D 5.3.2. Pilot action II, guideline for the improvement of underwater conditions substantiated by analysis of the obtained results from pilot action I

Blue technology - Developing innovative technologies for sustainability of Adriatic Sea

WP5 – Cooperation in innovation on robotic and sensors solution (TT) – pilot actions

Project References

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Expected date: 30/06/2023

Deliverable description: D 5.3.2. This deliverable presents how the multifunctional robotic and sensor solutions used in INNOVAMARE can be used for the improvement of underwater conditions.

Partner responsible for the deliverable: [CNR]

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INTRODUCTION

The ecosystem services provided by the Oceans and Waters to the humankind are endless. Natural resources, support wildlife, stable climate and, last but not least, employment opportunities. This is particularly true in coastal systems where the impact on anthropical activities is particularly evident and modifications, gradients and dynamics of natural phenomena, combined with coastal activities became a challenge in terms of sustainable management.

In order to deal with this challenge, the EU has developed an integrated coastal and marine policy with the aim to protect and conserve the health of oceans through the Marine Strategy Framework Directive (MSFD). MFSD is based on the Good Environmental Status (GES) concept: "The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive"1. The Directive sets out eleven qualitative descriptors which describe what the environment will look like when GES has been achieved.

- Descriptor 1: Biodiversity is maintained
- Descriptor 2: Non-indigenous species do not adversely alter the ecosystem
- Descriptor 3: The population of commercial fish species is healthy
- Descriptor 4: Elements of food webs ensure long-term abundance and reproduction
- Descriptor 5: Eutrophication is minimized
- Descriptor 6: The sea floor integrity ensures functioning of the ecosystem
- Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
- Descriptor 8: Concentrations of contaminants give no effects
- Descriptor 9: Contaminants in seafood are below safe levels
- Descriptor 10: Marine litter does not cause harm
- Descriptor 11: Introduction of energy (including underwater noise) does not adversely affect the ecosystem

In 2019 the Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans) launched an action called "Science for Good Environmental Status" (S4GES). The action proposes an innovative approach focused primarily on the functionality of the network of a marine subsystem, considered as a complex system, and no longer on the assessment of single descriptors. The success of this new approach could provide useful indications for reducing both financial and scientific resources used in environmental monitoring linked to the MSFD, also opening up new lines of research towards understanding the processes that link human impacts and the marine ecosystem [[1]].

Robotic solutions in the environmental monitoring sector

Within this context, the monitoring effort in terms of funds and persons hours made by the countries is huge. Monitoring surveys are conducted using research vessels, requiring high resources management and costs other than long preparation periods.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32008L0056

One of the main goals of researchers, not only in marine sciences but also on innovation side, is to achieve a and cost-effective monitoring of the marine and inland waters environments. In the last decade, many developments in robotics applied to the monitoring activities were achieved, identifying aquatic drones and the applications of smart solutions (Internet of Things – IoT) as a valid alternative to the classic approach [2, 3, 4, 5, 6]. As an example, Di Ciaccio and Troisi [7] made a bibliometric analysis of the global scientific literature on AUVs applied environmental monitoring applications.

In the InnovaMare context, the WP5 was devoted demonstrating the possibilities of robotics applications to environmental monitoring, in terms of multifunctional robotic, sensor solutions and Internet of Underwater Things (IoUT). These solutions, developed according to the Living Lab (LL) methodology, are flexible enough to provide integrated monitoring solutions that can be easily applied to several monitoring scenarios.
In the previous deliverables within the task 5.2, on pilots and solutions development, the multifunctional robotic and sensor solutions developed were described, detailing their hardware and software prototyping status. Moreover, use cases of potential application together with their connection to the MSFD descriptors were presented (table 1). This deliverable aims to present the results achieved using the robotic platforms and the smart buoys, developed within InnovaMare project, in the context of 3 main use case related with MFSD descriptors 1, 5, 6, 7, 10:

- Inspection and monitoring of aquaculture ecosystems
- Inspection and monitoring for marine litter detection
- Benthic habitat mapping.

Table 1: Potential use cases, technologies and target groups.

Use cases	Technologies to be used		Target Groups
	ASVs+SV*+ROV	Buoys	
Inspection and monitoring of aquaculture ecosystems	Map and detect biofouling in aquaculture cages (MSFD 5)	Water quality inspection of sea in aquaculture farms (MSFD 5, 7)	Aquaculture companies
Inspection and monitoring for harbours and marinas including marine litter detection	Creating high resolution bathymetryc 3D model (by Multibeam echosounder system; MBES) and/or mosaic of the seabed (MSFD 6) Sediment erosion near structures (MSFD 7) Automatic (offline) marine litter detection on mosaics (MSFD 10) Creating high resolution digital ortophoto (aerial), surface litter/pollution detection on ortophoto map Creating interactive maps/GIS for charting/tracking pollution/litter	Water quality monitoring in marinas to detect wastewater (MSFD 5, 7) Traffic activity detection using acoustic monitoring of the environments (MSFD 11)	Municipalities , Marinas, Environment al Protected Areas (EPAs), Marine Protected Areas (MPAs), coastal authorities
Benthic habitat mapping	Benthic habitat mapping (MSFD 1 and 6)		EPAs, MPAs
Cultural heritage inspection and monitoring	Submerged archeological sites monitoring Inspection of buildings		Cultural heritage inspection and monitoring

MULTIFUNCTIONAL ROBOTIC AND SENSOR SOLUTIONS

Partners have developed a series of different platforms and sensors that offer a higher degree of flexibility in the context of chosen use cases. The detailed description of the robotic platforms and sensors can be found in D 5.2.2 and D 5.2.3.

SWAMP Autonomous Surface Vehicle, developed by CNR to access and monitor extremely shallow water by means of portable, modular, reconfigurable and highly maneuverable robotic vehicles. Within InnovaMare project, SWAMP was equipped with a multifrequency multibeam echosounder (MBES), an automated field spectroscopy device (RoX), a SUNA V2 nitrate sensor, a high resolution and high sensitivity AI underwater camera Guard1.

Korkyra Autonomous Surface Vehicle, developed by FER, Laboratory for Underwater Systems and Technologies (LABUST), is complimentary to the SWAMP ASV as it has a different size, top speed enableing the integration of signalling maritime lights, surveillance camera(s), LIDAR or other sensors etc.

Buoys: as part of the platforms offered by FER, innovative smart marine buoys for long-term operation and persistent deployment in marine environments were developed. The buoy can operate as a remote marine platform performing water quality measurements, as well as a relay for an extended underwater sensor network.

Blueye Pro ROV

This Remotely Operated Vehicle (ROV) is a commercial product and it has not been developed by any of the INNOVAMARE partners. However, it can be connected to and support Korkyra ASV in some use case scenarios as it shall be seen in the Use Cases section and therefore it is briefly introduced here.

Use cases and GES descriptors

Use case 1: Inspection and monitoring of aquaculture ecosystems -GES 5

A multifunctional smart buoy unit and three underwater sensor units were deployed in Šibenik, Croatia, in a mussel farm at the mouth of the river Krka in June 2023 (Figure 1 and Figure 2).

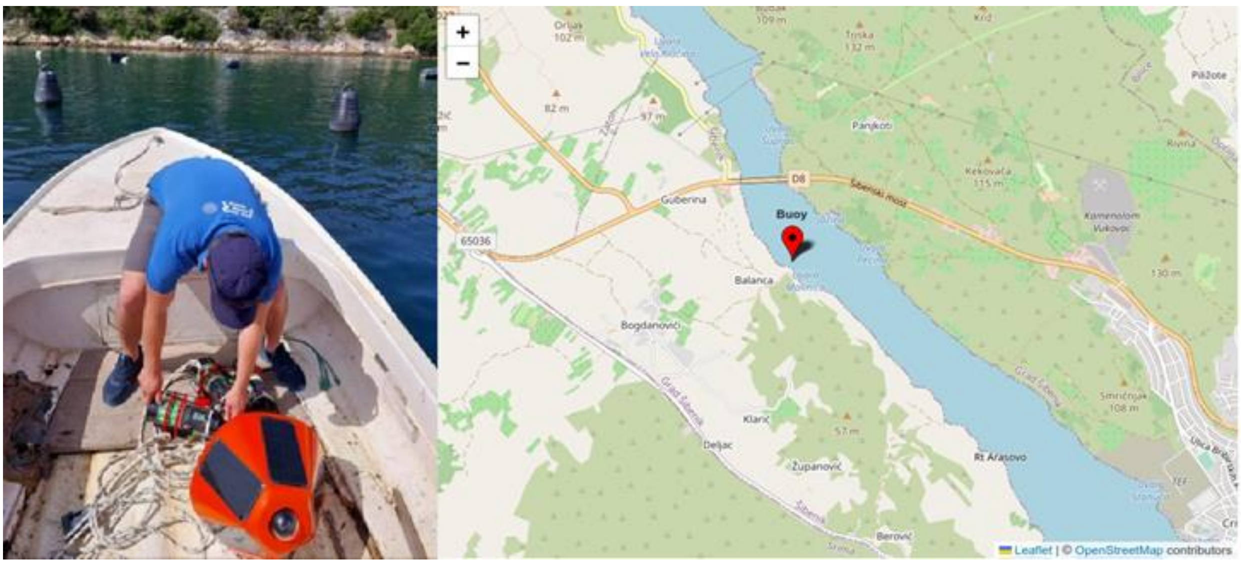

Figure 1: Buoy and sensor unit deployment (left), deployment location (right).

In order to address the specific needs of the use-case as outlined by the end users at the mussel farm, each sensor unit was equipped with a pressure/temperature sensor, a dissolved oxygen sensor, a conductivity/salinity sensor, and a chlorophyll sensor. The main goal is to be able to monitor these values long-term and provide real-time data access, and to detect significant fluctuations or raise alarms for certain levels of salinity in particular, as it is highly relevant to the growth rate and survival of mussels and oysters growing at different depths, and the effects of the freshwater influx from the river Krka can be severe. In order to monitor all layers of the farm, including habitats for both oysters and mussels, sensor units were deployed at a depth of 2m, 5m, and 15m respectively. An example of the software that allow real-time monitoring of the water parameters is shown in Figure 3.
The dataset acquired till now is not long enough to allow the presentation of results, but this buoy will stay deployed in the mussel farm beyond the duration of the project contributing to the sustainability of project outputs.

Figure 2: Buoy deployed in mussel farm.

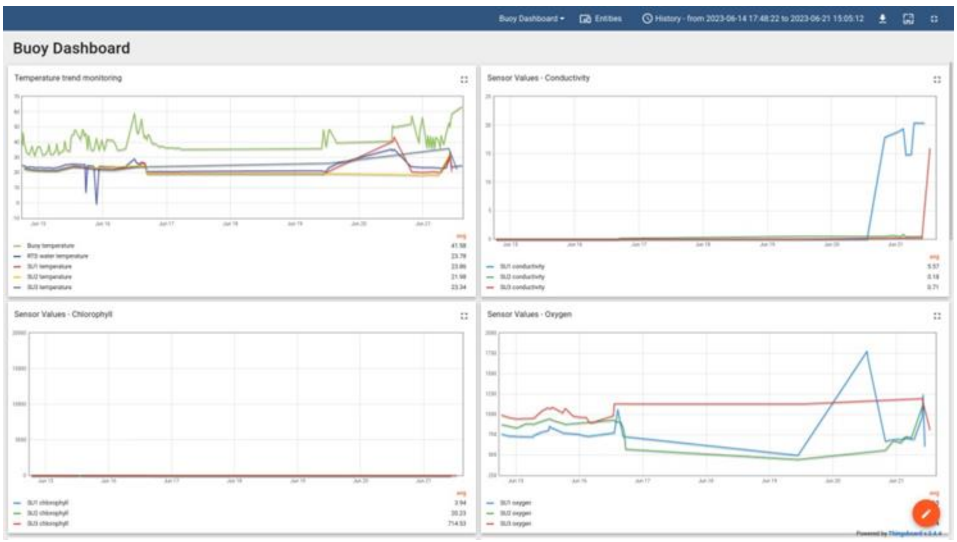

Figure 3: Example data display dashboard.

Use case 2: Inspection and monitoring for harbors and marinas including marine litter detection – GES 6, 7, 10

Inspection and monitoring for harbors and marinas needs bathymetric measurement. In very shallow waters, these operations are often difficult because of tidal ranges, obstacles presence, as safety of navigation is seriously reduced. Since unmanned marine vehicles, such as ASVs, can be remotely operated by pilots from safe locations, they are suitable for operations in dangerous areas, by virtue of their advantages of a lightweight, less load and shallow draft (Figure 4).

Figure 4: SWAMP/MBES system during acquisition in Sacca Fisola area.

From November 2022 to March 2023, three areas in Venice lagoon were investigated (Figure 5) with multibeam mounted on SWAMP.
The MBES system is a R2Sonic2020 I2NS; its highly portability, compactness, lightness and low power consumption make it particularly suitable to be mounted on an autonomous vehicle. The instrument is provided as an integrated solution including the wideband multibeam echosounder, an Inertial Measurement Unit (IMU), a Sound Velocity Probe from Vale-port, two GPS antennas, the Sonar interface module (SIM), a power inverter, and all the needed cables that were crafted at the appropriate length. During the four surveys, the entire potential of the multibeam echo sounder (MBES) and its integration with SWAMP system has been tested, demonstrating the system capability by performing fast high-resolution bathymetry.

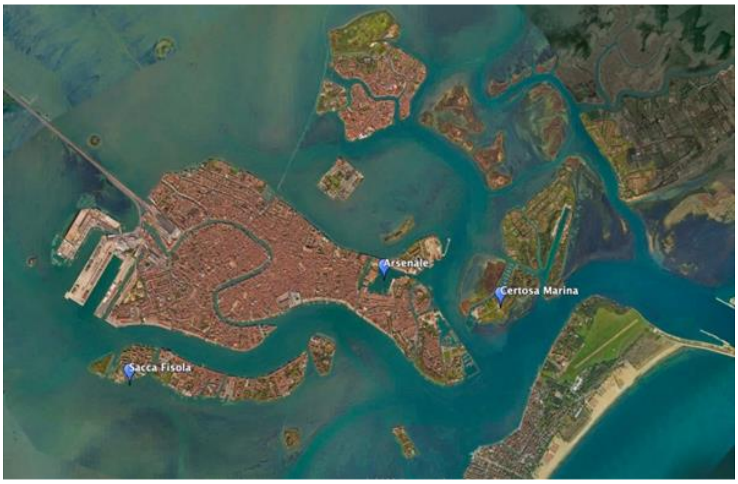

Figure 5: Locations investigated for use case on Inspection and monitoring for harbors and marinas including marine litter detection.

All instrumental offsets are measured referred to Centre of Gravity (COG). It can be assumed that the IMU position is the COG. Two GPS antennas are installed on an aluminum structure fitted along the vehicle's longitudinal axis, holding them at the required height above the water level and sufficiently distant from each other to ensure good positioning data. A centimeter accuracy in positioning is ensured by RTK correction.

Due to the small size, ASV and instrument deployed are sensitive to surrounding environment (especially waves generated by maritime traffic) and are easily affected by strong shakiness and massive bubble turbulence. So, further improvements are aiming at filtering data noise and improving the structure between IMU and antennas. The ASV was maneuvered following straight parallel lines guaranteeing full overlap in swath coverage. The biggest innovation for R2Sonic multibeam is the possibility to select in real-time on the fly from between 170 - 450 kHz to 1 Hz resolution, along with optional ultra-high resolution (UHR) 700 kHz. Moreover, with Multimode it's possible to capture data at different frequencies simultaneously. This system configuration of SWAMP-MBES allowed to map the Arsenale area, recognizing all the mooring posts present on the seabed (Figure 6) and the San Pietro-Certosa dock (Figure 7) where the multimode acquisition was tested simultaneously at 220, 320, 400 and 700 kHz. The results show how good the data can be also when the MBES sensor is mounted on an ASV, also giving the possibility to map the sedimentation areas that need to be dredged.

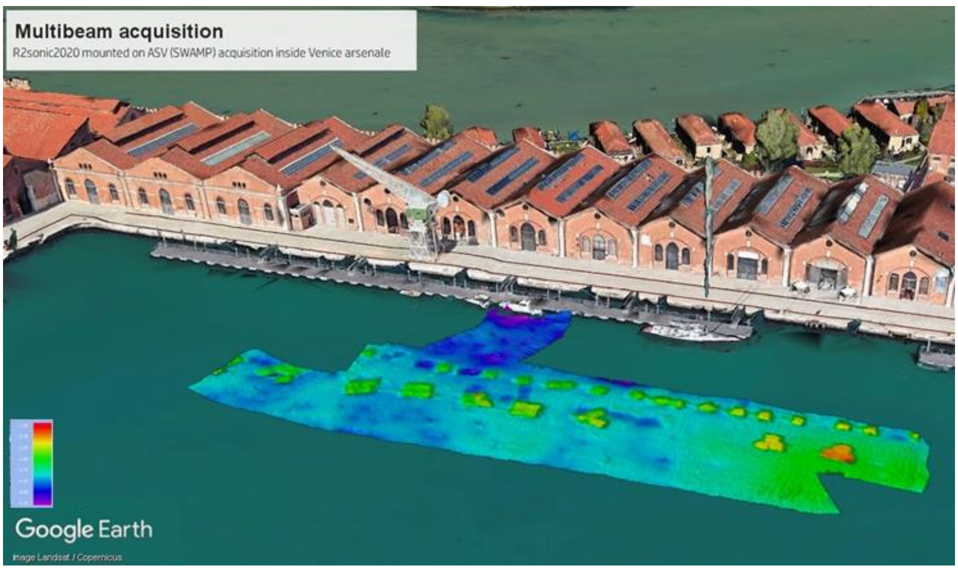

Figure 6: Arsenale multibeam acquisition.

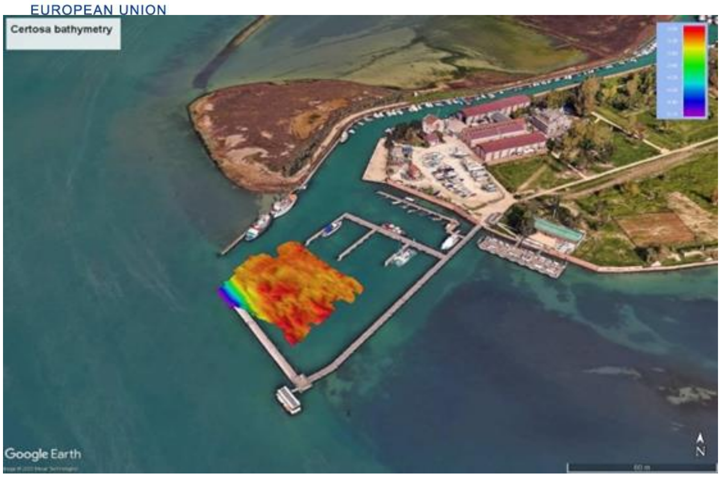

Figure 7: Certosa marina multibeam acquisition.

In Sacca Fisola an area interested by the presence of a marine litter hotspot [15] was mapped thanks to the SWAMP system (Figure 8). This area is used by the municipality of Venice for waste management. All logistic operations to move urban waste at the treatment plant involve the use of boats, increasing the risk to lose waste on the bottom of the channel. Moreover, the boats used for these actions are big and use tires as mechanical protection against accidental collisions with the dock.

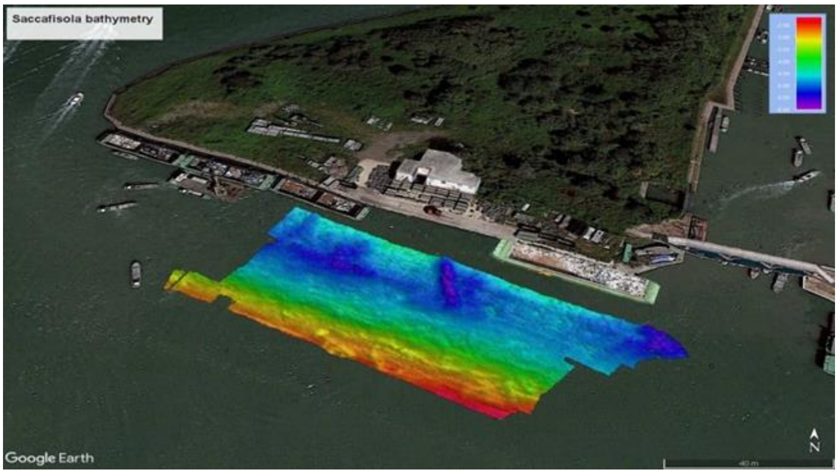

Figure 8: Sacca Fisola multibeam acquisition.

Through the use of SWAMP-MBES configuration it was possible to identify in the morphobathymetric data the presence of marine litter, such as tires and piles (Figure 9).

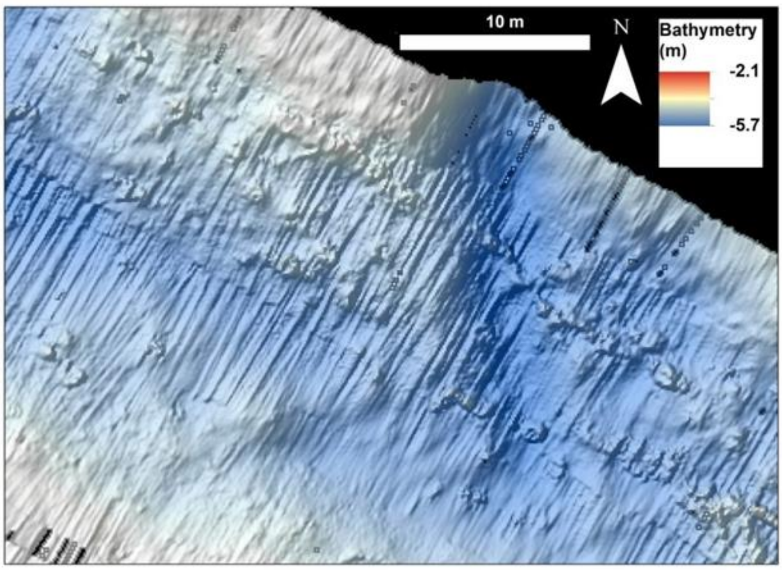

Figure 9: Bathymetry of the area of Sacca Fisola showing the presence of tyres and piles on the seafloor.

Use case 3: Benthic habitat mapping – GES 1, 6

Marine habitat mapping aims to gain a holistic representation of key marine habitats, their associated biological communities, their areal extent, distribution patterns, status, and physical conditions[2]. Within the context of MFSD and GES descriptors, benthic habitat mapping is connected mostly with descriptor 1 Biodiversity and 6 Seafloor Integrity.

During the project two field sampling campaigns were organized in Venice (Figure 10) to collect hyperspectral data over optically shallow waters along a transect, where different bottom substrate coverages are present (e.g. seagrasses, macroalgae, sand), using SWAMP-ROX-SUNA configuration, while another campaign in March was dedicated to the SWAMP – MBES configuration to investigate the Scanello channel.

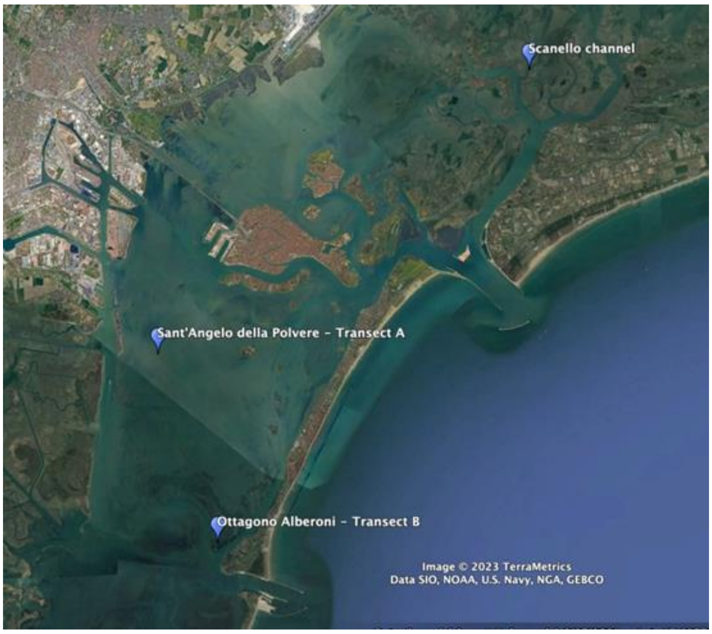

Figure 10: Investigated areas for benthic habitat mapping use case.

Submerged Vegetation

Two campaigns were carried out on the 1st and 2nd February 2023 and 28th and 29th of June 2023 in the central basin of the lagoon of Venice (Figure 11). In this report only the results of the first campaign are presented. The aim was to acquire continuous hyperspectral measurements in the visible and near infrared (VNIR) spectral region, using the SWAMP-ROX configuration, in order to determine the percentage coverage of sediment types and macrophyte species (both macroalgae and seagrasses) at seabed.

The acquired data were also post-processed in view of satellite remote sensing applications. Particularly, the above-surface water-leaving radiance (Lw) is calculated from the Lu measured by the RoX below the water surface. Lu is multiplied by the correction factor equal to 0.543, found in Zibordi et al. (2012), to consider the water-air interface. The calculated Lw is divided by the Ed, to obtain the remote sensing reflectance Rrs. Since Lw is measured in $Wm^{-2}\ nm^{-1}\ sr^{-1}$ and Ed in $Wm^{-2}\ nm^{-1}$, the Rrs is reported in sr^{-1}. Rrs derived from Rox was spectrally resampled to the Full Width at Half Maximum (FWHM) of PRISMA bands information (provided in the HDF5 metadata) covered by the in-situ instruments.

[2] *https://www.marineboard.eu/marine-habitat-mapping*

Then, BOMBER3 (Bio-Optical Model Based tool for Estimating water quality and bottom properties from Remote sensing images) [3] was be applied to PRISMA- resampled Rrs in shallow water mode to obtain bottom depth and distributions of three different types of substrates.
The results were compared with the depth measured with an echosounder at the 10 stations in Figure 11 and information on benthic vegetation collected from SWAMP using a remote underwater video device. Collected videos were later analysed by vegetation experts to determine the percentage coverage of sediment types and macrophyte species (both macroalgae and seagrasses). The water column height assessed from BOMBER in the optically shallow waters is shown in Figure
12. RoX-derived depth values varied between 0.4 and 3 m. Validation of bottom depth by means of echosounder data shows a good correlation within the range from 0.8 to 2 m. Figure 13 and Figure 14 describe the RoX-derived bottom types, defined according to the three types of benthic substrates. For transect A, the two macrophyte classes were added up and aggregated to obtain the macrophyte coverage, in which each point quantified the proportion of the surface covered by submerged vegetation. For transect B, where bare substrate is alternated with dense colonization, characterized mainly by pure populations of seagrasses or macroalgae, the two macrophyte species are now each displayed with a separate map. The distribution patterns are in accord with field observations.

Figure 11: Locations of two transect in central part of the lagoon of Venice.

[3] *BOMBER (Bio-Optical Model Based tool for Estimating water quality and bottom properties from Remote sensing images) is a software package for simultaneous retrieval of the optical properties of water column and bottom from remotely sensed imagery, which makes use of bio-optical models for optically deep and optically shallow waters*

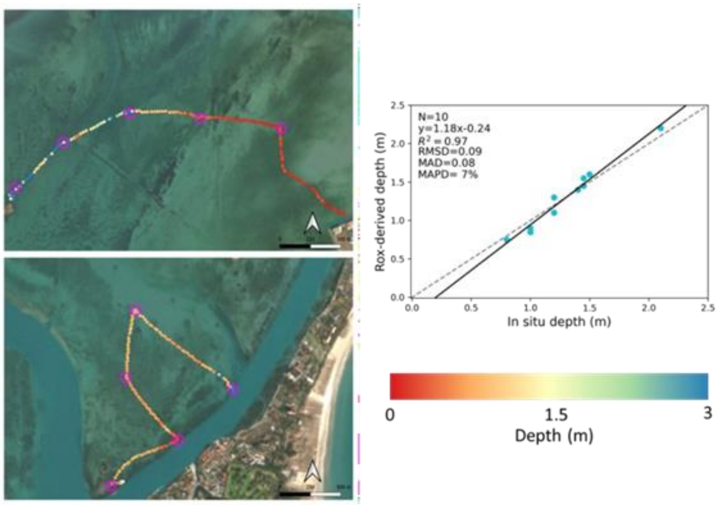

Figure 12: Water depth derived from BOMBER applied to PRISMA resampled RoX Reflectance. Scatter plot of RoX- derived water column height and in situ echosounder bathymetric data measured in 10 stations (magenta points). The fitting statistics are descry

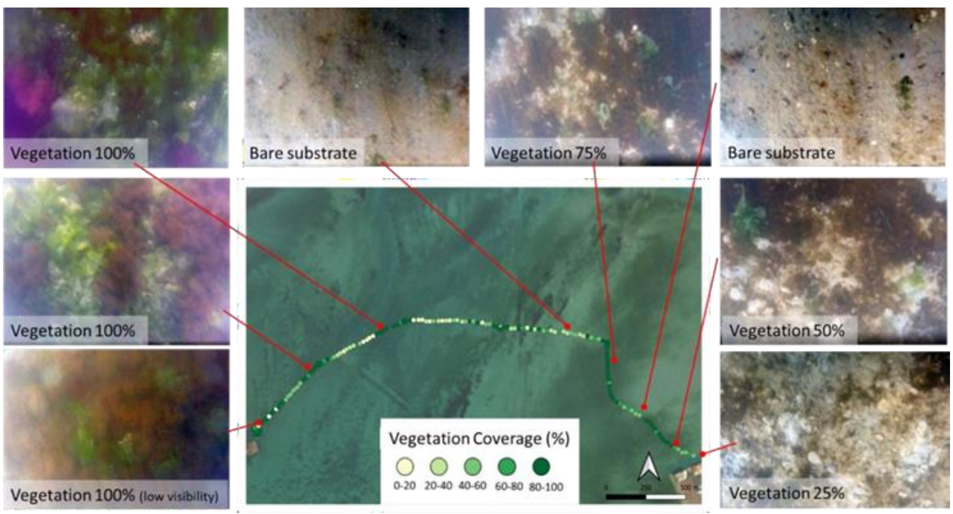

Figure 13: Submerged vegetation coverage derived from BOMBER applied to PRISMA resampled RoX Reflectance

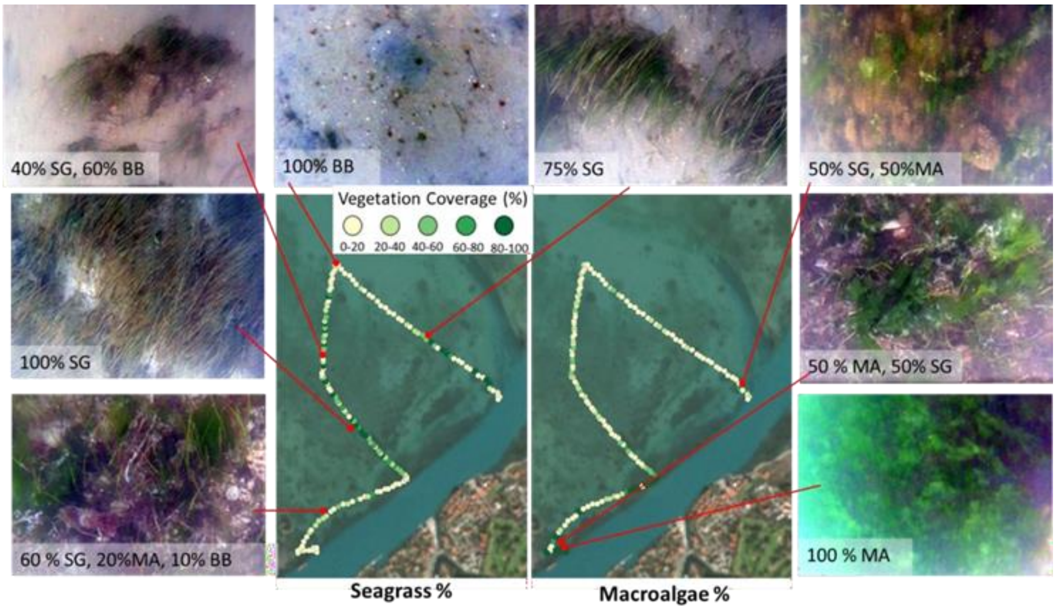

Figure 14: Benthic substrate distribution derived from BOMBER applied to PRISMA-resampled RoX Reflectance. MA: macroalgae, SG: seagrasses, BB: bare substrate.

The results highlighted the reliability of ROX sensor mounted on an autonomous robotic platform and the possibility to use the hyperspectral data to have also information on the bathymetry in shallow water areas. New information on this aspect will be also available from the last campaign in the end of June 2023.

The February campaign involved equipping SWAMP with an automated nutrient analyzer, the SUNA V2 (Submersible Ultraviolet Nitrate Analyzer) on the first and second days. The SUNA V2 is manufactured by SeaBird, and its installation on SWAMP was suggested and carried out in cooperation with OGS.

The instrument, the SUNA V2, was mounted on the SWAMP (Figure 15) in flow-through mode, which means that water was continuously passed through the instrument for analysis. To facilitate this, an SBE-5P pump was used in conjunction with the SUNA V2. The instrument's draft was positioned below the water surface at approximately half a meter. The sampling rate was on the order of one second.


Figure 15: SUNA-V2 Installed on SWAMP.

The aim of the experiment was to investigate the potential of using SUNA V2 on an ASV, capable of operating in coastal, lagoon, and shallow waters. The primary objective was to assess whether this application could yield reliable results for understanding nutrient concentrations in water, which is crucial for studying the interactions between hydrological, geochemical, and biological processes.

While the study of the dynamics of the lagoon ecosystem was not the main focus of the project, the experiment aimed to determine if repeated or sufficiently long campaigns using the SUNA V2 application could provide valuable insights into nutrient concentrations in the targeted waters.
The graph in Figure 16 shows how, thanks to the high sampling frequency, it was possible to capture both absolute values and nitrate variations along the entire SWAMP pathway in a very fine manner. The values obtained in this first experiment are in line with those obtained in other campaigns. In a second campaign planned for the end of June, in-situ sampling will be carried out at the same time as the SWAMP's navigation, with subsequent nitrate analysis in the laboratory, in order to obtain better evidence of the quality of the data obtained from SUNA-V2 and to plan its use in long-term monitoring campaigns.

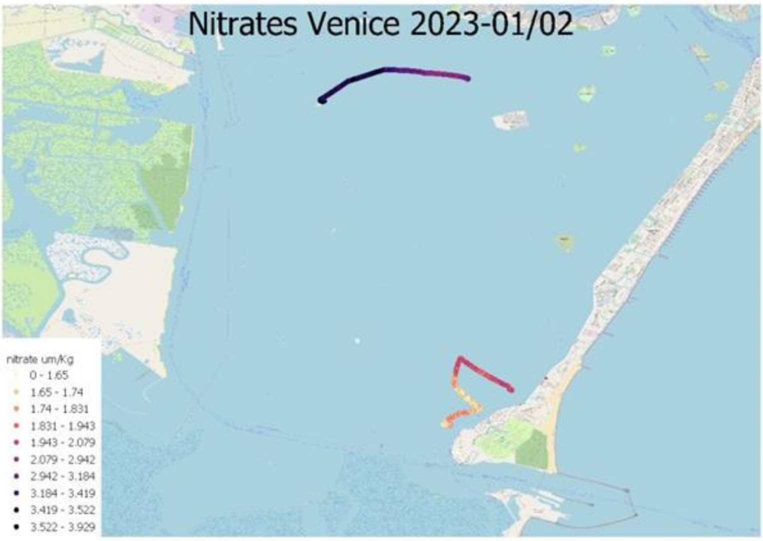

Figure 16: Nutrient gradient measured by SUNA V2.

Benthic features in Scanello Channel

Repeated multibeam surveys allow to monitor the morphological evolution of the tidal environments seafloor. Thanks to the SWAMP system it was possible to map the benthic features of a tidal channel in the Northern lagoon.

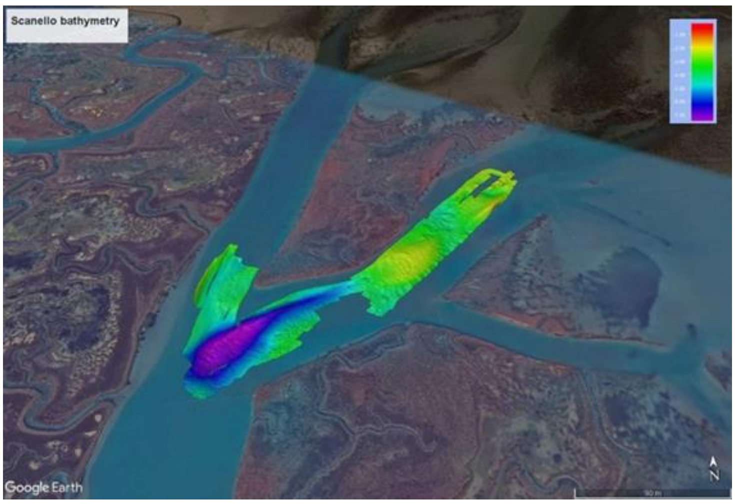

Figure 17: Scanello multibeam acquisition 2023.

Figure 18: Scanello backscatter acquisition 2023.

It is possible to evaluate the changes over time of a portion of a tidal channel in the Northern Venice Lagoon (the Scanello channel in Figure 17 and Figure 18) by comparing with the bathymetric data collected in 2013 [16]. Below the map of the bathymetric residuals where it is possible to see that (Figure 19), in the last 10 years, part of the tidal flats close to the salt marshes surrounding the channel have been strongly eroded over time, while most of the channel seafloor was stable. This strong erosive trend confirms the concern about the salt marsh erosion in the Venice Lagoon. Over the last century, the morphology of Venice lagoon has radically changed, as a whole, undergoing substantial deepening and land loss with more than 50% of the salt marsh surface lost from 1927 to 2002 [18]. An acceleration of the erosive processes occurred from 1970 to 2002 accompanied by the expansion of subtidal flats (areas deeper than 1 m) and the maximum time-average export from the Malamocco inlet flushing the central lagoon [18]. More recent studies have shown that the closures of the storm surge-barriers at the lagoon inlets can hinder the sediment accumulation on the salt marshes, increasing the fragility of their already precarious equilibrium and the adverse effects of sea-level rise, putting their survival at risk [18]. The SWAMP system easily deployable in such shallow environments and would be extremely useful to monitor this process over time with short automated repeated surveys in the most endangered areas that are difficult to reach with traditional vessels.

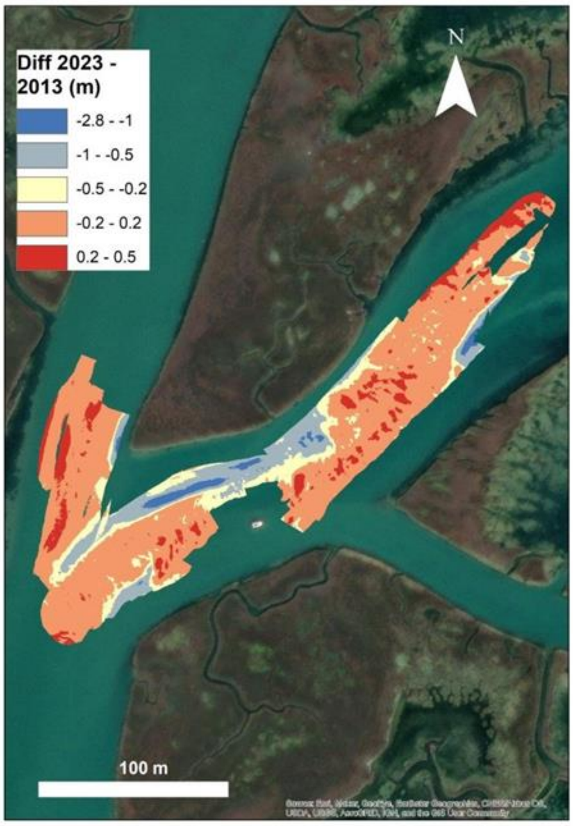

Figure 19: Difference between the bathymetric data collected in 2013 by Madricardo et al. [16] and the data collected with the SWAMP system.

The repeated surveys can not only assess the seafloor morphological changes over time, but they can be very useful in monitoring valuable benthic habitats thanks to the interpretation of the acoustic co-located backscatter data combined with in situ data.

It is now possible to map the spatial distribution of fine scale benthic habitats, even identifying the acoustic signatures of single sponges as it was demonstrated in the Scanello Channel in the Northern Venice Lagoon by Montereale Gavazzi et al. [17]. Specifically, the authors showed that tidal channels can have extremely valuable benthic habitats that need to be monitored over time.

In this case study, we demonstrated that SWAMP can be efficiently deployed to map the lagoon benthic habitats also in the tidal channels, where the extreme shallowness, the very high currents and turbidity make it difficult to use conventional methods for the monitoring (such as video inspections by divers).

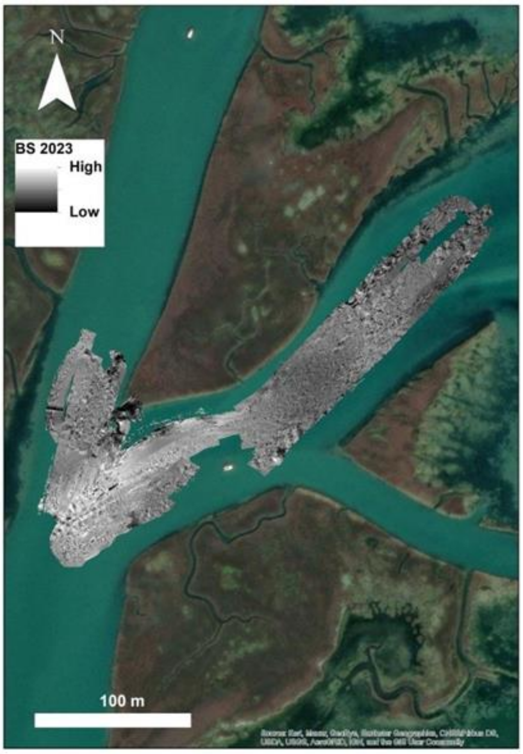

Figure 20: Acoustic backscatter intensity map in the study area.

It is then possible to monitor the presence of specific benthic features, such as the presence of large demospongiae on the seafloor by comparing the SWAMP backscatter data with the backscatter data collected in 2013 (Figure 20, Figure 21). Since they absorb all the sound energy irradiated by the MBES, they appear as black spots on the map [17]. The 2023 data confirm the presence of demospongiae on the channel seafloor (Figure 22).

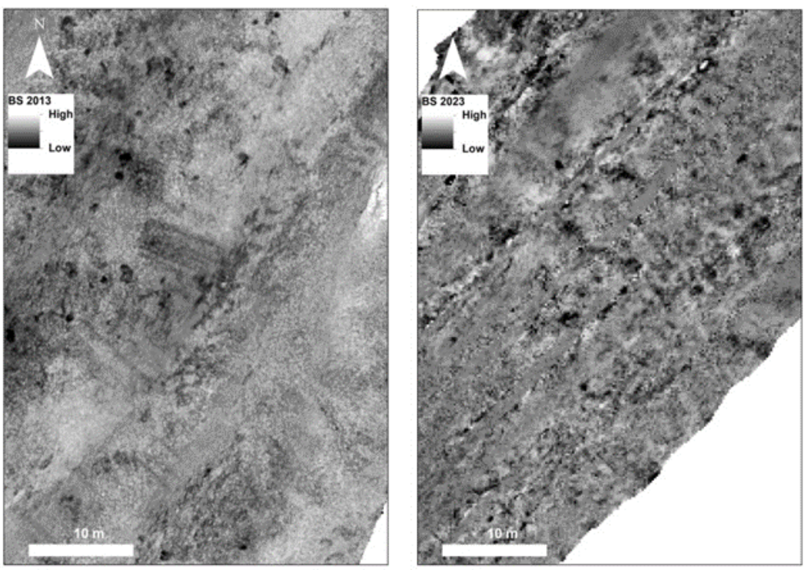

Figure 21: Scanello multibeam backscatter: comparison between 2013 (left) and 2023 (right). The black spots represent the position of demosponges on the seafloor [17] and the image of a demosponges identified in correspondence of the black spots in 2016.

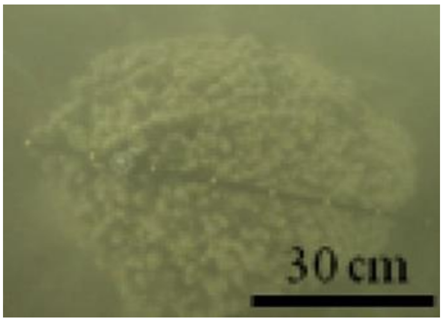

Figure 22: Image of a large demosponge in Scanello collected in 2013 [17].

Integration of different platforms and FAIR data in Robotics

During Innovamare project LABUST, FER, University of Zagreb and CNR's ISMAR and INM institute performed 2 cross-border exercises on inspection and monitoring of harbors, marinas and aquaculture ecosystems, including marine litter detection, adopting the a set of complementary platforms with a different set of capabilities and functionalities: the Shallow Water Autonomous
Multipurpose Platform (SWAMP) Autonomous Surface Vehicle (ASV) from CNR-INM, the Korkyra ASV, the Blueye Pro Remotely Operated Vehicle (ROV) and the Smart Buoy from LABUST, FER.
This configuration of vehicles aimed to showcase a heterogeneous multirobot system tackling this issue.

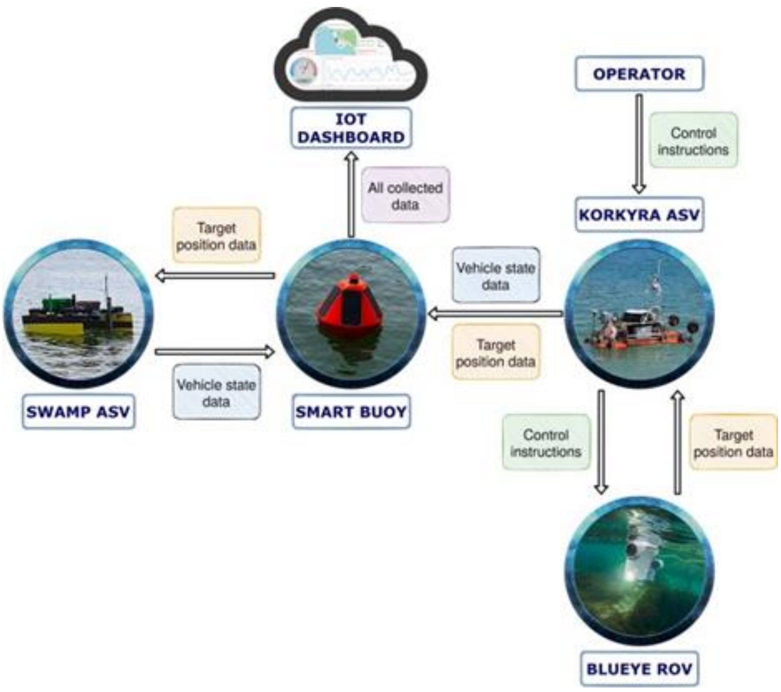

Figure 23: Agents and communication/data flow, example from the second cooperative scenario.

All agents from the abovementioned heterogeneous robotic system form an ad-hoc communication network spanning both underwater acoustic channels and surface WiFi comms (Figure 23). Blueye ROV collects visual data with an objective to find sea litter and other pollution factors, while acoustic sensor units monitor and report on water quality. ASV Korkyra is controlled to follow the ROV. Once sea litter is detected, its estimated georeferenced location is sent to the ASV SWAMP using the Smart Buoy as a relay, after which SWAMP moves to the given location. The buoy monitors the vehicles during the entire length of the mission, displaying their telemetry and status data on a graphical dashboard.
Partners involved in the exercise submitted a scientific paper to OCEAN 23 conference on the results of this action (Annex 1, row n. 4).

Communication and collaboration among scientists in terms of publications, sharing of data and results together with the possibility to reproduce experiments, reviewing and verifying outcomes as scientific community, established modern science in the last decades.
Particularly, the evolution of observational and experimental methods allowed to develop a high potential in terms of research sharing but, on the other hand, poses important challenges to openness, transparency.
The concepts of Open Science of Open Access were born to overcome all possible economic, legal and cultural barriers prevent the majority of researchers and citizens from accessing the methodology and results of research[4]. In this context, European Union is fostering the application of FAIR principles (Findability, Accessibility, Interoperability, and Reusability) as the basis for the findability, accessibility and reuse of research results also through the development of the European Open Science Cloud (EOSC)[5] initiative.

The guidelines connected to the FAIR principles in terms of metadata, i.e., descriptive information and requirements on data treatment are not provided in all the scientific context. In marine robotics, often data are collected during field expeditions and published as raw telemetry without following the FAIR principles.
While there are some efforts in place to improve data standardization [8], mostly these are either for industrial applications, such as Remotely Operated Vehicles (ROVs)[9–12], or military- originated[13], in other cases these attempts only address the construction of marine robots, but not their collected data[14]. The result is a lack of scrutiny when it comes to metadata and metadata standards as FAIRness enablers.

During INNOVAMARE project CNR and FER developed a Free and Open-Source Software (FOSS) that, using the established approach in Earth Sciences, allows to format and share datasets on marine robotic telemetry following the FAIR principles. State-of-the-art protocols for metadata and data formatting are proposed, applied and integrated automatically using Jupyter Notebooks to maximise visibility and ease of use. The method, outlined in a submitted scientific paper (Annex 1, row n. 1), aims to be a first fundamental step towards FAIR interdisciplinary observational science. Moreover, regarding multibeam, all data were acquired in specific QPS proprietary format like .qpd and .db, but also in XTF format. The xtf, eXtended Triton Format, is a proprietary binary but publicly available specification for raw data, therefore this format meets the FAIR criteria. As described by the Triton Imaging Inc 'The XTF file format was created to answer the need for saving many different types of sonar, navigation, telemetry and bathymetry information. The format can easily be extended to include various types of data that may be encountered in the future.

[4] Italian National Plan for Open Science
[5] The European Open Science Cloud (EOSC) is a virtual consolidated environment defined as a "data web", globally accessible, regulated by precise conditions, in which researchers, innovators, private companies and citizens can publish, find and reuse each other's data and tools for research, innovation and education purposes.

Conclusions and guidelines

This report has explained how marine robotics, particularly the several platforms developed by the INNOVAMARE partners, can be used for specific monitoring actions connected to GES descriptors. The developed platforms are somehow complementary, and each has a different set of sensors as well as a different set of capabilities, functionalities and potentialities. The analysed use cases address not only areas related to the MSFD descriptors but, more in general, other Blue Growth economy areas. It is worth notice that these use cases are representative of what the platforms can achieve but are not exhaustive and the platforms can be used in other contexts (in accordance with user needs).
The reliability of the environmental datasets obtained using autonomous platforms was not obvious, moreover, the possibility to have a full heterogeneous multirobot system able to communicate and exchange data, adapting the monitoring mission was a big achievement.

The aspect of the data FAIRness was also tackled by InnovaMare partners, allowing the possibility to reproduce the exercises, learning how solve eventual problems, the enlargement of the scientific community that works on robotics applied at environmental issues with consequent and auspicial speed up of solutions for environmental problems.

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Annex 1

Table of InnovaMare publications

n.	Year	Authors	Title	Conference/Journal	Typology
1	2023	Simona Aracri, Ditzia Susana Garcia Morales, Zurong ZHANG, Jan Peters, Francesco Giorgio-Serchi , Prof Annika Raatz, Corrado Motta, Roberta Ferretti, Francesca De Pascalis, Massimo Caccia	Ocean Soft Robots: Exploration and Data ChallengeThe Data Challenge for Soft Robotics in Marine Sciences	Singapore Ocean Soft Robots conference	Workshop
2	2023	Corrado Motta, Simona Aracri, Roberta Ferretti, Marco Bibuli, Gabriele Bruzzone, Massimo Caccia, Angelo Odetti, Fausto Ferreira, and Francesca De Pascalis	FOSS for FAIR Robotic Datasets	Scientific Data	Scientific paper Under revision
3	2023	Ferretti R., Bibuli M., Bruzzone G., Odetti A., Aracri S., Motta C., Caccia M., Rovere M., Mercorella A., Madricardo F., Petrizzo A., De Pascalis F.	Acoustic seafloor mapping using non-standard ASV:technical challenges and innovative solution	OCEANS 23 conference	Scientific paper
4	2023	Anja Babič, Fausto Ferreira, Nadir Kapetanovi, Nikola Miškovič, Marco Bibuli, Gabriele Bruzzone, Corrado Motta, Roberta Ferretti, Angelo Odetti, Massimo Caccia, Simona Aracri, Francesca De Pascalis	Cooperative marine litter detection and environmental monitoring using heterogeneous robotic agents	OCEANS 23 conference	Scientific paper
5	2023	Fausto Ferreira, Anja Babič, Martin Oreč, Nikola Miškovič, Corrado Motta, Roberta Ferretti, Angelo Odetti, Simona Aracri, Gabriele Bruzzone, Massimo Caccia, Federica Braga, Giorgia Manfè, Giuliano Lorenzetti, Gianmarco Scarpa, Francesca De Pascalis	Heterogeneous marine robot system for environmental monitoring missions	UT23 conference	Scientific paper