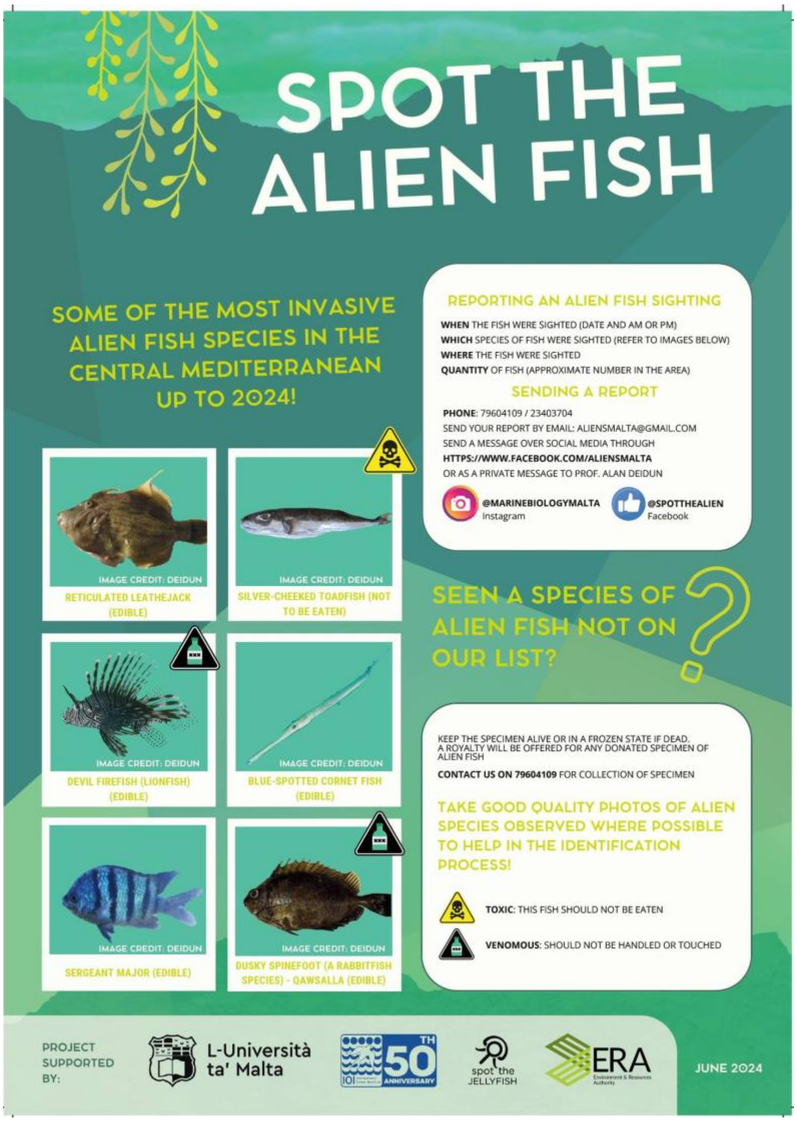

Figure 9. One of the posters for the Spot the Alien Citizen Science campaign distributed to sea users e.g. diving centers and fishing shops

Description of ingestion process to GBIF:

1) Transformation of the data into a table structure
2) Upload the data to the ITP

It was necessary to request a data hosting center to use the Integrated Publishing Toolkit (IPT), which allows us to manage our own datasets and publish them through GBIF (Malta does not have a data hosting center, so the one from a neighbouring country was used).

3) Map the data to Darwin Core terms
4) Fill in resource metadata using the IPT metadata editor
5) Publish the dataset
6) Register the dataset with GBIF

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The publication of the Spot the Alien dataset through GBIF facilitates interoperability with other international marine biodiversity data infrastructures, such as EMODnet Biology, OBIS, etc.

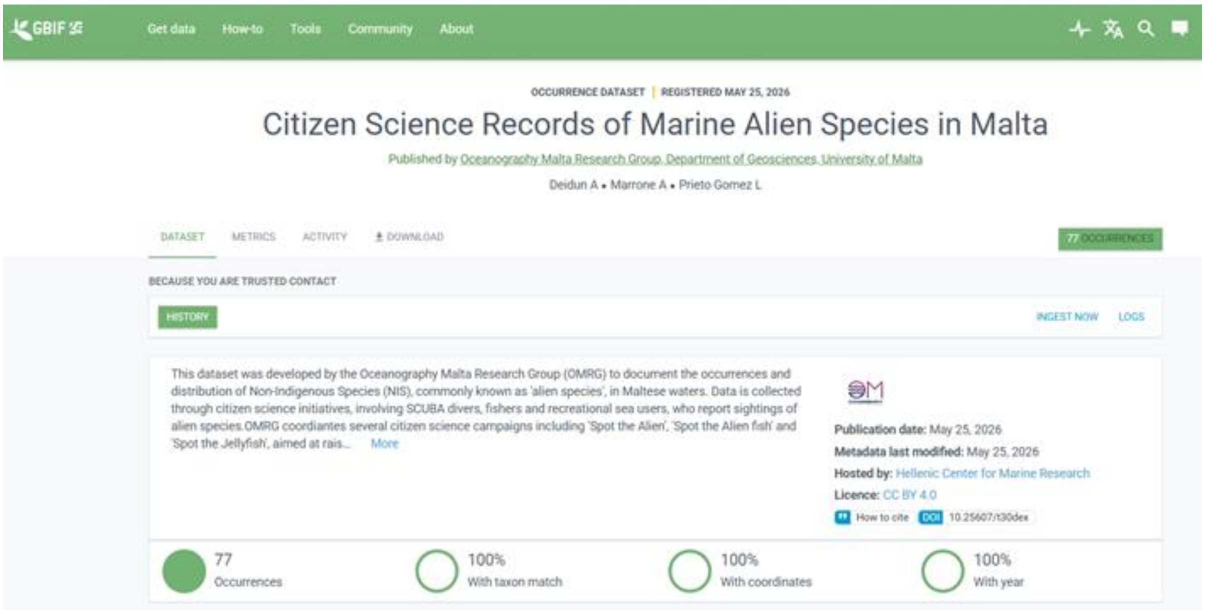

Figure 10. Final publication stage of the Spot the Alien data flow, showing the occurrence dataset published and indexed through GBIF https://www.gbif.org/dataset/c1183739-8c2e-4213-bf1c-f2c8fb83e275

A.6: Interbox: deploys fixed sensors for sea level monitoring and atmospheric parameters with automated uploads and QA/QC procedures.

Identified pathway: Integration into EMODnet Physics via standardized time-series data and QARTOD-compliant quality flags.

The interbox is already fully integrated into EMODnet Physics, meaning that this platform, besides being mature and scientifically validated, has reached the highest level of integration readiness.
The next step is the extension of the metadata dataset to include the practice/methodology and develop actions to scale up and extend the interbox networks globally.
The designed workflow for interbox may also represent a case-study for developing technical training material and support other initiatives following similar principles or pathways.

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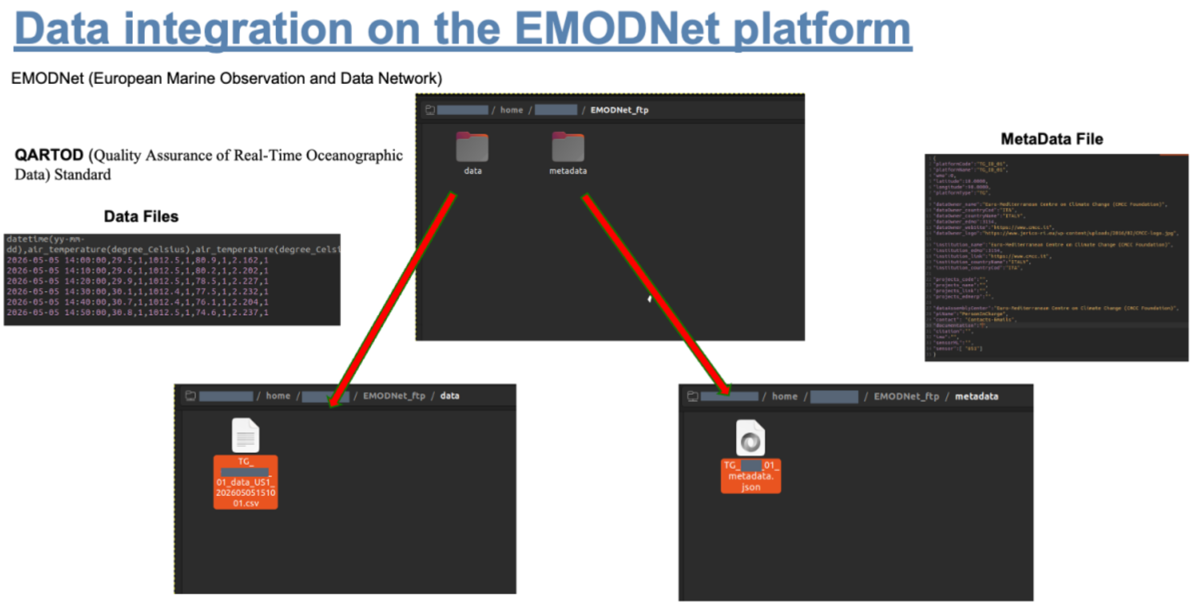

Figure 11. InterBox data flow on EMODnet


```
{
"platformCode":"TG_MEX_01",
"platformName":"TG_MEX_01",
"wmo":0,
"latitude":21.39433,
"longitude":-88.89067,
"platformType":"TG",

"dataOwner_name":"Euro-Mediterranean Centre on Climate Change (CMCC Foundation)",
"dataOwner_countryCod":"ITA",
"dataOwner_countryName":"ITALY",
"dataOwner_edmo":3154,
"dataOwner_webSite":"https://www.cmcc.it",
"dataOwner_logo":"https://www.jerico-ri.eu/wp-content/uploads/2016/02/CMCC-logo.jpg",

"institution_name":"Euro-Mediterranean Centre on Climate Change (CMCC Foundation)",
"institution_edmo":3154,
"institution_link":"https://www.cmcc.it",
"institution_countryName":"ITALY",
"institution_countryCod":"ITA",

"projects_code":"",
"projects_name":"",
"projects_link":"",
"projects_edmerp":"",

"dataAssemblyCenter":"Euro-Mediterranean Centre on Climate Change (CMCC Foundation)",
"piName":"Viviana Piermattei",
"contact": "viviana.piermattei@cmcc.it, juan.martinez@cmcc.it",
"documentation":"https://doi.org/10.3389/fmars.2025.1604069",
"citation":"",
"imo":"",
"sensorML":"",
"sensor":[ "US1"]
}
```


Figure 12. Example of InterBox Metadata

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Status to date: the InterBox, developed by CMCC, is an affordable, low-maintenance, and easy-to-install observing system designed to monitor water levels and meteorological variables at the ocean-atmosphere interface. The system's combination of high accuracy and low power consumption makes it well suited for integration into monitoring networks and citizen science projects, significantly enhancing spatial resolution. The installation of this system is part of a wide community science initiative, as part of a high school training course focusing on climate and oceanography. The goal is to improve scientific information for all by enhancing ocean and coastal monitoring, promoting open access to data, and fostering collaboration to bridge knowledge gaps.

Figure 13. InterBox system

Specifications

Water Level

Sensor	HY-SRF05
Range	2 - 450 cm
Resolution	≈ 2 mm
Accuracy	3 mm

Data Transmission

LoRa

Power Output	Up to +20 dBm at 3.3V
Frequency	868/915MHz
Max Distance	10km (ideal conditions)

Globalstar

Power Output	17.5 dB
Antenna	TAOGLAS SP.1615.25.4.A
Antenna Type	Active

Barometric Pressure

Sensor	MS5803
Range	10 to 1300 mbar
Resolution	0.012 mbar
Accuracy	± 2.5mbar

Air Temperature

Sensor	DS18B20
Range	-55°C to +125°C
Resolution	12 bits
Accuracy	±0.5°C (-10°C to +85°C)

Relative Humidity

Sensor	DHT20
Range	0~100%
Resolution	0.024%RH
Accuracy	± 3%RH

Figure 14. Interbox specifications

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An automated quality control (QC) procedure inspired by the QARTOD (Quality Assurance of Real-Time Oceanographic Data) framework is applied to ten-minute median values derived from one-minute observations of water level.

An example of data transfer and dissemination through EMODnet is available at: https://map.emodnet-physics.eu/platformpage/?platformcode=TG_RIM_01&source=cp&integrator=CMCC

Figure 15. Installation of InterBox during training activities with master degree students

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Figure 16. Training activities with master degree students

A.7: MINKA: MINKA is a citizen observatory, coordinated by ICM-CSIC, inspired by iNaturalist, a worldwide citizen observatory that has demonstrated to be very effective for participants' engagement and massive participation.

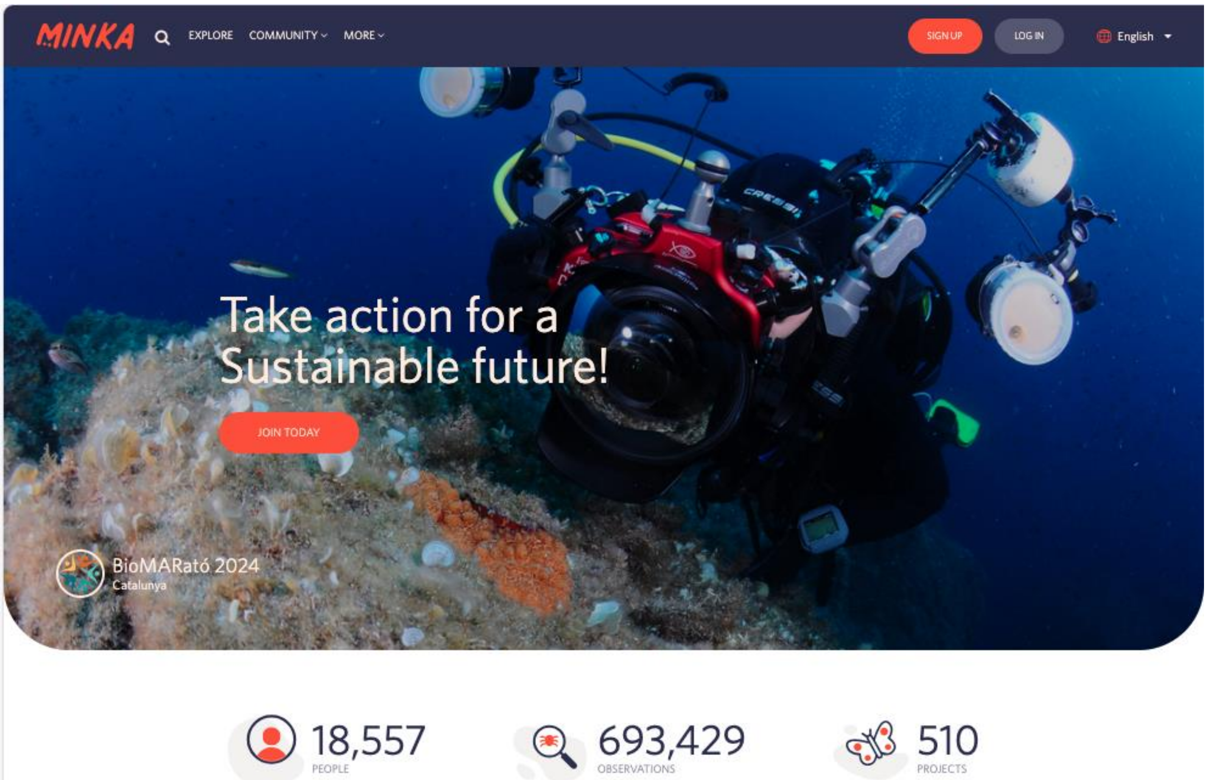

Figure 17. MINKA citizen observatory. https://minka-sdg.org/

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Identified pathway: Strong alignment with EMODnet Biology via GBIF ingestion pipelines and Darwin Core formats.

Status to date: The initial code of iNaturalist has been progressively adapted, particularly for marine observations. As an example, iNaturalist has a panel that allows pre-selection of what is considered the most popular taxonomic groups. This panel is highly biased towards terrestrial groups in iNaturalist. In MINKA, this has been adapted and expanded allowing access to a wide range of marine groups.

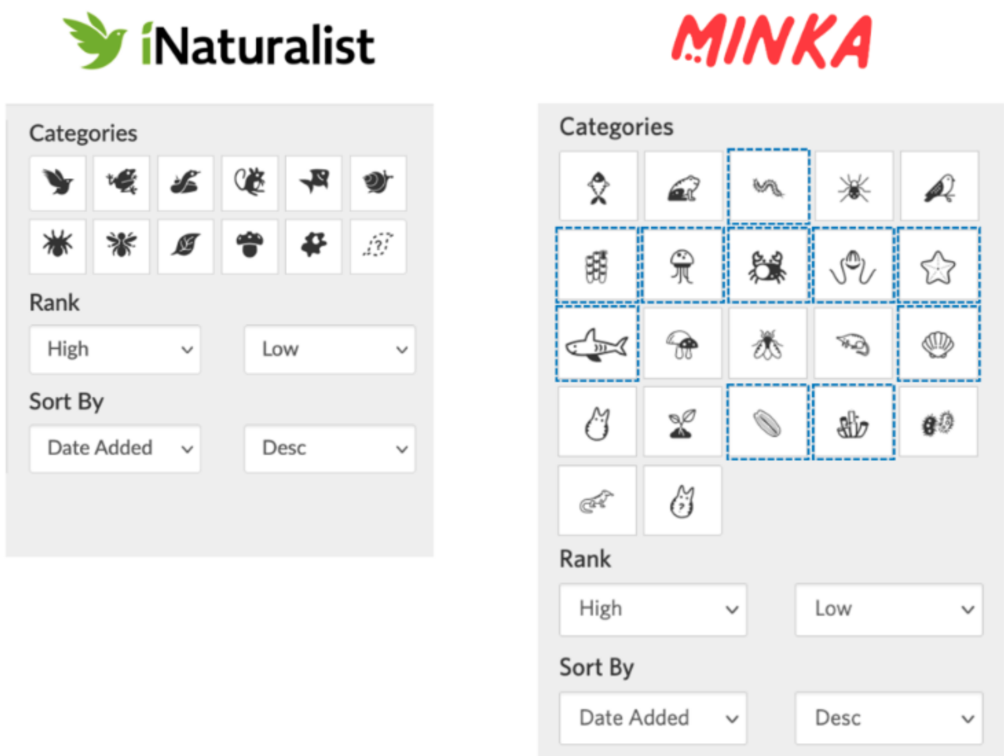

Figure 18. Adaptation for managing marine observations in MINKA. (left) Initial filter panel for searching observations in iNaturalist. (right) MINKA filter panel with specific filters for marine taxons (icons highlighted in dotted blue). Adapted from Liñan et al (2026)

Following the iNaturalist principle, MINKA has certain rules for controlling the quality of the observations. First, the observation should be verifiable. A verifiable observation is an observation that: (1) has an accurate date; (2) is accurately georeferenced (i.e. has lat/lon coordinates); (3) is supported by a digital media (photos or sounds); (4) isn't of a captive or cultivated organism. The verifiable observations may acquire the level of Research Grade (RG) when more than one participant has contributed to its identification, and more than 2/3 of the identifiers agree on a taxon

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at species-level. This algorithm is now in process to be improved, including the support of AI for automatic classification.

Research grade observations are regularly uploaded to GBIF as dedicated datasets.

Figure 19. Example of a MINKA dataset reported in GBIF from a previous project https://www.gbif.org/dataset/9a51436f-3c81-4b1a-92d6-6f0c1dbb05de.

The advantage of reporting through GBIF is that it is possible to track the number of citations of the dataset, thanks to the literature data tracking service provided by GBIF (https://www.gbif.org/literature-tracking)

A.8: BioMARathon: this is a specific large-scale event (Liñan et al. 2026) designed to maximize the long-term engagement of participants for coastal biodiversity monitoring.

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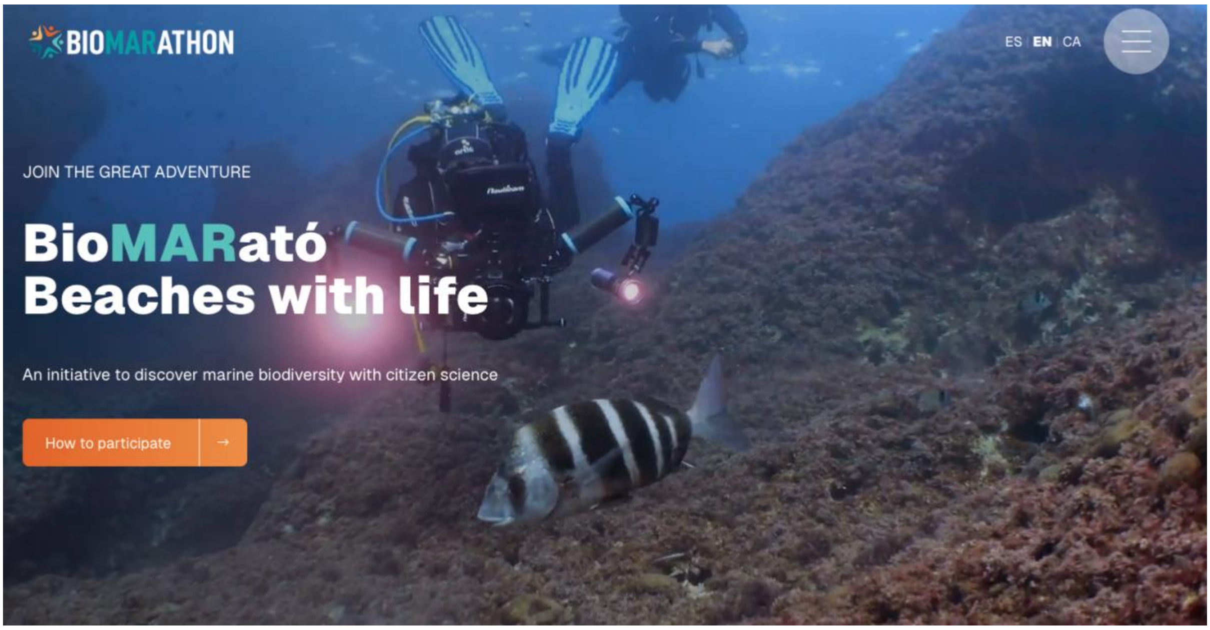

Figure 20. BioMARathon portal https://biomarato.org/en/

The bioMARathon follows the strategies and the engagement framework proposed by Liñan et al. 2022. This approach has demonstrated to be highly effective to engage and consolidate a large community of practice. The first proof of concept has been developed in the Catalan Coast, in one of the CS_MACH1 case studies, showing the exponential increase both in participation and reported observations (see figure below).

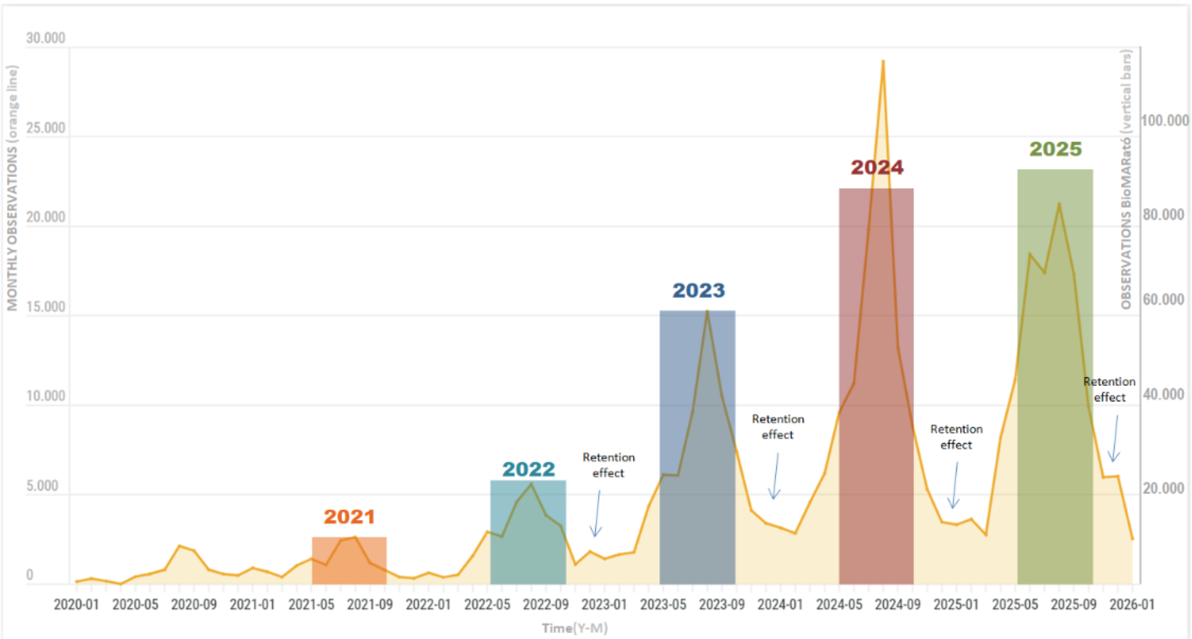

Figure 21. Evolution of the number of observations per month from January 2020 to January 2026 performed in the local BioMARathons (Catalonia coasts). The shaded

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vertical bands indicate the annual BioMARató periods, running approximately from the first Saturday of May until mid-October. Adapted from Liñan et al (2026)

The BioMARato portal allows the creation and management of events at different regions (https://biomarato.org/en/#regions), allowing to extend and scale this approach to other CS-MACH1 case studies.

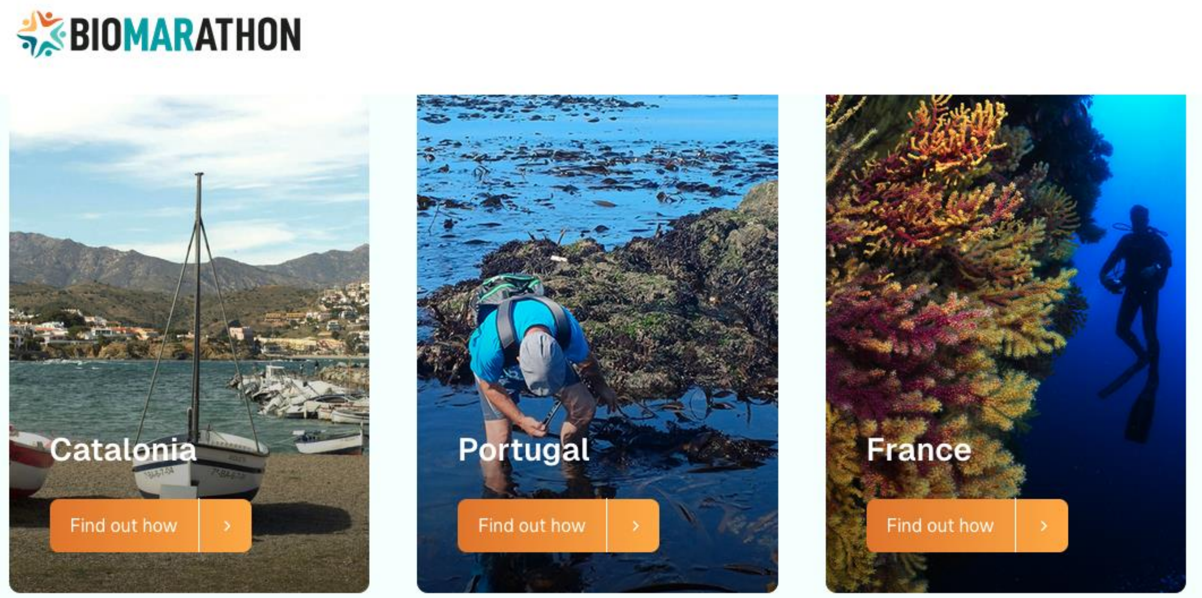

Figure 22. Examples of active regions organizing BioMARathons at present (2026)

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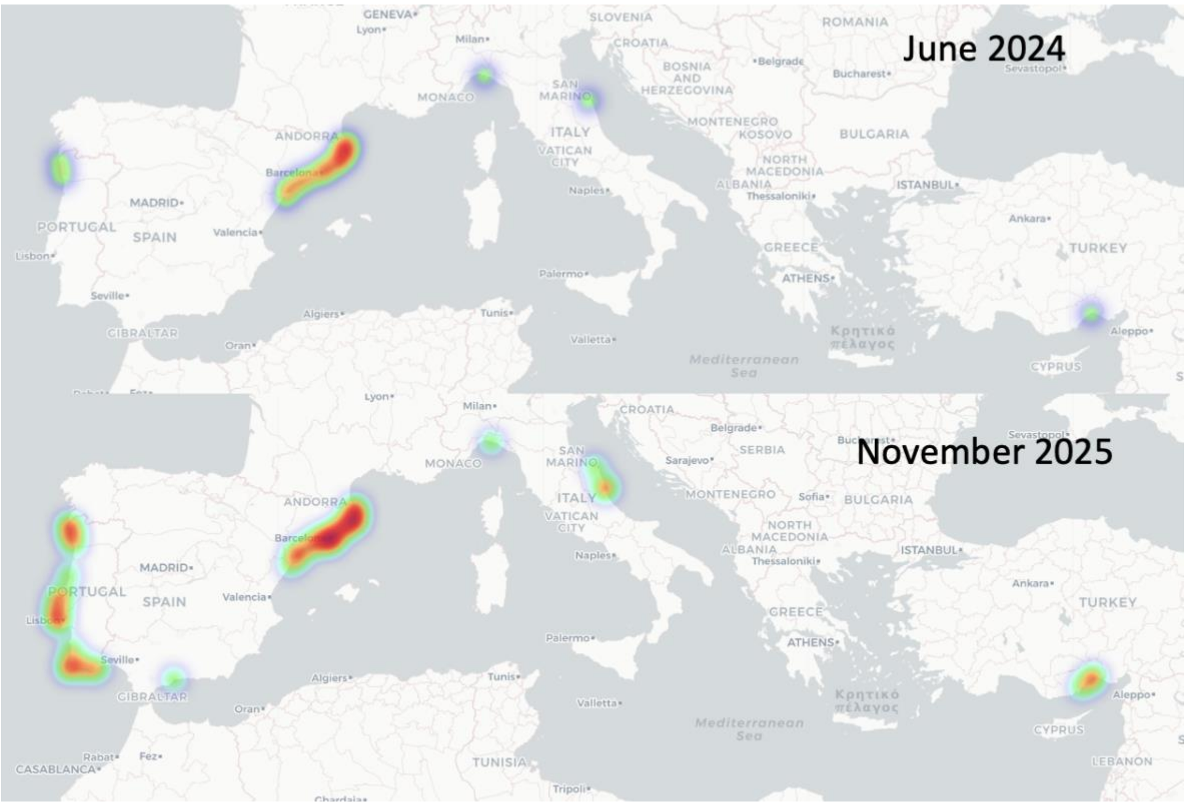

Figure 23. Headmaps showing the observations reported in MINKA, originated mainly during the BioMARathons, showing the potential expansion and scalability of this large scale engagement strategy.

A.9: EyeonWater: collects optical water quality data (colour, turbidity) via mobile application. EyeOnWater is a global citizen science initiative that empowers the public to monitor the health of natural water bodies by simply snapping and uploading a photo of the water's color. The EyeOnWater app helps citizen scientists match the color of their local water body to a standardized scale, the Forel-Ule scale, which is a historical method used for over a century to determine ecological health.

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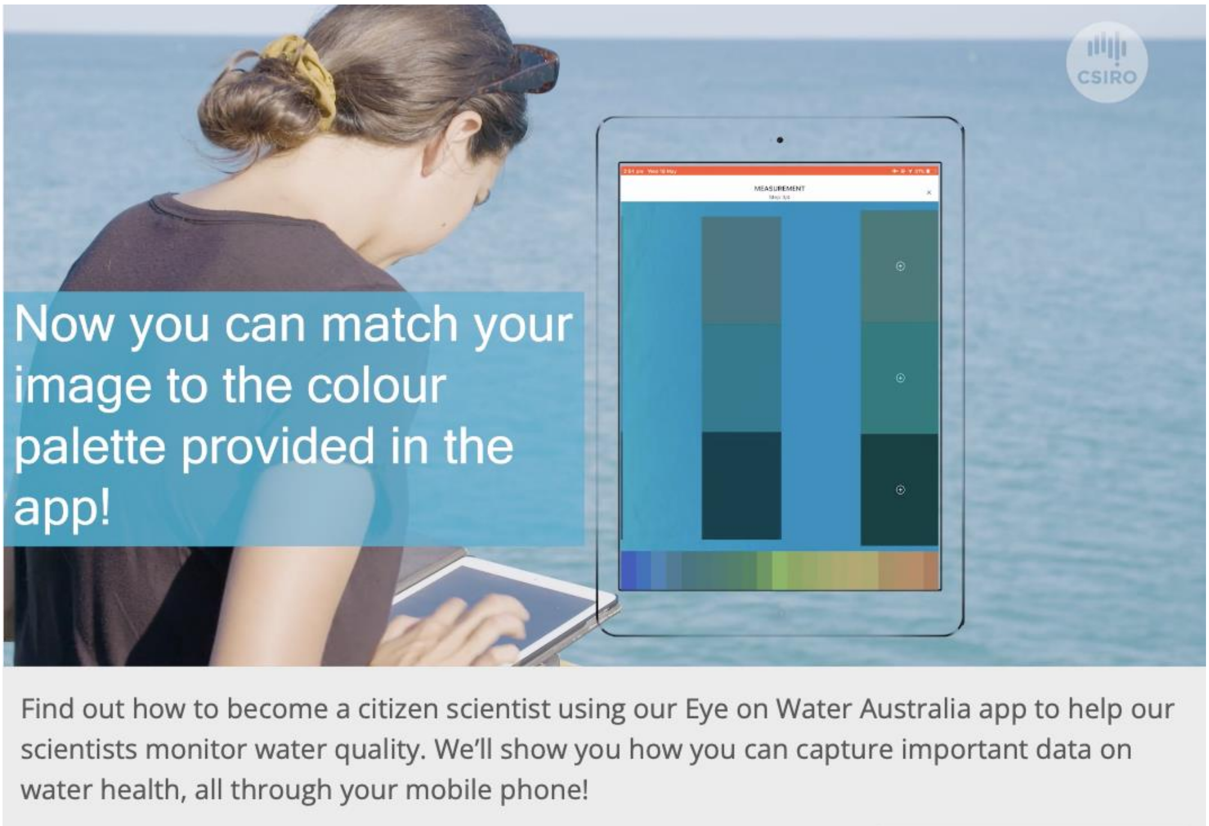

Figure 24. EyeOnWater app which lets to record additional metrics like Secchi disk

Identified pathway: Potential integration as data collections in SeaDataNet data centers feeding into Chemistry (if quality accepted), requiring clear metadata, describing quality, and conditions. Especially acceptance as an additional data source is important.

B. Northern European Seas

Northern pilots show stronger integration with long-term monitoring approaches and emerging technological innovation in imaging and sensor deployment.

B.1: SSI and ScubaNetwork: SSI Scuba Schools International and the ScubaNetwork initiative collaborate in the development of citizen science approaches based on recreational diving activities, contributing to the collection of distributed in situ marine observations through connected dive communities and digital diving platforms. The initiative combines diver-generated environmental observations, dive computer telemetry and georeferenced metadata acquisition to support participatory marine monitoring and environmental stewardship. The observing approach relies on measurements collected during routine dives, including temperature, depth, location and additional contextual environmental parameters associated with dive profiles.

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Identified pathway: temperature into EMODnet Physics, contextual environmental parameters into EMODnet Biology/GBIF and EMODnet Chemistry

Status to date: the initiative demonstrates significant operational potential because recreational divers provide repeated observations in coastal and shallow-water areas that are often under-sampled by conventional oceanographic infrastructures. About 200.000 SSI data dives (profiles) are already available into EMODnet Ingestion, covering both internal waters and open waters.
ScubaNetwork, circa 90.000 dives, are already available into EMODnet Ingestion, making the scuba divers networks and their capacity to offer repeated observations in coastal and shallow-water massively interesting.

The current integration has already identified critical actions to integrate these dives into EMODnet Physics:

- Data model
- Filtering of the marine data
- Outliners and QC/QF
- Automation in data processing
- Adoption of EMODnet/SeaDataNet recommendations and NERC vocs
- Feedback to citizen

Similar actions are needed to facilitate the integration into EMODnet Chemistry and EMODnet Biology/GBIF.

B.2: KOSMOS : An Open Source Underwater Video Protocol for Monitoring Coastal Fishes and Habitats: The French Institute for the Exploitation of the Sea (Ifremer) has set up a collaboration with a FabLab (Digital Fabrication Laboratory) to develop a low-cost video lander from an existing scientific lander (STAVIRO). The STAVIRO protocol had been widely used since 2007 in both tropical and temperate ecosystems, and became an Ocean Best Practice in 2022
(https://repository.oceanbestpractices.org/handle/11329/1939).
It relies on a rotating camera that records the underwater seascape at 360° without distorting the field of view, without light and with no bait. The mobile fauna thus remains barely affected by the presence of the lander. Furthermore, a deployment is rather fast (15-20 min), so that many can be realised per day at sea.
A FabLab is a digital fabrication laboratory providing access to the environment, skills, and materials for people to learn from others expertise and stimulate innovation (https://fabfoundation.org/getting-started/#fablabs).
A FabLab relies on volunteers and aims at outreach, and as such implements collective intelligence and fosters citizen science.

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The Konk Ar Lab (KAL), the FabLab from Concarneau in Brittany welcomes everyone that aims to learn how to make things or to share his/her skills.
This collaboration between Ifremer and KAL naturally evolved the protocol to encompass citizen participation in both technological developments and data collection. Hence, the KOSMOS now includes recycled plastic and reconditioned batteries, among other ideas contributed by the group.

Identified pathway: Potential contribution to EMODnet Seabed Habitats, requiring alignment with habitat classification schemes and metadata standards.

Status to date: Currently, the KOSMOS 4.0 comprises a single camera controlled by a Raspberry Pi using Python-based codes. A mobile app has been developed to simply switch on and off, adjust image capture parameters and document field metadata on the boat. Version 5.0 is stereo and is currently being validated.

Figure 25. The KOSMOS lander (V4.0)(left) with example of image collected (right)

So far, the protocol has been implemented by both citizens and scientists in several areas in Western Brittany, with over 300 deployments since 2021. Citizens may deploy from their boat or be onboard scientific boats. They are also involved in the technological evolution and maintenance of the instrument. Data are collected according to a sampling design that aims to establish assessments of fish communities and benthic habitats covering the area of interest. Other sampling designs are considered depending on the questions which may be related to anthropogenic impacts, Marine Protected Areas, fish stock assessment, fish behaviour, etc..
The workflow from image capture to data products is currently being automated to ensure completion and alignment of metadata in a FAIR perspective, to facilitate data QA/QC, and to improve user experience in video debushing.
Output data from the KOSMOS protocol are:

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- fish counts per species or higher-level taxonomic group. Other species like turtles are also observed depending on the region.
- fish length and distance to fish (in the stereo version)
- biotic and abiotic cover of sea bottom and other habitat descriptors that enable characterizing the nature and status of the habitat at observation locations.
- temperature and depth
- images that are reused for educational and scientific purposes
- all associated metadata (from field and annotation)

Derived products are indicators of fish abundance, biodiversity measures, and habitat status, illustrated by images.

B.3: Barnacle Observer: combines temperature and salinity sensors with observational reporting to track barnacle blooms.

Identified pathway: Integration into EMODnet Biology (species dynamics) and Physics (environmental parameters), pending metadata standardization.

Status to date: The Swedish Boating Association (Svenska Båtunionen) runs a volunteer-driven citizen science programme called Barnacle Observer (Havstulpanobservatör), started in 2018, that tracks when barnacle larvae settle so boat owners know when to clean hulls and avoid unnecessary antifouling use. The scheme operates each summer on the Swedish coastline. In 2025 about 150 observers joined to provide weekly records from their local piers and boats during the season. Volunteers receive a simple black monitoring plate to suspend in the water about 30-50 cm below the surface at a jetty or boat, check the underside weekly, and report counts via the initiative's reporting tool so the team can issue localised SMS/email barnacle warnings when settling is detected. Starting in 2026, forty observers will be equipped with an EnvLogger temperature sensor from ElectricBlue, and three sites will deploy a micro-CTD from Star-Oddi together with a low-cost current profiler to add co-located environmental context to the biological observations. The data collected by the low-cost sensors will be following the EU-funded LandSeaLot project data protocol in order to flow into EMODnet Physics, and the CS-MACH1 team is facilitating the FAIRification of the data collected related to the barnacles to ensure interoperability and reuse.

Maccaferri Futura: the description is reported in the A.3. Section 'Southern European Seas', as it will be implemented in both the pilot areas.

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Interbox: the description is reported in the A.4. Section 'Southern European Seas', as it will be implemented in both the pilot areas.

Eye on Water: the description is reported in the A.6. Section 'Southern European Seas', as it will be implemented in both the pilot areas.

C. Extended Use Cases

The Integrative Use Cases were identified and engaged through the networking and community-building activities conducted during the first phase of CS-MACH1 project. They emerged from interactions among pilot initiatives, technology providers, data managers, and citizen science communities, highlighting opportunities for collaboration around common environmental challenges and data integration objectives. Through project sharing, integrative pilots effectively function as knowledge transfer hubs, enabling the transition from local experimentation to coordinate, system-level implementation. These cases are covered by selected MCSI already equipped with cost-effective methodologies to collect data in pilot demonstrations.

C.1 LIFE EUSharks: this initiative integrates multi-country biodiversity observations using standardized survey protocols, photographic documentation, and species occurrence reporting. Through project sharing, it demonstrates how harmonized methodologies can support cross-border ecological monitoring, particularly for mobile species such as sharks and rays. Importance: Highlights the role of shared protocols and transnational collaboration in building coherent biodiversity datasets.

Proposed Pathway: Survey/app data → Darwin Core format → GBIF → EMODnet Biology ingestion pipeline.
Requirements: Species taxonomy (WoRMS), georeferenced occurrence data, DwC-A packaging.
Potential: Strong interoperability via GBIF–EMODnet Biology linkage.

C.2 MedFever - MedShark: combining high-frequency temperature measurements (e.g., HOBO sensors) with structured metadata workflows, this pilot bridges citizen-collected data and research-grade datasets. Its integration with repositories such as SeaNOE illustrates the importance of data publication and long-term accessibility. Importance: Demonstrates how shared infrastructure and repositories can elevate citizen science data to scientific and operational use.

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Proposed Pathway: HOBO sensor data → NetCDF/ODV → repository (SeaNOE) → EMODnet Physics.
Requirements: CF conventions, time-series standardization, quality flags (QARTOD).
Potential: Direct ingestion via existing repositories + EMODnet Physics aggregation workflows.

C.3 Secchi Disc: A classic example of methodological standardization through simplicity, the Secchi Disk approach combines low-tech optical measurements with mobile applications and global data platforms. Its widespread adoption is largely due to effective project sharing and protocol dissemination, enabling consistent turbidity measurements worldwide. Importance: Shows how simple, shared methodologies can achieve global comparability and long-term datasets.

Proposed Pathway: App-based measurements → CSV/JSON → standardized turbidity variables → EMODnet Physics.
Requirements: Harmonized units, metadata completeness (location, time, method), vocabulary alignment.
Potential: Integration via REST API or batch ingestion, with simplified citizen science schema.

C.4 Observation.org: This platform represents a mature, highly interoperable system, integrating mobile data collection, standardized biodiversity protocols, and automated data pipelines to GBIF. Through extensive project sharing, it provides a reference model for scaling citizen science initiatives while ensuring data quality and accessibility. Importance: Serves as a benchmark for interoperability, FAIR compliance, and integration into global biodiversity infrastructures.

Proposed Pathway: App → central database → Darwin Core → GBIF → EMODnet Biology.
Requirements: Taxonomic standardization (WoRMS), occurrence records, licensing metadata.
Potential: Already aligned with FAIR principles, enabling seamless EMODnet integration.

C.5 Sail4oxygen: Although still emerging, this initiative points toward the integration of mobile observation platforms (e.g., sailing vessels) with environmental monitoring technologies. It highlights the potential of shared deployment strategies and mobile sensing approaches. Importance: Illustrates future opportunities for expanding observation networks through shared mobility-based methodologies.

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Proposed Pathway: Mobile observations → CSV/NetCDF → centralized repository → EMODnet Physics/Chemistry.
Requirements: Parameter standardization (oxygen, temperature), metadata harmonization.
Potential: Integration via API-based ingestion or delayed-mode data submission.

C.6 SHARE4MED: the SHARE4MED initiative, developed within the framework of the NEXTMED programme, has expressed strong interest in adopting the INTERBOX approach as a distributed and interoperable solution for participatory marine and environmental monitoring in the Mediterranean region. The initiative recognises the potential of INTERBOX to support citizen science activities through low-cost sensing technologies, telemetry-enabled observations and FAIR-oriented environmental data sharing workflows. The envisaged integration pathway focuses on the use of INTERBOX systems for the collection and dissemination of near real-time environmental observations, including coastal and marine parameters acquired through community-based monitoring activities. In particular, the modular architecture of INTERBOX, its interoperability-oriented design and its compatibility with EMODnet Physics integration workflows make it particularly suitable for supporting distributed observation networks across Mediterranean coastal communities.

C.7 OpenCTD: OpenCTD exemplifies the value of open-source hardware sharing, providing a low-cost, reproducible oceanographic sensor system that can be deployed and adapted across multiple projects. Its “build–deploy–retrieve” methodology supports hands-on citizen engagement while fostering standardization through shared designs and documentation. Importance: Enables widespread adoption of oceanographic measurements and promotes hardware interoperability across initiatives.

Proposed Pathway: Sensor-generated profiles → CSV/NetCDF → standardized metadata → ingestion via EMODnet Physics.
Requirements: Calibration metadata, CF-compliant variables, SeaDataNet vocabularies (P01/P02).
Potential: Integration through SOS or API endpoints for near-real-time data streams.

C.8 Smartbotia: Smartbotia is a device that can be connected to sailing vessel electronics and some complementary devices (similar to OceanoVox). The data include meteorological measurements at sea level and some sea surface parameters recording real-time navigation, GPS, and marine sensor data (Air Pressure, Air Temperature, Wind Direction, Wind Speed, Wind Vector, Humidity, Wave Height,

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Wave Period, Sea Temperature). Sailors with a SmartBotia app and cloud integration, can optimise their experience (through sail trimming optimisation, automatic logbook, real-time GPS tracking), and are provided with a template agreement to consent to data sharing with the scientific data collector (AWI) and register device codes in OceanOPS, ensuring unique identifiers.

Proposed Pathway: Sensor-generated profiles → CSV/NetCDF → standardized metadata → ingestion via EMODnet Physics.
Requirements: Calibration metadata, CF-compliant variables, SeaDataNet vocabularies (P01/P02).
Potential: Integration through SOS or API endpoints for near-real-time data streams.

C.9 KdUINO / KduPRO: Low-cost optical sensors for monitoring water transparency:
KdUINO is a low-cost, Do-It-Yourself (DIY) moored optical instrument, originally developed at ICM-CSIC, that estimates the diffuse attenuation coefficient of downwelling irradiance (Kd), a key proxy for water transparency and water quality (Bardaji et al., 2016). The system measures underwater light intensity at different depths using low-cost photonic sensors connected to open-source hardware (Arduino-based platforms), enabling automatic estimation of Kd via regression analysis of the Beer-Lambert law. The original KdUINO demonstrated that reliable Kd measurements can be obtained using affordable citizen-science instrumentation (<100 Euros for the first prototype), with validation against commercial oceanographic sensors and successful deployment in citizen science workshops and educational activities. The KdUINO concept evolved into the KduPRO, a modular system designed for environmental monitoring in coastal and continental waters (Rodero et al., 2022). KduPRO replaces the cable-connected architecture of KdUINO with fully independent sensor modules, each containing light sensors, storage and acquisition electronics. This modularity improves deployment flexibility, robustness against sensor failures, scalability and ease of use by non-specialized users. The system uses low-cost optical sensors measuring irradiance in multiple spectral bands,

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including photosynthetically active radiation (PAR), and incorporates cosine-corrected optical diffusers to improve measurement quality.

The KduPRO framework has been validated through comparative experiments with commercial LI-COR underwater quantum sensors, showing strong consistency and high correlation between measurements obtained from the low-cost system and reference oceanographic instrumentation.

Figure 26. Underwater deployment of the modular KduPRO monitoring system to estimate water transparency

The system also integrates automatic quality control procedures based on the coefficient of determination (r^2) of the Beer-Lambert regression, enabling the rejection of unreliable estimations and supporting operational monitoring applications.

Recent *developments* within the EMBIMOS research group include the design of a multispectral version of the platform (KduPRO multispectral), which integrates optical measurements across multiple wavelengths to support monitoring of coastal ecosystem dynamics (Rodero et al., 2025). These new prototypes are being developed as modular citizen-science-ready observing systems capable of supporting FAIR data workflows and interoperability with European marine data infrastructures.

The KdUINO/KduPRO family targets integration into EMODnet Physics and SeaDataNet through the generation of standardized water transparency observations, including diffuse attenuation coefficient (Kd) in multispectral wavelengths. By adopting standardized metadata models and marine vocabularies (e.g. OceanSites and NERC vocabularies), KdUINO observations can be integrated into citizen science platforms such as MINKA, enabling FAIR and interoperable environmental data workflows.

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Proposed Pathway: low-cost optical observations → standardized metadata and QA/QC → upload and visualization through MINKA → interoperability with EMODnet, SeaDataNet and other marine data infrastructures.

MINKA is proposed as the citizen-science gateway for KdUINO/KduPRO observations, allowing participants to upload georeferenced measurements, associated metadata and contextual images through participatory workflows aligned with FAIR principles. This integration supports both citizen engagement and the generation of interoperable marine environmental datasets.

Additionally, through the AMRIT project (Advanced Marine Research Infrastructures Together), work is ongoing with OceanOPS to develop a dedicated GOOS Passport for the KdUINO family of sensors and observing systems. This initiative aims to improve the visibility, discoverability and interoperability of KdUINO observations within international ocean observing frameworks and facilitate their future integration into sustained marine observing networks.

C.10: Cruise4Science (SwanHellenic): the Swan Hellenic Cruise4Science / Cruising4Oceans initiative represents an operational example of citizen-supported ocean observation integrated into European marine data infrastructures. Through its expedition vessels SH Vega and SH Diana, Swan Hellenic operates onboard met-ocean monitoring systems and scientific sampling activities during voyages in remote regions including the Arctic, Greenland and Antarctica. The initiative combines environmental telemetry, citizen science participation and scientific partnerships to collect near real-time oceanographic observations from areas that are traditionally under-sampled by conventional observing systems.

Proposed pathway: The collected datasets include sea temperature, salinity, conductivity and broader met-ocean parameters acquired through scientifically validated onboard instrumentation and telemetry workflows. Since December 2024, these observations have been made accessible through the European Marine Observation and Data Network (EMODnet), making Swan Hellenic the first shipping company to operationally provide citizen science environmental observations to the EU Mission “Restore our Ocean and Waters” through EMODnet ingestion pathways.

The initiative demonstrates strong alignment with EMODnet Physics objectives, particularly regarding operational oceanography, FAIR data sharing and the integration of distributed observing systems into interoperable European marine data services. The telemetry-enabled infrastructure allows continuous acquisition and dissemination of environmental observations during expedition cruises, while also engaging passengers and onboard experts in complementary citizen science activities

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such as biodiversity observations, phytoplankton monitoring, whale sightings and environmental DNA (eDNA) exploration.

PILOTS TABLE

	PROJECT, INITIATIVE, SENSOR APP	LOCATION	PORTAL INGESTION (EMODNET & GBIF)	CHALLENGES	WEBSITE	GEO SPAN	FREQUENCY	VARIABLE COLLECTED	METHODOLOGY	STANDARDISATION	TYPE OF DATA FILE
PARTNERSHIP PILOTS	BECIS (EnvLogger)	Southern European Seas	in progress	Physics	https://electricblue.eu/temperature-envloggers	Mediterranean & Atlantic (operational focus: Liguria – Bogliasco, Portofino)	Weekly	Temperature	Low-cost in-water sensors	Data standardised, metadata not fully	CSV
PARTNERSHIP PILOTS	ANDROMEDA	Southern European Seas	Not yet	Pollution	https://citizenscience.eu/project/562	Malta - can be extended anywhere with kit availability	Seasonal (May-Sptember yearly)	Microplastics	Low-cost, app supported	Data standardised, metadata not fully	CSV
PARTNERSHIP PILOTS	Biomarathon	Southern European Seas	Yes	Biodiversity	https://biomarato.org/en/	Portugal (Porto) & Catalan coast	Seasonal (Apr–Oct yearly)	Invasive species	Web app surveys	Data & metadata standardised	API, JPEG, CSV, JSON
PARTNERSHIP PILOTS	Meteotracker	Southern European Seas	in progress	Physics	https://meteotracker.com/?srsltid=AfmBOorJLbs8kt75R4TzC4-DVub1ZgS6_iealF-sFw9bPmDy5abq-Tt_	Mainly Italy (potentially global)	Daily	Meteorological parameters	Low-cost weather sensors	Data & metadata standardised	API, CSV
PARTNERSHIP PILOTS	Spot the Alien	Southern European Seas	Not yet	Biodiversity	campaigns.ocean.mt	Malta (all coastal zone)	Continuous (24/7)	Invasive species presence	Social media + photos/videos	Data & metadata standardised	CSV, GIS, JPEG
PARTNERSHIP PILOTS	Interbox	Southern European Seas/Northern European Seas	Yes	Physics	https://www.cmcc.it/article/two-new-coastal-monitoring-stations-installed-in-italy-and-the-philippines	Global	Continuous	Sea level rise	Sensor	Data & metadata standardised	CSV
PARTNERSHIP PILOTS	Maccaferri Futura	Southern European Seas/Northern European Seas	Yes	Physics	www.maccaferrifutura.com	Mediterranea-Atlantic-North atlantic	Every week more or less	Temperature, Salinity, PH, dissolved oxygen, wind speed, wind direction, amt pressure	Low-cost device (SOOP Sailing Box) + boat telemetry data	Data & metadata standardised	API, CSV
PARTNERSHIP PILOTS	Eye on Water	Southern European Seas/Northern European Seas	Not yet	Pollution	https://eyeonwater.com/login	Global	Continuous	Water colour, turbidity	Mobile app	Data & metadata standardised	CSV, UNCLEAR
PARTNERSHIP PILOTS	Kosmos	Northern European Seas	Not yet	Biodiversity	https://kosmos.fish/	Coastal areas - France - can be extended to other areas	5-10 day trips per summer	Fishes & benthic habitats (video)	Low-cost video landers	Data & metadata standardised	CSV, JPEG, GIS, MP4
PARTNERSHIP PILOTS	Barnacle Observer	Northern European Seas	Not yet	Biodiversity	https://batunionen.se/miljo/batmiljo-for-batklubbar/hjalp-batlivet-att-bli-hallbarare-bli-havstulpanopbservator/ (in Swedish but ok with google translate)	Baltic Sea- all Swedish coast actually	Weekly (Jun-Sept)	Barnacle bloom + temperature + salinity	T sensors, CT sensors, web form	Not yet standardised	UNCLEAR, JPEG
EXTENDED PILOTS, INITIATIVES (CONTACTED BY PROJECT SHARING)	LIFE EUSharks	Southern European Seas/Northern European Seas	Not yet	Biodiversity	https://www.europeansharks.eu/#about	IT, FR, HR, ES, SL	Continuous	Species (sharsk & rays) presence/location	Surveys; photso & videos		CSV
EXTENDED PILOTS, INITIATIVES (CONTACTED BY PROJECT SHARING)	MedFever - MedShark	Southern European Seas/Northern European Seas	Not yet	Physics	http://medfever.it/	IT - Thyrrenian sea	every 15 min	Temperature at different depths	HOBO sensor		CSV, ODV
EXTENDED PILOTS, INITIATIVES (CONTACTED BY PROJECT SHARING)	Sail4oxygen:	Southern European Seas/Northern European Seas	in progress	Physics	https://www.sail4oxygen.org/	North Sea		CTD, dissolved oxygen	multiparametric probe		CSV
EXTENDED PILOTS, INITIATIVES (CONTACTED BY PROJECT SHARING)	Secchi Disc	Southern European Seas/Northern European Seas	Not yet	Physics	https://play.google.com/store/apps/details?id=uk.ac.plymouth.matmutt.secchi&hl=it	Global	Anytime	Water transparency / turbidity	Mobile app + Secchi disk	Data & metadata standardised	CSV
EXTENDED PILOTS, INITIATIVES (CONTACTED BY PROJECT SHARING)	observation.org	Southern European Seas/Northern European Seas	in progress	Biodiversity	https://observation.org	Global	Continuous	Species presence	Mobile app + protocols	Data & metadata standardised	CSV, API
EXTENDED PILOTS, INITIATIVES (CONTACTED BY PROJECT SHARING)	KdUINO/ KduPRO	Southern European Seas	in progress	Biodiversity	https://minka-sdg.org/users/sign_in	Spain	Continuous	diffuse attenuation coefficient of downwelling irradiance (Kd)		Data & metadata standardised	CSV, API

Figure 27. Table reporting the pilots implemented by the MCSIs involved in the partnership across two geographical regions (Southern and Northern European Seas), as well as the integrative pilots developed within the project.

V. Pilots operational strategy

The operational strategy of WP5 is designed to translate the outcomes of the pilot assessment and co-design process into practical demonstration activities capable of

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validating the integration of Marine Citizen Science observations within European and international marine data infrastructures. Building upon the pilot selection, maturity assessment, and integration pathways described in the previous sections, the operational phase, to be deployed in Task 5.2, aims to demonstrate the complete value chain from data acquisition by citizens to FAIR-compliant data publication and reuse.

Pilot implementation will be carried out across a diverse portfolio of initiatives operating in Northern and Southern European Seas, encompassing physical oceanography, biodiversity monitoring, and marine pollution observations. The selected pilots provide complementary testing environments covering different technologies, observation protocols, data management approaches, geographical contexts, and levels of data management maturity. This diversity is essential to evaluate the applicability and scalability of the methodologies and recommendations developed within WP3.

The operational strategy, supported through WP3 established data integration pathways and WP4 tailored training toolkit, has four primary objectives:

- Demonstrate the acquisition and management of citizen-generated marine observations using low-cost technologies and established observation protocols;
- Improve the FAIRness, interoperability, and integration readiness of pilot datasets;
- Validate integration pathways towards European and international marine data infrastructures;
- Assess the scalability and transferability of data management approaches across different Marine Citizen Science initiatives and thematic domains.

Pilot Deployment and Data Collection

Pilot activities will support the deployment and operation of low-cost sensors, mobile applications, imaging systems, and citizen observation protocols identified during the assessment phase. Data collection activities will focus on generating observations relevant to target infrastructures including EMODnet Physics, EMODnet Biology and Ecosystems, EMODnet Chemistry, SeaDataNet, EurOBIS, and GBIF. Particular attention will be given to documenting observation methodologies, metadata requirements, quality assurance procedures, and data management workflows to ensure traceability and reproducibility of observations. The pilot implementation and demonstrations will contribute to addressing monitoring gaps identified within coastal and marine environments while testing practical solutions for integrating distributed citizen-generated observations into operational marine data services.

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Capacity Building and Training Activities

Training activities will support both individual pilots and Integrative Use Cases by addressing the data and metadata gaps for ingestion identified during the maturity assessment. Training materials developed within WP4 and refined through WP5 activities will include operational guides, e-books, sensor deployment protocols, metadata management procedures, FAIR data practices, and repository ingestion workflows.

Training sessions will be delivered through a combination of online resources, on-site demonstrations, and practical workshops. Particular emphasis will be placed on improving participants' understanding of metadata requirements, controlled vocabularies, quality assurance procedures, and data publication mechanisms required for integration into European data infrastructures.

Data Harmonisation and FAIRification

A key objective of the operational phase is the progressive FAIRification of pilot datasets. Activities will focus on improving metadata completeness, adopting controlled vocabularies, implementing quality control procedures, and aligning data formats with the requirements of target repositories and infrastructures.

The implementation of FAIR principles will be supported by the methodologies and recommendations developed within WP3, providing an opportunity to test their applicability under real operational conditions. Pilot activities will therefore contribute both to data integration and to the validation of the CS-MACH1 assessment and interoperability framework.

Integrative Use Cases

In addition to the implementation of CS-MACH1 partners pilot activities, WP5 will support the deployment of Integrative Use Cases identified through the networking activities conducted during the first phase of the project. These use cases provide opportunities to combine observations originating from different Marine Citizen Science initiatives and to evaluate interoperability across technologies, thematic domains, and geographical regions.

The Integrative Use Cases will serve as operational demonstrations of cross-platform data integration, enabling the assessment of common metadata models, harmonised quality assurance procedures, and shared data management approaches. They will also provide a practical environment for testing the scalability and transferability of the methodologies developed within the project.

Timeline and Operational Implementation

Pilot implementation activities will be progressively deployed between 2026 and 2027. Initial activities will focus on training delivery, preparation of observation protocols,

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deployment of low-cost technologies, and establishment of data management workflows.

During summer 2026, pilot activities will begin across both Northern and Southern European Seas, involving initiatives supported by technologies such as EnvLoggers, Meteotracker, Interbox, EyeOnWater, and biodiversity monitoring platforms. Additional deployments and operational testing will continue throughout 2027.

Specific activities include:

- Deployment of environmental monitoring sensors;
- Biodiversity observations through citizen science communities;
- Marine pollution monitoring activities;
- Testing of metadata and FAIRification workflows;
- Repository ingestion demonstrations;
- Validation of interoperability mechanisms;
- Development and testing of Integrative Use Cases.

The implementation schedule remains adaptive and may be refined according to pilot readiness, seasonal observation requirements, technology availability, and opportunities arising from networking activities conducted throughout the project.

Monitoring, Evaluation, and Feedback

Pilot implementation will follow an iterative approach in which operational experiences, technical challenges, and lessons learned are continuously documented and evaluated. Feedback collected from pilot coordinators, citizen science communities, technology providers, scientists, and data managers will contribute to refining integration procedures, training materials, and technical recommendations.

The outcomes of the pilot demonstrations will provide practical evidence of the feasibility of integrating Marine Citizen Science observations into established marine data infrastructures while supporting the validation and refinement of the framework developed within WP3.

This continuous feedback mechanism ensures that the operational activities of WP5 contribute not only to the successful implementation of pilot demonstrations but also to the long-term development of sustainable and scalable pathways for the integration of citizen-generated marine observations within European marine data ecosystems.

VI. Assessment of Data Management Maturity

As part of WP3, a cross-cutting assessment of the identified Marine Citizen Science Initiatives (MCSI) was conducted to evaluate their readiness for integration into

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European marine data infrastructures, including EMODnet, EurOBIS, GBIF, and SeaDataNet.

The assessment was based on the Integration Readiness Indicator developed within WP3, which evaluates both technical and organisational aspects of data management maturity. The framework considers multiple dimensions, including:

- data collection protocols and standardisation;
- data formats and structure;
- metadata completeness and interoperability;
- adoption of controlled vocabularies and community standards;
- quality assurance and quality control (QA/QC) procedures;
- data accessibility, licensing, and FAIR compliance;
- publishing pathways and compatibility with existing infrastructures;
- attribution and ethical considerations;
- long-term stewardship capacity and sustainability.

Based on the assessment results, the initiatives can be grouped into three broad maturity levels:

1. High Maturity (Advanced / Integration-Ready)

Initiatives in this category demonstrate a high level of technical and organisational readiness for integration. They typically show:

- use of structured, machine-readable, and standardised data formats (e.g., NetCDF, Darwin Core Archive, API-based systems);
- comprehensive metadata aligned with community standards and reference vocabularies;
- established data publication workflows and compatibility with infrastructures such as EMODnet, GBIF, EurOBIS, or SeaDataNet;
- implemented QA/QC procedures, including automated validation where applicable;
- clear data accessibility pathways and long-term stewardship mechanisms.

Examples:

- ➢ **Interbox**: continuous monitoring system with advanced QA/QC workflows and strong integration potential;
- ➢ **Maccaferri Futura / SailingBox**: multi-parameter telemetry with structured data flows;

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- **MINKA / BioMARathon and Observation.org**: biodiversity observations supported by Darwin Core and GBIF-compatible workflows;
- **EyeOnWater**: large-scale optical observations with strong public accessibility and established data pipelines.

These initiatives are considered suitable for EMODnet ingestion with only targeted harmonisation, metadata refinement, or format alignment required.

2. Medium Maturity (Partially Standardized / Adaptable)

Initiatives in this category show significant potential but require targeted improvements before full interoperability can be achieved. Typical characteristics include:

- partially standardised data structures (often spreadsheet- or CSV-based);
- incomplete metadata or inconsistent use of controlled vocabularies;
- emerging QA/QC processes that are not yet fully automated;
- limited integration pathways or dependence on project-specific workflows.

Examples:

- **EnvLogger / BECIS-OutBe**: structured sensor-based data collection but requiring metadata enhancement;
- **Meteotracker**: automated data generation with further harmonisation needed for marine standards;
- **Secchi Disk**: strong methodology but variable metadata completeness;
- **Kosmos**: innovative observation approach requiring improved data structuring;
- **Spot the Alien**: valuable geo-referenced observations requiring stronger biodiversity data workflows.

These initiatives could become integration-ready through improvements in metadata, controlled vocabularies, quality procedures, and publication workflows.

3. Low Maturity (Early Stage / Fragmented Data Management)

Initiatives at this stage generally require more substantial development before integration into European data infrastructures. They are characterised by:

- heterogeneous or non-standardised data formats;
- limited metadata structures;

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- manual or fragmented data management workflows;
- absence of formal QA/QC procedures;
- limited long-term data stewardship mechanisms.

Examples include initiatives where data collection practices are established but integration workflows are still under development, such as:

- **ANDROMEDA**: structured sampling approach requiring stronger integration pathways and metadata alignment;
- **Barnacle Observer**: promising hybrid observations requiring further harmonisation;
- **Sail4Oxygen**: emerging initiative where data workflows and standards are still being established.

These initiatives represent valuable contributions to marine observation capacity but require additional support to achieve interoperability and FAIR-aligned publication.

Overall, the assessment shows that MCSI maturity varies considerably. While some initiatives are already positioned for direct integration into European marine data infrastructures, others would benefit from targeted support focused on metadata improvement, standardisation, QA/QC implementation, and sustainable data management practices.

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CS-MACH1 PILOT PORTFOLIO AND DATA MANAGEMENT MATURITY ASSESSMENT

Assessment based on WP3 methodology: standardisation, metadata, QA/QC, FAIR compliance and integration readiness

PILOT / INITIATIVE	THEMATIC DOMAIN	TARGET INFRASTRUCTURE	VARIABLES COLLECTED	TECHNOLOGY / METHODOLOGY	DATA FLOW STATUS	MATURITY LEVEL	MAIN GAPS / ACTIONS NEEDED
EnvLogger	Physics	EMODnet Physics	Temperature	Low-cost temperature logger	In progress	MEDIUM	Metadata harmonisation, QC/QF automation
Meteotracker	Physics	EMODnet Physics	Meteorological parameters	Low-cost weather sensors	In progress	MEDIUM	FAIR metadata implementation
Interbox	Physics	EMODnet Physics	Sea level, environmental variables	Autonomous monitoring station	Operational	HIGH	Scaling and interoperability
Maccaferri Futura (SailingBox)	Physics	EMODnet Physics / SeaDataNet	T, S, pH, pressure, wind, waves	Sailboat telemetry platform	Operational	HIGH	Advanced FAIR optimisation
EyeOnWater	Physics	EMODnet Physics	Water colour, turbidity	Mobile application	Planned	HIGH	Metadata and validation procedures
ANDROMEDA	Pollution	EMODnet Chemistry	Microplastics	Mobile app + AI classification	Planned	LOW	Standardised metadata model
Spot the Alien	Biodiversity	EMODnet Biology / GBIF	Invasive species occurrence	Mobile app	Planned	MEDIUM	QA/QC and FAIRification
MINKA / BioMARathon	Biodiversity	GBIF / EurOBIS	Species occurrence	Adapted iNaturalist platform	Operational	HIGH	Repository synchronisation
KOSMOS	Biodiversity & Habitats	EMODnet Seabed Habitats	Fish abundance, habitat cover, imagery	Video landers	Planned	MEDIUM	Habitat classification standards
Barnacle Observer	Biology & Physics	EMODnet Biology & Physics	Barnacle blooms, T, S	Citizen observations + sensors	Planned	LOW	Metadata standardisation
LIFE EUSharks	Biodiversity	EMODnet Biology / GBIF	Sharks and rays occurrence	Surveys, photos, videos	Planned	TBA*	Harmonised data model
Sail4Oxygen	Physics	EMODnet Physics	CTD, dissolved oxygen	Multiparametric probe	In progress	LOW	Automated ingestion
Secchi Disc	Physics	EMODnet Physics	Transparency, turbidity	App + Secchi disc	Planned	MEDIUM	Metadata automation
Observation.org	Biodiversity	GBIF	Species occurrence	Mobile app	In progress	HIGH	Minor interoperability improvements
KdUINO / KdUPRO	Physics	EMODnet Physics	Diffuse attenuation coefficient (Kd)	Low-cost optical buoy	In progress	MEDIUM	Metadata harmonisation

THEMATIC DOMAIN LEGEND: Physics; Pollution; Biodiversity; Biodiversity & Habitats; Biology & Physics

DATA FLOW STATUS: Operational; In progress; Planned

MATURITY LEVEL (based on Section VI): High (Integration-ready); Medium (Improvements needed for full interoperability); Low (Early stage / fragmented); TBA* (To be assessed / Extended use case)

* Extended initiatives not yet fully assessed with the WP3 maturity framework.

Disclosure on the use of AI: This figure was designed with the support of artificial intelligence tools to enhance visual clarity and presentation. The content is based on the analysis carried out within CS-MACH1 by the consortium partners.

Figure 28. Table reporting the pilots portfolio and the maturity level. Artificial Intelligence was used solely to support the visual layout of this figure. The scientific content, assessment methodology, and results remain the responsibility of the authors.

VII. Final Remarks and Readiness for Implementation

During the first phase of the project (M1–M12), the co-design process—supported by systematic pilot analysis and continuous stakeholder engagement—has led to the development of a robust, scalable, and interoperable framework, including data pathways documented in D3.1, that underpins the transition toward pilot implementation within Task 5.2.

This phase has established the conceptual, methodological, and technical foundations required for implementation, including the definition of harmonized use cases, mapping of data flows and technologies, and alignment with FAIR principles and European marine data infrastructures (EMODnet, SeaDataNet, GBIF). In particular, it has enabled:

- The identification and refinement of priority use cases across Southern, Northern, and Integrative pilot initiatives
- The mapping of data flows, technologies, and methodologies used across pilots
- The definition of harmonized protocols and minimum requirements for data collection, metadata, and quality control

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- The alignment of pilot activities with FAIR principles and existing European standards and infrastructures (e.g., EMODnet, SeaDataNet, GBIF)

A key outcome of M1–M12 is the establishment of a common interoperability layer, including:

- Adoption pathways for standard data formats (NetCDF, CSV, Darwin Core Archive)
- Use of controlled vocabularies (SeaDataNet NVS, Darwin Core, CF conventions)
- Alignment with metadata standards (ISO 19115/19139, SeaDataNet CDI)
- Definition of data ingestion mechanisms (APIs, OGC services, repository-based workflows)

Furthermore, the analysis has demonstrated that the pilots already employ a wide range of mature and deployable technologies, including low-cost sensors, mobile applications, telemetry systems, and citizen-driven observation tools. These technologies, combined with emerging quality assurance and validation practices, confirm a high level of technical readiness for the next phase.

Within Task 5.2, the project will build directly on these results by moving into the implementation and validation phase, where the focus will shift to:

- Testing end-to-end data workflows (from acquisition to EMODnet ingestion)
- Validating interoperability across platforms and domains
- Assessing data quality, comparability, and usability in operational conditions
- Demonstrating the integration of citizen-generated data into EMODnet thematic services

The inclusion of integrative pilots—identified through project networking and knowledge sharing—represents a strategic asset in this transition, as they provide tested tools, transferable methodologies, and pre-existing data pipelines. This significantly reduces implementation risks and accelerates the convergence toward standardized and interoperable systems.

Overall, the achievements of the M1–M12 phase position CS-MACH1 at a high level of readiness for implementation, ensuring that Task 5.2 can focus on operational validation rather than conceptual development. This structured progression supports a smooth transition from pilot design to real-world deployment, strengthening the role of Marine Citizen Science within European data ecosystems.

In this context, CS-MACH1 is well positioned to contribute to the systematic integration of citizen-generated data into EMODnet and other European infrastructures, ultimately supporting broader initiatives such as the Digital Twin Ocean. By transforming distributed observations into standardized, interoperable, and policy-relevant data streams, the project reinforces its role as a key enabler of next-generation marine monitoring and decision-making frameworks.

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