THE MARINE BIODIVERSITY OBSERVATION NETWORK PLANKTON WORKSHOPS

Plankton Ecosystem Function, Biodiversity, and Forecasting—Research Requirements and Applications

Maria Grigoratou, Enrique Montes, Anthony J. Richardson, Jason D. Everett, Esteban Acevedo-Trejos, Clarissa Anderson, Bingzhang Chen, Tamar Guy-Haim, Jana Hinners, Christian Lindemann, Tatiane Martins Garcia, Klas O. Möller, Fanny M. Monteiro, Aimee R. Neeley, Todd D. O'Brien, Artur P. Palacz, Alex J. Poulton, A. E. Friederike Prowe, Áurea E. Rodríguez-Santiago, Cécile S. Rousseaux, Jeffrey Runge, Juan F. Saad, Ioulia Santi, Rowena Stern, Alice Soccodato, Selina Våge, Meike Vogt, Soultana Zervoudaki, and Frank E. Muller-Karger

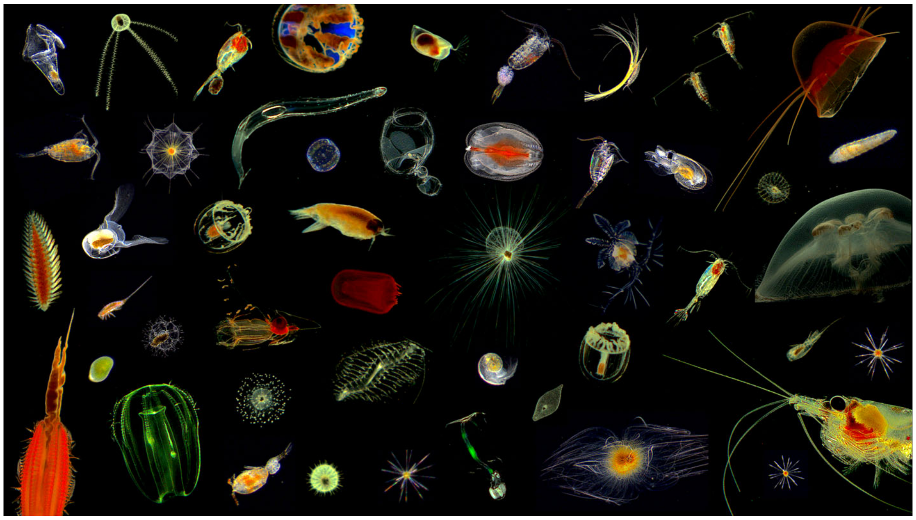

FIG. 1. *In situ* images of plankton species from the North and South Atlantic. Image credit: Klas O. Möller.

INTRODUCTION

Plankton is a massive and phylogenetically diverse group of thousands of prokaryotes, protists (unicellular eukaryotic organisms), and metazoans (multicellular eukaryotic organisms; Fig. 1). Plankton functional diversity is at the core of various ecological processes, including productivity, carbon cycling and sequestration, nutrient cycling (Falkowski 2012), interspecies interactions, and food web dynamics and structure (D'Alelio et al. 2016). Through these functions, plankton play a critical role in the health of the coastal and open ocean and provide essential ecosystem services. Yet, at present, our understanding of plankton dynamics is insufficient to project how climate change and other human-driven impacts affect the functional diversity of plankton. That limits our ability to predict how critical ecosystem services will change in the future and develop strategies to adapt to these changes.

The Marine Biodiversity Observation Network (MBON; https://geobon.org/bons/thematic-bon/mbon/, last accessed date: 22 Dec 2021), with the support of the Modelling Different Components of Marine Plankton Biodiversity team (MODIV; https://modiv.w.uib.no/, last accessed date: 22 Dec 2021), organized four virtual workshops (first in November 2020, second and third in October 2021, and fourth in November 2021) titled: "Plankton ecosystem functions, biodiversity, and forecasting—research requirements and applications" (https://eqmh.github.io/MBON-Plankton/index.html, last accessed date: 22 Dec 2021). The first workshop held in November 2020 was an initiative of the US-MBON and MODIV teams to bring together members of the ocean sciences community involved in plankton observing and modeling to meet, build rapport, and exchange expertise. The following workshops were organized to accommodate time differences: one for South, Central, and North America in October 2021; one for Africa, Europe, the Middle East, and India in October 2021; and one for East Asia and Oceania in November 2021. Each workshop was held for two consecutive days, and participation was limited to 20–25 participants per workshop to enable interactive discussions. In total, 80 participants from 26 countries attended at least one of the workshops (Fig. 2). A detailed list of participants can be found in the workshops' website (https://eqmh.github.io/MBON-Plankton/participants.html, last accessed date: 22 Dec 2021). The United States of America and Australia were the countries with the most participants, followed by Canada, Germany, China, the United Kingdom, and Argentina.

The objectives of the workshops were to: (1) identify requirements with respect to the definition of essential ocean variables (EOVs) and associated measurements, as well as compile the data needed to address critical knowledge gaps related to the role of plankton biodiversity functions to provide ecosystem services; (2) discuss ways to better link empirical observations to theoretical concepts of plankton biodiversity and ecosystem dynamics; and (3) suggest methods to better communicate the value of plankton to peers and non-scientific audiences.

DATA REQUIREMENTS

The workshops reviewed some current empirical and theoretical methods to study plankton biodiversity. Discussions focused on ways to advance monitoring efforts, understand and use the concept of EOVs and essential biodiversity variables to identify ecological processes that drive plankton diversity and can be studied with available data, and how observation networks such as MBON can help with model validation and forecasting. The main challenges and limitations of current approaches, and ways these could be overcome, highlighted in the workshops were:

1. The participants identified the minimal use of existing standardized frameworks for data collection, taxonomy reporting, unit conversion, and reporting of uncertainties, as well as the lack of global geographic coverage and data availability over time as the present major challenges for the community.
2. Most traditional plankton data are reported in global repositories and databases as bulk abundance (counts) or biomass (weight, carbon, or nitrogen content), without

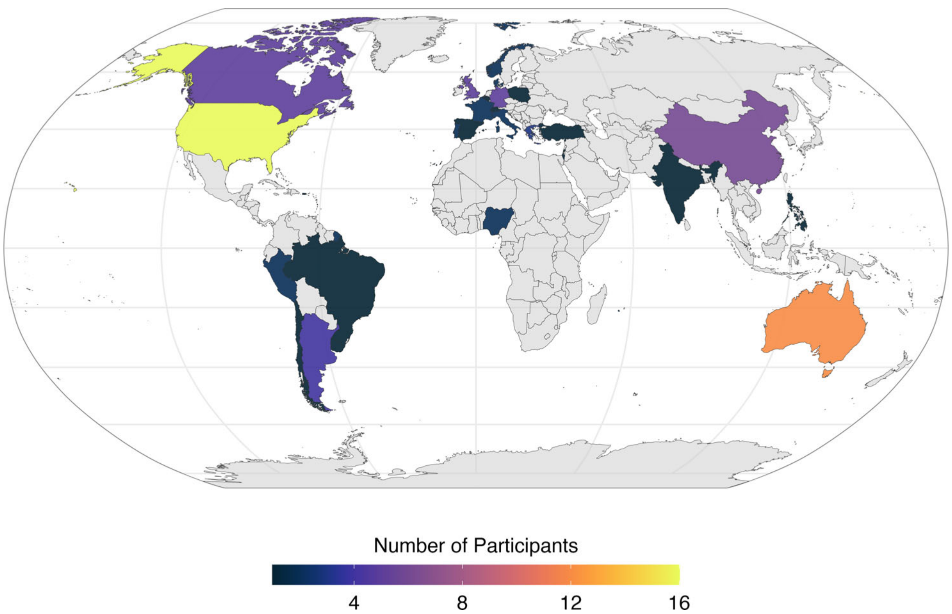

FIG. 2. Global map depicting the countries of residence of the participants who joined the MBON "Plankton ecosystem function, biodiversity, and forecasting—research requirements and applications" workshops in November 2020, and October and November 2021. The color bar shows the number of participants per country. Countries with no participants are in gray.

reports of traits or taxonomic identification beyond broad categories such as "bacteria," "phytoplankton," or "zooplankton." To better understand biodiversity and its link to ecosystem function, we need data that include species (or the highest taxonomic resolution available for each sampling and analysis method, such as molecular operational taxonomic units, metagenome assembled genomes for novel metagenomic data, or genus and family information for imaging data), rates (e.g., growth, respiration, ingestion, evolution, and acclimation rates as a response to environmental condition), and stoichiometry and traits (e.g., lipid content, size, foraging mode, behavior).

3. We continue to have little or contradictory empirical data on how dissolved CO_2 impacts plankton diversity and marine carbon export. Earth system models are sensitive to even small changes in rates (growth, grazing, remineralization, respiration), with substantial differences in carbon flux projections. Empirical data are fundamental to refine parameterizations and support more robust predictions.
4. Access to (historical) data varies based on countries; many have little to no available data, and many have data that are not openly available. However, since multiple international funding agencies have started to request that all project data become publicly available after the end of each funded project, this situation has been much improved in the recent decade.
5. Observers need to share data via existing databases, rather than creating new databases. Incentives are necessary to achieve this sharing pattern. Such incentives could include having the database destination (e.g., "Ocean Biodiversity Informatin System" [OBIS], https://obis.org/, last accessed date: 22 Dec 2021) that provides qualified staff who will help scientists reformat, document, and quality control their data and metadata and then assist the observer with attaining a Digital Object Identifier.
6. It is essential that plankton data—including plankton EOVs—are available together with physical and biogeochemical EOV data/metadata (environmental data along with physiological and functional trait data). International data archives should be used to generate lasting links between different data types measured during the same project. Having these data types together will facilitate model validation and testing hypotheses for biodiversity drivers.
7. Omics data can identify dominant genes expressed in the environment and how these can be related to important traits (e.g., nitrogen fixers; *nifH* gene). Though, as most omics data, especially for metazoans, are often only an index of presence and not of absolute abundance, and at present, do not provide a direct quantitative estimate of rates included in models (e.g., respiration, photosynthesis, protein synthesis) their use in modeling approaches remains a challenge.
8. Historical plankton abundance and biomass data are expressed only in terms of bulk abundance or biomass, making it difficult to relate them to trait-based methods that can bring new insights to ecophysiology and species distributions.
9. Insufficient funding and training opportunities are leading to a diminishing pool of skilled taxonomists and other plankton specialists and pose a substantial threat for the integration of future field observations, taxonomic work in the laboratory, data interpretation, and analysis and synthesis.

Participants discussed possible actions to overcome these challenges and limitations. There was agreement that observations in natural ocean habitats are fundamental to the formulation and testing of new hypotheses and conceptual models. More active communication between data providers and users will benefit the data collection, interpretation and analysis, and usability. For example, data that allow quantifying relationships among species traits (e.g., size, stoichiometry) will help inform understanding of species responses to environmental conditions. Although participants agreed that there is a lack of standardization of methods, data formatting, and distribution methods, in addition to a paucity of information on data quality and uncertainty, they also recognized the challenges of establishing a global protocol for field practices considering the regional environmental differences. For example, a net with a smaller mesh size is needed in tropical regions because plankton body size generally declines with warming (Campbell et al. 2021), in contrast a net with a larger mesh size which is towed faster is needed if the target is euphausiids rather than copepods. As a solution, participants suggested the use, further expansion, and explanation of existing protocols as best practices, and the set of minimum data and measurements required for data synthesis be laid out. Additionally, the creation of a community-driven unit conversion policy will help to normalize datasets and allow for a better understanding of variability and uncertainty. These approaches can help develop and validate models and minimize the uncertainty in data-driven meta-analysis studies.

It was also agreed that, as a community, we need to build capacity at three levels: taxonomic ability, data science, and data management. We need to highlight the fundamental role of taxonomists in providing high-quality data, and of data scientists for data-driven meta-analysis and synthesis. Databases should follow Findability, Accessibility, Interoperability, and Reuse principles, to credit and recognize the original data providers. Sufficient funds for the curation and archiving of project data should be included in future funding proposals at the national and international levels. Participants identified the ideal scenario for data users is interlinked data repositories, standardized conversion tables, interoperable data collection protocols, and documented uncertainty levels. Each is a rather challenging task. As a first step, participants recommend an inventory of plankton databases with a summary of their holdings such as the geographic area covered, time covered, types of plankton data included, and information on data format and access (e.g., GOOS Biology and Ecosystems Panel, https://www.goosocean.org/index.php?option=com_oe&task=viewGroupRecord&groupID=339, last accessed date: 28 Jan 2022).

THE UNSEEN VALUE OF PLANKTON

The value of plankton is mainly invisible and difficult to quantify, mostly because the public is aware of the ultimate ecosystem service delivered, but not the underlying ecosystem functions of organisms that deliver that service (e.g., the connection of plankton to fish and fisheries). That is, plankton are valuable through their provisioning of ecological and biogeochemical services that enhance the cultural and economic value of the marine environment. They are responsible for approximately half of the Earth's oxygen production and photosynthetic carbon fixation (Field et al. 1998), and play the fundamental "bio" role in biogeochemical cycling of carbon, nitrogen, oxygen, and many other elements. They are linked through the food web to higher trophic levels and generate economic and recreational benefits for humans. Plankton are involved in feedback processes that affect the evolution and survival of all marine species (Falkowski 2012), and promote marine biodiversity such as fish, benthic organisms, marine and even terrestrial birds, and mammals. Many participants highlighted that although public awareness of the value of the services provided by plankton are often unrecognized, plankton is usually known for negative reasons, such as blooms of pathogenic bacteria, harmful algae, or jellyfish.

The value of plankton to policy makers and the public can be highlighted by quantifying in economic terms and illustrating the link between plankton biodiversity and things we value (e.g., iconic species, recreational activities, water quality, carbon storage, nature conservation). Citizen science, education, science-art projects, and outreach activities are important ways to raise this awareness. There are many plankton-related outreach activities for all ages, but as outreach is commonly the least-funded component of scientific projects, it is imperative that we find ways to advance them. Models, virtual reality, and artificial intelligence could also be further developed as heuristic educational tools. One way to improve awareness is to integrate social scientists and those involved with science advice and policy into the development of research grants, approach mass media communication, and also consider opportunities presented by the Decade of Ocean Science for Sustainable Development (2021–2030) as proclaimed by the United Nations (https://en.unesco.org/ocean-decade, last accessed date: 22 Dec 2021).

NEXT STEPS

As we consider the challenge of monitoring the global ocean to understand and mitigate the negative effects of human activities and climate change on marine ecosystems, data remain the foundation for integrating empirical and theoretical approaches to deliver robust projections for policy and decision-making. The MBON plankton workshops provided an international space for data providers and data users to come together, discuss science, and consider new collaborations. Participants agreed that data consistency, comparability, and wider availability are necessary to move forward. They also highlighted the importance of better ways to communicate the value of plankton to scientists in various disciplines (e.g., fisheries, socioeconomics, policy) and to the public. As next steps, the participants decided to create two international groups to develop and publish:

1. A synthesis paper on the current limitations in data collection, analysis and accessibility, recommendations to overcome them, and ways to create common standards for data harmonization.
2. A synthesis paper on the value of plankton, written by a coalition of peers from diverse fields (oceanography, education, economics, art, citizen science).

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CONFLICT OF INTEREST

None declared.

AUTHOR CONTRIBUTIONS

All authors acted as chairs and note-takers during the workshops. MG, FKM, EM, AJR, JDE, EAT, CA, BC, CL, AP, FP, JR, SV, MV, and SZ organized the workshops. EM designed the website. MG, FKM, AJR, JDE, CL, and JR wrote the manuscript with the contribution of all authors. All authors gave feedback on the manuscript before submission.

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Maria Grigoratou, Gulf of Maine Research Institute, Portland, ME, USA; maria.grigoratou1@gmail.com

Enrique Montes, Ocean Chemistry & Ecosystems Division, Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, FL, USA

Anthony J. Richardson, School of Mathematics and Physics, University of Queensland, Brisbane, QLD, Australia; CSIRO Oceans and Atmosphere, Queensland Biosciences Precinct, St. Lucia, QLD, Australia

Jason D. Everett, School of Mathematics and Physics, University of Queensland, Brisbane, QLD, Australia; CSIRO Oceans and Atmosphere, Queensland Biosciences Precinct, St. Lucia, QLD, Australia; Centre for Marine Science and Innovation, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW, Australia

Esteban Acevedo-Trejos, Earth Surface Process Modelling, German Research Centre for Geosciences (GFZ), Potsdam, Germany

Clarissa Anderson, Scripps Institution of Oceanography, La Jolla, CA, USA

Bingzhang Chen, Department of Mathematics and Statistics, University of Strathclyde, Glasgow, UK; Hong Kong Branch of Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China

Tamar Guy-Haim, National Institute of Oceanography, Israel Oceanographic and Limnological Research, Haifa, Israel

Jana Hinners, Helmholtz-Zentrum Hereon, Geesthacht, Germany

Christian Lindemann, Department of Biological Sciences, University of Bergen, Bergen, Norway

Tatiane Martins Garcia, Instituto de Ciências do Mar (LABOMAR), Universidade Federal do Ceará (UFC), Fortaleza, Brazil

Klas O. Möller, Department Biological Carbon Pump, Helmholtz-Zentrum Hereon, Institute of Carbon Cycles, Geesthacht, Germany

Fanny M. Monteiro, Bristol Research Initiative for the Dynamic Global Environment (BRIDGE), School of Geographical Sciences, University of Bristol, Bristol, UK

Aimee R. Neeley, NASA Goddard Space Flight Center/Science Systems and Applications, Inc, Greenbelt, MD, USA

Todd D. O'Brien, NOAA Fisheries, Silver Spring, MD, USA

Artur P. Palacz, International Ocean Carbon Coordination Project, Institute of Oceanology Polish Academy of Sciences, Sopot, Poland

Alex J. Poulton, Lyell Centre for Earth and Marine Science, Heriot-Watt University, Edinburgh, UK

A. E. Friederike Prowe, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany

Áurea E. Rodríguez-Santiago, Caribbean Coastal Ocean Observing System (CARICOOS), University of Puerto Rico-Mayaguez, Mayagüez, PR, USA; Taller Ecológico de Puerto Rico, Boquerón, PR, USA

Cécile S. Rousseaux, Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, MD, USA; University of Maryland, Baltimore, MD, USA

Jeffrey Runge, School of Marine Sciences, University of Maine, Orono, ME, USA

Juan F. Saad, Centro de Investigación Aplicada y Transferencia Tecnológica en Recursos Marinos Almirante Storni (CIMAS-CONICET), Güemes, Argentina; Escuela Superior de Ciencias Marinas, Universidad Nacional del Comahue, San Antonio Oeste, Río Negro, Argentina

Ioulia Santi, European Marine Biological Resource Centre—European Research Infrastructure Consortium (EMBRC-ERIC) Headquarters, Sorbonne Université, Paris, France; Hellenic Centre for Marine Research (HCMR), Institute of Marine Biology, Biotechnology and Aquaculture (IMBBC), Heraklion, Greece

Rowena Stern, Marine Biological Association, The Laboratory, Plymouth, UK

Alice Soccodato, Atlantic International Research Centre, TERINOV—Parque de Ciência e Tecnologia da Ilha Terceira, Açores, Portugal

Selina Våge, Department of Biological Sciences, University of Bergen, Bergen, Norway

Meike Vogt, Environmental Physics Group, Institute for Biogeochemistry and Pollutant Dynamics, ETH Zurich, Zurich, Switzerland

Soultana Zervoudaki, Hellenic Centre for Marine Research, Institute of Oceanography, Athens, Greece

Frank E. Muller-Karger, College of Marine Science, University of South Florida, St. Petersburg, FL, USA