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ITINERIS

D5.24 Final report on the implementation and improvement of new biological and ecosystem observations and data release

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1. INTRODUCTION

Two synergistic efforts identify specific priority variables for biodiversity and ecosystems monitoring: Essential Ocean Variables (EOVs) by the Global Ocean Observing System (GOOS), and Essential Biodiversity Variables (EBVs) by the Group on Earth Observations Biodiversity Observation Network (GEO BON).

Many EOVs are also Essential Climate Variables (ECVs): a physical, chemical or biological variable or a group of interrelated variables, that contribute critically to the characterization of Earth's climate[1]. The concept of ECVs evolved in the late 1990s to focus resources on collecting a minimal number of "key variables" for which data records were necessary to understand the status and trends of climate variability. The ECVs were selected after assessment of readiness, feasibility, and impact on societal needs. The ECVs are now fundamental information for negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC).

EOVs, ECVs and EBVs are critical for describing ocean behaviors and interpreting the links between ocean, atmosphere, biosphere, hydrosphere, cryosphere, and anthroposphere. In addition, ECVs provide the necessary scales for understanding and predicting climate evolution, guiding mitigation, and adaptation actions.

GOOS is engaged in a continuous process of refining and expanding the list of essential variables and has added Biology and Ecosystems Essential Ocean Variables, called "BioEco EOVs" to the set of EOVs[2].

Following this example, GEO BON proposed a set of EBVs that can be used in monitoring programs and to understand patterns and changes in Earth's biodiversity. EBVs have been grouped into six classes or subcategories: genetic composition, species populations, species traits, community composition, ecosystem structure, and ecosystem functioning. The BioEco EOV definitions include "Complementary Variables," i.e. other EOVs and/or EBVs needed to fully describe the phenomena or understand impacts on EOVs of natural and anthropogenic pressures. This provides a link between the EOVs from GOOS and the EBVs proposed by GEO BON.

The need for more automated measures and analysis for biochemical and biological parameters has already been recognized at the European level, namely in the 2018 Landscape Analysis of the European Forum for Research Infrastructure - ESFRI[3]. The analysis highlighted that 99% of habitable marine areas lack basic biodiversity knowledge for their management and advocated for more efforts to employ new sensors and samplers that can be mounted on observing autonomous platforms – buoys, gliders and profilers – to also collect biological parameters.

In this direction, the WP5 of the ITINERIS project has the specific objective (OBJ2) to start filling the gaps in biological and ecosystem observations at the national level and to increase the measurements of BioEco EOVs and EBVs as national contributions to the European Ocean Observing System (EOOS), GOOS and GEO BON.

ITINERIS follows the ESFRI proposals by exploiting both automated and innovative technologies for monitoring BioEco EOVs and EBVs. ITINERIS uses automated platforms that acquire different

[1] https://gcos.wmo.int/en/essential-climate-variables/about
[2] https://goosocean.org/what-we-do/framework/essential-ocean-variables/
[3] ESFRI (2018), Strategy Report on Research Infrastructures – Roadmap 2018, printed on behalf of ESFRI by Dipartimento di Fisica - Università degli Studi di Milano, ISBN print: 978-88-943243-2-7, ISBN pdf: 978-88-943243-3-4

spatial scales and conduct high-frequency and continuous observations. A number of new biogeochemical/bio-optical sensors have also been deployed in key sites to improve observational capabilities, the understanding of marine ecosystems, and the assessment of their status and changes over time and space. ITINERIS recognizes that a proper integration between oceanographic and biological/ecological parameters is essential to broaden the range of observational activities, with the concept of ecological connectivity as a key driver of marine ecosystem functioning.

This deliverable D5.24 builds on the results of D5.5, which outlined the landscape of available observations and identified existing gaps in the monitoring of BioEco EOVs and EBVs across four RIs: eLTER-RI, EMSO-ERIC, Euro-Argo ERIC, and JERICO. While D5.5 focused on mapping the status as of 2023, at the beginning of ITINERIS, and identifying needs, D5.24 advances this analysis by examining how the same RIs have effectively implemented, or are in the process of implementing, the observation of BioEco EOVs and EBVs.

Specifically, this deliverable corresponds to the ITINERIS Intermediate Objective IO5.8, which emphasizes the implementation of tools and instruments that foster integration and harmonization among environmental RIs in Italy. As for D5.5, D5.24 concentrates on the same four RIs - eLTER-RI, EMSO-ERIC, Euro-Argo ERIC, and JERICO - as they are directly engaged in ongoing and targeted actions to strengthen the observation of BioEco EOVs and EBVs within the ITINERIS project.

eLTER-RI – Integrated European Long-Term Ecosystem, Critical Zone & Socio-Ecological Research Infrastructure

eLTER-RI is a pan-European *in-situ* research infrastructure whose mission is to study long-term ecological changes in terrestrial, freshwater and transitional ecosystems through a holistic "whole system" approach, based on the integration of different environmental disciplines, to understand the role and interactions of multiple and complex ecosystem variables.

The RI consists of 26 national networks, 500 research sites, and 50 LTER platforms, providing broad and systematic coverage of key European ecosystems, integrating the socio-ecological components. eLTER-RI comprises National Research Infrastructures (NRIs), and European level Central Services (CS), such as data access, training and harmonized methods and parameters (standard observations).eLTER is currently in the preparatory phase towards becoming a fully-fledged RI and ERIC (expected in 2027) and is funded by the European Commission through the H2020 and Horizon Europe projects eLTER PPP, eLTER PLUS and eLTER EnRich. The commitment of the Italian Ministry for Universities and Research (MUR) and the CNR led to the establishment of the eLTER-IT Joint Research Unit (JRU), which coordinates the Italian contribution to eLTER-RI and the national activities of the LTER-Italy network. The JRU is coordinated by the CNR and involves 28 Italian institutions including universities, research bodies and local authorities. The LTER-Italy network consists of 65 research sites distributed across the country, representing the main ecosystem typology of our country. 19 of these sites represent the marine and transitional water component of the Italian eLTER-RI.

EMSO ERIC – European Multidisciplinary Seafloor and water column Observatory

EMSO ERIC is a distributed infrastructure with observation facilities located at key sites across European seas, from the northern and north-eastern Atlantic, to the Mediterranean and the Black Sea, spanning various climatic zones from the sub-arctic to the sub-tropical . EMSO's mission is to support scientific and technological research to understand the complex interactions among the geosphere, biosphere, andhydrosphere by acquiring long time-series of observables by means of fixed platforms in the deep marine environment. These data related to different disciplinary sectors such as from oceanography, seismology, and biology) are intended to promote a multidisciplinary approach for studying climate and marine ecosystems evolution, as well as the occurence and evolution of extreme events of both natural and anthropogenic origin.

The acquisition of measurements in extreme environments such as the deep marine environment requires specialised knowledge of marine technologies and extensive field and logistics experience. These skills, developed by the technical-scientific personnel responsible of the functioning of the facilities, are made available to scientific and industrial users who require physical or remote access to the infrastructure for scientific or commercial purposes.

EMSO's vision is to position the RI among the leading institutions in the marine sciences, and as a key actor in the landscape of European Environmental research infrastructures and providing scientific and technological services to address the environmental challenges that affect the quality of life on our planet.

EMSO has been included in the ESFRI Roadmap since 2008 and was established as a European Research Infrastructure Consortium (ERIC) in 2016 by the governments of 8 Countries: France, United Kingdom, Greece, Ireland, Italy, Portugal, Romania, and Spain, with t Norway joining in 2021. EMSO is currently recognized in the latest ESFRI Roadmap as a 'Landmark' infrastructure, meaning it has entered the operational phase.

Euro-Argo ERIC – European contribution to the Argo programme

Euro-Argo ERIC is part of the international Argo programme (for more details, see http://www.argo.ucsd.edu), that was initiated in 1999 as a pilot project endorsed by the Climate Research Program of the World Meteorological Organization, GCOS and GOOS, and the Intergovernmental Oceanographic Commission. The Argo network is a global array of more than 3500 autonomous multi-sensor platforms, deployed over the world ocean, reporting 0-2000m subsurface ocean properties to a wide range of users via satellite transmission links to data centers.

The initial target of the international Argo programme was to achieve data coverage of 1 float per 3x3° grid cell and month over the global ocean. This data coverage is deemed to be sufficient to resolve many of the important global climate signals and support the enhanced real-time requirements of operational modelling applications in oceanography and meteorology.

Euro-Argo aims to provide, deploy and operate ¼ of the global Argo floats array and Italy is one of the countries contributing to this goal. Starting in January 2008 as a European project involving 25 organizations across 12 countries, Euro-Argo gained the status of a European Research Infrastructure Consortium (ERIC) in May 2014.

The Euro-Argo ERIC focuses on providing enhanced coverage in the European regional seas, to implement the new phase of Argo, with extensions towards biogeochemistry (BioGeoChemical-Argo), greater depths (Deep-Argo) and high latitudes and to provide quality controlled data and access to the data sets and data products to the research (climate and oceanography) and operational oceanography (e.g., Copernicus Marine Service) communities.

Argo must be considered in its ensemble: not only the instruments, but also the logistics necessary for their preparation and deployments, field operations, the associated data streams, data centers and data management. That's why Euro-Argo establishes a high level of cooperation between partners in all implementation aspects:

- operation at sea;
- array monitoring and evolution;

- technological and scientific developments;
- improving data access for research and operational oceanography (Copernicus Marine Service);
- link to the international management of the Argo programme;
- promote Argo, enlarge the Argo data user community and help answering its needs.

The Italian participation in Euro-Argo ERIC is coordinated by OGS (National Institute of Oceanography and Experimental Geophysics), it involves the CNR (National Research Council) and aims to sustain Argo, BGC-Argo and Deep-Argo with a focus on the European regional seas.

JERICO – Joint pan-European Research Infrastructure for Coastal Observations

The objective of JERICO is to formally design, implement and operate a pan-European Research Infrastructure, dedicated to set up a system of observation and related services for European coastal seas, thus empowering European research excellence and expertise for the benefit of society.

JERICO is an essential component of the worldwide efforts to a better understanding of coastal marine systems. JERICO also aims at being the future coastal component of the European ocean observing effort, as part of the Global Ocean Observing System, GOOS. Through multidisciplinary pan-European observations, JERICO seeks to improve the knowledge of how coastal marine systems respond to global and local drivers. By doing so, JERICO is strengthening the interactions between observations, experimentations, and numerical modelling.

Since 2011, JERICO has developed conceptual and practical expertise aimed at providing high-quality coastal observations and services to the marine scientific community and to a range of local, regional and European end-users.

JERICO, as an integrative system working across coastal disciplines, is progressing towards the definition of a sustainable infrastructure, harmonized at EU level with capabilities to deliver high-quality environmental data, access to solutions and facilities as services for researchers and users of the coastal domain.

JERICO benefits from both national efforts, put forth to better address the national coastal priorities, and other European initiatives. It aims at closing the critical gap in not having an integrated European Research Infrastructure addressing the complexity of marine coastal systems. JERICO is proposing to bridge the existing continental, atmospheric and open ocean RIs, thus filling a key gap in the ESFRI ecosystem.

The JERICO consortium is coordinated by the French lead partner IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer) and has recently worked on two projects, JERICO-S3, which has provided access to marine infrastructures and their data and experimentation at the transnational level, and JERICO-DS, for the design of the ESFRI phase. In April 2025, JERICO submitted its application to the 2026 ESFRI Roadmap.

The Italian participation in JERICO is coordinated by the CNR and involves the OGS (National Institute of Oceanography and Experimental Geophysics), making a fundamental contribution thanks to the long and strong traditions of research on marine issues and technological innovation assets related to the monitoring of the marine coastal environment of both institutes.

2. METHODOLOGICAL FRAMEWORK

This deliverable builds on the material and methodological framework developed in D5.5, which provided the first national-level assessment of gaps and capacities in the observation of EBVs and BioEco EOVs across the four Italian marine RIs: eLTER-RI, EMSO ERIC, Euro-Argo ERIC, and JERICO. The present work updates and extends the previous analysis by incorporating new information on sensors, laboratory instrumentation, and observational capabilities made available through the ITINERIS project, with a focus on recently acquired equipment.
The data collection followed a two-step approach:

- revisiting the baseline landscape of EBV and BioEco EOV observations described in D5.5;
- integrating contributions from new sensors and systems procured through ITINERIS investments (living document and annex of D5.6).

The survey methodology, originally developed in D5.3 and also applied in D5.5, was used to collect detailed metadata for each parameter, including sensor type, measurement depth and frequency, data format, and quality control level. Parameters were mapped to the relevant EBV classes defined by GEO BON (genetic composition, species populations, species traits, community composition, ecosystem structure, ecosystem function) and to the BioEco EOVs defined by GOOS (Biology and Ecosystems category, excluding Physics, Biogeochemistry, and Cross-disciplinary variables).
The updated analysis incorporated new sensors, equipment, and platforms acquired through ITINERIS, including autonomous samplers, imaging systems, and biogeochemical modules. These instruments significantly enhance observational capacity, particularly for biological and ecosystem variables. For each RI, new measurement capabilities were linked to the corresponding EBVs or BioEco EOVs, enabling the identification of newly monitored variables for each RI and the extension or densification of existing time series.
Updates were validated through direct consultation with RI supervisors to ensure accuracy regarding operational status and actual deployment of the new equipment. Special attention was given to avoiding overlaps or double-counting, particularly for facilities co-located across RIs.
The integration of these updates produced a harmonized overview, enabling both qualitative and quantitative comparisons with the baseline scenario established in D5.5. The results, summarized in updated tables and figures, provide clear evidence of the enhanced national capacity for EBV and BioEco EOV monitoring made possible by ITINERIS investments.

3. IMPLEMENTATION AND IMPROVEMENT OF NEW BIOLOGICAL AND ECOSYSTEM OBSERVATIONS

The BioEco EOVs and EBVs considered in this deliverable are the same used for D5.5 and are detailed in the first columns of **Error! Reference source not found.** and sum up to a total of 25: 7 BioEco EOVs and 18 EBVs. BioEco EOVs are selected from the full list of EOVs which can be found at the following link: https://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114, together with the full set of EBVs for the marine domain listed in this other link: https://github.com/EuropaBON/EBV-Descriptions/wiki .

The facilities considered for this deliverable, together with the updated list of automatic sensors and manual samplings, are listed in Annex 1.
In D5.5, it was observed that most of the facilities were concentrated in the Northern Adriatic, parts of the Ligurian Sea and selected lagoons in the northern and southern part of Italy and Sardinia, living a large portion of the Tyrrhenian and southern basins scarcely represented.
In the updated map (Figure 1), the spatial network expands considerably, with the addition of numerous Euro-Argo floats (yellow markers) and JERICO gliders and SVP drifters distributed across

the Ligurian, Tyrrhenian, Ionian, and western Mediterranean basins. This addition significantly densifies coverage in offshore areas, filling previous gaps far from the coast. The result is a transition from a network that was mainly focused on coastal and lagoon sites to a system that now includes a broader offshore dimension, extending across much of the central and western Mediterranean.
Overall, the updated situation demonstrates a substantial improvement in spatial coverage, with continuity from coastal lagoons to offshore basins and greater balance between the northern and southern sectors of the Italian seas. This shift represents not only a quantitative increase in observation points but also a qualitative expansion in terms of ecosystem and oceanographic representativeness.

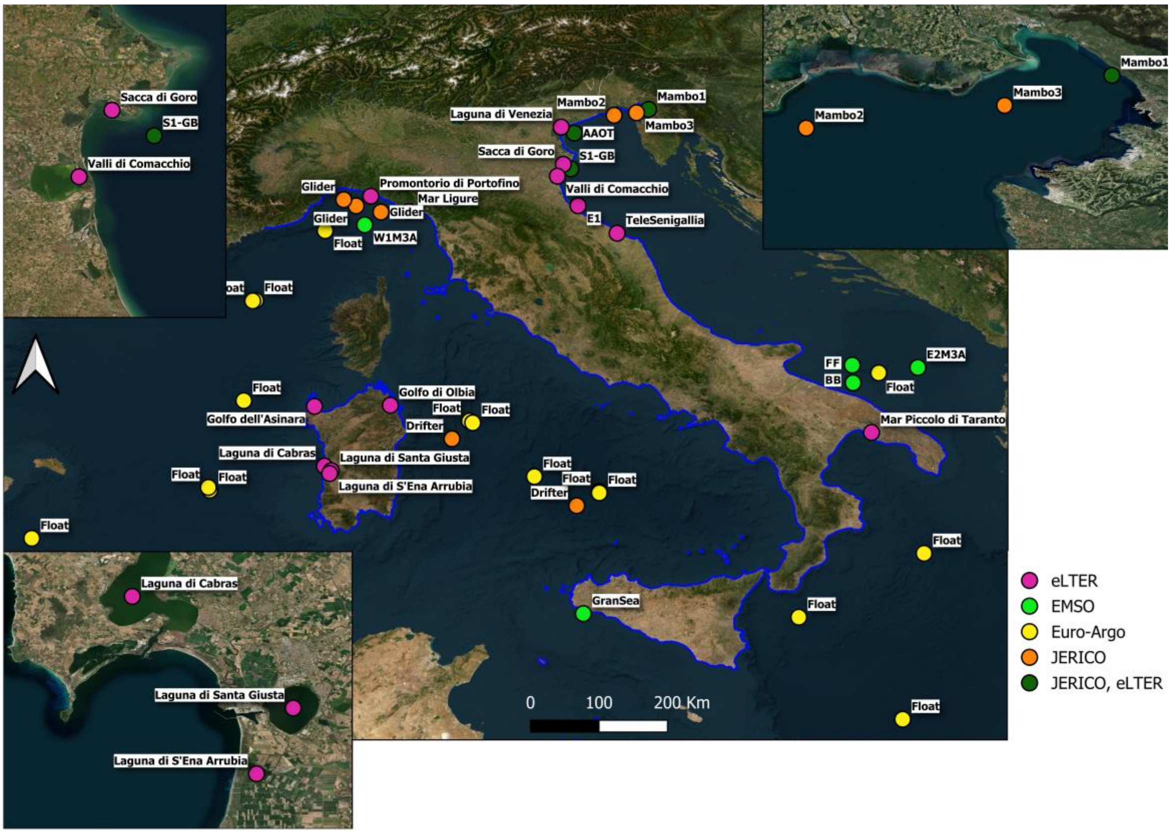

Figure 1 – ***Geographic distribution of facilities across the Mediterranean and Italian seas that contribute to the production of EBVs or BioEco EOVs and considered in this deliverable. The map does not include the facilities that are not yet deployed until December 2025 or those that are already deployed but for which the exact coordinates are not known.***

Table 1 - Number of measurements of BioEco EOVs and EBVs for the RIs considered in this deliverable. Rows in blue/light blue indicate the baseline situation reported in D5.5, while green rows show the number of total measurements after the implementations achieved during the ITINERIS project. If no additional green row is provided for a given EV, no new implementation was carried out for that specific EV. Number of automatic measurements by sensors are between parentheses.

Category	Subcategory	BioEco EOV/EBV full name	eLTER	EMSO	EuroArgo	JERICO
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Phytoplankton Biomass and Diversity	16 (5)	1 (1)	9 (9)	4 (4)
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Phytoplankton Biomass and Diversity	21 (10)	2 (2)	11 (11)	12 (12)
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Zooplankton Biomass and Diversity	4 (0)	0	6 (6)	1 (0)
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Zooplankton Biomass and Diversity	4 (2)	0	8 (8)	3(2)
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Fish Abundance and Distribution	2 (0)	1 (1)	0	0
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Fish Abundance and Distribution	8 (6)	1 (1)	0	0
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Seagrass Cover and Composition	0	0	0	0
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Macroalgal Canopy Cover and Composition	1 (0)	0	0	0
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Microbe Biomass and Diversity (*emerging)	1 (0)	0	0	0
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Invertebrate Abundance and Distribution (*emerging)	1 (0)	0	0	0
EOV	Ocean Biology and Ecosystems	EOV - Biology and Ecosystems: Invertebrate Abundance and Distribution (*emerging)	7 (6)	0	0	0
EBV	Community composition	EBV - Community composition: Functional diversity of marine phyto/zooplankton (based on traits)	5 (0)	0	2 (2)	1 (0)
EBV	Community composition	EBV - Community composition: Functional diversity of marine phyto/zooplankton (based on traits)	7 (2)	0	10 (10)	2 (1)
EBV	Ecosystem Function	EBV - Ecosystem function: Degree of seabed disturbance	0	0	0	0
Category	Subcategory	BioEco EOV/EBV full name	eLTER	EMSO	EuroArgo	JERICO
EBV	Ecosystem Function	EBV - Ecosystem function: Harmful marine algal blooms	5 (0)	0	0	0
EBV	Ecosystem Function	EBV - Ecosystem function: Harmful marine algal blooms	6 (0)	0	0	0
EBV	Ecosystem Function	EBV - Ecosystem function: Phenology of marine spring phytoplankton bloom	3 (0)	0	2 (2)	1 (0)
EBV	Ecosystem Function	EBV - Ecosystem function: Phenology of marine spring phytoplankton bloom	5 (2)	0	10 (10)	1 (0)

EBV	Ecosystem Function	EBV - Ecosystem function: Marine primary productivity	8 (3)	1 (1)	6 (6)	4 (3)
EBV	Ecosystem Function	EBV - Ecosystem function: Marine primary productivity	8 (3)	1 (1)	10 (10)	8 (7)
EBV	Ecosystem Structure	EBV - Ecosystem structure: Ecosystem distribution of hard corals habitats	0	0	0	0
EBV	Ecosystem Structure	EBV - Ecosystem structure: Ecosystem distribution of marine macroalgae canopy cover	1 (0)	0	0	0
EBV	Ecosystem Structure	EBV - Ecosystem structure: Ecosystem distribution of marine seagrass habitats	0	0	0	0
EBV	Ecosystem Structure	EBV - Ecosystem structure: Ecosystem distribution of oyster reef habitats	0	0	0	0
EBV	Ecosystem Structure	EBV - Ecosystem structure: Ecosystem distribution of oyster reef habitats	1 (0)	0	0	0
EBV	Genetic composition	EBV - Genetic composition: Genetic diversity of selected marine taxa	0	0	0	0
EBV	Specie Traits	EBV - Species traits: Phenology of migration of marine birds and mammals	0	0	0	0
EBV	Species Population	EBV - Species populations: Species distributions of marine fishes	2 (0)	0	0	0
EBV	Species Population	EBV - Species populations: Species distributions of marine fishes	8 (6)	0	0	1 (1)
EBV	Species Population	EBV - Species populations: Species abundance. of marine commercial fish species and long-distance migratory fish	0	0	0	0
EBV	Species Population	EBV - Species populations: Species distributions of marine birds	0	0	0	0
EBV	Species Population	EBV - Species populations: Species distributions of marine mammals	0	0	0	0
EBV	Species Population	EBV - Species populations: Distributions of marine turtle species nesting grounds	0	0	0	0
EBV	Species Population	EBV - Species populations: Species distributions of benthic marine invertebrates	3 (0)	0	0	0
EBV	Species Population	EBV - Species populations: Species distributions of invasive alien marine taxa of European concern	6 (0)	0	0	0
		TOTAL	**58 (8)**	**3 (3)**	**25 (25)**	**11 (7)**
		TOTAL	**87 (37)**	**4 (4)**	**49 (49)**	**26 (23)**

Figure 2 (a, b) illustrates the percentage of BioEco EOVs (blue) and EBVs (green) measured by each RI out of the 57 possible EVs. Panel (a) reports the baseline situation described in D5.5, while panel (b) presents the status after the ITINERIS project, highlighting the implementations achieved in the observation of EVs. A BioEco EOV or EBV is considered in the calculation whenever at least one measurement is available from any facility associated with the RI.

At baseline, eLTER already demostrated the highest level of coverage among the RIs, with a balanced contribution of both EBVs and BioEco EOVs. Following ITINERIS, eLTER significatly strengthened its observational portfolio, reaching nearly 50% of the possible EVs.

Initially, EMSO exhibited limited coverage, with only a few BioEco EOVs measured and no significant EBV observations. After ITINERIS, the implementation of new autonomous sensors led to a modest but measurable expansion, primarily within the BioEco EOV domain. Although the improvement remains limited, it represents an important step towards broadening EMSO's scope beyond its traditional focus on physical and biogeochemical variables.

At the time of D5.5, Euro-Argo had limited coverage of EBVs and only a small contribution to BioEco EOVs. The ITINERIS project substantially improved its observational capacity, with a significant increase in BioEco EOVs now reaching more of the 30% of the total EVs. This reflects the successful deployment of biogeochemical floats and additional modules that extended Euro-Argo's capabilities from physical parameters towards ecosystem-relevant variables.

JERICO's baseline capacity showed limited coverage, with both EBVs and BioEco EOVs represented at low percentages. Post-ITINERIS, there was a clear improvement in both categories. The gains reflect targeted investments in coastal observatories and biological sensors, which enhanced the RI's contribution particularly to community composition and ecosystem structure indicators.

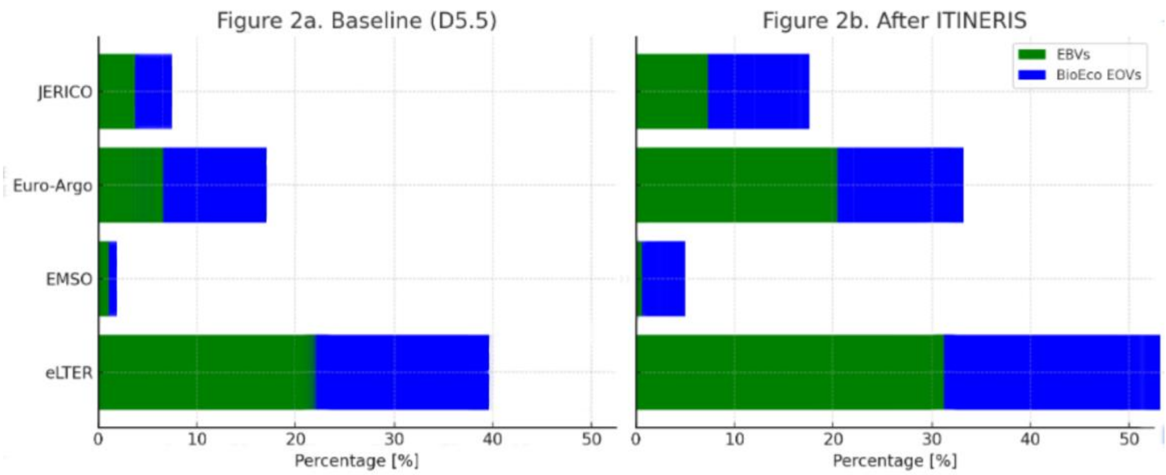

Figure 2 - Percentage of BioEco EOVs and EBVs measured by each RI included in this deliverable, expressed relative to the total set of possible EVs. Panel (a) shows the baseline situation reported in D5.5, while panel (b) illustrates the status after the ITINERIS project.

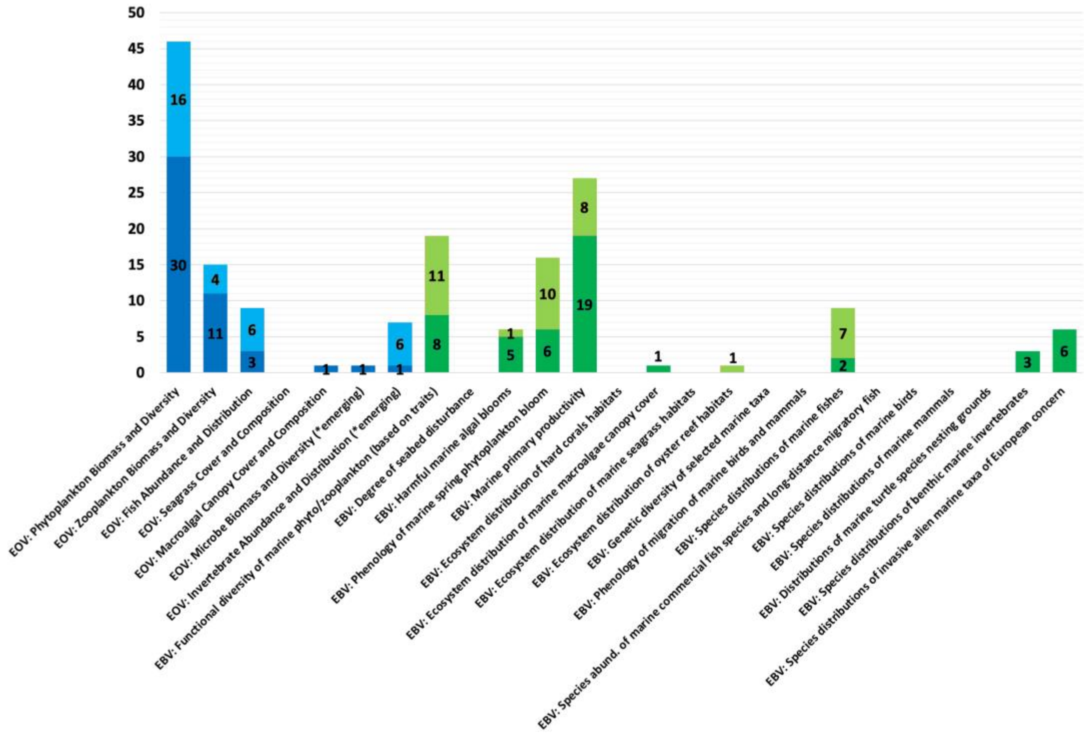

Figure 3 - Degree of implementation in term of number of measurements of BioEco EOVs and EBVs at the baseline (D5.5, dark blue and green) and after ITINERIS (light blue and green).

Figure 3 conveys the picture of the implementation of BioEco EOVs and EBVs, showing how ITINERIS has reinforced the baseline and fostered progress in several key areas. Phytoplankton biomass and diversity emerge as the most consolidated variable, with very high levels of implementation that confirm it as a cornerstone of marine monitoring. Marine primary productivity also shows a remarkable step forward. Zooplankton biomass and diversity maintain consistent levels of implementation, reflecting steady attention to this ecological component. Several other variables, such as harmful algal blooms, macroalgae, and benthic invertebrates, although still at lower levels, demonstrate growth, indicating that efforts are starting to extend beyond the most established areas. Even where implementation remains modest, for example in higher trophic levels like fish, the added contribution of the project suggests a gradual broadening of focus. Moreover, as it was already observed in D5.5, only two variables, namely the "EOV - Biology and Ecosystems: Phytoplankton Biomass and Diversity" and the "EBV - Ecosystem function: Marine primary productivity", are measured by all 4 RIs considered in this deliverable. It must be noted that the two variables are related as some measures of primary productivity may rely on phytoplankton biomass estimates.

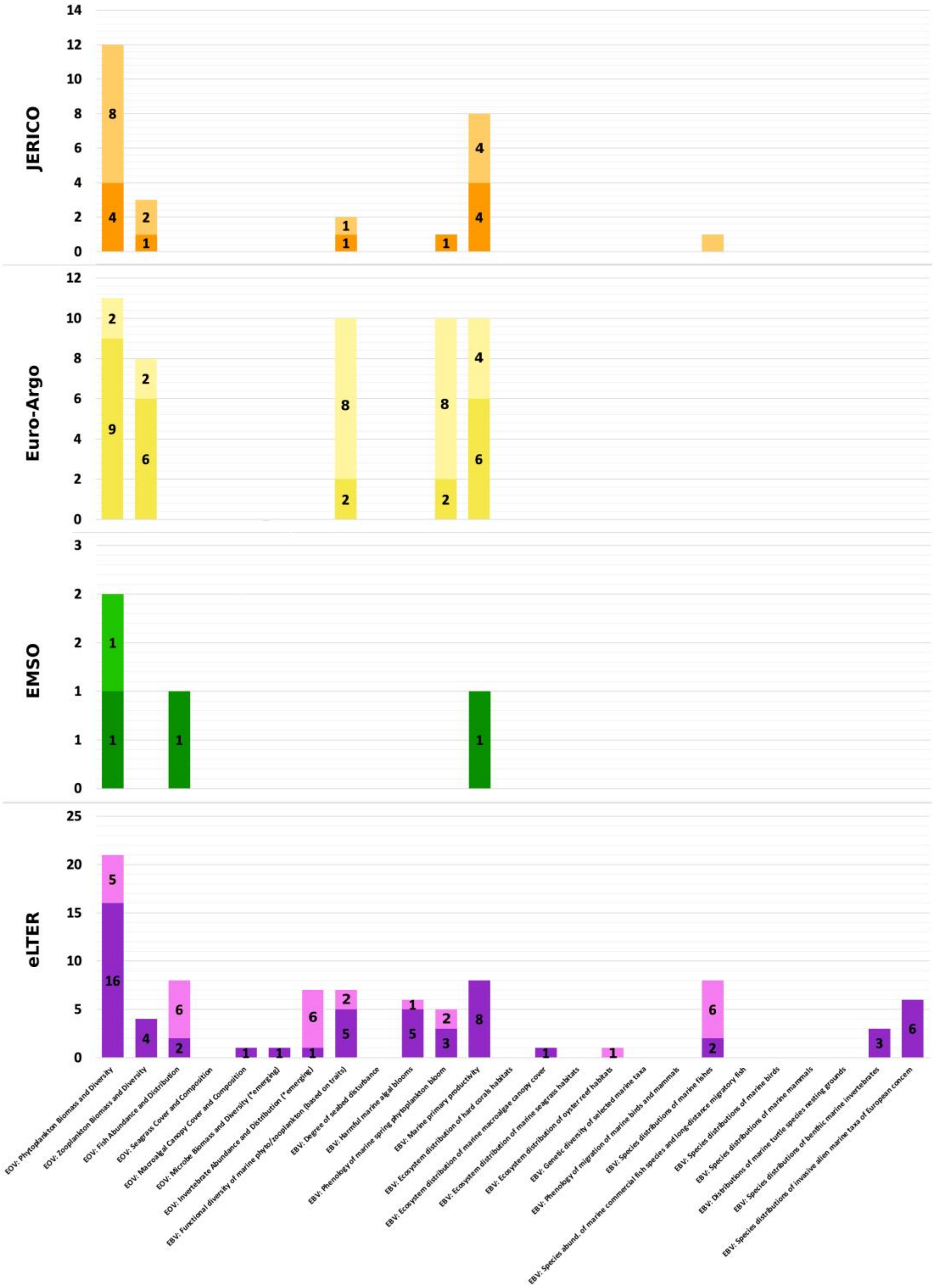

Figure 4- Histograms showing the actual contributions (lighter colors) of the four RIs to the measurement of specific BioEco EOVs and EBVs, compared to the baseline contributions reported in Deliverable D5.5 (darker colors).

Figure 4 shows that the implementation of EVs has progressed with varying intensity across variables, and that the contributions from each individual RI are unevenly distributed. The most consistent reinforcement is seen in phytoplankton biomass and diversity and marine primary productivity, where all four infrastructures (eLTER, EMSO, Euro-Argo, JERICO) contribute, confirming these variables as the backbone of observational capacity. Zooplankton biomass and diversity also receive substantial new inputs, particularly from Euro-Argo and JERICO.

Moderate increases are evident in fish abundance, supported primarily by eLTER and JERICO, as well as in benthic invertebrates, and harmful algal blooms, where eLTER plays a central role in expanding coverage.

By contrast, most EBVs related to species distributions of higher trophic levels -such as marine mammals, seabirds, reptiles, and migratory fish -show no new implementation, indicating that none of the infrastructures have yet contributed to these domains. The overall picture highlights a clear reinforcement in the observation of variables linked to lower trophic levels and primary producers, leaving a strong signal on plankton and productivity.

Figures 5 and 6 show the evolution in the distribution of BioEco EOV and EBV measurements, respectively, distinguishing between sensor-based and sample-based observations. In the baseline observed in D5.5, sensor-based observations accounted for 60% for the EOVs and 38% for EBVs, with the remainder carried out through manual sampling, largely concentrated in eLTER. In the updated situation, the role of sensors increases substantially, reaching around 76% of the total for the EOVs and 60% for the EBVs. This change highlights a clear reinforcement of automated monitoring, with sensor-based systems becoming the dominant approach for implementing EVs. While manual sampling remains present, its relative contribution has decreased in quantity, though not in scientific value or importance.

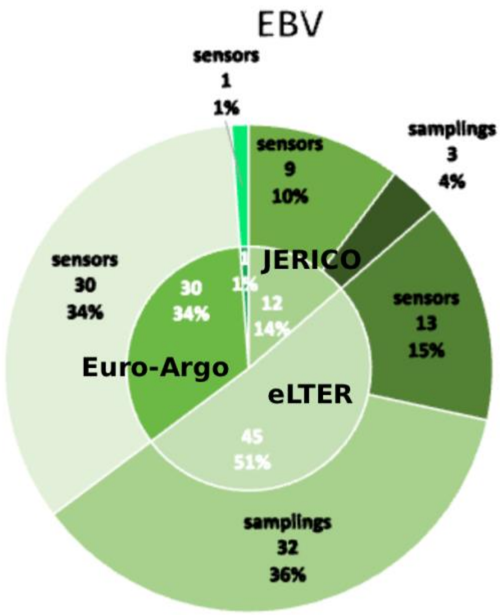

Figure 5 - Distribution for the updated measurements of EBVs among the RIs considered in this deliverable divided by the type of measurements: automatic sensors or manual samplings. Numbers indicate the number of EBV measurements for each RI and type. The percentages are with respect to the total number. EuroArgo and EMSO contributions are only due to automatic sensors.

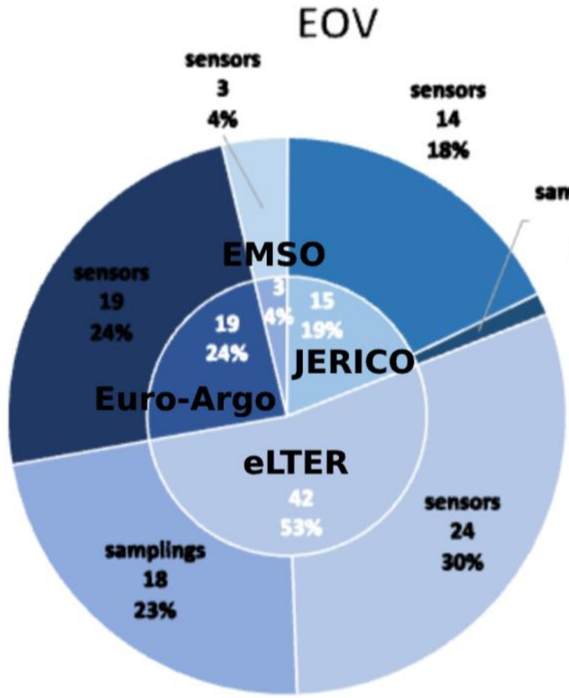

Figure 6 - Distribution for the updated measurements of BioEco EOVs among the RIs considered in this deliverable divided by the type of measurements: automatic sensors or manual samplings. Numbers indicate the number of BioEco EOV measurements for each RI and type. Percentages are with respect of the total number. EuroArgo and EMSO contributions are only due to automatic sensors.

4. PROGRESS IN ADDRESSING IDENTIFIED GAPS

Based on the gaps identified in the D5.5, the following progresses can be recognized:

- **Coverage of BioEco EOVs and EBVs**

At the national scale, coverage remains uneven, but ITINERIS has clearly increased the number of EV data streams. eLTER is consolidating its observational network, now covering nearly half of the EVs, while Euro-Argo and JERICO have significantly improved their contributions through the deployment of new sensors, floats, and coastal platforms. EMSO has also expanded. Several EBVs remain unmonitored (10 out of 18), along with the BioEco EOV "Seagrass cover and composition," which is still not observed by any RI. However, new measurements have been begun for fish abundance and distribution, benthic invertebrates, harmful algal blooms, and phenology of phytoplankton blooms, indicating partial progress. The overall gap is therefore only partially reduced, and many EBVs, particularly those linked to higher trophic levels, still lack systematic implementation.

- **Geographical distribution**

The scenario described in D5.5 was dominated by coastal lagoons and embayments. Following the implementation of ITINERIS, the addition of new Euro-Argo floats, JERICO gliders and SVP drifters, and EMSO facilities in offshore and southern basins has expanded observational coverage, particularly in the Tyrrhenian, Ionian, and Sicily Channel, as well as in Western Sardinia and the Ligurian Sea, thanks to the ITINERIS' EYES Cruise. This progress has also helped to fill previous geographic observation gaps, particularly in shelf areas, where new glider deployments now provide biogeochemical (BGC) measurements that were previously unavailable. As a result, the earlier imbalance in spatial coverage has been partially reduced, although coverage remains denser in northern sites and transitional systems. In addition, the deployment of BGC-Argo floats has extended coverage to the deeper regions of the Ionian and Tyrrhenian areas and in Western Sardinia and the Ligurian Sea, again due to the ITINERIS' EYES Cruise, while EMSO has reinforced its Southern Adriatic Regional Facility. However, several critical areas, such as the Strait of Otranto, the Strait of Messina, and parts of the central Adriatic remain undersampled.

- **Lack of facilities**

Most infrastructures increased their measurement capacity: EMSO added sensors and improved real-time transmission in the Southern Adriatic, while Euro-Argo deployed new biogeochemical floats equipped with optical and imaging sensors. JERICO expanded its observational network with new autonomous vehicles, gliders, and coastal observatories, especially in the North-Western Mediterranean. This has improved geographical representativeness beyond the North Adriatic. All these actions contributed to broadening the observational portfolio.

- **Automatic/sensor-based measures**

A significant improvement is recorded here. Across all RIs, the number of sensor-based measurements increased from 60% at baseline to 76% for EOVs and from 38% to 50% for EBVs after ITINERIS, mainly through Euro-Argo and EMSO (which rely exclusively on sensors) as well as through gliders and new imaging and cytometry devices introduced by eLTER and JERICO. Manual sampling remains important in eLTER, but the overall system has clearly shifted towards automation and real-time acquisition.

In terms of actual implementation and based on the plan outlined in the D5.5, eLTER has effectively reinforced its already strong baseline, maintaining leadership on EBVs and expanding to new variables such as fish abundance, while also introducing more automated acquisition. This confirms that the planned focus on increasing both the number of biological variables and automation was largely achieved. EMSO, which initially had limited coverage of biological and ecological components, implemented new sensors and improved data transmission in the Southern Adriatic and at the Western Mediterranean regional facility in the Ligurian Sea. These actions have concretely widened EMSO's scope to include some BioEco EOVs, in line with what was foreseen. Euro-Argo achieved a significant breakthrough by deploying BGC-Argo floats equipped with optical, radiometric, and imaging sensors. This led to a marked increase in BioEco EOV and EBVs coverage to over 30% of all EVs, exactly as anticipated in its strategic plan, which emphasized extension beyond physical parameters. JERICO, finally, increased the number of autonomous vehicles, gliders, drifters, and smart observatories, enhancing its contributions to phytoplankton, primary productivity, and fish abundance in coastal and shelf areas. While its facilities remain concentrated in pilot sites, the reported actions were concretely translated into new observations. Overall, all four infrastructures have implemented the measures outlined in the project.

5. ANNEXES

Annex 1 – List of facilities measuring BioEco EOVs and EBVs in the Marine domain (WP5) of the ITINERIS project.

#	Facility	Latitude [°N]	Longitude [°E]	Property
1	Piattaforma Oceanografica Acqua Alta	45.31425	12.50825	CNR-ISMAR
2	Meda S1-GB	44.73848	12.45263	CNR-ISMAR
3	Boa meteo-oceanografica E1	44.14325	12.57010	CNR-ISMAR
4	GRANSEA - shallow water station	37.56100	12.65483	CNR-IAS
5	Western Mediterranean regional facility (W1M3A)	43.83452	9.13163	CNR-IAS
6	Sacca di Goro	44.81195	12.33150	Univ.Ferrara
7	Valli di Comacchio	44.62058	12.23685	Univ.Ferrara
8	Laguna di Venezia	45.41306	12.29722	CNR-ISMAR
9	Senigallia-Susak (Meda TeleSenigallia)	43.70000	13.20000	CNR-IRBIM-Univ.Marche
10	Mar Piccolo di Taranto	40.48475	17.29961	CNR-IRSA
11	Golfo dell'Asinara	40.90597	8.32106	Univ.Sassari
12	Golfo di Olbia	40.92342	9.54428	Univ.Sassari
13	Laguna di Cabras	39.94381	8.48125	Univ.Sassari
14	Laguna di Santa Giusta	39.86744	8.59125	Univ.Sassari
15	Laguna di S'Ena Arrubia	39.82247	8.56617	Univ.Sassari
16	Promontorio di Portofino (MEDA2)	44.29662	9.22942	Univ.Genova

17	Mar Ligure Orientale	44.05000	9.84500	ENEA
18	MIRAMARE-MAMBO1	45.69867	13.70650	OGS
19	Boa Meteo Oceanografica MAMBO2	45.60267	13.15067	OGS
20	Boa Meteo Oceanografica MAMBO3	45.64400	13.51133	OGS
21	BGC-Argo Float (10)	float	float	CNR-ISMAR
22	BGC-SVP drifters	drifter	drifter	CNR-ISMAR
23	SeaExplorer Glider (3)	glider	glider	CNR-ISMAR
24	Float UVP6-LP	float	float	OGS
25	OGS Glider	glider	glider	OGS
26	South Adriatic regional facility (E2-M3A)	41.533667	18.04650	OGS
27	South Adriatic Mooring FF	41.48367	17.02296	CNR-ISP
28	South Adriatic Mooring BB	41.20479	17.11605	CNR-ISP