# Towards a coordinated European Observing System for Marine Macroalgae

Workshop Report
23 – 25 November 2021

*Macroalgal beds* (Image by: Isabel Sousa-Pinto)

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# SUMMARY

Marine macroalgae are submerged vegetated ecosystems in shallow coastal waters throughout the world. They play key roles for coastal societies, contributing to fishery yields, storm protection, biogeochemical cycling and storage, and important cultural values. In Europe, macroalgae research and monitoring are undertaken to understand their importance and impact under a changing climate, and to meet national and regional policy requirements. This online workshop aimed to bring various stakeholders together to engage in a conversation in an effort to ensure the conservation and sustainability of macroalgae into the future. Through a series of presentation 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 programs, and develop key questions and recommendations for macroalgal monitoring in Europe.

## Day 1

## WORKSHOP BACKGROUND: rationale, goals, and expected products

The macroalgal co-chairs, Isabel Sousa-Pinto and Lisandro Benedetti Cecchi, welcomed the participants and provided an overview on the importance of macroalgae and the goals of the workshop. Macroalgae are primary producers, releasing oxygen during the photosynthesis process, and play a role in oceanic biogeochemical processes such as nutrient recycling and carbon export. They also represent an important habitat and nursery for a wide range of marine organisms, and are used in many industrial applications such as food, feed, cosmetics, bioplastics, pharmaceuticals/nutraceuticals, human and animal health and biofuels. Due to their many important roles for marine and human life, it is important to understand the current observing capabilities for macroalgal to ensure the continued functioning of the ecosystem. The key goals of this workshop were to develop standard operating procedures for data collection and storage that encompasses existing monitoring protocols, create an idealized workflow accounting for national/regional coordination reporting, identify knowledge gaps and priorities to be addressed and provide recommendations on future priorities to the observing/data community and national and regional coordinators.

This workshop is undertaken as part of the EuroSea project. Toste Tanhua, the EuroSea project lead, provided an overview of EuroSea to all participants. EuroSea aims to improve and integrate European Ocean Observing and Forecasting Systems for the sustainable use of the Oceans. The project has 55 partners in 16 different countries, and sets out to deliver essential information needed for the wellbeing of humanity, and the safety and sustainable development of the blue economy. The project has three overarching goals:

- To improve the European ocean observing system and integrate into a global context
- Deliver ocean observation data and forecast to increase knowledge about ocean climate, marine ecosystems and their vulnerability to human impacts
- Demonstrate the importance of the ocean and the significance for an economically viable and healthy society

Following the presentation by Toste Tanhua, the co-chairs discussed the Biodiversity strategy 2030 and monitoring within European waters, and provided a summary on macroalgal monitoring programs within Europe through a EuroSea survey.

*Biodiversity strategy 2030 and monitoring within European waters*
The European Biodiversity Strategy 2030 provides a background for the monitoring of biodiversity, including macroalgae: the objective is to protect 30% seas, including 10% strict protection, and of ecosystem restoration, now formalized in the Restoration Law, that sets legally binding targets, requires an improvement of biodiversity monitoring. At the moment there are different initiatives that are developing plans to support this improvement: the "EuropaBON – Europa Biodiversity Observation Network: integrating data streams to support policy" has a goal to propose a framework for Biodiversity monitoring in Europe. Biodiversa+ , the European Partnership for Biodiversity, is also working on the improvement of Biodiversity monitoring, including by funding projects to work on this. This work should be done in collaboration with the international community and using the Essential Variables: the Essential Biodiversity Variables (EBV), developed by GEO BON/MBON and the Essential Ocean Variables (EOV) developed by the GOOS Biology and Ecology Panel

*Macroalgal monitoring within European waters*
The EuroSea project undertook a survey to identify marine monitoring programs within European waters. The survey identified 42 monitoring programs for macroalgae in Europe run by 35 different organizations, and the oldest program that has been consistently running first begun in 1952. Sampling frequency for the various monitoring programs varied from bi-monthly, monthly, quarterly, every 1, 2, 3, 6 years and two programs use an opportunistic sampling strategy. Of these 42 programs, 34 programs used standard operating procedures or best practices and 8 programs did not respond. There are many regional coordination organization within Europe such as the International Council for the Exploration of the Sea (ICES), The Baltic Marine Environment Protection Commission – also known as the Helsinki Commission (HELCOM), The Convention for the Protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention') and the Black Sea Commission. The EuroSea survey found that 16 programs contributed to one or more forms of regional coordination (e.g., ICES, HELCOM, OSPAR, Black Sea Commission), 6 were purely scientific research programs, and no information was provided by the survey respondents on the remaining 33 monitoring programs. With regards to data availability from these monitoring programs, 50% of the monitoring programs submitted their data to EMODnet, 19% in national data centers, 27% in other repositories (ICES, LTER-DEIMS, GBIF etc.) and 4% did not make their data publicly available.

Based on the key goals outlined above, this workshop first delivered presentations on Day 1 from various stakeholders to discuss data availability and pathways for data integration, funding for macroalgal monitoring, importance and sustainability of macroalgae, linkages with global and intergovernmental initiatives such as the Marine Biodiversity Observation Network (MBON), the Global Ocean Observing System (GOOS) and the Convention on Biological and potential integration with the monitoring of marine litter. Following these presentations, on Day 2 and 3 the workshop moved into a presentation and open discussion format to discuss standard operating procedures for visual surveys, eDNA and remote sensing, and integration of macroalgal monitoring with the monitoring of marine litter. This report follows the workshop format and presents a summary of the presentations, and discussion points and recommendations from the workshop.

# DATA SHARING PRACTICES

## *Overview of the Ocean Biodiversity Information System (OBIS)*

*Ward Appletans, OBIS*

The Ocean Biodiversity Information System (OBIS) is a platform for ocean biodiversity data. As data is collected from the user, it is integrated, standardized and quality controlled through the various OBIS nodes, and then integrated into a central data system. OBIS houses 80 million occurrence records, 150 million measurements or facts, 155 thousand species, +4,000 datasets. The majority of users are scientists, and more than 10 papers per month cite OBIS as their data repository or data source. OBIS records presence/absence, abundance/biomass, habitat/ecosystems, historical records, tracking/biologging and introduced

ExendedMeasurementOrFact Extension in 2017 where genetic metabarcoding and quantitative PCR data as well as satellite and drone data can be included.

## *Overview of EMODnet Biology*

*Joana Beja, EMODnet Biology*

EMODnet Biology started in 2009 with a focus on marine biological data from six marine regions (Arctic, Atlantic, Baltic, Black Sea, Mediterranean, North Sea) and 9 functional groups (angiosperms, macroalgae, benthos, birds, fish, mammals, phytoplankton, reptiles and zooplankton). EMODnet Biology uses the EurOBIS data infrastructure, as such all data flows to OBIS and the Global Biodiversity Information Facility (GBIF). EMODnet Biology aims to develop interoperable products for assessing the environmental state of the overall ecosystems and sea basins. There are 343 datasets in EMODnet Biology with macroalgal data, and macroalgae products within the MEDISEH: Mediterranean Sensitive Habitats project. EMODnet Biology has two thematic logs: EMODnet Seabed Habitats which provide seabed habitat data within Europe and EMODnet Human Activities which provides access to marine data and activities carried out in European waters. EMODnet Biology, EMODnet Chemistry and EMODnet Seabed Habitats support the Marine Strategy Framework Directive (MSFD) through various pathways. EMODnet Biology ran a stakeholder event in May 2019 to promote the use of EMODnet integrated datasets for MSFD assessments. EMODnet Chemistry has a pan-European marine litter database and maps that form the official monitoring data baseline for MSFD reporting, and EMODnet Seabed Habitats maps are classified according to MSFD habitats and are currently being used for MSFD. In June 2021, EMODnet and Copernicus published a catalogue with products relevant for the MSFD descriptors (except Descriptor 4) in the Baltic Sea.

## *Understanding data flow*

*Ward Appletans and Joana Beja*

All data provided from individual providers, European Regional nodes, Regional OBIS nodes (e.g., medOBIS, OBIS Black Sea and OBIS U.K), Thematic OBIS nodes that contain European Marine Data (e.g., OBIS SEAMAP, OBIS Deep Sea, Harmful Algal Bloom) contribute their data to EuroOBIS. All European Marine Data is then made available in OBIS and GBIF – this is a two-way data flow (Figure 1).

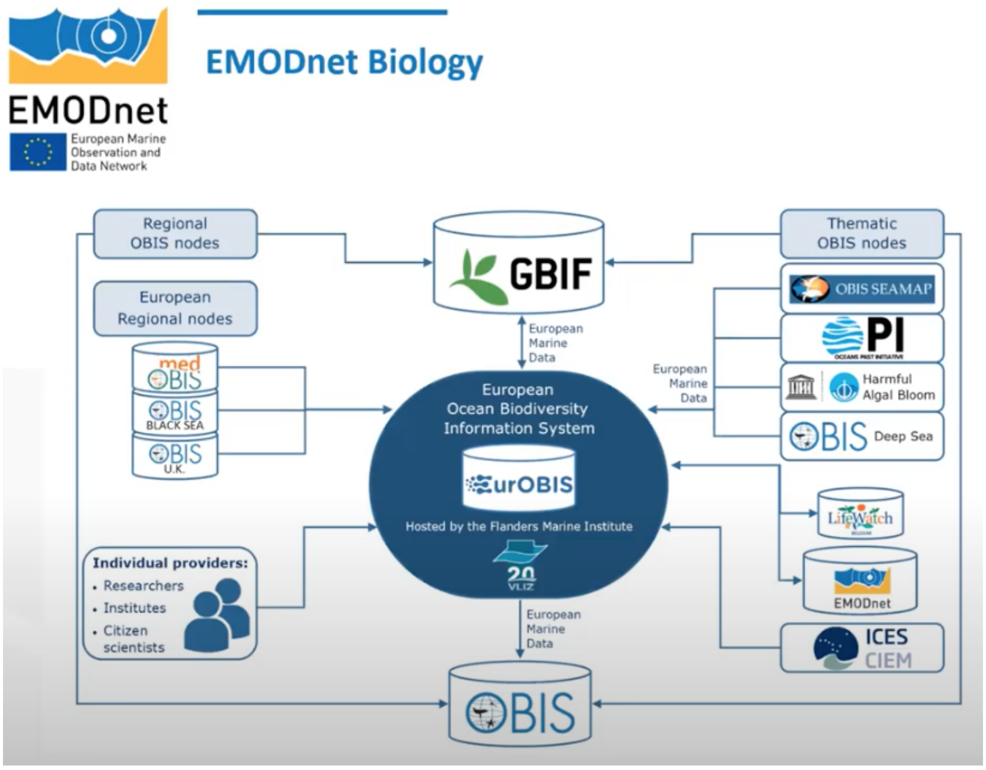


Figure 1: The various data providers that contribute to EMODnet Biology (source: Joana Beja's presentation at the macroalgal workshop).

To conclude this discussion on data, Ward Appletans undertook a live, online survey with the workshop participants. 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 standardized 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 did not know if their data is formatted following international standard and 41% said no data standards were followed
- 58% said datasets do not have a Digital Object Identifier (DOI), 32% do have a DOI

A key recommendation from this survey and discussion is to educate and train the public on data standards and encourage the community to ensure data are following the FAIR (findable, accessible, interoperable and reusable) data principles. One way forward is to ensure that funders require FAIR data in projects, which will significantly improve data availability. Additionally, requesting researchers to provide metadata and letting the aid platforms do the reformatting will improve the transfer and use of these platforms. For example, TemperateReefBase uses this method.

# SUSTAINABILITY AND INTEGRATION

In Session 2, there were presentations on sustainability 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 programs such as the Convention on Biology Diversity, and lastly integration with other monitoring programs, with a focus on marine plastics.

## *Horizon Europe: The EU Research and Innovation Programme*

*Rodrigo Ataide, DG Mare*

Horizon Europe is the biggest EU Research and Innovation Programme with € 95.5 billion allocated for the years 2021-2027. Horizon Europe has 3 pillars to support the activities.

**Pillar I – Excellent Science** – European Research Council, Marie Sklodowska-Curie and Research Infrastructures.

**Pillar II – Global challenges and European Industrial competitiveness** – 6 clusters on Health, Culture, Creativity and Inclusive Society, Civil Security for Society, Digital, Industry and Space, Climate, Energy and Mobility, and Food, bioeconomy, natural resources, agriculture and environment. (Cluster 6 has a dedicated 'Ocean, seas and waters' component')

**Pillar III – Innovative Europe** – European Innovation Council, European Innovation Ecosystems, and Europe Institute of Innovation and Technology.

Mission Restore our Oceans and Waters aims to restore our oceans and waters by 2030 and 25,000 km of free-flowing rivers, reducing plastic litter at sea by 50%. Specifically, the objectives are to: 1) Protect and restore marine and freshwater ecosystems and biodiversity in line with EU Biodiversity Strategy, 2) Prevent and eliminate pollution in line with EU Zero Pollution Action Plan, and 3) Make the sustainable blue economy carbon-neutral and circular in line with EU Climate Law.

For the purposes of this workshop, there is a particular Horizon call of interest which is the Horizon-CL6-2021-CIRCBIO-01-09 'Unlocking the potential of algae for a thriving European blue bioeconomy.

## *EU macroalgae sector and needs for ocean observation*

*Maris Stulgis and Zoi Konstantinou, DG MARE*

The European Green Deal is the EU's answer to climate change, biodiversity loss and environmental degradation. The farm-to-fork initiative will contribute to achieving a circular economy and specifically mentions algae.

EU macroalgae production is small compared to other countries (e.g., Asia is currently dominating the market). In Europe there are 151 companies that produce macroalgae in 12 countries. As of 2019, macroalgae production was estimated to weigh ~267,489 tons wet weight and there is potential for growth as the cold, nutrient-rich waters across Europe's marine areas are suitable for macro-algae cultivation. Within the Blue Bioeconomy Forum Roadmap, macroalgae can contribute to the following areas of the EU: 1) sustainable aquaculture, 2) sustainable food systems and food security, 3) contribution to climate mitigation and adaptation and 4) circular economy and bio-based products. The EU algae Initiative and macroalgal production is to improve the governance framework, support the improvement of the business environment, increasing social awareness and acceptance, and closing the knowledge, research, technological and innovation gaps.

How will the macroalgal sector be sustainable? There will need to be more cultivation than harvesting, and harvesting will have to be managed well. Whilst there is in-situ and satellite data, there is a lack of cooperation between member countries on ocean observation for multiple activities. In order to improve this, the Ocean Observation Initiative was established to improve connections between member states on research, monitoring and business development. Observations on temperature, salinity, water velocity, wave power, nutrients, heavy metals etc. are required as a base for a full understanding of macroalgal potential, ecosystem services and impact.

## *Linking GOOS and MBON to advance the monitoring and assessment of macroalgae globally.*

*Frank Muller-Karger, University of South Florida*

GOOS was established under co-sponsorship from the International Oceanographic Commission (IOC), World Meteorological Office (WMO), United Nations Environment Program (UNEP) and the International Science Council (ISC) to deliver information essential for sustainable development, safety, wellbeing and prosperity. In 2014, at the same time that the Biology and Ecosystems panel of GOOS was established, the Marine Biodiversity Observation Network (MBON) was established to standardize and integrate data to understand marine biodiversity and ecosystem function. Marine Life 2030, a program under the United Nations Decade of Ocean Science, aims to bring various groups together, including GOOS and MBON, to connect science and user needs, build technical capacity, standardize and coordinate marine life monitoring and broaden participation and mainstream applications of biodiversity information.

The two frameworks within GOOS and MBON are the Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs) respectively. The Macroalgal canopy cover and composition EOV specification sheet has been curated and designed by Lisandro Benedetti-Cecchi and reviewed by Emmett Duffy (Smithsonian Environmental Research

Centre, and seagrass EOV lead) and David Obura (CORDIO East Africa, and hard coral EOV lead). The sub-variables for the macroalgal EOVs (e.g., canopy species diversity, canopy height, stem density, plant condition, plant size classes, photosynthetic efficiency and biomass, and areal extent) are used to derive habitat extent, canopy health indices, global geographic distribution, primary production, and essential fish habitat extent. Some of the supporting variables required for this EOV include photosynthetic active radiation (PAR), Temperature, Nutrients, Salinity, Sediment, Substratum type, water clarity, minimum fluorescence and effective quantum yield. The macroalgal EOV specification sheet requires continual updates and review from the community, a key need moving forward.

## *Macroalgae and the CBD Post-2020 Global Biodiversity Framework*

*Nic Bax, The Commonwealth Scientific and Industrial Organisation, Australia*

There has been a decline in kelp forests in 28% of ecoregions for which there are data available. Despite over 500 Multilateral Environmental Agreements (MEAs) focused on monitoring and assessment, habitat loss is still the second largest driver of ecosystem change.

The Convention on Biology Diversity (CBD), which opened for signatures in 1992, has a goal for sustainable use, conservation and equity. There are 192 countries, stakeholders and non-governmental organizations (NGOs) that meet every 2 years at the Conference of the Parties (COP). Prior to 2020, countries reported what they were doing, but the post 2020 agenda focuses instead on the status of biodiversity. The vision is that by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits for all people. The approach is a post 2020 global monitoring framework following the theory of change. It has 4 status goals and 24 action targets which indicates how countries are responding to loss of biodiversity. Headline indicators on the status goals and action targets will be reported by each country. With regards to the headline indicators, macroalgae are noted within Goal A.0.1 which is on habitat status (Goal: Extent of selected natural and modified ecosystems (i.e. forest, savannahs and grasslands, wetlands, mangroves, saltmarshes, coral reef, seagrass, macroalgae and intertidal habitats)). It is classified as a ‘systems in place requiring global/thematic expansion’. Other areas the macroalgal community could contribute to include Goal A.0.2 on Species Habitat Index, Target 4.0.2 on plant genetic resources for food and agriculture secured in medium or long-term conservation facilities, and Target 6.0.1 on rate of invasive alien species spread.

Whilst macroalgae does not yet have the same profile of coral reefs, mangroves and seagrasses, there are opportunities to raise the profile through carefully selected marine indicators used in the many MEAs and ocean reports. The CBD Post-2020 global biodiversity framework indicators will influence Strategic Development Goals (SDG) indicators for 2030 and the new UN SEEA Ecosystem Accounts. Macroalgal status (extent, connectivity and integrity) could be a key indicator. Being relevant requires the community to come together to agree on monitoring protocols, data handling, reporting standards etc. and one way to do this is through the UN Decade for Ocean Science for Sustainable Development, particularly through Marine Life 2030. A key recommendation moving forward is to bring the macroalgal community together to raise the profile of macroalgae and reporting into various MEAs, potentially through the Global Ocean Macroalgal Monitoring Network (GOMON).

## *Integrating macroalgal and marine litter monitoring: rationale and opportunities.*

*Artur Palacz, IOCCP/IO PAN, Poland*
*Matteo Vinci, EMODnet Chemistry*
*Victor Martinez Vicente, Plymouth Marine Laboratory*

Marine Plastics Debris has been recognized as an emerging EOV, and a first version of the EOV Specification Sheet was prepared with support from the EuroSea project. By supporting the development of an Integrated Marine Debris Observing System (IMDOS), GOOS aims to utilize the capacity of the ocean observing system to support marine plastics debris monitoring and address gaps in monitoring and knowledge required for regional (e.g., EU MSFD Descriptor 10) and global (e.g., SDG Target 14.1) policy targets.

There are opportunities to integrate macroalgal and marine litter monitoring because the in situ observing methods are the same for marine litter as they are for macroalgae (i.e., visual scuba diving and/or ROVs). In addition, there are minimal requirements for seafloor macroplastics (>2.5 cm) to be included in the standard operating procedures (e.g., rectangle area/line transect for counting litter items, reported in density of litter items per category per $m^2/km^2$). There is a harmonized list of macrolitter categories for standardized monitoring available, developed by the MSFD Technical Group on Marine Litter, and advanced development of a unified marine litter ontology (UNEP Global Partnership on Marine Litter Ontology Community of Practice) to support harmonized data flows to inform regional and global indicator frameworks. Furthermore, EMODnet and OBIS are ready to ingest marine plastics data, however visual survey data products are in the planning stages at present. There already exists some interaction between plastics pollution and macroalgae, which is an open research question, and there is interest from a few monitoring groups to augment existing macroalgal monitoring surveys with parallel shallow seafloor macrolitter observations. There is also the possibility of retrospective analysis of macroplastic abundance on shallow seafloors through archived imagery from past macroalgal surveys. Similarly, there are opportunities for applying common satellite remote sensing algorithms to provide large scale surface ocean estimates of floating macroplastic patches and floating macroalgae; and to set common requirements for future developments in coastal biodiversity and marine plastic debris observations from space.

Some challenges that could be encountered include: 1) A different focus is required with litter items being as small as 2.5 cm (this proved very challenging when attempting integration with marine mammal surveys), 2) Many macroalgal sites do not show macrolitter accumulating (thus not all areas might require regular observations), 3) Main research interest isin the interaction between microplastics and macroalgae (accumulation in the seabed, adhesion on the organisms) but no logistic benefit of combining surveys, and 4)
It is not possible to integrate sampling requirements for eDNA and microplastics (very large water volumes required for the latter). A key recommendation moving forward is to establish initial pilots within interested macroalgal monitoring initiatives in collaboration with the MSFD Technical Group on Marine Litter and EMODnet Chemistry (for data ingestion), and if possible, combine surveys with cleanup.

## Day 2

### BEST PRACTICES AND STANDARD OPERATING PROCEDURES

Day 2 focused on best practices and standard operating procedures for visual surveys, eDNA and remote sensing. The session started with an overview presentation by Lisandro Benedetti-Cecchi and Jarret Brynes (University of Massachusetts Boston). Each sub-topic was open for discussion and led by a moderator. The discussion on visual surveys was led by Nova Mieszkowska (University of Liverpool), eDNA was led by Aschwin Engelen (CCMAR, Universidade do Algarve) and remote sensing by Victor Martinez Vicente (Plymouth Marine Laboratory). To engage the online participants, an online tool, Padlet, was used. Within Padlet, we could ask questions and participants could respond to the question by posting texts and comments. Below we summarize the overview presentations, and questions and responses from the discussion section.

### *The need for macroalgal observations*

*Nova Mieszkowska, University of Liverpool*

There is a global ecological emergency that carries a financial cost of $1 trillion by 2100. There are long-term changes from multiple stressors (e.g., ocean acidification, climate change, microplastics etc.), extreme events (e.g., heatwaves, increased storms), habitat loss, algal blooms and others. There are various efforts to European directives and drivers that are in place:

- The EU Biodiversity Strategy wants to establish a larger EU-wide network of protected areas on land and at sea by 2030.
- The European Green Deal aims to protect, conserve and enhance the EU's natural capital.
- The EU Habitats Directive include EU wide Natura 2000 ecological network of protected areas
- Marine Spatial Planning Directive which has been put into place to cope with increasing demand for maritime space while preserving the proper functioning of the marine ecosystems
- Nature Best Solution, which has been highlighted in the European Green Deal, EU Biodiversity Strategy for 2030, and the new EU Strategy on Adaptation to Climate Change. Macroalgae are important in the Blue Bioeconomy and Biotechnology, not just for seaweed farming, but they are also needed for pharmaceuticals etc.
- Blue carbon because coastal ecosystems sequester and store large quantities of organic carbon. Macroalgae sequesters similar amounts of carbon to all other blue carbon habitats combined, further highlighting the importance of macroalgae.

Consistent monitoring has highlighted the impacts of climate change and extreme events on macroalgal sites within the MarClim sites in the United Kingdom. There is a need for better integration and harmonization of methodologies, protocols and data to ensure that we can measure changes at a much wider geographic scale.

## *In Situ Observations of Macroalgae: Principles and Best Practices*

*Jarret Brynes, University of Massachusetts Boston*

Jarrett provided an overview of the previous macroalgal workshop held at the University of Tasmania to develop visual observing standard operating procedures. A key problem is how do we assess change in algal abundance over time with our eyes? There is a wide variety of methods used in intertidal and subtidal environments. In a survey of 74 different programs, sample units can vary from large belt transects, small quadrats or points, area per sample unit could range from 0.25 $m^2$ to 250 $m^2$, length of areas sampled ranged from 10 m to 600 m, there were between 2 to 100 replicates per event, sampling frequency varied from monthly to decadal, measurement type ranged from percent cover, count and biomass and the taxonomic specificity could include species, genus, functional groups or combination of these. Having different techniques may or may not be a problem. For example, it is not a problem as long as units can be converted between monitoring programs, and if looking at the same species in the same location, but it is a problem when we look at different species across different systems.

The new goal is to develop a protocol for an individual researcher to follow one macroalgal community at one site over time. The sampling protocol is currently being prepared for the intertidal and subtidal setting and pilots are being undertaken in the UK and the Gulf of Maine, USA. CATAMI is being used as a solution to non-taxonomic identification. Legacy data is still important and an ontology of sampling has been devised that will incorporate pre-existing programs. This will allow ingestion, as long as they can put the data into the standardized format.

## *Molecular techniques (eDNA): Monitoring macroalgae from a bottle of water*

*Aschwin Engelen, Universidade do Algarve*

Traditional monitoring requires taxonomic expertise and is time consuming, whereas eDNA, a mixture of shed DNA without physical presence of the organism or the entire microorganism, can be collected from a water sample or the sediments. Briefly, the water is collected and filtered. The filter will contain the DNA which is then extracted and amplified. The DNA will then be sequenced and the sequence will go through a bioinformatics pipeline to get a barcode to identify the organism. There are technical issues (e.g., contamination) thus it is important to have positive and negative controls. The advantages are that it requires no taxonomic expertise, can detect cryptic and low abundance organisms at any life stage, fieldwork is simple and fast with minimal training requirement, it is non-destructive, can provide within species insights, reveal genetically cryptic species and/or variance within a species and can integrate across the tree of life. The disadvantages is that we are not able obtain information on abundance, biomass or size structure (this can be partially overcome by targeted approach with qPCR), molecular costs are high but prices are going down with further technique development, outsourcing sequencing and bioinformatics is time consuming, and requirement for controls. Key challenges are to create a uniform protocol 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.

## *EU Marine Strategy Framework Directive Technical Group on Marine Litter: Shallow Seafloor Macro Litter surveys*

*Georg Hanke, Joint Research Centre, European Commission*

The goal of the MSFD Descriptor 10 "Marine Litter" (which includes plastic as well as other types of litter/debris) is to ensure that properties and quantities of marine litter do not cause harm to the coastal and marine environment. Specifically, D10C1 focusses on the fact that composition, amount and spatial distribution of litter on the coastline, in the surface layer of the water column and on the seabed, are at levels that do not cause harm to the coastal and marine environment. Litter shall be monitored on the coastline and may additionally be monitored in the surface layer of the water column and on the seabed. Information on the source and pathway of the litter shall be collected, where feasible. The MSFD Technical Group on Marine Litter is part of the MSFD Common Implement Strategy working group set up to inform, discuss, agree, advise and provide guidance. The working group is chaired by France and the European Commission Joint Research Centre.

Macro litter monitoring required an agreed list of litter items for acquisition of comparable data. The Joint List of Litter Categories for unambiguous identification of macro litter was developed by the Technical Group on Marine Litter in close collaboration with the Regional Seas Convention (OSPAR, HELCOM, MAP, BSC). A workshop was also undertaken to look at the different methodologies for different compartments (e.g., visual, imaging, trawling etc.). A recommendation from this is to have rectangular survey sites, observing and removing litter items in that defined rectangular site, choose multiple rectangular survey sites in the monitored area for improving representability and use the metric of litter abundance ($m^2/km^2$). Since 2013, there has been guidance for the monitoring of marine litter, but this is currently being updated. In an effort to harmonize the monitoring of shallow seafloor litter, the next steps include setting up data ingestion portals for individual surveys by EMODnet, implementing the Joint List of Litter Categories at large scale across all matrices, enable and facilitate opportunistic, targeted and voluntary data acquisition and ultimately, establish shallow seafloor macro litter monitoring at large scale.

# DISCUSSION

Following the end of the presentations for Day 2, the workshop transitioned into a discussion session using an online platform, Padlet. A series of questions were posted on the platform and sessions moderators engaged with the participants with these lists of questions. The questions and summary of answers are recorded below.

## *Visual surveys*

*Nova Mieszkowska, University of Liverpool*

1. **Do the current monitoring programs meet the European reporting needs (e.g., MSFD, Habitats Directive etc.) and the needs of the algal sector?**

   - There are a number of diversity methods (e.g., reduced species list, green algal cover etc.) that are intended for specific contexts and thus may not be applicable for wider application.
   - Article 17 reporting occurs once every 6 years which is too infrequent.
   - It is necessary to undertake more inter-calibration for indicators.

2. **Can they answer pressing biodiversity questions (e.g., impact of climate change, macroalgal blooms etc.)**

   - There are two hurdles to overcome – 1) mixing datasets with different protocols, and 2) uniting those data sets with assessments of impacts at matching spatial and temporal scales. Questions on ecosystem function require more interoperable data for content that addresses spatial and temporal scales.
   - Some countries look at impact of harvesting (e.g., France and Norway) but more countries should also investigate this
   - Macroalgal blooms are ephemeral and thus difficult to capture with annual monitoring. Thus, more frequent monitoring is required.
   - Monitoring methods tend to focus on percent cover, however the translation from percent cover to biomass is not straightforward. However, percent cover is a good match for remote sensing.
   - There is a need to design programs that separate climate signals from confounding processes across spatial and temporal scales. One method forward is to undertake causal analysis from Econometrics and how to solve the problem of Omitted Variable Bias (e.g., The Causal Mixtape by Scott Cunningham).

3. **How can we design a monitoring program to fit multiple objectives?**

   - There is a need for more baseline/reference data
   - There is a need for protocols for remote and non-remote areas (e.g., eDNA protocols will change depending on access to facilities such as freezers)
   - OBIS eDNA webinar includes link for data properties (https://obis.org/2021/10/13/gendatawebinar/)
   - GBIF has an eDNA guide (https://data-blog.gbif.org/post/gbif-molecular-data/)
   - There is an eDNA notebook (https://iobis.github.io/notebook-dnaderiveddata/)

4. **Are there existing links between monitoring programs? Have any cross comparisons been done between existing monitoring programs?**

   - GBIF and OBIS are common links
   - Production of collaborative papers using multiple datasets (e.g., BIOTIME)

## *eDNA*

*Aschwin Engelen, Universidade do Algarve*

1. **Which monitoring programs already integrate eDNA?**

   - There are some monitoring programs on marine fauna that integrate eDNA but this would be good to integrate with macroalgae, noting that reference data is needed.

2. **What would you expect to gain by using eDNA?**

   - eDNA can
     - Gain more accurate community characterizations (e.g., identifying rare/cryptic species which often get overlooked)
     - Be used to estimate biomass, abundance and density (https://onlinelibrary.wiley.com/doi/10.1002/ece3.3764)
     - Reveal taxa not seen visually
     - Identify taxa not known as genetics reveal cryptics that are not seen in the morphology
     - Be used to explore metabarcoding or reveal targeted taxa (e.g., endemic, invasive, important etc.)
   - However, it can be difficult to separate eDNA detections from live specimens in a habitat, or if eDNA is from debris drifting away. Circulation is a known effect on eDNA detections for invertebrate fauna, and during spawning. (https://onlinelibrary.wiley.com/doi/full/10.1002/ece3.4213)

3. **Which eDNA protocols are used?**

   - Visual survey operators could take a water sample and send it to labs with eDNA facilities to begin developing an inter-calibration database.

4. **Is there a local barcoding reference database?**

   - Curation is a big problem for eDNA samples.

## *Marine litter*

*Artur Palacz, International Ocean Carbon Coordination Project / Institute of Oceanology Polish Academy of Sciences*

1. **Are there examples of programs which combine visual surveys to monitor both macroalgae and seafloor plastics?**

   - A programme combining both types of surveys has been operating in Estonia, led by Tiia Möller-Raid (University of Tartu, Estonia), based on a series of recently completed and ongoing projects. Survey overview available from: TÜ EMI 2018. Monitoring of seafloor litter in coastal sea of Estonia, development of methodology and assessment for MSFD reporting *(in Estonian).*
   - A pilot study engaging citizen science divers to monitor seafloor macrolitter was initiated in the project AWARE, with potential for survey co-design
   - Retrospective visual analysis could be undertaken in areas where images from visual surveys are being archived

2. **Can the macroalgal survey SOPs accommodate the needs of seafloor macrolitter monitoring considering that the visual monitoring methods are very similar, if not the same? What are the potential obstacles and how can they be overcome?**

   - The basic requirements for simple transects/survey of areas look compatible, but practicalities for litter collection need to be explored.
   - An obstacle would be to standardize the litter records. Acontrolled vocabulary needs to be promoted, with guidance from EMODnet and in consultation with international initiatives such as the UNEP GPML Ontology Community of Practice.

3. **Hotspots of litter accumulation may not coincide with location of Marine Protected Areas (MPAs) or biodiversity hotspots. On the other hand, the need to maintain MPAs litter-free is more critical. How do we select priority areas for joint biodiversity and litter monitoring?**

   - As there is almost no data yet, widespread monitoring could be beneficial. This includes supposed-to-be pristine areas as well as local hotspots (e.g., close to cities or even historical dumpsites).
   - Substratum type is incredibly valuable information for marine litter

## *Remote sensing*

*Chuanmin Hu, University of South Florida*

This discussion session started with a presentation by Chan Min Hu on remote sensing methods to observe macroalgae from space, followed by a discussion. To observe macroalgae from space, first it is important to measure reflectance and biomass density and determine their relations. Then it is a multistep process of detecting the spatial anomaly, classifying the spectral shape, use a field-based algorithm to analyze the image, then aggregate many images (spatial/temporal binning) to see how often each pixel contain macroalgae, and how much macroalgae is contained within the pixel. There is a remote sensing macroalgae monitoring currently being undertaken called *Sargassum* Watch from Space (SaWS) (https://optics.marine.usf.edu/projects/saws.html). The same concept was applied to other regions and species (e.g., *Ulva* green macroalgae, *Sargassum horneri* macroalgae). Detecting and quantifying floating macroalgae can be achieved from nearly all VNIR satellite sensors. The techniques are relatively mature and there are existing systems for certain regions. There is no perfect satellite to achieve the goal of daily monitoring because there is a tradeoff between coverage, resolution and revisit frequency. Currently remote sensing methods have some challenges including data gaps in coastal waters, understanding and quantifying uncertainties, understanding spatial/temporal patterns for better forecasts, automating for different regions to better fit user needs and transferring the methodology to other floating matters (e.g., marine litter).

1. **What are some of the pressing biodiversity/macroalgal scientific questions?**

   - Spatial/temporal distributions of different types of macroalgae and their associated biodiversity
   - What are the driving factors behind these spatial/temporal changes?
   - What are their roles in marine ecology and carbon cycling?
   - When do they transit from a useful habitat to marine or beach nuisance?
   - What are the best ways to mitigate inundation impacts?

2. **For marine litter from remote sensing, we have found that accumulation of litter on frontal structures and on shorelines are the most important and tractable scenarios at present. Do you think that they are also the most important for macroalgae monitoring and scientific purposes?**

   - No because macroalgae tend to self-organize and form elongated slicks (rafts) that are not necessarily aligned with fronts. They can follow wind and currents to meander to various shapes. Eddies may aggregate macroalgae, but the mechanism is not fully understood.

3. **What is the minimum level of aggregation among macroalgae to be useful for biodiversity studies (e.g., is it sufficient to classify macroalgae in green, brown, or red for a specific question or more separation is required?)**

   - Red, green and brown is useful but sometimes species-specific data are necessary (e.g., monitoring invasive species or biodiversity)
   - More information is required than just color, such as the size of macroalgae aggregation.

4. **For floating marine litter from remote sensing, it is important to have at least one observation per day. Would this also be important/useful for macroalgae?**

   - Higher frequency is better but not always necessary. Macroalgae do not change very fast (doubling time may be a week), so weekly cloud free observations may be enough for large-scale distributions. However, for beaches and nearshore waters, more frequent observations are required to know their changing locations in a timely fashion. For whole community monitoring, quarterly observations are fine but for picking up blooms, monthly or even weekly repeat times are necessary.

5. **For detecting accumulations of floating marine litter from remote sensing, it is important to have at least a spatial resolution of 10 m. Would this also be important/useful for macroalgae research?**

    - There is a tradeoff between spatial resolution and spatial coverage (revisit frequency). For open-ocean monitoring, Sentinel-3 resolution and coverage are good enough. For nearshore/coastal waters, Sentinel-2 (10 m) or higher resolution is preferred. But for nearshore-coastal waters, we also need more frequent data than Sentinel-2.

## Day 3

## WORKSHOP SYNTHESIS

### *Synthesis from visual surveys*

There is a need to identify how datasets can be interoperable, and work towards standardisation of protocols. More baseline data is required from visual survey observations that can facilitate integration with eDNA and remote sensing.

### *Synthesis from eDNA*

Based on the programs currently being undertaken by workshop participants, 19% of the participants include eDNA in their survey. There are no common established protocols amongst participants but there is motivation to develop a common protocol and begin a pilot project. Key future steps forward are to develop standard operating procedures from sampling to data curation, identify locations to undertake pilot project and identify funding mechanisms to undertake the projects (funding will depend on scale of operations).

### *Synthesis from remote sensing*

For marine litter and remote sensing, the accumulation of litter on frontal structures and on shorelines are the most important and tractable scenarios at present. Based on workshop participant discussions, the community is interested in benthic (sub and inter tidal) ecosystems. Identifying green, red and brown algae are useful but this needs to be enhanced to determine if species specific data can be obtained. With regards to sampling frequency, once a month is adequate but under some instances (e.g., cloud cover, tidal height etc.) greater frequency is needed. More validation and standardization is required to match in situ data with current satellite capability and a key focus should be developing this cross calibration.

### *Synthesis from marine litter*

Observing methods for seafloor plastics are the same as for macroalgae (i.e., visual scuba diving and ROVs). There are minimal requirements for seafloor macroplastics (>2.5 cm) to be included in the Standard Operating Procedures. These requirements would be a rectangular area/line transect for counting litter items and litter items reported in density of litter items per category per $m^2$/$km^2$. There is a harmonized lit of litter categories for standardized monitoring currently available, advanced development of marine litter ontology to support indicator frameworks (e.g., MSFD and SDG), and EMODnet and OBIS are ready to ingest marine plastics data (visual survey data products are in planning stages only). However, some challenges do exist, such the difficulty in integrating programs (e.g., plastics monitoring with marine mammal surveys) when litter is as small as 2.5 cm, many macroalgal sites do not show macrolitter accumulating and thus not all areas might require regular observations and it is not possible to integrate sampling requirements for eDNA with microplastics as very large water volume is required for eDNA. A key recommendation moving forward is to develop a pilot project that combines visual surveys with macrolitter monitoring. Initial exchange with Nova Mieszkowska on MarCLIM was facilitated through this workshop.

## *Next steps following the workshop*

Following these summaries, we used Padlet to get feedback from the participants on 3 questions:

1. Where do we want to be in 10 years?

    - Have standardized monitoring protocols which includes data availability
    - Have an integrated community
    - Have a standard macroalgal cover and composition layer that is updated quarterly on OBIS so we can study change
    - Have a reference community for reporting and informing policy
    - Data flowing smoothly from local repositories or a GDAC into a harmonized resource in OBIS
    - An updated bank of taxons for morphology and genetics
    - An established citizen science program for monitoring macroalgae

2. What are the key recommendations?

    - Ensure that MSFD requirements are more consistent across Europe
    - Develop training protocols for data by OBIS/EMODnet
    - Make data deposition into an OBIS affiliated repository requirement for funding
    - Establish an online location where all individuals monitoring macroalgae in Europe can communicate and liaise with each other about their monitoring protocols and activities.
    - Improve communication with remote sensing groups
    - Develop the use of satellites and increase the number of validation sites
    - Seek agreement on data models, workflows, and infrastructure required to support data aggregation to OBIS
    - Develop new pilot projects combining visual macroalgal and macrolitter coastal surveys
    - Undertake further workshops to build the community
    - Develop a SCOR Working Group proposal

3. What are the important questions to address for macroalgae?

    - What are the current limitations for combining data for marine macroalgae?
    - Which are the areas of the ocean currently under sampled?
    - What are the current connections among marine macroalgae observing system?
    - What are the limitations around the different methodologies being used by different monitoring projects?
    - How do we improve validation of remote sensing data?
    - How can we sync our macroalgal measurements with environmental measurements at different scales in a standardized way to assess the effects of global change drivers on macroalgae?

## WORKSHOP SUMMARY: key recommendations moving forward

- Current monitoring programs 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. Additionally, Article 17 reporting occurs once every 6 years which is too infrequent.

- MSFD requirements should be more consistent across Europe.

- 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.

- environmentalDNA (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 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.

- Various reasons drive the lack of data availability. To combat this efforts should focus on: 1) Developing training  protocols by OBIS/EMODnet, 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.

- 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 programs can be integrated.

- 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.

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