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JERICO-S3 DELIVERABLE

Joint European Research Infrastructure for Coastal Observatories
Science, Services, Sustainability

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1. EXECUTIVE SUMMARY

The European marine projects and landmarks jointly present a significant asset to support the observation, monitoring, and study of marine systems from the land to the open ocean. Together, with the marine RI projects, they can provide an integrated pan-European multidisciplinary platform, combining *in situ* and remote observations of physical, chemical, and biological parameters with experimental manipulation, to provide the basis for a holistic understanding of European marine systems and support European policies. Collaboration between environmental RIs is necessary to effectively support the progress towards implementing the European Ocean Observing System (EOOS) and efficiently using the available infrastructure, human and financial resources. JERICO, in collaboration with other environmental RIs, has taken steps to foster the collaboration, and to effectively support the progress towards implementation of the EOOS.

2. INTRODUCTION

With changing climate patterns, water ecosystems become more exposed to extreme hydrological events, leading to a need for an improved scientific understanding of all relevant processes to inform policy and to increase Europe's resilience to the impacts of climate change. Long time series are instrumental in understanding the coupling between the water cycle, the changing climate, environmental pollution, and ecosystems. It is of vital importance to ensure that such data series are continued, given past investments: the intrinsic added value of a time-series grows exponentially as time passes. In fact, numerous time-series allowed us to better assess the status of marine ecosystems and the impact of climate change and anthropic activities (McGowan 1990, Karl 2010, Koslow and Couture 2013, Cloern et al. 2016).

Environmental Research Infrastructures (RIs; Fig. 1) play an important role in improving the understanding of the Earth system by delivering observational data, providing access to observation and experimentation tools, and providing services to a broad range of users. Most of the current environmental RIs (including the marine RIs) were initially established separately from each other to serve a specific science community and often focus on limited aspects or phenomena of the Earth System. However, the Earth System's interlinked nature requires better organisation of the RI landscape and scientific communities to transcend the well-established boundaries of disciplines and domains and work towards a common holistic understanding of the environment as one system.

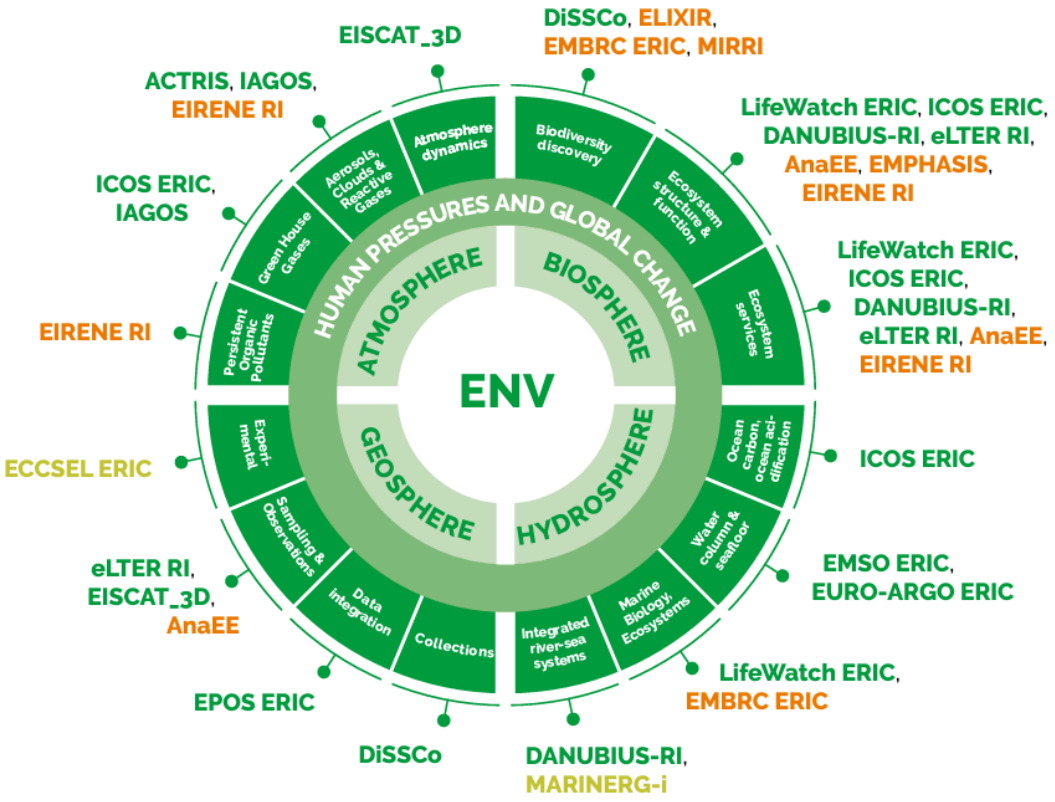

Figure 1. The Landscape of the Environment domain (ESFRI Roadmap 2021). The colour codes refer to different domains: **Energie (ENE)**, **Environment (ENV)**, **Health & Food (H&F)**.

To foster cooperation and coordination with existing European RIs at different regional, national and transnational levels, as well as other relevant communities (such as numerical modelling, Earth observation, decision-makers and industry) was the general objective of the JERICO-S3 WP2. This was to be done by integrating knowledge, approaches, methods and activities between JERICO and other Earth science communities and stakeholders. Collaborating with other environmental RIs is necessary to effectively support the progress towards implementing the European Ocean Observing System (EOOS) and efficiently using the available infrastructure, human and financial resources.

In the current deliverable, we describe the existing collaborations between European marine, river and terrestrial RIs, such as EMSO, EMBRC, ICOS, DANUBIUS, LIFEWATCH, GROOM, AQUACOSM, in order to foster interoperability and synergies to contribute to a comprehensive European RI service provision, and to implement the EOOS. Strategic alignments can also be achieved in the future through a set of case-specific activities carried out at regional and European levels (involvement in projects and relevant initiatives). These activities encompass sharing technologies, best practices to contribute to the interoperability and standardisation of data, field operations, equipment handling and maintenance, and calibration practices across the European RI landscape. Shared organisation of brokerage events with industry, stakeholders, policymakers and other events for the promotion of RIs are also planned. At the local/regional level, joint collaborations are already explored within the JERICO Pilot Supersites (PSSs).

3. MAIN REPORT

3.1. Marine Research Infrastructures landscape in Europe

Research Infrastructures (RIs) are large-scale facilities that provide resources and services for the scientific communities to conduct high-level research and foster innovation. There are currently three marine RIs as European Research Infrastructure Consortiums (ERICs)[1]:

1. Euro-Argo[2] - Europe's contribution to the Argo programme observing the oceans;
2. European multidisciplinary seafloor and water column observatory[3] (EMSO);
3. European Marine Biological Research Centre[4] (EMBRC).

Besides, there are also several ERICs with a marine component.

1. European carbon dioxide capture and storage laboratory[5] (ECCSEL);
2. WindScanner[6] - wind energy research network;
3. International centre for advanced studies on river-sea systems[7] (DANUBIUS-RI);
4. Integrated Carbon Observation System[8] (ICOS);
5. Svalbard Integrated Arctic Earth Observing System[9] (SIOS);
6. KM3NeT 2.0[10] - a network of deep-sea neutrino telescopes in the Mediterranean Sea with user ports for Earth and Sea sciences;
7. European Plate Observing System[11] (EPOS);
8. LifeWatch[12] - providing e-science research facilities to scientists investigating biodiversity and ecosystem functions and services.

In parallel, since 2010, the EU Framework Programmes for Research and Innovation (FPs) INFRAIA and INFRADEV calls have led to the creation of European marine RI projects such as JERICO RI[13], Eurofleets+[14], GROOM RI[15], and later EUMR2[16], MINKE[17] and EuroGO-SHIP[18]. The nation's involvement in several ERICs and marine RI projects, together with the evolution of national research infrastructure roadmaps has stimulated the reorganisation and consolidation of national efforts in some countries (e.g., Finland, Italy, France), leading to the creation of a variety of national networks involving national agencies, research centres and universities. The European marine RIs and national networks have become key players in the collection of ocean *in situ* data for research and operational

[1] https://research-and-innovation.ec.europa.eu/research-area/environment/oceans-and-seas/marine-research-infrastructures_en
[2] https://www.euro-argo.eu/
[3] https://emso.eu/
[4] https://www.embrc.eu/
[5] https://www.eccsel.org/
[6] https://www.windscanner.eu/
[7] https://www.danubius-ri.eu/
[8] https://www.icos-cp.eu/
[9] https://sios-svalbard.org/
[10] https://www.km3net.org/
[11] https://www.epos-eu.org/
[12] https://www.lifewatch.eu/
[13] https://www.jerico-ri.eu/
[14] https://www.eurofleets.eu/
[15] https://www.groom-ri.eu/
[16] https://www.eumarinerobots.eu/
[17] https://minke.eu/
[18] https://eurogo-ship.eu/

services and should become the backbone of the sustained European Ocean Observing System[19] (EOOS).

In the European marine RI landscape, RIs either exploit a single type of observation platform (e.g., fixed platforms for EMSO ERIC, profiling floats for EURO-ARGO ERIC, research vessels for Eurofleets+ and EuroGO-SHIP, autonomous vehicles for GROOM RI) or are thematic in focus, relying on a multi-platform approach (e.g., ICOS-OTC for assessing CO_2 emissions and JERICO for 'holistic appraisal of coastal marine system changes'). In addition, the MINKE marine RI project is transverse, building an innovative 'ocean data quality' framework based on accuracy and completeness to support the observation of Essential Ocean Variables (EOVs).

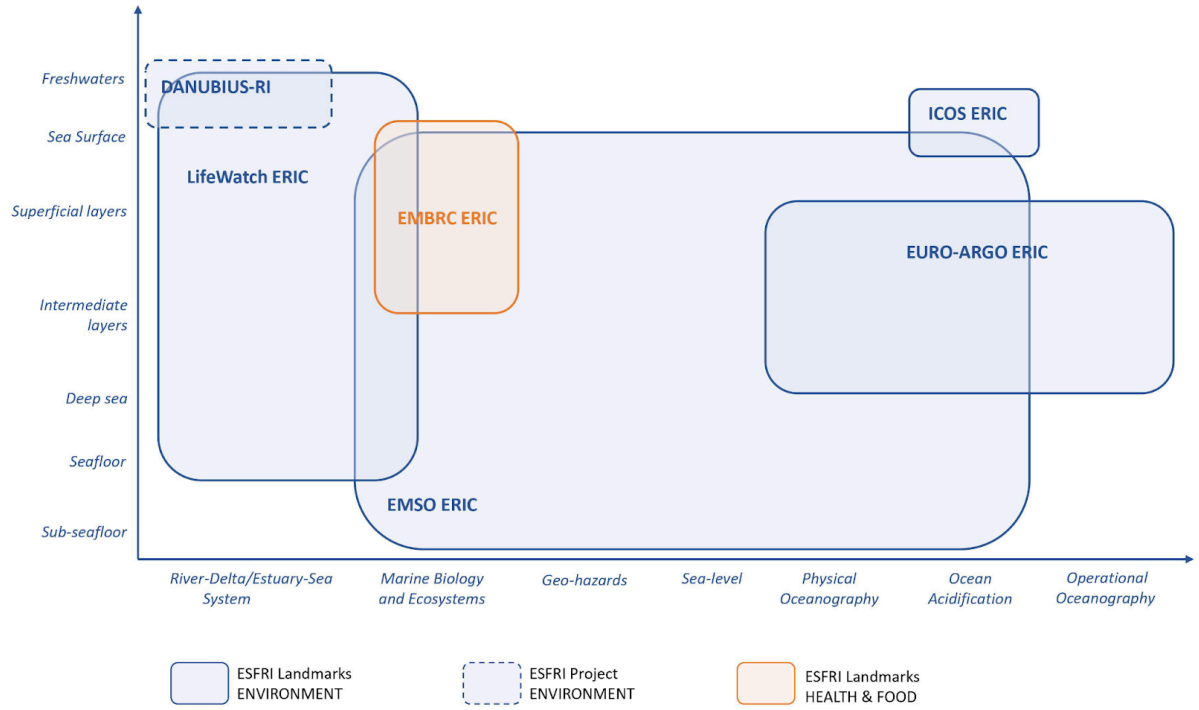

Figure 2. The different domains covered by the European marine RIs versus depth from the seafloor to sea surface and freshwater (Dañobeitia et al., 2023[20]).

The European marine ERICs jointly present a unique force to support the observation, monitoring, and study of marine systems from the land to the open ocean (Fig. 2). Together, with the marine RI projects, they can provide an integrated pan-European multidisciplinary platform, combining *in situ* and remote observations of physical, chemical, and biological parameters with experimental manipulation, to provide the basis for a holistic understanding of European marine systems and support European policies. Marine RIs promote the dissemination and updating of harmonised data standards, and other methods, ontologies and data and other resource catalogues following FAIR (Findable, Accessible, Interoperable, Reusable) principles, facilitating the exchange of data, as well as the development of integrated services. The data, products and services offered by the marine RIs are essential contributions to the European Open Science Cloud[21] (EOSC) initiative. European marine RIs also aim to structure research communities and implement guidelines and best practices laid

[19] https://www.eoos-ocean.eu/
[20] https://www.frontiersin.org/articles/10.3389/fmars.2023.1047251/full
[21] https://eosc-portal.eu/

out in international frameworks of the Intergovernmental Oceanographic Commission[22] (IOC), such as the Global Ocean Observing System[23] (GOOS), Genomics Standards Consortium[24] (GSC), and the European Ocean Biodiversity Information System[25] (EurOBIS), and seek to actively contribute to the United Nations Decade of Ocean Science[26].

As the coastal ocean is currently a high priority in different EU policies but also of the UN Decade for Sustainable Development, Europe needs dense enough, well-instrumented sites and regions to study, observe and monitor waters of the coastal shelf. A comprehensive analysis of the changes impacting coastal ecosystems requires an integrated basin approach to understand the impact of different drivers and to find measures for coastal preservation, management and planning. Long-term observations are needed to address transversal scientific and societal challenges acting at various spatio-temporal scales and to understand large-scale processes that can significantly impact coastal and littoral areas. This could only be achieved at the pan-European level with close collaboration between different actors. For the sustained development and efficient operation of ocean observing systems in Europe and globally, information and data sharing, and collaboration and coordination of actions are needed to avoid duplications and use available resources efficiently. JERICO, in collaboration with other environmental RIs, has taken steps to foster the collaboration (as is reported in deliverable D2.1), and to effectively support the progress towards implementation of the EOOS. Below are concise descriptions of JERICO and the marine RIs with the closest collaborations that have been established so far with JERICO.

3.1.1. JERICO

JERICO is an integrated pan-European multidisciplinary and multi-platform research infrastructure dedicated to a holistic appraisal of coastal marine system changes. The aim is to seamlessly bridge existing continental, atmospheric and open ocean RIs, thus filling a key gap in the European landscape, as well as reducing overlaps (Fig. 3), increasing efficiency, and enabling and fostering interoperability. JERICO aims to organise, harmonise, and integrate existing coastal observing activities and initiatives in order to address both pre-identified region-specific and pan-European scientific and socio-economic challenges.

The Vision of the JERICO is to be the pan-European integrated gateway to long-term scientific and harmonised observations and related services for coastal marine systems.

The JERICO mission is to enable a sound understanding of the responses of coastal marine systems to natural and anthropogenic stressors. To do so, JERICO adopts a systematic approach to monitor, observe, explore and analyse coastal marine systems in order to reach reliable information on their structuration and functioning in the context of global change. Multi-platform marine RIs are an effective and promising strategy for developing an integrated observation system to face the global challenges that affect the Ocean, including the coastal areas. JERICO encompasses the whole range of environmental sciences, technologies and data sciences. It achieves global, regional and local observations through the implementation and harmonisation of a set of complementary platforms and multidisciplinary observation

[22] https://www.ioc.unesco.org/en
[23] https://www.goosocean.org/
[24] https://www.gensc.org//
[25] https://www.eurobis.org/
[26] https://oceandecade.org/

systems. JERICO enables open access to state-of-the-art and innovative facilities, resources, FAIR data and fit-for-purpose services, fostering international science collaboration.

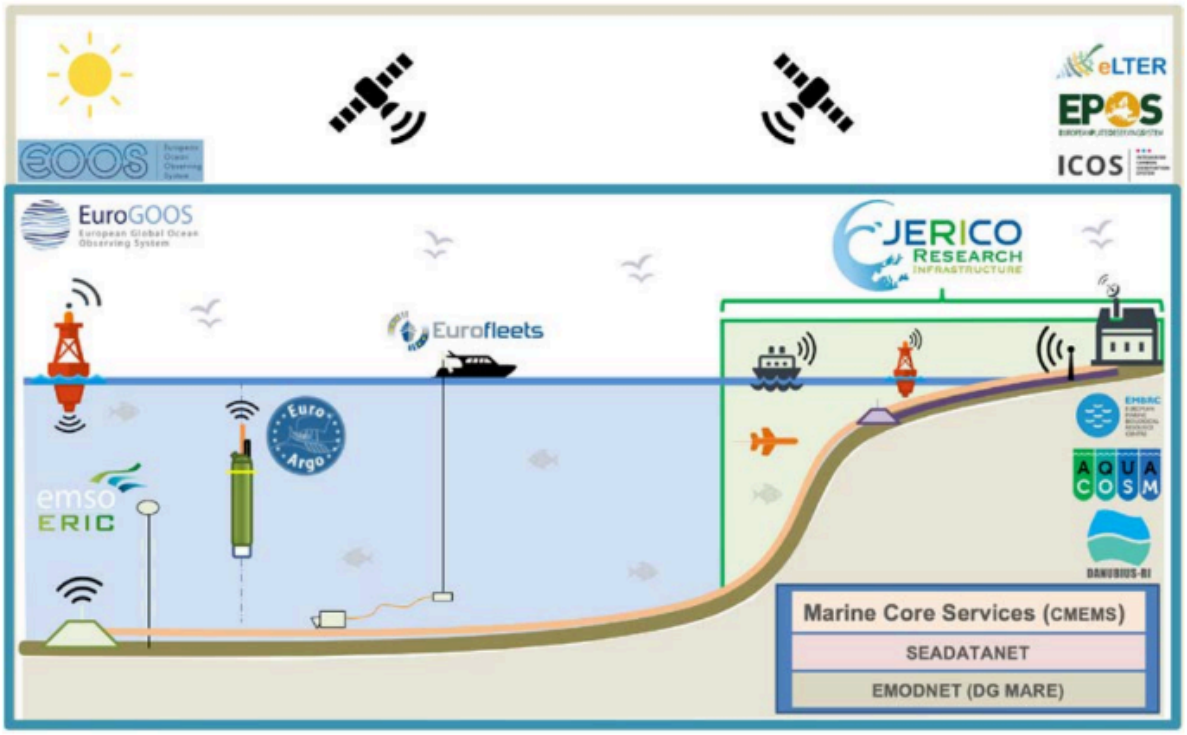

Figure 3. Schematic illustrates how JERICO is a key component of the European marine research landscape.

The components for the JERICO consist of the central hub, the coastal observatory network, i.e. systems which consist of multidisciplinary observational platforms and stations that are available for scientific teams and industry partners to lead research and experiments, as well as the JERICO-CORE. JERICO-CORE is envisioned as the unified central hub of JERICO to discover, access, manage and interact with JERICO resources, including services, datasets, software, best practices, manuals, publications, organisations, projects, observatories, equipment, data servers, e-libraries, support, training, and similar assets as well as Technical and Thematic Expert Centers.

The current JERICO infrastructure is highly complex, with a large variation in types of observing platforms (with varying technological requirements), the extent of national observing capabilities and the national organisation of JERICO infrastructure (number/types of national partners). The most widespread current national JERICO RI infrastructures included are fixed platforms (platforms or buoys), high-frequency radars, gliders, Ferrybox systems, tide gauge networks, and research vessels. Other platforms involve drifters (surface/profile), profilers (cable/buoy-based), various autonomous observation systems (ROV, AUV, drones), wave buoy network, weather buoy network, benthic landers, in addition to calibration and test facilities.

JERICO is characterised by multidisciplinary teams, which implies the availability of different resources and interlinkages among different capacities, with the ability to approach research questions from different perspectives. While consisting of the national RIs, finding a balance in addressing the pan-European, regional and national societal needs might often be

challenging. The identification of common scientific questions resulted in the elaboration of a common general scientific framework structured in Key Scientific Challenges (KSCs), Specific Scientific Challenges (SSCs), and Research Axes (RAs) (see D1.3 of JERICO DS).

3.1.2. DANUBIUS RI

The ESFRI Project International Centre for Advanced Studies on River-Sea Systems (DANUBIUS RI) supports interdisciplinary research in river-sea systems (Figure 1). It is the only physical pan-European RI devoted to supporting research on transitional zones between coastal marine and freshwater areas. The development of DANUBIUS RI as a distributed environmental RI builds on existing expertise to support interdisciplinary research on River-Sea Systems, covering whole river basins and the coastal waters that they influence. Addressing the conflicts between sustainable development, environmental change and environmental conservation in River-Sea Systems, DANUBIUS RI's mission is to facilitate and contribute excellent science on the continuum from river source to sea, offer state-of-the-art research infrastructure, and to provide the integrated knowledge required to sustainably manage and protect River-Sea Systems. DANUBIUS RI's goal is to overcome the fragmentation of science, knowledge, data and management approaches in rivers and seas by integrating spatial, temporal, disciplinary and sectoral thinking. It will provide science-based solutions to societal risks arising from global and climate change as well as coincident extreme events. Likewise, it will offer a source-to-sea perspective to resolve the problems of adverse human impacts on water and sediment quality and quantity, hydromorphology, biodiversity and ecosystem functioning.

3.1.3. EMSO ERIC

European Multidisciplinary Seafloor and water column Observatory (EMSO ERIC) aims to explore the oceans, better understand phenomena, and explain the critical role of these phenomena in the broader Earth systems. It consists of a system of regional facilities placed at key sites around Europe, from the North East to the Atlantic, through the Mediterranean, to the Black Sea. EMSO Observatories are equipped with multiple sensors, placed along the water column and on the seafloor, constantly measuring different biogeochemical and physical parameters that address natural hazards, climate change and marine ecosystems. EMSO offers data and services to a large and diverse group of users, from scientists and industries to institutions and policymakers.

3.1.4. ICOS ERIC

Integrated Carbon Observation System (ICOS ERIC) is a distributed RI that facilitates carbon cycle research and provides necessary information on greenhouse gases (GHGs). ICOS conducts long-term observations in the atmosphere, ecosystems, and oceans. It generates high-precision and standardised data to monitor the present state and extrapolate the future behaviour of the global carbon cycle and GHG fluxes to predict environmental changes and mitigate their impacts. ICOS has a cross-domain approach to enable understanding of the carbon cycle and to provide necessary information on the land-ecosystem exchange of CO_2, CH_4 and N_2O with the atmosphere. ICOS helps to elaborate an account of the Earth system and its response to climate change and other environmental challenges and advances the fulfilment of the United Nations' Sustainable Development Goals and the European Union's Societal Challenges, especially those concerning climate change. ICOS Ocean Thematic Centre (OTC) currently coordinates 22 ocean stations in seven countries, monitoring carbon uptake and fluxes in the North Atlantic and the Nordic, Baltic and Mediterranean Seas. The

measurement methods include sampling from research vessels, moorings, buoys and commercial vessels (so-called Ships of Opportunity - SOOP). They all have been equipped with state-of-the-art carbonate system sensors.

3.1.5. EMBRC ERIC

The European Marine Biological Resource Centre (EMBRC) is Europe's 'research infrastructure' for marine biological resources providing access to marine resources, as well as cutting-edge services and facilities that allow researchers, from both academia and industry, to study the ocean and develop innovative solutions to tackle societal issues. EMBRC gathers more than 70 marine stations and institutes in 9 countries across Europe. By offering a wealth of marine biological laboratories and stations dedicated to the investigation of marine organisms and ecosystems and making their services and resources available to European and international research/innovation communities, EMBRC promotes marine solutions to address societal issues (e.g. global warming, food shortages) and develop novel products (pharmaceuticals, cosmetics, nutraceuticals).

3.1.6. LifeWatch ERIC

The ESFRI Landmark e-Infrastructure for Biodiversity and Ecosystem Research (LifeWatch ERIC) has a cross-domain approach and a focus on the Grand Challenges of preserving biological diversity and protecting ecosystem health. LifeWatch ERIC is an e-Infrastructure that enables knowledge-based solutions to environmental managers by providing access to a multitude of sets of data, services and tools about the role of biodiversity in ecosystem functioning and conservation. LifeWatch ERIC is committed to providing Virtual Research Environments (VREs), virtual labs (vLabs) and Big Data paradigm-based tools to conduct cutting-edge research, but also to boosting technological innovation, continuously improving the performance of VREs, opening up new fields for socio-economic development, establishing synergies with various national and regional stakeholders, and promoting democracy and creativity in science.

3.1.7. e-LTER RI

The Integrated European Long-Term Ecosystem, critical zone and socio-ecological system Research Infrastructure (eLTER RI) is a distributed RI to facilitate high-impact research and catalyse new insights about the compounded impacts of climate change, biodiversity loss, soil degradation, pollution, and unsustainable resource use on a range of European socio-ecological systems. eLTER RI aspires to develop the scientific capacity to improve the understanding of terrestrial, freshwater, and transitional water ecosystems. Combined with a socio-ecological approach to studying integrated human-nature systems and commitment to integrating stakeholder knowledge, it provides a solid foundation to inform policy-maker systems to find evidence-based sustainable solutions for addressing current and emerging challenges. eLTER RI provides researchers with access to over 500 sites across Europe and biogeographical regions, establishing and offering harmonised and standardised data, services and training useful to citizens and experts in their joint efforts to find sustainable solutions to the Grand Societal Challenges.

3.1.8. GROOM RI

The Gliders for Research, Ocean Observation and Management (GROOM) RI is a distributed European RI harnessing the advantages of Marine Autonomous Systems (MAS). MAS, among which are the underwater gliders, are highly capable platforms that can collect ocean surface

and water column measurements at a wide range of spatio-temporal scales and, in recent years, they have become ubiquitous for marine research, Ocean Observing Systems (OOSs) and for industrial applications. GROOM RI integrates national infrastructures for MAS and promotes a collaborative approach of collecting and sharing oceanographic data, and of supporting MAS development and innovation. It provides access to platforms and services to the broadest range of scientific and industrial users, as well as to other marine RIs in the offshore and coastal domains. By maintaining a unique centralised provision of cyber-infrastructure, data and knowledge, it optimises the use of MAS in Europe to study climate and marine environments, and also supports operational services and the blue economy.

3.1.9. AQUACOSM

EU network of mesocosm facilities for research on marine and freshwater ecosystems open for global collaboration (AQUACOSM)[27] aims to strengthen the EU network of mesocosm facilities and promote joint research initiatives, capacity building and standardisation with extensive Transnational Access to more than 60 different sites or installations at 28 selected leading and highly complementary European mesocosm facilities. AQUACOSM encompasses a large geographic range from the Arctic to the Mediterranean with unique infrastructures in catchments from mountains to lowlands; rivers, ponds, lakes, estuaries and the sea.

3.2. Synergies/collaborative actions

3.2.1. Technological, scientific and societal synergies

In order to support the European Commission in the implementation of current and future policies, marine RIs of the Environmental Research Infrastructures (ENVRI)[28] community sent an official statement to members of the Mission Board for Healthy Oceans, Seas, Coastal and Inland Waters in June 2020, emphasising the unique opportunity to support the observation, monitoring, and study of marine systems from the land to the open ocean by combining *in situ* and remote observations of physical, chemical, and biological parameters with experimental manipulation for a holistic understanding of European marine systems (JERICO ESFRI Application, 2020). Complementarity and added value in the observation and services would be created by better coordinating the RIs efforts in the marine domain.

The range of services offered by different RIs will have to evolve with the need, but also will need to be tailored and will have to increase scientific knowledge and understanding not just in the scientific community but across society, policy and industry. RIs will have to work synergistically if they are to meet their end-user needs and enable the sustainable management of environmental resources. The global and European strategic agendas indicate the need to increase protected areas and restore degraded ecosystems, hence calling for intense research on ecosystem services, which are only partially covered by the existing RIs and on limited scales. These needs extend, for example, to monitoring biodiversity and ecosystem changes, supporting developing and implementing Essential Biodiversity Variables (EBVs)[29] as ecological data products underpinned on data and metadata standards, data quality, data preservation and open data policies. Another aspect that needs further attention

[27] https://www.aquacosm.eu/
[28] https://envri.eu/about/
[29] https://geobon.org/ebvs/what-are-ebvs/

is environmental contamination and its interplay with climate change, hazards and risks associated with toxic mixtures. Influenced by the biodiversity loss, the taxonomic information gap needs to be overcome, in order to discover and describe the biodiversity and its temporal and spatial changes. Rapid advances in genetic sequencing and information and communication technology, including big data analysis of genetic sequences, and mass digitisation, can be integrated to provide more automated systems concerning genomics, species and ecosystem analysis. Also, focusing on invasive or harmful species requires RIs to adjust their data lifecycles in order to enable rapid alert systems and better monitoring and modelling. Observations and experiments need further scientific integration.

Following an integrative approach is also essential for developing trusted products, derived from observations when stakeholder expectations are linked to biological/biogeochemical processes since those are most often cued through physical-chemical-biological interactions. As we intend to move to more complex multi-disciplinary systems and to integration across geospatially diverse observing systems, interoperability across data and information systems will be increasingly important. Such interoperability is facilitated through the use of common methods and approaches. JERICO has developed a best practices maturity scale (JERICO S3 D5.2), which identifies the key attributes of mature methods that will support the adoption of such methods for operational observing systems. These can also stimulate and facilitate technology developments so new technologies can be introduced into the observing, data and information systems.

3.2.2. JERICO products towards collaboration

3.2.2.1. Coastal EMSO Generic Instrument Module

JERICO RI in the framework of the JERICO projects has developed several products which can promote collaboration and synergies with other RIs. A good example is the JERICO cEGIM, a standardised coastal observing platform based on the EMSO Generic Instrument Module (EMSO-EGIM), (Lanteri et al., 2022). The central feature of coastal EGIM (cEGIM) is a standardised approach to measuring a set of significant oceanographic variables by using consistent sensor and hardware specifications and deployment concepts with the same setting for each sensor, the same qualification and calibration methods and the same data format. This development comes as a response to the significant technological evolution of ocean observatories around the world which often creates issues related to compatibility and interoperability of the acquired data. Thus, cEGIM is a generic long-term observation module able to measure a set of common coastal EOVs on the one hand and to integrate different sensor packages adapted to particular fields of study (e.g. plankton variability, BGC eutrophication) on the other (Delory et al., 2021). It is based on the Communication and Storage Front-end (COSTOF2), a platform developed by Ifremer and able to accommodate twelve sensors by providing them controlled power, a common time base, large data storage capacity, communication channels with local or remote users as well as an active anti-biofouling protection. The platform is able to work in a very low power environment with an event triggering capability – increase frequency of measurements during phenomena. cEGIM can be exchanged between different RIs, as, for example, DANUBIUS provides standardised measurements, aiding interoperability and harmonisation.

3.2.2.2. JERICO CORE

The JERICO-CORE e-infrastructure is crafted to cater to the needs of current virtual users while also accommodating future adaptations. It aims to enhance the FAIRness (Findability, Accessibility, Interoperability, and Reusability) of data and ensure clear identification of assets, facilitating links between related resources from various origins through established use of unique identifiers for data and platforms. The interrelated nature of the information within the JERICO-CORE inventory streamlines the process of discovering and accessing resources at their original sources. This understanding of the connections among information, data, metadata, documentation, tools, and workflows enhances asset traceability and improves data FAIRness.

The requirements for JERICO's e-infrastructure were gathered from three main sources: the JERICO-S3 and JERICO-DS projects, and consultations with other Research Infrastructures and institutions. The JERICO community, as documented in JERICO-DS MS13 "e-JERICO requirements compiled," has consistently sought a dependable, knowledge-based platform to unify data, analyses, processes, and communicate the outcomes of coastal observations from diverse technical infrastructures.

Additionally, the role of JERICO within the ENVRI landscape is crucial in defining its interface with other key partners (e.g. EMODnet, Blue-Cloud, CMEMS) and determining the technical requirements for interoperability with existing infrastructures. A recurring requirement is the need to adapt to the existing infrastructure landscape and methodologies, rather than creating a competing system. JERICO's value as a pan-European initiative lies in its ability to provide high-quality integrated data and related services in a harmonised manner from a single-entry point.

To achieve this, JERICO-CORE has signed a Memorandum of Understanding (MoU) with the European Plate Observing System (EPOS) to utilise their code for visualising catalogue resources. Another MoU with Blue-Cloud allows the use of their Virtual Lab to provide Virtual Research Environment (VRE) capabilities to JERICO-CORE. The concept also includes Application Programming Interface (API) services to access catalogue information and a Virtual Access Metrics System (VAMS) for metrics.

3.3.2. Bilateral collaborations and agreements

The environmental RIs actively look for synergies and collaboration opportunities with others, often with the ones from the other domains. The marine RIs have been engaging with each other for years, and new funding opportunities, specially created to facilitate integration and co-development, are relevant now and in the future. The cooperation has been set up, and opportunities have been created not only between and to the ESFRI Landmarks and Projects but also with other relevant projects and initiatives. For example, data from the DANUBIUS RI supersites can be made available to the LifeWatch ERIC virtual laboratories. In return, LifeWatch ERIC can provide knowledge on how to empower the range of e-services to be provided within DANUBIUS RI. DANUBIUS RI is seen as a connection between EMSO (marine observatories) and the upstream part of the water continuum, up towards the freshwater basins. ICOS ERIC supports DANUBIUS RI via atmospheric research towers in coastal wetland areas. EMBRC ERIC is of major importance to DANUBIUS RI in understanding the genetic biodiversity from freshwater to marine organisms. JERICO is

seamlessly bridging the existing continental, atmospheric, and open ocean RIs landscape. AQUACOSM is actively pursuing RI-RI collaboration with European environmental RIs (e-LTER, ICOS, DANUBIUS, JERICO) as the multidisciplinary joint research, combining observational data and modelling approaches with targeted mesocosm experiments. The collaborations between RIs also involve shared capacity building via symposia, expert summits, and open workshops, aiming to co-design future aquatic research actions and their RI demands.

JERICO-S3 WP2 (Linking scales and communities) fostered the cooperation and coordination with existing marine RIs at different regional, national and transnational levels. The internal workshop "JERICO in RIs network" was organised as a session of the JERICO-WEEK (14-18 March 2022, online) to redefine the best way to proceed in framing JERICO within the European RI landscape. The discussions aimed to find ways that JERICO could do together with other RIs to increase the capacity. The signing of Memoranda of Understanding (MoU) was found to be one possible solution. The following internal workshop, "Other RIs: Update of Effort, Call to Action", was organised as a session of the JERICO-DAYS (28-30 June 2022, Lisbon) to already show practical examples of the steps done at the "Coordination level" toward formal engagements.

3.3.2.1. DANUBIUS RI

The signing of the Memorandum of Collaboration (MoC) with DANUBIUS RI was discussed to collaborate at the interface of mutual research areas, namely in the transition zone from riverine systems to estuaries and the coastal zone. The key common topics were the promotion of interoperability of data and services across their respective disciplines fostering cross-disciplinary access to and use of scientific data, and collaborating on the implementation of shared use of facilities where feasible and of mutual benefit. The MoC has not been signed but the close collaboration has been followed over the years in several JERICO PSSs and also in the frame of recently funded projects (see below).

Two JERICO PSSs - North-West Mediterranean (NWMED) and North Sea (NSea) PSS focused on improving river-coastal system best practices, data collection, database gathering/standardisation/harmonisation, calculation of riverine substances input to coastal waters and exploration of new/complementary methods. Since 2022, a research station with ferrybox and carbonate system sensors has been operating in the Elbe River in collaboration with DANUBIUS-RI.

In the NWMED PSS and CHANNEL/NSEA PSS, links to DANUBIUS RI for impacts of freshwater and particle discharge from major rivers are established. The aim is to share observations to study coastal dynamics and improve the linking between JERICO PSSs and DANUBIUS RI sites.

3.3.2.2. EMBRC ERIC

Simultaneous and consistent information on all components of the system (physics, biogeochemistry, biology) is needed to understand ecosystem functioning in the coastal areas. Whereas EMBRC is developing a strategy for fixed point 'omics-based observation around its long-term study sites, JERICO, with a network of stationary observations, gliders, and autonomous vehicles, has the potential to add significantly to biodiversity observation by filling in the gaps along Europe's coastline. Therefore, a collaboration with EMBRC ERIC was

regarded as relevant. The signing of the MoC was discussed with EMBRC ERIC to cooperate for the coordination of biological observations of the coastal seas of EU Member States. No bilateral agreement has been signed so far but the cooperation is to be facilitated via future projects to improve and increase biological observation of the ocean, share experiences and best practices related to biological observations, and avoid duplication. In order to ensure complementarity between fixed point observatories and temporary observation points, JERICO and EMBRC must explore complementary methodologies and metadata standards to ensure the comparability of data between their sites. Deployment of similar sampling technologies should also be explored and calibration exercises carried out on a regular basis between the observatories in both RIs.

3.3.2.3. EMSO ERIC

The EMSO ERIC consortium comprises standalone and real-time fixed platforms mainly located in the open ocean to continuously observe different biogeochemical and physical variables that address natural hazards, climate change and marine ecosystems using advanced sensor arrays. In regional seas, the connection with the JERICO infrastructure is essential to observe the land-sea continuum that is relevant to scientific and societal needs. Common integration of platforms is needed to observe the different spatial and temporal variabilities. The MoC to facilitate cooperation between the EMSO ERIC and the JERICO in relation to ocean observation with emphasis on fixed platforms in Europe has been discussed. The aim was to define and formalise the roles and relationship between the EMSO ERIC and the JERICO to clarify their respective roles in contributing to developing the EOOS and to provide the basis to increase collaboration between both RIs in order to reduce the complexity in the EOOS landscape. The MoC was not signed, but the close interaction between the two RIs has already been achieved on several occasions. For example, the integration actions connected with the UPC OBSEA[30] observatory as the NWMED PSS node and EMSO ERIC took place, offering support during the EMSO physical access project TRIPLE-VTESTS at the NWMED observatory OBSEA. Also, the integration of observation platforms between EMSO ERIC and JERICO by adapting and test-proofing the EMSO Generic Instrument Module (EGIM) to coastal applications. Several integrating activities are planned in different recently financed projects (see below).

3.3.2.4. GROOM RI

GROOM and JERICO, two EU-funded projects, aiming towards ESFRI Landscape status, have expressed their mutual desire to cooperate to promote interoperability of data and services across their respective disciplines of Marine Autonomous Systems (MAS) and coastal ocean science, fostering cross-disciplinary access to and use of scientific data, and collaborating on the implementation of core services and e-infrastructures for ensuring access to users and stakeholders. Both RIs, with a long and well-established reputation in ocean observation using MASs, consider international collaboration important to improve strategic research areas to achieve scientific excellence and strengthen their research capacity in the area of related ocean observations. There is a strong will to sign the MoC to facilitate cooperation between the GROOM and the JERICO in relation to the coordination of glider activity in Europe and to define and formalise the roles and relationship between the GROOM and the JERICO. This will help to provide clarity on their respective roles in contributing to the

[30] https://emso.eu/portfolio-items/obsea/

development of the EOOS and will also provide the basis to increase collaboration between both RIs and reduce the complexity in the EOOS landscape. In addition, it will be a way for further discussion in relation to the ESFRI roadmap and interaction with the EuroGOOS Glider Task Team.

3.3.2.5. AQUACOSM RI

An obvious area for cooperation with AQUACOSM was identified as the Transnational Access (TA). JERICO was invited to attend the AQUACOSM-plus (AQ+) kick-off meeting in April 2020 to discuss and explore the possibility of organising joint TA calls between JERICO-S3 and AQ+. At the local-regional level, the areas to carry out specific activities were identified as the Gulf of Finland (GoF), the North Western Mediterranean (NW-MED) and the Cretan Sea (CS) and joint experiments were developed (see JERICO-S3 D4.4). As a joint approach for GoF Pilot Supersite (PSS), NW-MED PSS and CRETAN PSS, connecting experimental work (mesocosms studies jointly with AQUACOSM) and coastal observing systems was done to understand better the impacts of global warming and extreme coastal events on phytoplankton communities.

Three TA projects were funded (JERICO S3 WP8) in the GoF PSS, providing access to the AQUACOSM mesocosm experiment. The main objectives of funded projects were:

- to study the Baltic Sea plankton community's metabolic and structural responses to extreme events, such as heatwaves;
- to transfer knowledge and harmonisation of competence between European RIs, by collaboratively further developing best practices and technology solutions, especially for plankton imaging;
- to compare data obtained using different measuring systems and devices;
- to compare the responses of the Baltic Sea communities to heatwave with the similar experiment setup in the Mediterranean region.

In NW-MED PSS in 2021, a synergy between the JERICO-S3 observing community and the AQUACOSM-plus mesocosm experimenting community was established via AQUACOSM-plus TA funds to study the effect of extreme events on phytoplankton by monitoring alkalinity and pH.

In CRETAN PSS, similar experiments in collaboration with the AQUACOSM-plus were carried out:

- to study the effect of episodic introduction of airborne microbes into the marine ecosystem;
- to study extreme event effects on phytoplankton with new sampling strategies (i.e. methods, sensors);
- to compare several phytoplankton sensors and lab analysis methods, for biomass and PP, under oligotrophic conditions.

For the JERICO-S3 community, the main benefit was using the mesocosms to establish new sampling strategies and best practices, focusing on making these transferable to existing *in situ* platforms of the CRETAN PSS and Eastern Mediterranean in general.

Besides the collaborations listed above, all JERICO PSSs have links to ICOS ERIC, in many cases in making observations together but also related to developing and sharing databases,

managing dataflows and developing and facilitating common practices. Additional links to EURO-ARGO ERIC, EUROFLEETS+ and LifeWatch ERIC are also visible in one or several PSSs (Table 13 in JERICO S3 D4.1, JERICO S3 D4.4).

3.3.3. Common workshops held until 2024

3.3.3.1. Cooperation Framework between Marine Research Infrastructures

A workshop "Cooperation Framework between Marine Research Infrastructures" was organised as a side event to the 9th EuroGOOS International Conference on May 5th 2021. Representatives from 11 marine RIs (EURO-ARGO ERIC, EMSO ERIC, LifeWatch ERIC, ICOS ERIC, Danubius RI, JERICO, EMBRC ERIC, EuroFleets, GROOM, EU MarineRobots and SeaDataNet) gathered to discuss future strategy under a co-designed collaborative plan within the landscape of the UN Decade of Ocean Science and the EOOS, with the aim to address and plan the next steps for the following topics:

- sharing of knowledge and expertise;
- strengthening cooperation on both field activities and new technologies;
- creating robust interactive data interfaces;
- promoting joint activities on marine research and services;
- raising public awareness on marine environmental issues.

The main outcome was to agree and prioritise the list of suggested joint collaborative actions. The collaboration actions identified during the meeting to be prioritised included:

- Development of a European OceanOPS system;
- Development of integrated monitoring strategies;
- Creation of joint education and training programmes;
- Identification of common metrology standards and data inter-comparison procedures;
- Collaboration on technology development and sensor integration;
- Publication of a white paper on the role and value of marine RIs;
- Transnational / Trans-RI research projects;
- Joint participation in funding proposals;
- Identification of project deliverables for adoption across marine RIs;
- Implementation of FAIR data principles;
- Creation of common communications message(s).

Over the last three years, the advancement has been in all identified collaboration actions, and JERICO has contributed to all priority areas.

3.3.4. Participation in Initiatives

3.3.4.1.EOOS Operations Committee

The EOOS Operations Committee is part of the EOOS governance representing the ocean observing implementers at national, regional and pan-European levels to help with the long-term sustainability of the ocean observing efforts in Europe and to implement EOOS progressively. It aims to provide information about relevant opportunities for EOOS, support the flow of information on ocean observing activities across scales, identify system requirements to meet user needs for sustainable ocean observing, support and enable the EOOS implementation plan, provide advice to the EOOS Steering Group about changes in the

ocean observing landscape and identify actions for EOOS to further its goals and objectives, advocate for coordinated and integrated sustained ocean observing system, contribute to the mapping of infrastructure, technology and human capacity, and identify shared priorities through the development of a work plan. All European MRIs are members of the EOOS Operation Committee and the Committee is currently chaired by the JERICO coordinator. JERICO plays a crucial role within the EOOS framework by integrating and coordinating European coastal observatories, promoting best practices, and enhancing the quality and interoperability of oceanographic data. JERICO's extensive network and expertise in coastal observations contribute significantly to the committee's objectives of enhancing infrastructure, technology, and human capacity. Through JERICO's leadership, the committee is well-positioned to address emerging challenges, foster innovation, federate RIs and initiatives, and ensure that ocean observing systems effectively meet the diverse needs of stakeholders at various scales.

3.3.4.2. BEERi

The European RIs of the environmental field have long been collaborating in the ENVRI cluster. The support provided by the FP7 and Horizon 2020 research projects ENVRI (2011–2014), ENVRIPLUS (2015–2019) and ENVRI FAIR (2019–2022) has contributed to improving the cooperation between organisations and people, to achieve significant results of common interest, and to increase the visibility of all RIs, in Europe and globally. The ENVRI community is overseen and strategically led by the Board of European Environmental Research Infrastructures (BEERi)[31], set up in 2015. The BEERi helps to share perspectives across the different domains, adopt common strategies for engaging with selected activities and opportunities, and act as a unified voice for European environmental RIs. BEERi is composed of the directors or coordinators of the environmental RIs in Europe and meets regularly to work on common strategies, positions, policies and participation.

Many RIs have signed the Memorandum of Understanding (MoU) for the establishment of the ENVRI Community to enable cooperation and to provide and advocate a common vision of the European RIs in the field of environmental sciences. The Parties to the MoU engage in undertaking joint activities towards the following objectives:

- supporting each other by sharing experiences and good practices in an open spirit;
- elaborating and promoting a common strategic vision;
- achieving a common representation of the ENVRI Community towards various stakeholders;
- increasing the communication and the visibility of environmental RIs, their activities, their role and their needs, in Europe and globally;
- providing training and building capacity of the RI staff;
- engaging in ENVRI-related projects and maintaining the results obtained in previous projects.

JERICO, being part of the ENVRI community and represented at the BEERi (not yet signed the MoU), has benefitted from collaborations and co-design over the years in its specific implementation needs (e.g., via learning from other RIs and sharing knowledge on lessons learned). Involvement in BEERi has provided greater visibility to JERICO developments and has given a stronger voice in communicating the opportunities to a broader stakeholder group

[31] https://envri.eu/beeri/

and needs to the European Commission. It has also facilitated engagement in many collaborative projects.

3.3.5. Common Projects to facilitate the RI integration and co-development

3.3.5.1. AMRIT

The European Marine Research Infrastructures (MRIs) and national networks have become key players in ocean *in situ* data collection for research and operational services. The core MRIs as EMSO ERIC, EURO-ARGO ERIC and ICOS ERIC, and EuroFleets+, EuroGOSHIP, GROOM RI, JERICO and MINKE as INFRA projects, are the main providers of *in situ* ocean data for the EOOS and Copernicus. These RIs, being aware that the lack of effective cross-coordination prevents them from fully supporting frontier research, while the lack of integration makes it difficult to reach a critical mass for EOOS and results in significant cost duplication, decided to join forces in designing and implementing an EOOS Technical Support Center (EOOS TSC) for:

- a fully integrated information service across the data value chain from early planning stages to final delivery to users;
- a cross-platform fully standardised data acquisition methodology for Essential Ocean Variables;
- a collaborative federal structure to operate these services, relying on the MRIs and their members.

The EOOS TSC will be the cornerstone in establishing and maintaining the EOOS, upon which European ocean observing can be strengthened in the coming decades. AMRIT will provide a catalyst for the development and consolidation of MRIs throughout Europe, providing a benchmark for operational coordination and collaboration.

3.3.5.2. GEORGE

Next-generation multiplatform Ocean observing technologies for research infrastructures (GEORGE[32]) will advance the global technological competitiveness of European ocean observing RIs (EMSO, ICOS, Euro-Argo) through the development and demonstration of a state-of-the-art biogeochemical, multi-platform observing system for characterisation of the ocean carbon system. GEORGE aims to advance the technology readiness level of novel sensors enabling for the first time systematic autonomous, *in situ* seawater CO_2 system characterisation, and CO_2 fluxes on moving and fixed platforms. These sensors will be integrated into state-of-the-art platforms augmented with the latest in autonomous technology, enabling new observing capabilities. Technologies, methods and Standard Operating Procedures (SOPs) for carbon observing are aimed to be harmonised across a framework for multi-platform, cross-ERIC ocean observing, from sensor to data repositories. GEORGE will build capacity in ERICs through the provision of training in the use of new technologies and SOPs on data handling and reporting to staff and member organisations. Technology will be co-developed between industry and ERICs, ensuring a direct route to market and potential for scalability.

[32] https://george-project.eu/

3.3.5.3. LandSeaLot

In the recently funded Horizon Europe project LandSeaLot, the overall aim is to strengthen observational capabilities in the land-sea interface dynamic zone through integrated *in situ* measurements, satellite observation, and modelling. JERICO, DANUBIUS RI, and Earth Observation (EO) communities joined forces, improving the observing capacities along the land-to-sea interface. The project includes strategically located Integration Labs piloting improved monitoring techniques and sensors in the Black Sea, Aegean Sea, Mediterranean, Atlantic, North Sea and Baltic Sea. It will provide open information (FAIR) and demonstrators of data-driven management in the land-sea interface, focusing on key environmental challenges, including eutrophication, plastic pollution, biodiversity conservation, and climate impacts.

Through this collaboration, the JERICO RI community will have the opportunity to connect with the two related communities, those of DANUBIUS RI and ICOS ERIC in line with the land-sea continuum concept. Inconsistencies in the current data will be dealt with and methods promoting data integration will be developed. Under this RI partnership, observation gaps will be analysed while specific efforts will be devoted to the analysis of the different observation methods and protocols used in freshwater or marine waters and between observation communities. Considering that the project is strongly targeting stakeholders, the JERICO community will have the opportunity to connect with new groups and categories and most importantly to widen the current suite of products and services offered. Furthermore, the collaboration with the other two RIs will allow the development of synergistic products and services, responding to user requirements that each individual RI cannot meet.

3.3.5.4. BlueCloud

Blue-Cloud is an initiative aimed at creating a digital environment for the open and seamless integration of marine data and services across Europe. It supports the co-development and integration of environmental RIs through several key mechanisms. Blue-Cloud provides a centralised platform where marine data from various sources can be aggregated, accessed, and shared: it integrates data from European marine and oceanographic research infrastructures, facilitating a more coordinated and efficient approach to environmental research. By promoting and implementing common interoperability standards, Blue-Cloud ensures that data from different RIs can be easily combined and compared. This harmonization of data formats, metadata, and protocols is crucial for more effective collaboration and integration in the future. Blue-Cloud provides Virtual Research Environments where researchers can work together on shared projects, accessing the same datasets and computational resources in a collaborative online space. VREs facilitate co-development by enabling real-time collaboration and integration of efforts. These tools are designed to foster interdisciplinary collaboration. By providing these capabilities, Blue-Cloud significantly enhances the ability of environmental RIs in Europe to co-develop and integrate their research efforts, leading to more comprehensive and impactful environmental studies and solutions. This is particularly true in the case of JERICO, as JERICO-CORE relies on Blue-Cloud capacities and Virtual Labs to offer various services to the coastal science community.

4. CONCLUSIONS

The present document outlines the strategic integration and collaborative actions undertaken by JERICO to enhance our understanding and management of marine and coastal systems. Through a series of well-coordinated efforts and partnerships, several RIs have made significant strides towards achieving a holistic and integrated approach to marine research.

The collaboration among marine RIs has fostered technological advancements and scientific breakthroughs that are crucial for the comprehensive observation and monitoring of marine environments. By combining in situ and remote observations with experimental manipulation, the RIs have worked towards a more unified understanding of European marine systems. This integrative approach has been instrumental in addressing complex issues such as biodiversity loss, environmental contamination, and the impacts of climate change. Key initiatives, such as the development of the Coastal EMSO Generic Instrument Module (cEGIM) and the JERICO-CORE e-infrastructure, highlight the commitment to standardising methodologies and enhancing interoperability. These efforts not only facilitate seamless data exchange but also improve the reliability and accessibility of marine data across different platforms and RIs. The present document underscores the importance of bilateral collaborations for JERICO, as seen in the partnerships with DANUBIUS RI, EMBRC ERIC, EMSO ERIC, GROOM RI, and AQUACOSM RI. These collaborations have promoted data sharing, methodological harmonisation, and the development of joint research projects. Notable achievements include the integration of observational platforms, the alignment of biological observation strategies, and the establishment of new sampling methods and best practices.

Moving forward, continued focus on interoperability, data integration, and stakeholder engagement will be crucial for JERICO. The collaborative frameworks established through workshops and agreements should be leveraged to address emerging challenges. The alignment with global and European strategic agendas will ensure that JERICO, together with the other RIs of the landscape, remain at the forefront of scientific discovery and environmental management.

In conclusion, the collective efforts undertaken by JERICO demonstrate a robust commitment to enhancing our understanding of marine ecosystems and promoting sustainable management practices. The ongoing collaboration and integration of resources and knowledge will be pivotal in addressing the complex and dynamic nature of marine environments, contributing in the end to the resilience and health of our oceans and coastal areas.

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