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Description	This deliverable provides (1) updates to D1.2 'Map the current state of biological observations in Europe', (2) a report on the two workshops and global review undertaken to progress capacity and coordination of ocean observation, and (3) outlines key steps forward that will improve our capacity to predict biological and ecosystem changes under a changing climate.
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Work Package title	Governance and Coordination of ocean observing and forecasting systems
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Comments	The delay of the deliverable was caused by Covid-19 related disruptions causing some delay in recruitment plans and people taking up their roles remotely. Additionally, tasks undertaken to improve the deliverable (2 workshops + 1 review), that were not foreseen in the outline, were taking additional time but were worthwhile to bring the European and global community together to further progress ocean observation.

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Executive summary

This report provides updates to D1.2 'Map the current state of biological observations in Europe" that monitor Essential Ocean Variables (EOVs). In the original submission, we identified 363 marine monitoring programs across 29 European countries that monitor phytoplankton, microbes, zooplankton, benthic invertebrates, fish, birds, marine mammals, turtles, seagrass, macroalgae, and hard coral. In this report, we have updated our catalogue to 532 monitoring programmes. We also undertook two workshops and produced one review article. The first workshop on macroalgae included discussions on the status of the Standard Operating Procedures (SOPs) for the different survey methods, as well as presentations by leading researchers, data managers/coordinators and representatives from the Directorate-General Marine Affairs and Fisheries (DG MARE) of the European Commission (EC). The workshop participants identified key areas that need addressing such as standardisation of protocols, better data management, and improved coordination and communication. The second workshop on seagrass builds on current and parallel global efforts to establish SOPs. Because of these parallel efforts that are laying the groundwork for data management and interoperability, we undertook a European focussed workshop which identified the top 100 priority questions that, if answered, would strongly advance seagrass conservation in Europe towards rich and resilient seagrass ecosystems that would benefit both nature and people. The top 100 questions are spread across 9 themes - Monitoring and Assessment, Biodiversity and Ecology, Drivers and Threats, Conservation and Restoration, Fisheries support, Ecosystem services, Communications, Blue carbon, Governance, Policy and Management.

Whilst EuroSea is focussed within the European region, it is important that components built in this study help progress ocean observation on a global scale, and that Europe gains in efficiency and outcome from this interaction with global experts and structures. To that end, we used the results from D1.2, specifically on zooplankton, to engage the global observing community in an effort to (1) synthesise our current understanding of zooplankton in a changing climate, (2) determine key knowledge gaps, (3) identify all monitoring programmes globally, (4) determine data availability from observing programmes, and (5) design an integrated observing programme that would meet user needs. A review article, currently under review, was developed as an outcome to highlight key knowledge and geographic gaps that need urgent attention.

Moving forward, the two workshops and review article identified the need for improved data availability, standardisation of protocols and better coordination via community engagement (e.g., working groups) and/or regional/global efforts (e.g., European Ocean Observing System, Global Ocean Observing System).

1. Introduction

1.1. Architecture of marine environmental governance in Europe

With the pressure on marine ecosystems continually increasing due to climate change and our need for food, transportation and recreation, sustained observations on the status and trends of key indicators for the ocean and marine life are required to inform policy and regulatory frameworks that guide the management of these ecosystems (Tanhua et al. 2019, Miloslavich et al. 2018, Muller-Karger et al. 2018, Jetz et al. 2019). At the national level, many countries still lack a coherent integrated policy for marine monitoring (Grip 2017). Within the European continent, there is no single policy or set of policies to manage the marine environment (Grip 2017). The Water Framework Directive (WFD) (2000/60/EC) was adopted in 2000 with the aim to achieve 'good status' for all water bodies, including marine/coastal waters up to one nautical mile, from shore by 2015. Whilst the WFD improved monitoring and assessment of water bodies in Europe, the many implementation challenges have seen the deadline extended from 2015 to 2021, and again from 2021 to 2027 (Voulvoulis et al. 2017, Carvalho et al. 2019).

Extending beyond national shorelines, over the last 30 years four Regional Seas Conventions formed the pillars that facilitated cooperation amongst neighbouring countries to protect the marine environment. In 2008, the European Union adopted the Marine Strategy Framework Directive (MSFD) (2008/56/EC), aimed at protecting the marine environment and natural resources, and creating a framework for the sustainable use of European marine waters. To achieve this goal, the Directive established four European marine regions using the geographical boundaries of the Regional Seas Convention.

The four European Regional Sea Conventions and European marine regions as identified by the Directive are:

- The Convention for the Protection of the Marine Environment in the **North-East Atlantic** of 1992 (further to earlier versions of 1972 and 1974) – the OSPAR Convention (OSPAR)
- The Convention on the Protection of the Marine Environment in the **Baltic Sea** Area of 1992 (further to the earlier version of 1974) – the Helsinki Convention (HELCOM)
- The Convention for the Protection of Marine Environment and the Coastal Region of the **Mediterranean** of 1995 (further to the earlier version of 1976) – the Barcelona Convention (UNEP-MAP)
- The Convention for the Protection of the **Black Sea** of 1992 – the Bucharest Convention.

The implementation of the MSFD is the responsibility of each individual EU Member State. Member states that are sharing a marine region are to cooperate and coordinate their activities using existing regional cooperation structures, such as the Regional Sea Conventions. Despite being a legally binding EU directive, MSFD does not provide a legal framework or governing structure, therefore each Member State can define the *Good Environmental Status* without full coordination and collaboration with neighbouring countries (van Tatenhove et al. 2014). Aside from the main EU Directives (i.e., WFD and MSFD) that drive most of the coastal and offshore monitoring (Painting et al. 2020), other European legislation around marine monitoring include the Environmental Quality Standard Directive (EQS, 2008/105/EC), the Habitats Directive (HD, 92/43/EEC), the Birds Directive (BD, 2009/147/EC) and the Data Collection Framework Regulation for the Common Fisheries Policy (CFP, Council Regulation (EC) No 199/2008). Despite these European legislations, Painting et al. (2020) surveyed 12 European countries (Finland, France, Germany, Greece, Ireland, Italy, Malta, Norway, Poland, Spain, Sweden and the United Kingdom) and determined that 88% of the respondents indicated that the current monitoring programme was either partially adequate (60%) or not adequate (28%) to monitor environmental threats. Insufficient spatial and temporal resolution, insufficient data or parameters measured (on phytoplankton compositions, marine mammals, reptiles, birds, invasive species, marine litter, and contaminants in sediment and biota), and lack of integration (e.g., of monitoring programmes, indicators, and descriptors) were identified as key gaps in current monitoring programmes (Painting et al. 2020). Additionally, the MSFD system only uses two classes (good and bad) to assess the status, and using more classes (e.g., Water Framework Directive, WFD) would provide more information on trends and changes observed (Van der Zande et al. 2019).

At present, there is no central information system that provides adequate information on the spatial and temporal extent of marine monitoring programmes within Europe, or globally. Such information can be located with regional reporting organisations (e.g., HELCOM, ICES, etc.) or in data repository centres (e.g., Ocean Biodiversity Information System (OBIS), Global Biodiversity Information Facility (GBIF), EMODnet etc.), but this information is for a select number of programmes that fall within its purview. An interactive online portal (https://bioeco.goosocean.org) was recently launched by the Biology and Ecosystems Expert Panel of Global Ocean Observing System (GOOS) that aims to highlight all marine monitoring programmes that monitor phytoplankton, microbes, zooplankton, benthic invertebrates, fish, birds, sea turtles, marine mammals, macroalgae, seagrass, hard coral and mangroves in the global ocean. Version 1.0 of this portal, launched in July 2022, contains information from 576 programmes gathered through the EuroSea survey (D1.2) and the PEGASus/Future Earth programmes, and programme contacts are further updating the information through the GeoNode edit interface of the GOOS BioEco Portal. Observing programmes not currently included in the portal are invited to add their data and metadata, to ensure that their programmes are being represented. When funding is secured, the portal is expected to be fully operational (i.e., contain the data and metadata for all marine monitoring programmes in the global ocean, and connect and feed live information into assessments and reports such as the annual GOOS Report Card (http://ocean-ops.org/reportcard) on the status of the ocean observing system) by June 2025.

1.2. Coordination action to improve ocean observing by the Global Ocean Observing System (GOOS)

Scientific information is required to support all levels of management and governance, and this requires frameworks and coordinated action for ocean observing. In 1991, the Intergovernmental Oceanographic Commission (IOC) created the Global Ocean Observing System (GOOS) in an effort to gather the information required to improve forecasts of climate change, the management of marine resources, mitigating the effects of natural disasters, and the use and protection of the coastal zone and coastal ocean. GOOS utilises the Framework for Ocean Observing (FOO) (2012) to guide its implementation of an integrated and sustained ocean observing system. Under the FOO, ocean observations are organised around scientific or ocean observing community-defined Essential Ocean Variables (EOVs).

Life within the ocean falls under the purview of the Biology and Ecosystems (BioEco) Expert Panel of GOOS. The Panel proposed BioEco EOVs based on their relevance in helping to solve science questions and addressing societal needs, their contribution to improving the management of marine resources, and their feasibility for global measurements in terms of costs, availability of technology and human capabilities. This led to the development of 12 BioEco EOVs: phytoplankton, microbes, zooplankton, benthic invertebrates, fish, birds, sea turtles, marine mammals, macroalgae, seagrass, hard coral and mangroves (Miloslavich et al. 2018).

With funding from the PEGASus/Future Earth programme, the BioEco Panel conducted an audit of active marine monitoring programmes that monitored at least one BioEco EOV to understand the scope and scale of existing biological ocean observations. Only 7% of the global ocean surface area had active BioEco marine monitoring and these programmes were unevenly distributed (Satterthwaite et al. 2021). Monitoring programmes were concentrated in coastal regions of the United States, Canada, Europe, and Australia, with extensive gaps in most of the world's oceans (Satterthwaite et al. 2021).

Less than half (42%) of the monitoring programmes surveyed were part of a national and/or international coordinating network such as GOOS, the Marine Biodiversity Observation Network (MBON), Long Term Ecological Research (LTER), the U.S Integrated Ocean Observing System (IOOS), Integrated Marine Observing System (IMOS), OceanSITES and Global Alliance of Continuous Plankton Recorder Surveys (GACS) (Satterthwaite et al. 2021). Of the marine biological observing programmes that were surveyed, 66% had accessible data (either publicly accessible or by request) whilst 34% had limited data access because of a moratorium associated with current use, the data provider or another entity (e.g., contractor) had access to the data, only the data provider had access to the data, or unknown data restrictions (Satterthwaite et al. 2021). Nearly two-thirds of observing programmes that had limited access due to a moratorium, restricted or fully restricted access stated that they were working to make their data fully open whilst others were not working to make their data open due to the lack of sufficient resources such as funding and personnel (Satterthwaite et al. 2021). Almost all (~95%) of the programmes surveyed used Standard Operating Procedures or Best Practices, however further analysis of survey results highlighted that only 10% of these programmes shared protocols with other programmes (Satterthwaite et al. 2021).

Erin Satterthwaite's survey results are disappointing but the landscape of sharing data and methodologies is gradually (albeit slowly) changing as compliance with Findable, Accessible, Interoperable and Reusable (FAIR) and CARE guiding principles becomes recognised as good research practice (Wilkinson et al. 2016, CARE Principles for Indigenous Data Governance). Research should be transparent and reproducible. The sharing, adoption and use of the same methodologies and practices globally is a major opportunity for progressing interoperability and intercomparability enabling datasets to be analysed in a consistent manner. It is the vision and mission of the GOOS/IODE Ocean Best Practices System (OBPS) *to have agreed and broadly adopted methods across ocean research, operations and applications* by hosting a sustained open access Repository for easy discoverability and access to local, regional and global methodologies. Methods in the OBPS repository provide insight into ways of doing ocean observing and sharing those methods with the global ocean community. They take the form of standard operating procedures, handbooks, manuals, videos and others.

The benefits of sharing data and using best practices in addition to improved system interoperability and data comparability include: Collaborative opportunities; Efficient use of time (cost savings); Greater trust in data; Streamlined regulatory control, and Higher funding success. But, from the Erin Satterthwaite survey it is obvious there opportunities to further support the use of Best Practices - suggestions include:

- Publishers should require academic/peer-reviewed papers to include the citation/identification of methodologies and standards used, alongside the growing requirement for dataset citations
- Career recognition of best practices/standards creation and documentation
- Networks support and Ocean Decade support for adoption and use of best practices and standards
- Increased endorsement activity and recognition for published methodologies

- Facilitate the sharing of methodologies (through OBPS)
- Provide multi-language support so that methodologies can be translated and therefore more easily shared globally.

'Best practice' has become the expected phrase in every research proposal - the Ocean Best Practices System advocates that *to be fully elevated to a best practice, a promising method will have been adopted and employed by multiple organisations* (i.e. shared and adopted amongst the global ocean community including in low income (less developed) countries). GOOS has worked with the Ocean Best Practice System to develop an integrated GOOS endorsement process, so that best practice/s that are adopted across a GOOS network or community can be identified as such in the OBPS repository.

The availability and use of best practices need to be propagated globally, particularly for biological observations. When these are adopted by long term monitoring systems, there is both interoperability and consistent time series that can address trends and impacts. Yet, the BioEco audit was unable to identify active, long-term biological monitoring programmes for most of the surface ocean (93%). Whilst this initial study provides a useful baseline for assessing the current status and gaps, more in-depth regional assessments are required to gain a better understanding of the scope and scale of existing biological ocean observations. This in-depth analysis to identify networks and programmes in greater detail should either be through EOV specific initiatives or regional initiatives (e.g., EuroSea).

1.3. EuroSea as a regional project that advances our knowledge of ocean observing

EuroSea, an initiative funded through the European Commission research funding programmes Horizon 2020, seeks to address these gaps, and brings together key European ocean observing and forecasting groups to deliver information and support decision-making. A key **objective** within Work Package 1, (Governance and Coordination of ocean observing and forecasting system with IOC/UNESCO, GEOMAR, EuroGOOS, SOCIB, IO PAN, IEEE, EMB, MET OFFICE), is to strengthen and extend the BioEco networks throughout the European seas.

To achieve this objective, Work Package 1 will:

1. Map the current state of biological observations in Europe that have a set of biological EOVs,
2. Develop global networks for ocean biology observations, including workshops to reach agreement on observation strategies, data sharing practices, and best practices and standard operating procedures, and strengthening engagement with national and international research and observation programmes.

In this report, we identify observing programmes (D1.2). We define observing programmes as singular programmes that may or may not have sub programmes. Networks on the other hand include coordinating efforts such as HELCOM, ICES, Argo etc. In this preliminary exercise, we identify observing programmes and ask the observing programmes if they are part of a larger coordinating network. Where available, we report this in the spreadsheet provided in the Appendix. Monitoring is defined as repeated sampling in the same region.

Due to the various political and geographical definitions of Europe, for the purposes of this analysis, Europe includes the countries, dependencies and territories listed below (Table 1).

Table 1. List of European countries, dependencies and territories included in this analysis

Albania	Germany	Norway (Svalbard)
Andorra	Greece	Poland
Armenia	Hungary	Portugal
Austria	Iceland	Romania
Azerbaijan	Ireland	Russia
Belarus	Italy	San Marino
Belgium	Kazakhstan	Serbia
Bosnia and Herzegovina	Latvia	Slovakia
Bulgaria	Liechtenstein	Slovenia
Croatia	Lithuania	Spain
Cyprus	Luxembourg	Sweden
Czech Republic	Malta	Switzerland
Denmark (Faroe Islands and Greenland)	Moldova	Turkey
Estonia	Monaco	Ukraine
Finland	Montenegro	United Kingdom (Scotland and Wales)
France	Netherlands	Vatican City
Georgia	North Macedonia	

2. Status of the observing system in Europe

2.1. Task 1: Map the current state of biological observations in Europe

Identifying priority BioEco variables for ocean observing comes from two synergistic efforts: the EOVs through GOOS (Miloslavich et al. 2018), and Essential Biodiversity Variables (EBVs) from the Group on Earth Observations Biodiversity Observation Network (GEO BON) (Muller-Karger et al. 2018). The BioEco EOVs are marine focussed and grouped into eight functional groups (phytoplankton, microbes, zooplankton, benthic invertebrates, fish, birds, sea turtles, marine mammals) and four habitat states (macroalgae, seagrass, hard coral and mangroves) (Miloslavich et al. 2018) whilst the cross-domain (land, ocean, atmosphere) EBVs are grouped into six classes (genetic composition, species populations, species traits, community composition, ecosystem structure, and ecosystem function) (Muller-Karger et al. 2018). The EBVs are integrated into the EOV framework by the marine component of GEO BON - MBON - based on biodiversity observation requirements (e.g. taxonomic diversity, species distribution and population abundance) (Figure 1).

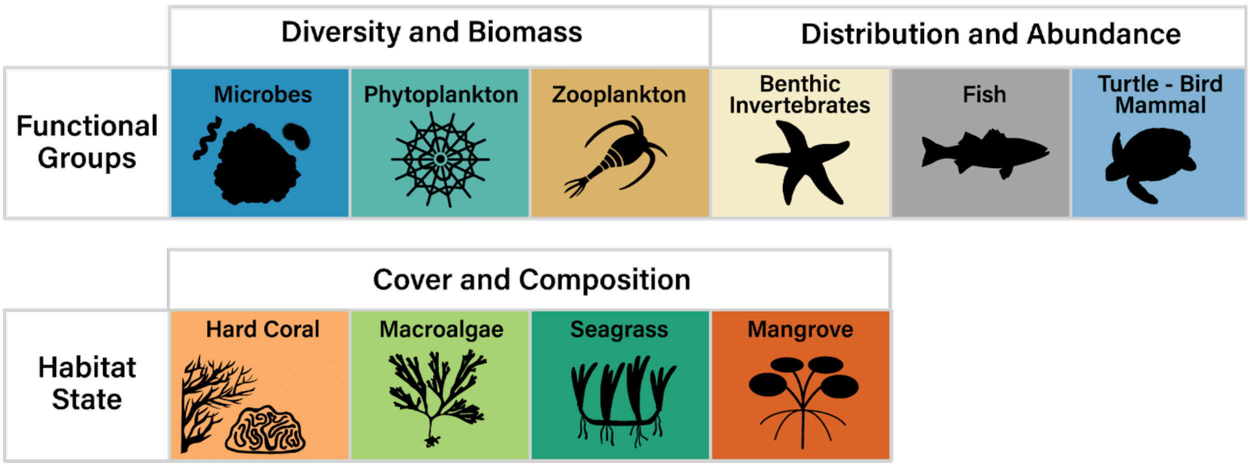

Figure 1. Biology and Ecosystems Essential Ocean Variables (EOVs)

For the purposes of Task 1, we identified monitoring programmes that monitored the EOVs listed in Figure 1, noting that mangroves are not present within the European continent. The process of identifying monitoring programmes within Europe started from the global survey undertaken as part of the PEGASuS/Future Earth project (Satterthwaite et al. 2021). The global survey identified 127 active marine monitoring programmes in Europe. Active programmes were defined as those that sampled at least once in a five-year period. Through the EuroSea project, we cross-validated these 127 monitoring programmes to determine if they are still active. Subsequently, we identified additional programmes and contact information through web/social media searches, GOOS National Focal Points in Europe and the EOOS Operations Committee.

Through these two efforts combined, we identified a total of 296 unique marine monitoring programmes that monitor at least one BioEco EOV within European waters (Deliverable 1.2 identifies marine monitoring programmes until 22 February 2021, and the updated numbers of 296 unique monitoring programmes in this report are correct as of 25 May 2022). These marine monitoring programmes could have multiple sub-programmes within the overall programmes, or undertake monitoring in various locations. Consequently, the spreadsheet provided in the Supplementary material contains 532 entries that reflect the different sub-programmes and locations. Some monitoring programmes are undertaken for purely scientific and/or conservation reasons, however most programmes identified were undertaken to meet European reporting needs (e.g., ICES, HELCOM, ACCOBAMS, MSFD, WFD, OSPAR, Barcelona Convention, Black Sea Convention, spreadsheet in supplementary material includes further details for each programme). Many programmes also utilise existing research infrastructures (e.g., the Joint European Research Infrastructure of Coastal Observatories (JERICO-RI), European Marine Biological Research Centre (EMBRC), LifeWatch, etc., spreadsheet in supplementary material includes further details for each programme).

Of these 532 monitoring programmes, four programmes involved the collaboration of two countries (2 x Norway and Scotland, 1 x Spain and Scotland, 1 x Belgium and France), and 17 programmes are considered 'Regional' as the monitoring programme involved more than two countries. The rest of the programmes were national marine monitoring programmes. Marine monitoring programmes were identified in 30 countries within Europe, and we include Faroe Islands and Greenland within Denmark as they are a constituent country of the Kingdom of Denmark (Table 2, Figure 2). The three countries where marine monitoring programmes have yet to be identified but have coastal waters are Bosnia and Herzegovina, Monaco, and Montenegro.

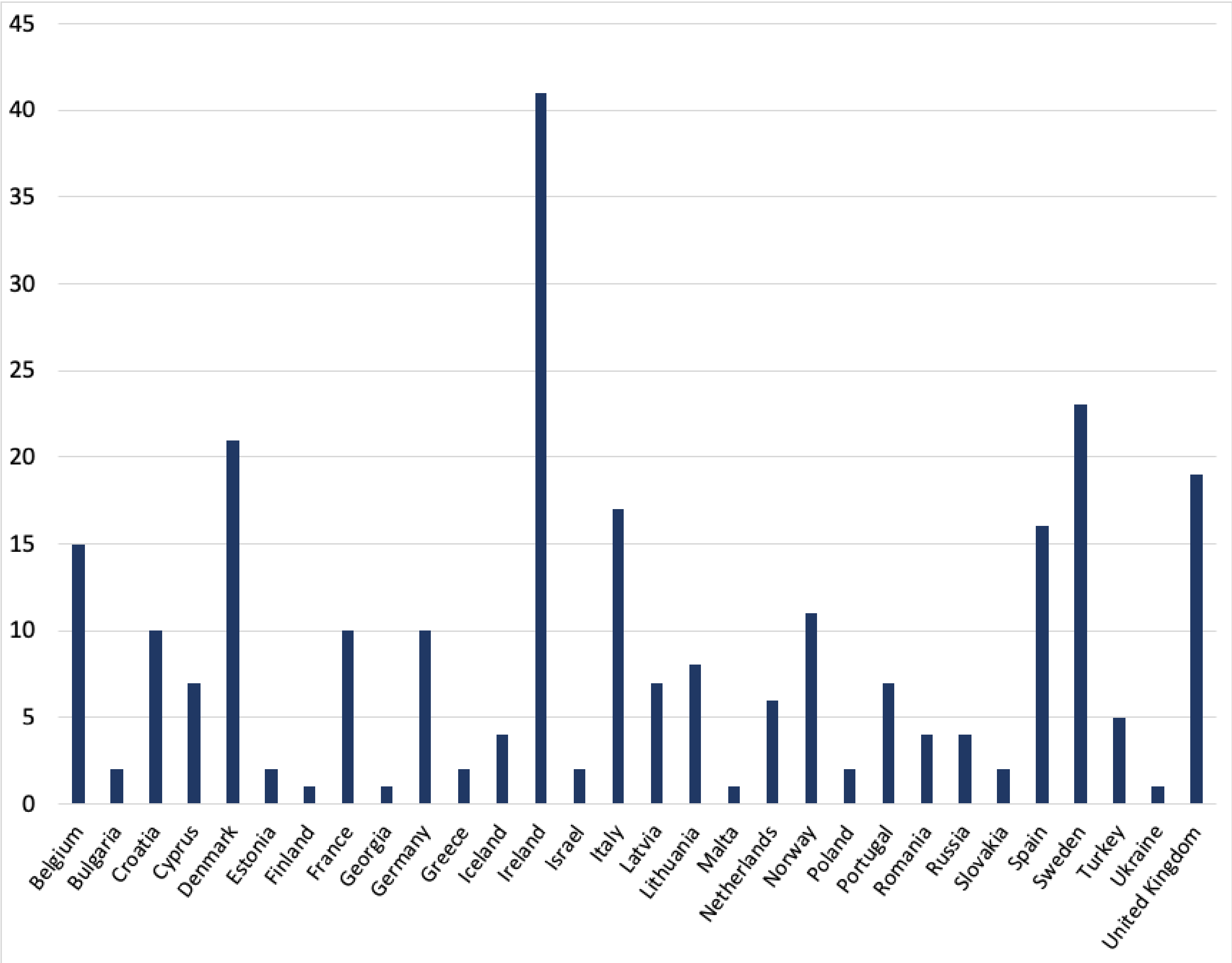

Figure 2. Number of unique observing programmes identified for each country as of 25 May 2022.

Each monitoring programme can monitor either one EOV, or in many cases, the monitoring programme sampled two or more EOVs (Figure 3). For programmes that sampled two or more essential variables, the sampling may or may not be occurring simultaneously. By far, monitoring for phytoplankton was the most abundant (225 programmes) followed by fish, (169 programmes), zooplankton (133 programmes), benthic invertebrates (115 programmes), marine mammals (79 programmes), microbes (57 programmes), birds (57 programmes), macroalgae (47 programmes), turtles (32 programmes), seagrass (28 programmes), and lastly hard coral (19 programmes) (Figure 4). There are no monitoring programmes for mangroves in Europe as they grow in sheltered tropical and subtropical coastal areas across the globe. However, some countries (e.g., France) have overseas territories where mangroves are monitored. Detailed breakdown of marine monitoring programmes are provided as a spreadsheet in the Supplementary document.

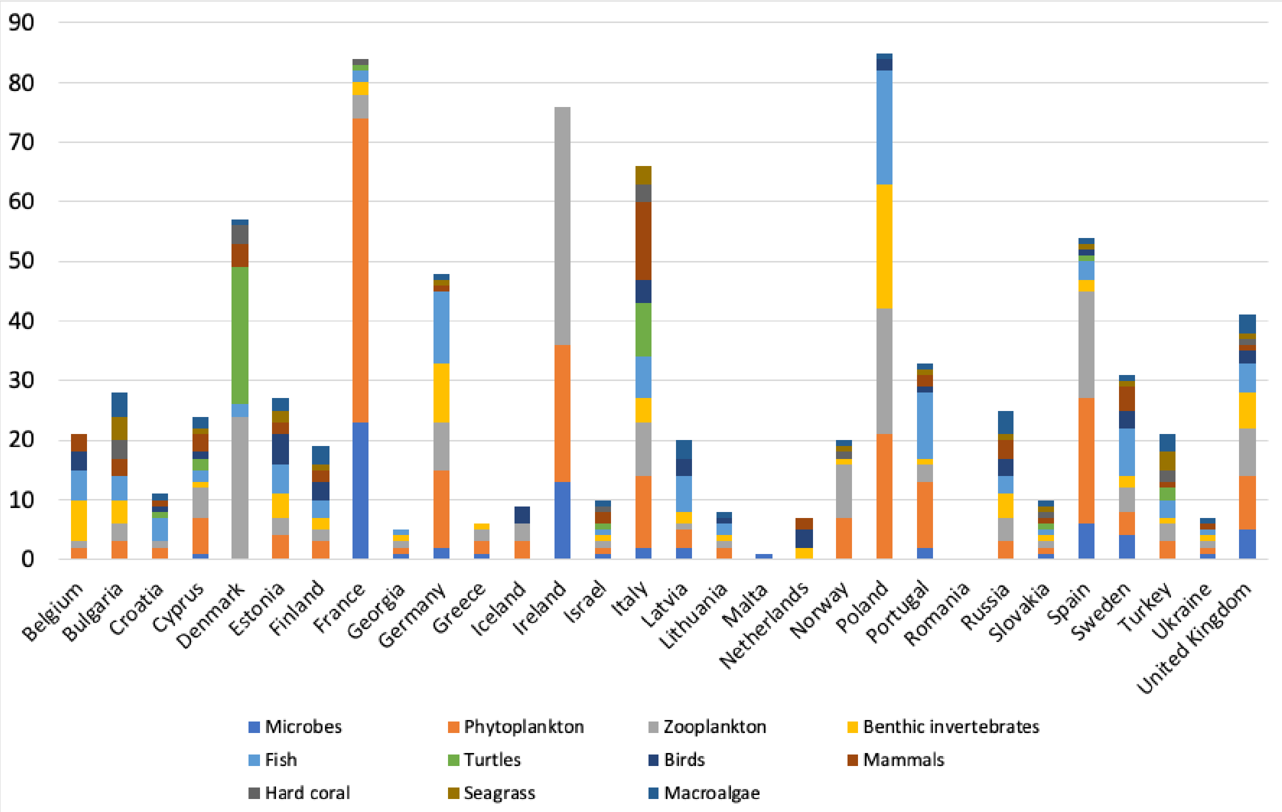

Figure 3. Number of observing programmes for each Essential Ocean Variable by country as of 25 May 2022.

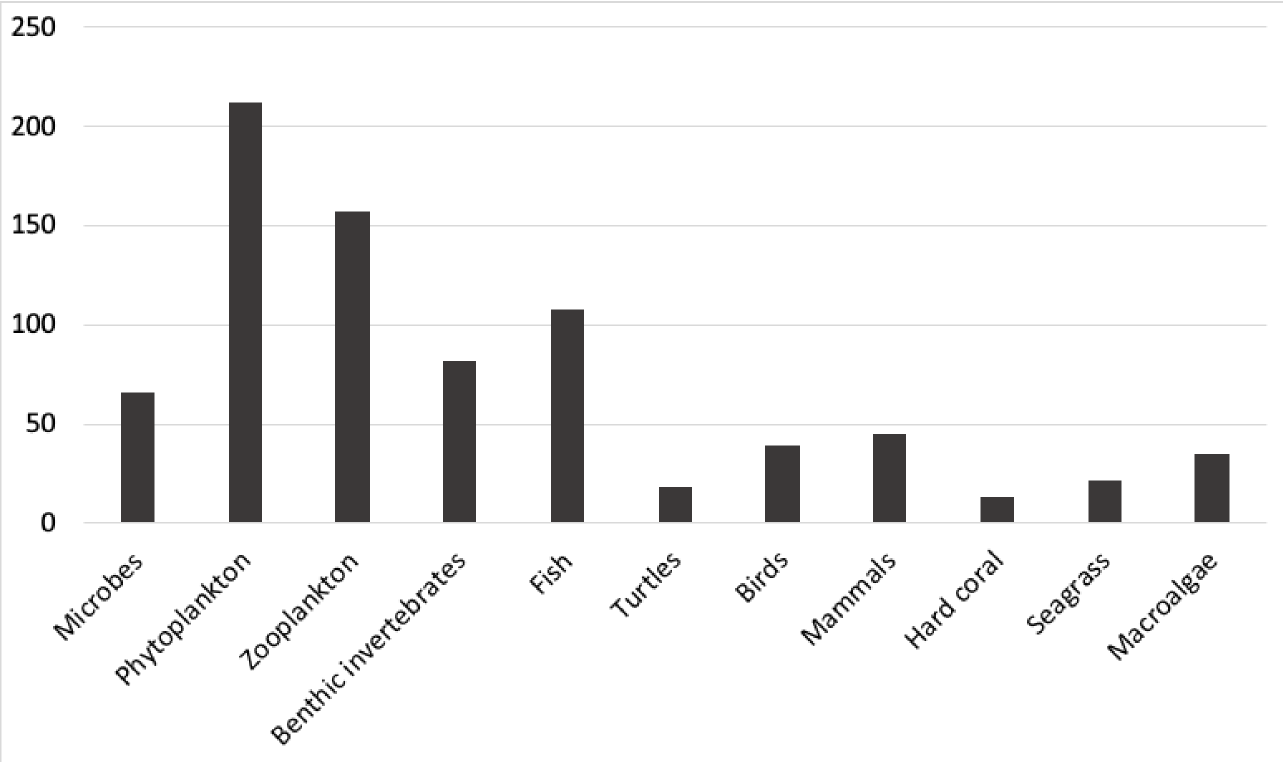

Figure 4. Number of observing programmes by Essential Ocean Variable for all countries combined as of 25 May 2022.

Of the 532 entries (i.e., including sub programmes), 448 of these used some form of Standard Operating Procedures or Best Practices (25 of these are Citizen Science programmes) (Figure 5). Twenty-five programmes did not use any Standard Operating Procedures or Best Practices, 2 programmes are currently preparing the Standard Operating Procedures, and no information was available for 57 of these programmes. Sampling frequency mostly ranges from sub-daily observations (e.g., when using FerryBox and gliders) to annual observations. Of the 532 entries, 12 monitoring programmes undertook sampling with more than one year in between sampling (e.g., every 2, 3 and 6 years). Six monitoring programmes were sampled opportunistically - two of which are Citizen Science projects (eOceans and The Secchi Disk that monitor fish and water transparency and phytoplankton respectively). No information on sampling frequency for 86 of these entries.

The availability of the data collected from these monitoring programmes is critical to understand how various stressors (e.g., climate change, extreme events etc.) influence ocean ecosystems. Of the 532 entries, we were unable to determine data availability for 222 programmes. 32 programmes do not make their data publicly available, and 278 programmes have their data available in various data repositories (e.g., OBIS, GBIF, EMODnet, Copernicus, ICES, HELCOM, OSPAR, PANGAEA. National Biodiversity Data Centre etc., spreadsheet in supplementary material includes further details for each programme).

Whilst this list of observing programmes is not exhaustive for the entire European region, our analysis highlights that most observing programmes monitor phytoplankton, zooplankton, benthic invertebrates, and fish, with fewer programmes for microbes, birds, marine mammals, turtles, hard coral, seagrass and macroalgae, and there are large gaps to our understanding of data availability and improving access to monitoring data. To improve our knowledge on the number of observing programmes and temporal and spatial extent of observations, we should endeavour to:

- Engage with national, regional, and global coordinators, projects and networks to identify observing programmes. Such networks include, but are not limited to:
    - SCOR working groups such as C-GRASS: Coordinated Global Research Assessment of Seagrass Systems, CoNCENSUS: Advancing standardisation of COastal and Nearshore demersal fish visual CENSUS techniques, P-OBS: Integration of Plankton-Observing Sensor Systems to Existing Global Sampling Programs
    - Established networks such as Argo, AniBOS (Animal Borne Ocean Sensors), OceanSITES etc.
    - GOOS Regional Alliance such as EuroGOOS for the European region, Black Sea GOOS, Mediterranean Operational Network for GOOS (MONGOOS), GOOS for Africa, Indian Ocean GOOS (IOGOOS), North-east Asia Regional GOOS (NEAR-GOOS), South-east Asia GOOS (SEAGOOS), Pacific Islands GOOS (PI-GOOS), Australia's Integrated Marine Observing System, the US Integrated Ocean Observing System (US IOOS), Wider Caribbean GOOS (IOCARIBE GOOS), GOOS Regional Alliance of the South-east Pacific (GRASP), and the Regional Alliance for the Upper Southwest and Tropical Atlantic (OCEATLAN).
    - GOOS National Focal Points, which are the appropriate contact points in each European Member State, through the European Ocean Observing System (EOOS) Operations Committee in order to activate greater national awareness of their biological observing systems.

- Organise community workshops that bring various stakeholders together.
    - Observing programmes can be a national and/or regional requirement and are thus administered through federal agencies that may utilise the expertise of researchers within academic institutions to undertake the work. However, monitoring programmes can also be undertaken for purely scientific and/or conservation reasons by academic institutions and/or philanthropic organisations. Thus, organising thematic workshops that focus on a single EOV will bring various groups together and improve our understanding of spatial and temporal coverage of the monitoring programmes, across Europe and globally, by community.

- Improve data availability through a combination of education, and formal requirements, and ensure transfer of data between repositories.
    - Data collected but unavailable through data repositories impedes our ability to understand regional and/or global patterns. Researchers, and various other data collectors (e.g., industry, non-governmental organisations etc.) should be encouraged to make their data public. Noting that much of the data is collected for research purposes, funders, administering organisations and research journals amongst others, should encourage that data is rapidly available following publication of research findings. Funders can also ensure that data is available by formally requiring it as part of funding requests. Lastly, there should be data flowing between the different repositories. This is currently underway in Europe, where data from various European data repositories are being pooled and shared between different repositories (see Figure 1 in Macroalgal workshop report, Supplementary material). However, some types of data collected, particularly on commercial fish, can be restricted.

2.2. Task 2: Develop global networks for ocean biology observations, including workshops to reach agreement on observation strategies, data sharing practices, and best practices and standard operating procedures, and strengthening engagement with national and international research and observation programmes

For Task 2, we focus on three out of the 12 BioEco EOVs. Specifically, we undertook two workshops on macroalgae and seagrass, and produced one review paper on zooplankton in a changing climate. The first workshop on macroalgae was undertaken in November 2021 and the second workshop on seagrass was undertaken in March 2022, and the review paper was submitted in April 2022. These EOVs were chosen as there are existing global developments.

In this section, we discuss the summary of the two workshops and the review paper, and recommendations that were identified. Links to full workshop reports are provided in the Reference.

European workshops on macroalgae and seagrass

Macroalgal observations in Europe

From Task 1, the EuroSea survey identified 47 macroalgal monitoring programmes in Europe run by 35 different organisations, with the oldest programmes consistently operational since 1952. Sampling frequency for the various monitoring programmes varied from bi-monthly, monthly, quarterly, every 1, 2, 3, 6 years and two programmes use an opportunistic sampling strategy. Of these 47 programmes, 40 programmes used Standard Operating Procedures (SOPs) or Best Practices (BPs), 2 programmes did not use SOPs or BPs and 5 programmes did not respond (including 3 that are Citizen Science Projects). 13 out of these 47 programmes were purely scientific research programmes whilst 21 programmes contribute to one or more forms of national or regional (e.g., ICES, HELCOM, OSPAR, Black Sea Commission) requirement. No information on the remaining programmes. With regards to data availability from these monitoring programmes, 2 programmes did not make their data publicly available and no information provided for 11 programmes. The remaining 34 monitoring programmes submitted their data to various data repositories (OBIS, national data centres, EMODnet, ICES, LTER-DEIMS, GBIF etc.).

Macroalgal workshop: Rational and recommendations

The EuroSea macroalgal workshop undertaken as part of Task 2 built on two previous macroalgal workshops undertaken by the Biology and Ecosystems Panel of GOOS. The first workshop, entitled "Planning the implementation of a global long-term observing and data sharing strategy for macroalgal communities" was held in September 2018 at the Institute for Marine and Antarctic Studies, Hobart, Australia. The workshop was co-chaired by Craig Johnson and Lisandro Benedetti-Cecchi. This workshop brought together 30 international scientists with expertise in a variety of survey methods and data management and set out to develop a global, coordinated strategy for monitoring macroalgal assemblages. Specifically, the aims were to (1) identify existing datasets at all geographical scales, (2) review technological monitoring approaches and define SOPs, (3) recommend approaches to consolidate existing data and associated metadata in a data system under the principles of FAIR data (Findable, Accessible, Interoperable, and Reusable), and (4) plan the implementation of an international, standardised, innovative and cost-effective system for monitoring marine macroalgae. The workshop compiled metadata on nearly 80 macroalgal monitoring programmes and found that sampling scale, methodologies, and the 'target' zone (subtidal and intertidal) varied. Data availability and format are also variable and represent a challenge along with the sustainability of data collection. The workshop working group reached an agreement on a Roadmap for the next steps to develop a global observing system for macroalgal communities.

This led to the second macroalgal workshop on data architecture entitled 'Macroalgal Essential Ocean Variable (EOV) data processing and workflow workshop' in October 2019 at the Institute for Marine and Antarctic Studies, Hobart, Australia. The workshop was led by Peter Walsh and Patricia Miloslavich. Building on the recommendations from the first workshop the second workshop was aimed at drafting the SOPs for the different survey methods (visual surveys, genetics, acoustics, remote sensing and AUV/BRUV imagery), developing the data architecture (data processing and workflow) and establishing the Global Ocean Macroalgal Observing Network (GOMON) along with its terms of reference, governance structure and membership.

Using these two global workshops as a base, the EuroSea macroalgal workshop focussed on key topics relevant to the European community. The workshop, entitled "Towards a coordinated European Observing System for Marine Macroalgae", was held online in November 2021 due to COVID travel restrictions. The workshop was co-chaired by Lisandro Benedetti-Cecchi and Isabel Sousa-Pinto. To ensure that the progress from the previous two workshops continued, whilst being European focussed, the workshop included updates on the status of the SOPs for the different survey methods, as well as presentations by leading researchers, data managers/ coordinators and representatives from the Directorate-General Marine Affairs and Fisheries (DG MARE) of the European Commission. This workshop encouraged and challenged the participants to identify key gaps (observation strategies/protocols, knowledge, coverage etc.), identify mechanisms to integrate with other monitoring programmes, and develop key questions and recommendations for macroalgal monitoring in Europe.

The workshop started with talks on data sharing practices, by Ward Appeltans on the Ocean Biodiversity Information System (OBIS) and by Joana Beja on EMODnet introducing their respective data centres followed by an online survey to determine data availability. Of those that attended the workshop and participated in the survey:

- 65% did not have their data in a public domain and 35% did have their data publicly available
- 67% said they were not obliged to put their data in the public domain and 33% said they were obliged to do so
- The most common reasons for not publishing in open access were because they were waiting to publish their research first (29%), not allowed to (12%), not standardised and thus difficult to use (12%), too complex/time consuming (6%) and others (42%). For 'others' part of the data is accessible and part is not accessible.
- Most of the data is archived at the institutional repository (50%), national repository (40%), personal desktop/cloud (30%), OBIS (20%), GBIF (15%), Pangaea (10%), EMODnet/EuroOBIS (5%) and ICES (5%). Respondents could tick multiple options.
- 47% said their data was restricted and required permission for each use, whilst 29% were in the public domain and 24% by attribution/attribution + non-commercial.
- 47% of people responding did not know if their data is formatted following international standards and 41% said no data standards were followed.
- 58% said datasets do not have a Digital Object Identifier (DOI), 32% do have a DOI.

Following the discussion on data availability, there were a series of talks from the Directorate-General Marine Affairs and Fisheries (DG MARE) of the European Commission and other key stakeholders on funding opportunities, sustainability of macroalgal use, more specifically macro-algae sector in Europe and needs for ocean observation, and the challenges in marine macroalgal restoration. This was followed by presentations on integration with organisations involved in ocean observation such as the Marine Biodiversity Observation Network (MBON), and the Global Ocean Observing System (GOOS), macroalgal data requirements for intergovernmental programmes such as the Convention on Biology Diversity, and lastly integration with other monitoring programmes, with a focus on marine plastics. Key highlights from these talks were the critical need for increased and improved macroalgal observations, with funds available through the EU Research and Innovation Programme.

Discussions on macroalgal observing in Europe provided valuable insights which should be used to guide the progress of the macroalgal EOV in Europe. Key recommendations from the macroalgal community include:

- Standardisation of protocols
    - Current monitoring programmes do meet the European reporting needs (e.g., MSFD, Habitats Directive etc.) because the various methodologies being used are intended for specific contexts and thus may not be suitable for wider application.
    - Various sampling methodologies and lack of consistent data flow impede our ability to also answer pressing biodiversity questions on a larger spatial and temporal scale.
    - Environmental DNA (eDNA) can be a useful addition to current observing strategies and provide qualitative information on species presence, including rare/cryptic species. However, key challenges are to create a uniform protocol or best practices that can be used by everyone, and the need for a reference database to know what is being collected/sampled, as there are few macroalgal examples that can serve as a reference.

- Improved structure and reporting
    - Article 17 reporting occurs once every 6 years which is too infrequent.
    - MSFD requirements should be more consistent across Europe.

- Better data management
    - Various reasons drive the lack of data availability. To combat this, efforts should focus on: 1) Developing training protocols by OBIS/EMODnet, to be made available also through the global Ocean Best Practices System) 2) Making data deposition into an OBIS affiliated repository requirement for funding, and 3) Seek agreement on data models, workflows, and infrastructure required to support data aggregation to OBIS

- Integrating various monitoring efforts/Better collaboration
    - Integration of various monitoring efforts is a key step needed. New and emerging methods macroalgal monitoring methods can be integrated into traditional methods to improve calibration and validation. For example, eDNA and remote sensing can improve and extend monitoring capabilities in space and time but needs calibration and validation through established in-situ visual survey methods. Additionally, observing methods for seafloor plastics are the same as for macroalgae (i.e., visual scuba diving and ROVs), thus sampling programmes can be integrated.

- Improved communication
    - Communication between various stakeholders needs to be improved. An online platform should be established where all individuals monitoring macroalgae in Europe can communicate and liaise with each other about their monitoring protocols and activities.

Seagrass observations in Europe

From Task 1, the EuroSea survey identified 28 seagrass monitoring programmes in Europe run by 22 different organisations, with the oldest programmes consistently operational since 1974. Sampling frequency for the various monitoring programmes varied from opportunistic, weekly, monthly, quarterly to every 3 to 6 years. Of these 28 programmes, all use SOPs or BPs (including 2 that are Citizen Science Projects). 4 out of these 28 programmes were purely scientific research programmes whilst 19 programmes contribute to one or more forms of national or regional (e.g., ICES, HELCOM, OSPAR, Black Sea Commission) requirements. No information on the remaining programmes. With regards to data availability from these monitoring programmes, 1 programme did not make their data publicly available and no information provided for 6 programmes. The remaining 21 monitoring programmes submitted their data to various data repositories (OBIS, national data centres, EMODnet, ICES, LTER-DEIMS, GBIF etc.).

Seagrass workshop: Rational and recommendations

The EuroSea seagrass workshop undertaken as part of Task 2 built on current global efforts in building the seagrass community. These two efforts are the 1) C-GRASS: Coordinated Global Research Assessment of Seagrass Systems SCOR Working Group and 2) Smithsonian MarineGEO's curation of the long-running SeagrassNet database. The C-GRASS working group is currently undertaking a scientific synthesis of status and trends in global seagrasses and best practices for coordinating interoperable data related to seagrass distribution and trends. This project includes a review of peer-reviewed and grey literature, and unpublished data, on seagrass occurrence and ecosystem characteristics; and development of a data schema, specification sheet, and best practices supporting the GOOS Essential Ocean Variable 'Seagrass cover and composition.' C-GRASS will also produce, in collaboration with World Seagrass Association, a virtual handbook of standard protocols and best practices for collecting, curating, and sharing data on seagrass ecosystems which will be contributed to the Ocean Data Standards and Best Practices Project of the International Oceanographic Data and Information Exchange (IODE). In parallel, Smithsonian MarineGEO inherited the SeagrassNet database in 2020 and has been working to verify the over 100,000 quadrat-level observations from 126 sites in 33 countries, spanning a period from 2001-present. Upon completion of the quality control steps in late 2022, the dataset will be made publicly available on OBIS, and MarineGEO will continue to support partners in generating new observations at existing SeagrassNet sites and new MarineGEO observatories. The SeagrassNet database will be joined with other datasets as part of the C-GRASS working group to synthesise the current status and trends of seagrasses worldwide.

Building on these two global efforts, the seagrass workshop focused on key topics that were relevant to the European community, and would advance the conservation of seagrasses in the region. The workshop, entitled "Priorities for Conservation, Monitoring and Research of Seagrass Ecosystems in Europe", was held as a hybrid in-person/online workshop in March 2022. The workshop co-chairs were Lina Mtwana Nordlund and Richard Unsworth. The workshop co-chairs and facilitators were jointly running the workshop from London, United Kingdom with online participants from across Europe.

In Europe, seagrass research and monitoring are undertaken to understand how these critical ecosystems are changing and to meet national and regional policy requirements, however there are key knowledge gaps and this workshop brought the seagrass community together to formulate, identify and compile important questions that, when answered, would strongly advance seagrass conservation in Europe towards rich and resilient seagrass ecosystems that would benefit both nature and people.

Through a series of question development and subsequent voting using the Delphi method, the seagrass community within the European region identified 293 questions across 9 themes (Monitoring and Assessment, Biodiversity and Ecology, Drivers and Threats, Conservation and Restoration, Fisheries support, Ecosystem services, Communications, Blue carbon, Governance, Policy and Management). Workshop discussions synthesised these 293 questions to the top 100 priority questions for conservation, monitoring and research of seagrass ecosystems in Europe. These questions are:

Ecosystem services & Communication:
15 questions were identified in this theme largely around quantifying the value of seagrass ecosystems, implications of anthropogenic pressures and climate change, knowledge sharing and communication to various stakeholders.

Drivers & Threats
12 questions were identified in this theme that sought to answer the impacts of extreme events, climate change, anthropogenic activities, contaminants, and pathogens on seagrass response, and how factors such as species, and genetic diversity influence resilience.

Monitoring & Assessment
11 questions were identified that covered seagrass abundance and distribution, data availability, methodology, and citizen science programmes to quantify seagrass status.

Biodiversity & Ecology
20 questions were identified that focuses on the response of seagrass to pressure, importance of seagrass in under-studied regions like the Black Sea, ecosystem services, food web interactions, impact of non-native species, herbivory, and ecological feedbacks (e.g., sediment-light interactions).

Conservation & Restoration
16 questions were identified around seagrass restoration and aid recovery, conservation measures, spatial and temporal scales, transplantations, genetic makeup of donor material, genetic variability, and public involvement.

Blue carbon
9 questions were identified that sought to answer the effects of seagrass meadows on greenhouse gas emissions and removals, carbon sequestration capacity, effects of multiple threats and engagement with policymakers.

Fisheries support
5 questions were identified under fisheries support largely around the fisheries species associated with seagrass communities, development of new fisheries techniques and communication to various stakeholders (e.g., scientist, managers, policymakers, and public).

Governance, Policy & Management
12 questions were identified around improved and integrated management to prevent seagrass degradation and loss, stakeholder engagement to advance restoration and conservation, methods to deal with context-dependent responses and collaboration amongst European seagrass researchers.

Moving forward, these 100 questions can be used as the backbone to develop indicators to monitor and assess the state of the marine environment. Additionally, the development of a global monitoring network for seagrasses that engages various stakeholders (scientists, managers, policy makers etc.) can strengthen the scientific understanding of the status and trends of seagrass ecosystems at different places around the world and highlight key gaps (e.g., the data needed to inform policies of nations to sustain seagrass ecosystems).

Global review on zooplankton

As noted in Satterthwaite et al. (2021), one method to continue identifying observing capacity is by EOV or by region. The EuroSea survey (D1.2) allowed us to identify observing programmes within Europe across all 11 EOVs. Using the results from the EuroSea survey, we reached out to the global community to gain an improved understanding of the observing capacity of one EOV, zooplankton. Zooplankton are a critical link for energy transfer between phytoplankton and higher trophic levels and play an important role in global biogeochemical cycles. We engaged a global team of ecologist, biogeochemist, modellers and managers to (1) synthesise our current understanding of zooplankton in a changing climate, (2) determine key knowledge gaps, (3) identify all monitoring programmes globally, (4) determine data availability from observing programmes, and (5) design an integrated observing programme that would meet user needs.

In reviewing existing reports on the varying responses of different zooplankton groups to climate change, despite multiple interacting stressors, three "universal" responses to ocean warming have been identified: poleward shifts in the geographical range, shifts in phenological timing and shifts towards smaller body size. However, these changes are not consistently observed. Range shifts vary greatly in strength and direction and are often species-specific. Additionally, smaller copepod species are likely to dominate under ocean warming, with cascading effects on fisheries production and carbon sequestration, however, this trend has not been observed in the Southern Ocean where average copepod community size shows a shift towards larger copepod species, and reasons for this change are still unknown. In terms of ecosystem function, changing zooplankton biomass, density and distribution will impact nutrient and carbon cycling, and energy transfer to higher trophic levels. For example, in the Japan/East Sea region, increased squid catches were due to increases in zooplankton biomass, particularly euphausiids and amphipods (Kang et al. 2022). In contrast, in the Straits of Georgia and more broadly within the Northern California Current, lower zooplankton biomass resulted in the impoverished growth and survival of juvenile salmon and herring (Mackas et al. 2013, Daly et al. 2017). It is important that data collected from various research and monitoring programmes be made publicly available to fully understand how zooplankton are changing under a changing climate, and examine the response to ecosystem function.

We identified 174 long-term zooplankton monitoring programmes in the global ocean, 79 of these were within the European region. Long-term monitoring programmes are well represented in coastal Australia, Europe, South Africa, and North America, but large gaps exist in coastal Asia, South America and much of Africa. Further, long-term monitoring programmes are severely lacking in offshore, open ocean locations. Moving forward, we must fill these gaps, either through establishing long-term monitoring programmes and/or developing new technologies that facilitate data collection in these remote locations.

Of all these monitoring programmes, ~19% had their data freely available, 9% partially available (i.e., part of the data available and part restricted/unavailable for various reasons), 13% available on request, 7% not available and ~52% were undefined (i.e., unable to determine data availability). An overwhelming 81% of the data collected from long term monitoring programmes is either partially available, not publicly available, or not 'Findable', which prevents the scientific community from answering large-scale questions about the response of zooplankton to climate variability (i.e., NAO) and long-term climate change. Renewed effort is needed from the research community, funders, and journals alike to ensure that crucial long-term monitoring data, particularly on zooplankton abundance, biomass and diversity required to understand phenology and range shifts, is made publicly available for global analysis to be undertaken.

The synthesis paper is currently under review in *Nature Communications*.

Task 2 Summary

The workshops and review article on seagrass, macroalgae and zooplankton respectively have allowed the observing community to make significant strides forward in identifying and improving knowledge and geographic gaps. For the macroalgal EOV, the EuroSea workshop identified that the key next step would be the establishment of a network that would coordinate, communicate, and integrate different protocols and data and work towards improving the status of macroalgal observation. For the seagrass EOV, observing programmes in Europe should actively engage with global efforts currently underway through C-GRASS and SeagrassNet that are working on establishing common protocols for monitoring and data flow. As the foundation for building an integrated observing system is currently underway through C-GRASS and SeagrassNet, the EuroSea workshop could address the next crucial step which is to identify key scientific knowledge gaps. Addressing these questions will improve the conservation of seagrass communities in European waters. For the zooplankton EOV, observing programmes should work towards making their data available, and the global community should work together to build observing programmes in underrepresented regions. More targeted workshops and reviews on different EOVs would be beneficial in improving the status of ocean observing in European, and global, waters.

Conclusion

The two workshops and review article allowed us to examine the capacity for ocean observing not just within Europe, but extended into the global ocean. Interestingly, much of the recommendations that stemmed from the macroalgal workshop are also applicable to advancing seagrass and zooplankton observations, as well as other EOVs, in the global ocean. The four recommendations outlined below are key to improving our capacity to monitor ocean health.

1. Improve data availability

While short-term studies yield valuable data that elucidate mechanistic responses to seasonal change, they cannot demonstrate decadal variability or long-term trends in marine ecosystems and communities. The seagrass community are actively working on data availability through the C-GRASS SCOR working group, however, the macroalgal workshop highlighted that only 35% of the participants had their data in the public domain, and the zooplankton review showed that an overwhelming 81% did not follow the FAIR data principles. Thus a key step forward is to educate and encourage programmes to make their data publicly available.

One such platform that can house the data has been developed by the Biology and Ecosystems data team. The team have developed an open access portal containing an interactive map along with metadata and spatial information of global ocean observing programmes monitoring biological and ecosystem EOVs. The aim is to establish and ensure a continuous flow of BioEco EOV data from observing programmes into OBIS as well as metadata on the observing programmes from the OBIS database into the BioEco metadata portal. This flow of (meta)data will ease the workload and time consumption of data providers, while controlling for duplication, quality and availability of metadata. These efforts require funding for continuity, but can act as a catalyst to improve data availability from observing programmes.

Additionally, there are many data repositories that exist (e.g., GBIF, EMODnet, OBIS, national data repositories) and efforts should be made towards developing higher interoperability/technology to exchange information between different platforms/databases.

2. Standardisation of protocols

Of the 532 entries we have that recorded observing programmes/sub-programmes within Europe, 448 programmes/sub-programmes use some form of SOPs and BPs, 25 programmes/sub-programmes do not, and no information on the remaining 57 programmes/sub-programmes. SOPs and BPs can use a range of methodologies. To work toward a 'uniform protocol', convergence of existing protocols/methodologies is essential. It remains unclear how many programmes identified here share sampling protocols. By ensuring that protocols/methodologies are shared in the Ocean Best Practices System (OBPS), a convergence process guided by Expert Panels can follow the OBPS Endorsement of methodologies. This would increase data sharing and data interoperability as well as trust in the data and information.

Standardised monitoring protocols are one way forward in creating interoperable datasets, but regular intercomparison studies are also required. We are unable to determine how many programs undertake intercomparison studies using the same methodology, but this question was not included in our original survey. An intercomparison study was undertaken between phytoplankton taxonomists across the DNAMAP program in Denmark and it was found a two-fold difference in estimates from the same sample, using the same method (Jakobsen et al. 2015), highlighting the importance of undertaking such internal reviews. It is important to examine if national and international intercalibration exercises are underway, and the results of which should be publicly available.

3. Community engagement

The seagrass community has demonstrated that working groups, such as C-GRASS, can significantly push progress in ocean observing across multiple areas (e.g., data, observation, intercomparison etc.) simultaneously. Participants in the macroalgal workshop have highlighted the desire and need for a network that can work on standardisation of protocols, data management, integration into existing programs, as well as improve communication from all stakeholders. Similarly, the zooplankton community highlighted large knowledge and geographic gaps, as well as limitations in data availability. A key step forward would be for each community to form working groups or networks that can progress the advancement of the ocean observing in a regional/global capacity. There are some that exist within the European regions (e.g., through HELCOM that have working groups on phytoplankton, fish, marine mammals, marine litter, benthic habitats, seabirds amongst others), and efforts should be made to identify these working groups and determine level of activity/engagement within each working group.

4. Improved coordination

Coordination at EOV level: The macroalgal workshop highlighted the need for the development of a coordinating agency or programme to improve communication between various stakeholders and facilitate standardisation of protocols and knowledge exchange. Coordination at the EOV level can take many forms, for example through the formation of a working group. The Scientific Committee for Oceanographic Research (SCOR) has an annual funding round that supports such working groups. The seagrass community formed the C-GRASS working group through SCOR, and this working group has successfully synthesised the status and trends in global seagrasses and best practices for coordinating interoperable data related to seagrass distribution and trends.

Regional coordination: The European Ocean Observing System (EOOS) framework is working towards better coordination of ocean observing within Europe. EOOS is led by EuroGOOS and supported by key stakeholders European Marine Board and JPI Oceans. In 2020-2023 many EOOS activities are supported through Horizon 2020 project EuroSea. In May 2021, EOOS published a concept note on the need to integrate biological observations into ocean observations. Using the information from EuroSea D1.2 (Map of observing networks) and D1.4 (Report on European BioEco networks), EOOS has an opportunity to take the next steps to bring the biological observing community together, and coordinate interactions between observing programmes and global coordination frameworks. There are two complementary frameworks that aim to support and coordinate global biological observing systems: (1) GOOS Biology and Ecosystems EOVs, and (2) Marine Biodiversity Observation Network's (MBON) Essential Biodiversity Variables (EBVs). Moving forward, EOOS should identify key pathways that can facilitate integration of biological observations into ocean observations and coordinate the European biological ocean observing within the two global frameworks.

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