Proposal for a SCOR working group on
Standard protocols for the development of an atlas of marine plankton biogeography

Abstract

Deciphering the structure and functioning of marine planktonic ecosystems is becoming increasingly important to help us understand and predict their role in an Earth System Science context. This is especially critical as climate change and other anthropogenic impacts are altering marine ecosystems at an unprecedented rate. Marine planktonic ecosystems are key players in driving global biogeochemical cycles. They respond to changes in environmental conditions such as global warming and ocean acidification, but they also drive global biogeochemical cycles themselves. Thus, a major reorganization in plankton biogeography due to climate change will feed back onto climate and global biogeochemical cycling by modulating ocean CO_2 storage and emissions of climatically important trace gases. A recent data collection effort, the MARine Ecosystem DATa (MAREDAT) initiative, brought together over 500’000 abundance and biomass measurements. For the first time, it is possible to investigate plankton biogeography at the global scale, and within the context of a diverse set of applications from marine ecosystem model validation to applications in theoretical ecology and remote sensing. The MAREDAT datasets are publically available with unique, citable digital object identifiers (DOIs) at the data publisher PANGAEA and summary papers on methods and the data are published in the open-access journal *Earth System Science Data*. However, many existing data sources could not be included in the initial release of MAREDAT, and important biases remain in both the temporal and spatial domain. Furthermore, the analysis of the MAREDAT data set reveals that a more uniform structure would allow data to be useful for a wider range of applications.

Here, we propose a SCOR working group for the development of new protocols for the reporting and collection of global-scale planktonic ecosystem data such as abundance and biomass measurements. We also propose to include pigments, which can be used to estimate phytoplankton taxonomy, as well as those biological rates and plankton physiological traits that can be geo-referenced, as each will further define plankton biogeography. Furthermore, we propose to pioneer a standard methodology for the interpolation of scarce biological data. The working group would develop a common protocol for data reporting for a global plankton atlas in collaboration with data archives and data users from different fields, and implement them for the new release of MAREDAT in 2015. It would then test and recommend new global data interpolation routines based on neural networks, biomes or other large-scale properties. The working group would answer important questions on how to link different data sources, such as biomass, pigment and trait data, and would collaborate on the analysis of the data for an improved understanding of marine ecosystem structure and functioning in a changing world. The main product of the proposed SCOR group would be MAREDAT2015, an extension of the MAREDAT2012 global atlas of plankton biogeography (http://www.earth-syst-sci-data.net/special_issue7.html). The working group would define guidelines on standard data protocols and quality control during year 1 of the working group, collect and archive data during years 2 and 3, and publish MAREDAT2015 at the end of the third year. The fourth year of the SCOR working group would be dedicated to the analysis of the data, in collaboration with colleagues from trait ecology and remote sensing fields, and the results would be published in a scientific article.

1. Rationale

Anthropogenic climate change has been shown to impact marine planktonic ecosystems in several crucial ways: On a global scale, the ocean is simultaneously undergoing warming, deoxygenation and ocean acidification (Doney, 2010); that is, the ocean is “warming up, losing breath, and turning sour” (Gruber, 2011). Increased stratification in subtropical and temperate latitudes may limit nutrient availability and decrease primary productivity over the coming century (Steinacher et al. 2010). These changes may already be underway: For example, the oligotrophic regions of the oceans appear to be expanding (Polovina et al. 2008), Pacific species have been shown to migrate into the Atlantic (Reid et al. 2001), zooplankton species shifts have been recorded in the North Atlantic (Beaugrand et al. 2004, 2008), and regime shifts have occurred in the Black and Caspian seas due to overfishing and the invasion of non-native species

(Oguz & Gilbert, 2007). These and many more studies show that climate change and other anthropogenic impacts affect ecosystems across multiple trophic levels and in many different ways (Doney et al. 2012).

Marine planktonic ecosystems play an important role in the global biogeochemical cycling of key elements such as carbon, nitrogen and sulfur. Marine plankton form the base of the food web, and are of crucial importance for everything from the marine biological pump and ocean CO_2 storage, to global fisheries and food security in developing countries. Specific plankton groups produce nitrogen, sulfur and organohalide-based trace gases that can affect climate and atmospheric chemistry. Marine biodiversity forms a resource that is exploited in many industrial ways from the use of genes that code for low-temperature enzymes in detergents, to food supplies and animal food stocks. However, many marine ecosystem services related to global biogeochemical cycling, food provision and genetic diversity are still poorly quantified (Worm et al. 2006), since not all aspects of marine ecosystem structure and composition are routinely monitored on the global scale. Thus, changes in lower trophic level marine ecosystem structure and functioning may crucially impact global climate in the long term, and through trophic cascades the livelihood of millions of people relying on marine resources. The FAO estimates that about one billion people worldwide rely on fish as their primary source of animal protein (FAO, 2000).

Recent advances in remote sensing now allow the estimation of different plankton functional groups and size structure from space using relationships between phytoplankton and water-leaving reflectance (Alvain et al. 2005), backscattering (Kostadinov et al. 2009, 2010) or pigment concentrations and chlorophyll-a (Hirata et al. 2008, 2011). However, most remote sensing algorithms have been validated using only a few hundred data points in limited ocean regions (e.g. Hirata et al. 2011, Alvain et al. 2012). Extensive sets of validation data are essential for groundtruthing these algorithms in order to use the high-resolution products to monitor patterns of change in lower trophic level marine ecosystems on the synoptic global scale.

Satellites are an essential tool for present and past assessment of marine planktonic ecosystem changes, but in order to quantify potential future change, ecosystem model simulations are required (Bopp et al. 2001, Hashioka et al. 2009, Steinacher et al. 2010). Marine ecosystem models are becoming increasingly complex (Follows et al. 2007), and the availability of trait data for their parameterization, and biomass data for their evaluation, is an important determinant in the rate of progress (Le Quéré et al. 2005). Models thus require information on both the biomass and behavior of the groups modeled, with many parameters still poorly constrained (Anderson et al. 2005), as well as bulk properties such as net primary or bacterial production (Buitenhuis et al., *submitted*). Marine ecosystems are still significantly less well understood than their terrestrial analogues, and an understanding of marine ecosystem structure and functioning based on first principles of ecology remains elusive. Observational evidence remains episodic, and limited to a few regions with good data coverage.

Data availability remains one of the primary limiting factors for the development of important tools to understand, detect, and project potential changes in marine ecosystem structure and functioning that may have wide implications for present and future marine ecosystem service provision. For improved understanding of plankton biogeography and its drivers, existing data need to be compiled in a global atlas (Buitenhuis et al. 2013) to facilitate ecosystem model and remote sensing algorithm validation. An atlas of plankton biogeography will need to include data on the abundance and biomass of different marine planktonic ecosystem constituents, data on phytoplankton pigments for comparison with satellite products, physiological rates and behavioral traits for model development and validation, and bulk rates such as primary and bacterial production, nitrogen fixation and calcification.

We propose the formation of a SCOR working group to build upon existing efforts to establish a global marine planktonic ecosystem database (Buitenhuis et al. 2013) by developing guidelines on how to optimize such an atlas for use in applications from theoretical ecology to model development and for the validation of remote sensing algorithms. The proposed SCOR group would bring together marine ecosystem scientists from different fields to achieve a product that fulfills an extensive set of data requirements: The SCOR working group will need to develop guidelines and standard protocols on how to extract, quality control and archive existing data, and how to record abundance and biomass information together with crucial ancillary information for every important plankton functional group. Data will need to be open access, well documented and easy to use for a diverse community with different data needs. In order for the data to be useful for the quantification of ecosystem services, scarce and variable biological data will need to be interpolated to larger scales of common function, such as that of biomes or biogeochemical provinces of the ocean (Longhurst, 2010). Different data streams, such as abundance, pigment, rate and trait data will need to be combined in new and innovative ways to translate plankton biogeography into ecosystem function. The proposed SCOR working group would further scientific progress by taking a first step in this direction. This working group will incorporate institutional data contacts and spatial survey data sources identified by SCOR working groups 125 and 137. While those previous groups focused more on single geographic point time series, this group will pursue additional spatial (larger area) data. Together, these efforts will create a global collection of long temporal and comprehensive spatial plankton data sets.

1.1 Scientific Background

The MARine Ecosystem DATa (MAREDAT) has recently published the first global atlas of marine plankton functional type abundance and biomass data in a special issue of the journal *Earth System Science Data* (ESSD; Buitenhuis et al. 2013). The initiative has collected around 500’000 abundance and biomass observations for 11 autotrophic and heterotrophic plankton functional types: the diatoms (Leblanc et al. 2012), coccolithophores (O’Brien et al. 2013), nitrogen fixers (Luo et al. 2012), *Phaeocystis* (Vogt et al. 2012), picophytoplankton (Buitenhuis et al. 2012a), bacteria (Buitenhuis et al. 2012b), micro- (Buitenhuis et al. 2010, 2013), meso- (Moriarty and O’Brien, 2012) and macrozooplankton (Moriarty et al. 2013), as well as pteropods (Bednarsek et al. 2012) and planktic foraminifers (Schiebel and Movellan 2012). Furthermore, MAREDAT contains a global HPLC pigment database with ca. 34’000 measurements (Peloquin et al. 2013). The MAREDAT datasets are publically available with unique, citable digital object identifiers (DOI’s) at the data publisher PANGAEA (http://www.pangaea.de/search?q=maredat+), and summary papers on methods and the data are published in the open-access journal ESSD (http://www.earth-syst-sci-data.net/special_issue7.html); both mechanisms provide an important route for observational scientists to receive proper credit for their work.

Recent years have also seen an exponential increase in the availability of plankton trait data, describing plankton behavior, metabolic rates, morphology and life cycle characteristics. Published phytoplankton trait data comprises maximum growth rates for 105 marine phytoplankton species (Edwards et al. 2012), minimum nitrogen and phosphate cell quota, nutrient uptake rates for iron, nitrate, phosphate and ammonium, half-saturation constants for nutrient and light uptake (Klausmeier et al. 2004; Litchman and Klausmeier 2008; Edwards et al. 2012), and optimal temperatures for phytoplankton growth (Thomas et al. 2012). Zooplankton trait data on size distribution, feeding strategies and behavioral patterns are also abundantly available (Forster et al. 2011, Kiørboe, 2008, Kiørboe 2011). In their recent review, Barton et al. (2013) suggest that an initiative to collect trait data in a concerted manner similar to MAREDAT is essential for further progress on the understanding of marine planktonic ecosystem structure and functioning.

MAREDAT data have been recognized as valuable for applications in biogeography, biological oceanography, biogeochemistry, as well as for marine ecosystem model validation purposes and for the quantification of important ecosystem services such as those related to the global biogeochemical cycling of important elements. Furthermore, the data can be used for the validation of new methods to detect and monitor plankton groups from space. The initial analysis of the data sets has revealed their potential to link patterns in global plankton biogeography that have not previously been understood. A major limitation of the present data set is the poor spatial and temporal resolution of the data in some under-sampled ocean regions. There is a consensus that much more data exists, and that a second release of the atlas is necessary in order to allow for a better representation of global plankton distribution (Buitenhuis et al. 2013).

MAREDAT has started to shed light on global plankton biogeography in terms of abundance and biomass (Buitenhuis et al. 2013). However, in order to quantify marine ecosystem service provision and its drivers, a combination of biomass with trait and rate data is necessary. In terrestrial ecosystems, trait and abundance measures have been combined into multiple indices of, for example., functional diversity, which is shown to relate to the magnitude of ecosystem services concerning production, nitrogen fixation and above- and below-ground biomass (e.g. Randerson et al. 2009; Clark et al. 2012). In order to quantify ecosystem services in the marine realm, a similar effort is necessary to understand, model and predict present and future changes in marine planktonic ecosystems, and their consequences for ecosystem service provision. The systematic data collection we propose opens the door for a variety of different applications. Raw data can be used 1) to predict spatio-temporal patterns in species characteristics (Edwards et al. 2012, Thomas et al. 2012), 2) to elucidate biodiversity patterns (O'Brien et al., in prep., Worm et al. 2006, Irigoien et al. 2004, Rutherford et al. 1999), 3) to study the flow of matter across different trophic levels (Buitenhuis et al. 2013), 4) to study ecological niches of plankton species (Brun et al., in prep., Irwin et al. 2012), 5) to investigate species and biome shifts in marine planktonic ecosystems (e.g. Beaugrand, 2004, Beaugrand et al. 2008, Alvain et al. 2013), 6) to assess global patterns of elemental ratios that are crucial for global biogeochemical cycling (Martiny et al. 2013), and 7) to determine the drivers of plankton biogeography (Dutkiewicz et al. 2011, Luo et al., 2013). Data will also be useful to quantify ecosystem services related to global biogeochemical cycling; that is, for the determination of rates of primary production (Buitenhuis et al., *submitted*) nitrogen fixation (Luo et al. 2013), DMS production (Schoemann et al. 2005), and opal production and export (Sarmiento and Gruber, 2006).

In parallel, the data can be used to inform other fields of marine ecology, provided that it is made available in the appropriate format. Advances in remote sensing allow for the discrimination of several types of plankton from space (Alvain et al. 2012, 2013, Hirata et al. 2011). These algorithms still differ significantly in their results, but the availability of easily accessible validation data offers great chances for future ecosystem monitoring on the global scale. Furthermore, marine ecosystem models have now reached the level of complexity required to resolve different players in the marine food-web differentially, through either the inclusion of plankton functional groups (Le Quéré et al. 2005, Hood et al. 2006) or flexible biodiversity (Follows et al. 2007), or through the representation of plankton traits in trait-based models (e.g. Bruggeman and Kooijman 2007). Global model inter-comparison efforts such as the MARine Ecosystem Inter-comparison Project (MAREMIP) have started to validate model projections against satellite and experimental data, as well as hypotheses from theoretical ecology. These studies find significant differences in the model structure and functioning, and the drivers of plankton biogeography (Hashioka et al. 2012, Sailley et al., *in press*, Vogt et al., in preparation). For realistic simulations of future ecosystem structure and functioning, as well as ecosystem service provision, an understanding of the mechanisms driving these factors is crucial.

Since an update of MAREDAT is planned for the year 2015 that will take into account the experiences of the first MAREDAT release, a coordination of the efforts to collect plankton biomass data in the future is essential. The data will be optimized to be suitable for studies in several different disciplines of oceanography and ecosystem modeling, and it is thus essential to establish common protocols on the reporting, quality control of the data, and on the use and development of new and innovative interpolation methods. Furthermore, the combination of different methodologies for data collection for different plankton groups into one consistent product needs to be addressed. A combination of different types of data, which is of utmost importance for the understanding of properties related to functional diversity and ecosystem service provision, will only be possible if data fulfill compatibility requirements and follow common standards. A mutual exchange of experiences and data needs between members of MAREDAT, field-based biological oceanographers, ecologists working on the characterization of plankton traits and ecosystem modelers will guarantee an optimization of the versatility of the data for use in different disciplines of marine ecosystem research. Thus, the establishment of a SCOR working group on this issue is timely and arguably one of the best ways to bring together available expertise. Expertise on data collection and archiving from the MAREDAT community will be complemented by that of the trait community and ecosystem modelers for the development of the MAREDAT2015 global atlas of plankton biogeography. The mutual collaboration on new and important concepts in ecosystem research, such as the quantification of functional diversity or the new and innovative use of statistical tools common in terrestrial ecosystem research, such as species distribution models, as well as the joint analysis of different data sources, will be of tremendous benefit for both communities. Thus, a SCOR working group is optimal for community and expertise building in this area, with a focus on building a common base for the understanding of marine planktonic ecosystem structure and functioning, and present and future global plankton biogeography.

In times when the ocean is undergoing unprecedented changes due to anthropogenic climate change, the proposed SCOR working group on plankton biogeography is timely, due to (1) an increased availability of data owing to progress with *in situ* collection methods (2) the availability of statistical tools such as species distribution models (Elith et al. 2006) or concepts such as functional diversity (Tilman et al. 1997) that have yet to be explored in the marine realm, and (3) an increased international collaboration between the researchers interested in these questions. A SCOR working group would allow us to build on our existing expertise, and shape a tightly linked and fully interdisciplinary community of scientists tackling new standards for future data collection, archiving and collaborative analysis of important issues in marine ecosystem research.

1.2 Detailed questions that would be addressed

In the proposed SCOR working group, we would address the following key methodological questions in marine ecosystem research:

(1) How accurate and yet intuitive are the vocabularies used by data archives to describe what is measured in marine ecosystem research, particularly in plankton ecology?
(2) Which formats and standards should be adopted to provide data products that are most useful for a wide variety of applications in marine ecosystem research?
(3) Which methods of quality control are most sensible for the post-processing of scarce and highly variable marine planktonic ecosystem data sets that span several orders of concentrations, and may change on the daily scale?
(4) Which ancillary data are essential for the correct interpretation of the recorded data?
(5) How can different data types be combined to address new questions of ecosystem research?
(6) How can data be interpolated to larger scales using new and innovative techniques such as biome-scale interpolation, neural networks and other methods?
(7) How can we as a community assist each other in the interpretation of our data sets?
(8) How should future measurement programs be designed in a way to provide data of maximum usefulness for the international research community? Which data do we lack, and how can we inform the experimental community and funding bodies of our data needs?

1.3 Timeliness and relevance of the activity

The proposed activity is timely, as global data sets have only recently become available, and standards for their formats, archiving and quality control have not yet been set. Defining standards for these data sets, and joining forces in their interpretation will provide added value to the scientific community, and will speed up research on the impact of climate change on marine ecosystems. Furthermore, a SCOR working group will increase the international visibility of these efforts, and may lead to joint proposals with a larger impact. The understanding gained through the joint analysis and collection of the different ecosystem data streams will be of particular importance for the economies of developing countries, and for those countries that rely heavily on the use of goods and services from the sea.

1.4 Relevance for SCOR sponsorship

The proposed topic of this proposal is highly relevant for SCOR sponsorship, since it addresses a topic at the forefront of current marine ecosystem research, focuses on global patterns of marine biogeography and potential changes in marine ecosystem structure and functioning, and because it will solve essential methodological questions that would otherwise remain unanswered were it not for the synergy between the MAREDAT and trait communities that a SCOR working group provides on an international level. The improvement of scientific methods to collect, compile and archive data, and the intent of the proposed SCOR working group to actively inform the observational community about our data needs and the gaps in our knowledge is completely within the scope of SCOR. The proposed working group would allow knowledge transfer from SCOR working groups 125 (Global Comparisons of Zooplankton Time Series) and 137 (Patterns of Phytoplankton Dynamics in Coastal Ecosystems: Comparative Analysis of Time Series Observation), but it would focus on open ocean and global scale patterns of both autotrophic and heterotrophic constituents of lower trophic level ecosystems, and the combination of different data types.

2. Statement of Work/Terms of Reference

The proposed working group would

(1) summarize and assess the current status of biomass, pigment and trait measurements with a particular focus on the format of existing databases
(2) compile a comprehensive list of standard protocols for data reporting and archiving for each of the major plankton groups, collection method and data types
(3) use existing structural frameworks for organizing information to formalize concepts describing what is measured in marine ecosystem research, and build standard vocabularies that will be (a) accurate enough for an intelligent/automated compilation/integration of data, and (b) intuitive enough for data discovery using facetted search engines
(4) establish common, generally agreed quality control procedures for the compilation of plankton data
(5) collaborate with data archives such as PANGAEA, BCO-DMO, and COPEPOD, and with SeaDataNet, the ICSU World Data System and the IMBER data management group in order to implement these standard procedures in the large data archives
(6) develop new methods to interpolate scarce biological data to scales relevant for the quantification of important ecosystem services
(7) disseminate those procedures widely to ensure rapid adoption by the community
(8) inform the observational community of our data needs and current gaps in our understanding of marine ecosystem structure and functioning
(9) collaborate on the analysis of different data sources using statistical tools from terrestrial ecosystem research and important concepts of theoretical ecology, and the quantification of important ecosystem services.

2.1 Conferences and Workshops planned

Pre-meeting: The Copenhagen trait-based workshop from August 26-28, 2013 will bring together scientists listed as members of proposed SCOR working group, but it will not rely on SCOR funding. This meeting presents an ideal occasion for a pre-meeting among the members of the proposed SCOR working group, and for discussion between members of trait ecology and plankton biogeography on how to combine abundance and biomass data with trait and pigment data. Furthermore, a discussion on how to link abundance and trait data for a better quantification of ecosystem services can be started.

Kick-Off Meeting: In order to provide good international visibility and assure high attendance, the kick-off meeting would coincide with a major relevant international conference. A thematically suitable meeting would be the Ocean Sciences Conference (February 2014, Hawaii, USA), where a relevant session proposed jointly by several working group participants has been accepted. An alternative conference suitable for the kick-off meeting of the proposed SCOR working group meeting could be the IMBER Open Science Conference in Bergen in July 2014. A common session between the trait and biomass community has just been accepted for this meeting. The title of the session is "Data synthesis and modeling of marine planktonic ecosystems with plankton functional types and trait-based models".

Further Meetings: Further candidates for meetings could be the ASLO Aquatic Sciences meeting in 2015 in Granada, Spain, where another joint session could be proposed. In the beginning of

2017, the proposed SCOR working group would host a workshop at the University of East Anglia to discuss the progress of the data compilation for MAREDAT2015, and further steps. The focus of the workshop would be the development of data interpolation strategies for scarce and highly variable data sets, and the joint analysis of the MAREDAT2015 datasets.

Products: The main final product of the SCOR working group is the updated MAREDAT2015 atlas of global plankton biogeography by the end of 2016, consisting of a set of at least 12 papers on plankton abundance, biomass and pigment data and geo-referenced trait data. A common quality control procedure for newly submitted data will be published along with guidelines on the best format of data submission and publication. The latter will contain information on how to report taxonomic information, which ancillary data to include the definition of standard units for abundance, biomass and pigment data that are suitable for a wide set of applications in biological oceanography and marine ecosystem modeling. Common software will be created and published on the MAREDAT website (www.maredat.info) that handles (1) the quality control procedure, (2) the generation of gridded products, and (3) routines for the interpolation of data to larger scales using novel techniques (e.g., Lana et al. 2011; Landschützer et al., 2013). A white paper will be written by the end of year 3 that informs funding bodies and experimental scientists of the gaps in our current understanding of marine ecosystem structure and functioning, and details future data needs for improved ecosystem understanding. The first joint interpretation of the data and recommendations from the group will also be highlighted in a high-profile publication written by the group at the end of year 4.

2.2 Working group activities/Capacity building

From a socioeconomic perspective, many issues in current marine ecosystem research, such as the quantification of potential impacts of global change on marine ecosystem service provision is highly important for developing countries and economies in transition. The results of the proposed activity will inform policy makers and the public on potential hotspots of ecological change, and on locations with a high degree of diversity. The proposed SCOR working group would bring together the MAREDAT community with marine ecosystem modelers who are part of the MAREMIP initiative, as well as researchers working on trait-based models and members of the remote sensing community. These communities have a common goal – the understanding of present and future marine ecosystem structure and functioning – but are currently not linked through an international working group. The SCOR working group would thus facilitate the important exchange of ecosystem data between different ecosystem researchers working toward a common goal. For example, the remote sensing community may require data for the evaluation of their algorithms, while marine ecosystem modelers will need physiological rates/trait data to implement further complexity into their models. A SCOR working group would also lead to the identification of data requirements and needs by these different communities, and how MAREDAT could accommodate a maximal set of such needs through sensible and simple data standards. Bringing modelers and experimentalists together around a table would also increase the international visibility of marine ecosystem research, and will lead to future collaboration, ideas and findings. The SCOR working group would also increase efficiency in the expansion and establishment of global plankton data sets. The MAREDAT community already has experience with the generation of a global plankton atlas, and this know-how can be exploited by the trait community to collect and archive data more effectively. In addition, close contacts will be established with members of the terrestrial ecosystem community through the use of statistical tools and concepts that are common in terrestrial ecosystem research. Building necessary capacities in developing countries can be fostered by providing access to open-source data, best practice manuals and standard protocols that will augment access by members from countries with limited financial and infrastructural means to generate their own data. Additional funding would be requested from SCOR's travel grant program to finance the attendance of at least one additional young scientist from a developing country to attend international meetings, whenever the proposed SCOR group members meet. Thus, young scientists would be trained in essential networking and technical skills while being introduced to leading international members in the field.

2.3 Timeline

Year 1 (2014): Establishment of common protocols for data collection and archiving, as well as quality control procedures, data call for MAREDAT 2015
Milestones:
A) Compilation of guidelines specific for each data type, method and plankton group.
B) Identification of traits with sufficient data coverage, in space and time, to incorporate into atlas.
C) Development of guidelines for quality control.
D) Dissemination of the guidelines.
E) Data call for MAREDAT 2015.

Year 2-3 (2015 - 2016): Data collection for MAREDAT2015
Milestones:
A) Special MAREDAT issue set up in a relevant journal such as ESSD.
B) Quality control procedures developed.
C) Data collection for the different plankton groups to be included in MAREDAT 2015.
C) Individual MAREDAT2015 papers published as discussion papers.

Year 3 (2016): Publication of an updated global atlas of plankton biomass (MAREDAT2015), as well as standard protocols and software.
Milestones:
A) Final version of individual MAREDAT2015 papers published in collaboration with data archives and publishers.

Year 4 (2017): Joint analysis of abundance, biomass, pigment and trait data, joint publication.
Milestones:
A) Development of methods to interpolate scarce and highly variable biological data sets to larger scales.
B) Initial paper analyzing and comparing MAREDAT2015 data across different plankton groups.

3. Working Group Membership

3.1 Full Members

1 Meike Vogt (co-chair), f, senior scientist, ETH Zürich, Switzerland: Meike is one of the co-coordinators of MAREDAT 2012 and has several years of experience in the collection of standardized plankton data for use in biological oceanography and ecosystem modeling. Meike will provide expertise on standard protocols and data collection for use in model validation and marine ecology, and will co-coordinate MAREDAT2015.
2 Erik Buitenhuis (co-chair), m, senior scientist, University of East Anglia, UK: Erik is one of the co-coordinators of MAREDAT 2012 and has been working on data collection and ecosystem model development and validation for 15 years. Erik will provide expertise on data protocols and data interpolation for use in model validation and marine ecology, and will co-coordinate MAREDAT2015.
3 Stephane Pesant, m, senior scientist, MARUM, University of Bremen, Germany: Stephane coordinates data integration for several European projects and is editor for biological data collections at PANGAEA, data publisher for Earth and Environmental Sciences. PANGAEA is a strong building block of the ICSU World Data System. Stephane is a member of MAREDAT and SeaDataNet, and will provide expertise on data archiving and reporting. Stephane is a coordinator of Tara-Oceans and of the Ocean Sampling Day (http://www.microb3.eu/work-packages/wp2) aimed at the gathering of information on marine ecosystems and biodiversity.
4 Yawei Luo, m, senior scientist, Xiamen University, China: Yawei is a member of MAREDAT, and an expert on nitrogen fixers and nitrogen fixation. Yawei will provide expertise on data collection and on the reporting of traits related to global biogeochemical cycling.
5 Todd O'Brien, m, senior scientist, NOAA, USA: Todd is the head of the COPEPOD database and has years of experience in the collection and archiving of zooplankton data. Todd will provide expertise on data standards and data interpretation, and he is a member of MAREDAT.

6 Róisín Moriarty, f, senior research associate, University of East Anglia, UK: Róisín is an expert on zooplankton ecology and physiological traits, and a member of MAREDAT. Róisín is currently analyzing diversity patterns in MAREDAT, and will provide expertise on data collection and interpretation. She is an experienced plankton functional type modeller with end-to-end knowledge of marine ecosystem modeling from data collection, implementation in models and model-data validation.
7 Maria Deng Palomares, f, senior researcher, University of British Columbia and World Fish Centre Philippines, Canada/Philippines: Maria is an expert on fish population dynamics and fish data, and she is now coordinator of the SeaLifeBase, a project whose aim is to provide a 'FishBase-like' database for all other marine organisms that are not included in fish databases. Maria would provide input on data formats and archiving, and she would link our group with the scientists working on higher trophic level ecosystems, such as the FishBase team.
8 Takafumi Hirata, m, senior scientist, Hokkaido University, Japan: Takafumi Hirata is the executive officer of the MARine Ecosystem Modeling Inter-comparison Project (MAREMIP) and an expert on the detection of plankton functional groups from space. Takafumi will provide expertise on remote sensing, and the data needs of the remote sensing community.
9 Severine Alvain, f, senior scientist, CNRS, France: Severine Alvain is an expert on the detection of phytoplankton groups from space. Severine will provide expertise on remote sensing, and collaborate on the data requirements of the remote sensing community.
10 Forough Fendereski, f, PhD student, Gorgan University, Iran: Forough is a marine ecologist working on plankton biogeography, and on neural networking methods for the definition of marine biomes. She will provide expertise on the intelligent clustering and interpolation of marine ecosystem data, and on the collection of data in under-sampled regions.

3.2. Associate Members

1 Nicolas Gruber, m, professor, ETH Zürich, Switzerland: Nicolas Gruber is a marine biogeochemist with years of experience in marine ecosystem modeling. Nicolas has been part of several large data collection enterprise such as the CARINA oxygen data, and he has been a member of MAREDAT. Nicolas will provide input on marine ecosystem modeling and the data needed for the quantification of important ecosystem services related to global biogeochemical cycling.
2 Thomas Kiørboe, m, professor, DTU-Aqua, Denmark: Thomas is an expert on zooplankton traits. Thomas will advise MAREDAT2015 on how to provide data that can easily be combined with trait information for the quantification of important ecosystem services.
3 Elena Litchman, f, professor, Michigan State University, USA: Elena is a theoretical ecologist and an expert on plankton trait data. Elena will provide expertise on how to make abundance and biomass data useful for applications in theoretical ecology, on the interpretation of patterns from first principles and on the combination of trait and abundance data.
4 Scott Doney, m, professor, Woods Hole Oceanographic, Institution, USA: Scott Doney is a marine ecosystem modeler with many years of experience in ocean biogeochemistry and climate modeling. Scott is the head of the steering committee of MAREMIP, and will provide input on how to make MAREDAT2015 as useful as possible for model validation. Scott will also provide input on novel interpolation methods and quality control.
5 Stephanie Dutkiewicz, f, senior scientist, MIT, USA: Stephanie is a senior scientist in the MIT marine ecosystem modeling group and an expert on phytoplankton biogeography and trait-based ecosystem modeling. Stephanie will provide expertise on trait biogeography and the use of the data for modeling purposes.
6 Andrew Barton, m, postdoctoral fellow, Duke University, USA: Andrew is an ecosystem modeler and trait ecologist with an interest in building a global marine lower trophic level trait data base. Andrew will collaborate on the combination of abundance and trait data.
7 Chantal Swan, f, postdoctoral fellow, ETH Zürich, Switzerland: Chantal is an expert on remote sensing and HPLC pigments. Chantal is a member of MAREDAT and will provide input on how to link pigment and abundance data, and on how to use pigment data for the validation of remote sensing methods.
8 Ralf Schiebel, m, professor, University of Angers, France: Ralf Schiebel is an expert on foraminifera and palaeoceanography, and a member of MAREDAT. Ralf will provide expertise on long-term changes in marine ecosystem structure and functioning, with a focus on calcifying organisms.

9 Karine Leblanc, f, senior scientist, MIO CNRS, France: Karine Leblanc is a member of MAREDAT and an expert on marine biology with a focus on diatoms and biogeochemical flux measurements. Karine will provide input on the perspective of data originators, and will link the modeling and data analysis community with the observational community.
10 Nina Bednarsek, f, postdoctoral fellow, NOAA, USA: Nina Bednarsek is a member of MAREDAT, and an expert on the impact of ocean acidification on marine calcifiers. Nina will provide input on zooplankton ecology, and the potential impacts of global change on calcifiers.
11 Colleen O'Brien, f, PhD student, ETH Zürich, Switzerland: Colleen O'Brien is a marine ecologist, and a member of the MAREDAT. Colleen will provide expertise on data standards and data organization, and on issues related to plankton biodiversity.

4. References

Anderson, T. R., Plankton functional type modelling: running before we can walk? Journal of Plankton Research, 27, 1073–1081, 2005.

Alvain, S., C. Moulin, Y. Dandonneau, and F. Bréon, Remote sensing of phytoplankton groups in case I waters from global SeaWiFS imagery, Deep-Sea Research I, 52, 1989-2004, 2005.

Alvain S., Loisel H. and D. Dessailly, Theoretical analysis of ocean color radiances anomalies and implications for phytoplankton groups detection in case 1 waters, Optics Express Vol. 20, N°2, 2012.

Alvain S., Le Quéré C., Bopp L., Racault M.F., Beaugrand G., Dessailly D. and Buitenhuis E., Rapid climatic driven shifts of diatoms at high latitudes, Remote Sensing of Environment, in press, 2013.

Barton, A. D., Pershing, A. J., Litchman, E., Record, N. R., Edwards, K. F., Finkel, Z. V., Kiørboe, T. and Ward, B. A., The biogeography of marine plankton traits, Ecology Letters, 16, 522-534, 2013.

Beaugrand, G., The North Sea regime shift: Evidence, causes, mechanisms and consequences, Progress in Oceanography, 60, 245 – 262, 2004.

Beaugrand, G., M. Edwards, K. Brander, C. Luczak, and F. Ibanez, Causes and projections of abrupt climate-driven ecosystem shifts in the North Atlantic, Ecology Letters, 11, 1157 – 1168, 2008.

Bednarsek, N., Možina, J., Vogt, M., O'Brien, C., and Tarling, G. A., 'The global distribution of pteropods and their contribution to carbonate and carbon biomass in the modern ocean', Earth System Science Data, 4, 167-186, doi:10.5194/essd-4-167-2012, 2012.

Bopp, L., Monfray, P., Aumont, O., Dufresne, J.-L., Le Treut, H., Madec, G., Terray, L., Orr, J. C., Potential impact of climate change on marine export production, Global Biogeochemical Cycles, 15:1, 81–99, doi: 10.1029/1999GB001256, 2001.

Boyce, D. G., M. L. Lewis, and B. Worm, Global phytoplankton decline over the past century, Nature, 366, 591 – 596, 2010.

Bruggeman, J. & Kooijman, S. A. L. M., A biodiversity-inspired approach to aquatic ecosystem modeling, Limnology and Oceanography 52:1533-44, 2007.

Brun, P., Vogt, M., Payne, M. P., O'Brien, C., Gruber, N., Buitenhuis, E., Le Quéré, Leblanc, K., Luo Y.-W., Ecological niches of observed phytoplankton species in the global ocean, *in preparation*.

Buitenhuis, E. T., R. B. Rivkin, S. Sailley, and C. Le Quéré, Biogeochemical fluxes through microzooplankton, Global Biogeochemical Cycles, 24, doi:10.1029/2009GB003601, 2010.

Buitenhuis, E. T., W. K. W. Li, D. Vaulot, M. W. Lomas, M. R. Landry, F. Partensky, D. Karl, et al., Picophytoplankton biomass distribution in the global ocean, Earth System Science Data, 4, 37 – 46, 2012a.

Buitenhuis, E. T., W. K. W. Li, M. W. Lomas, D. M. Karl, M. R. Landry, and S. Jacquet. Bacterial biomass distribution in the global ocean, Earth System Science Data, 5, 301 – 315, 2012b.

Buitenhuis, E. T., Vogt, M., Moriarty, R., Swan, C., Bednarsek, N., Doney, S., Leblanc, K., Le Quéré, C., Luo, Y., O'Brien, C., O'Brien, T., Peloquin, J., Schiebel, R., Swan, C. 'MAREDAT: Towards a World Ocean Atlas of Marine Ecosystem Data, Earth System Science Data, *in press*, 2013.

Buitenhuis, E. T., T. Hashioka, and C. Le Quéré, Combined constraints on global ocean primary production using observations and models, Global Biogeochemical Cycles, *submitted*.

Clark C. M., D. F. B. Flynn, B. J. Butterfield, and P. B. Reich, Testing the link between functional diversity and ecosystem functioning in a Minnesota grassland experiment, PLoS ONE, 7, doi:10.1371/journal.pone.0052821, 2012.

Doney, S. C., The growing human footprint on coastal and open-ocean biogeochemistry, Science, 328, 1512-1516, 2010.

Doney, S. C., Ruckelshaus, M., Duffy, J. E., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., Grebmeier, J. M., Hollowed, A. B., Knowlton, N., Polovina, J., Rabalais, N. N., Sydeman, W. J., and Talley, L. D., Climate Change Impacts on Marine Ecosystems, Annual Review of Marine Science, 4: 11-37, doi: 10.1146/annurev-marine-041911-111611, 2012.

Dutkiewicz, S., B. A. Ward, F. Monteiro, and M. J. Follows, Interconnection of nitrogen fixers and iron in the Pacific Ocean: Theory and numerical simulations, Global Biogeochemical Cycles, 26, GB1012, doi:10.1029/2011GB004039, 2012.

Edwards, K. F., M. K. Thomas, C. A. Klausmeier, and E. Litchman, Allometric scaling and taxonomic variation in nutrient utilization traits and maximum growth rate of phytoplankton, Limnology and Oceanography, 57, 554 – 566, 2012.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, S.Ferrier, A. Guisan, et al., Novel methods improve prediction of species' distributions from occurrence data, Ecography, 29, 129–151, 2006.

FAO, The State of World Fisheries and Aquaculture 2000. FAO, Rome, Italy, 2000.

Follows, M. J., S. Dutkiewicz, S. Grant and S. W. Chisholm, Emergent biogeography of microbial communities in a model ocean, Science, 315, 1843-1846, doi: 10.1126/science.1138544, 2007.

Forster, J, and Hirst, A. G. and Atkinson, D., How do organisms change size with changing temperature? The importance of reproductive method and ontogenetic timing, Functional Ecology, 25, 1024-1031, 2011.

Gruber, N., Warming up, turning sour, losing breath: Ocean biogeochemistry unde global change, Phil. Trans. R. Soc. A, 369, 1980-1996, doi: 10.1098/rsta.2011.0003, 2011.

Hashioka, T., T. T. Sakamoto, and Y. Yamanaka, Potential impact of global warming on North Pacific spring blooms projected by an eddy-permitting 3-D ocean ecosystem model, Geophysical Research Letters, 36, L20604, doi:10.1029/2009GL038912, 2009.

Hashioka, T., Vogt, M., Yamanaka, Y., Le Quéré, C., Noguchi Aita, M., Alvain, S., Bopp, L., Hirata, T., Lima, I., Sailley, S., and Doney, S. C., Phytoplankton competition during the spring bloom in four

Plankton Functional Type Models, Biogeosciences Discussions, 9, 18083-18129, doi:10.5194/bgd-9-18083-2012, 2012.

Hirata, T., J. Aiken, N. Hardman-Mountford, T. Smyth, and R. Barlow, An absorption model to determine phytoplankton size classes from satellite ocean colour, Remote Sensing of the Environment, 112, 3153 – 3159, 2008.

Hirata, T., Hardman-Mountford, N. J., Brewin, R. J. W., Aiken, J., Barlow, R., Suzuki, K., Isada, T., Howell, E., Hashioka, T., Noguchi-Aita, M., and Yamanaka, Y.: Synoptic relationships between surface Chlorophyll-a and diagnostic pigments specific to phytoplankton functional types, Biogeosciences, 8, 311-327, doi:10.5194/bg-8-311-2011, 2011.

Hood, R. R., E. A. Laws, R. A. Armstrong, N. R. Bates, C. W. Brown, C. A. Carlson, F. Chai, S. C. Doney, P. G. Falkowski, R. A. Feely, M. A. M. Friedrichs, M. R. Landry, J. K. Moore, D. M. Nelson, T. L. Richardson, B. Salihoglu, M. Schartau, D. A. Toole, and J. D. Wiggert, Pelagic functional group modeling: progress, challenges and prospects, Deep-Sea Res. II, 53(5-7), 459-512, 2006.

Irigoien, X., J. Huisman, and R. P. Harris, Global biodiversity patterns of marine phytoplankton and zooplankton, Nature, 429, 863 – 867, 2004.

Irwin, A. J., A. M. Nelles, and Z. V. Finkel, Phytoplankton niches estimated from field data, Limnology and Oceanography, 57, 787 – 797, 2012.

Kiørboe, T., A mechanistic approach to plankton ecology, Princeton university press, NJ, 2008.

Kiørboe, T., How zooplankton feed: mechanisms, traits and trade-offs, Biol. Rev. Camb. Philos. Society, 86, 311-339.

Klausmeier, C. A., E. Litchman, T. Daufresne, S. A. Levin, Optimal nitrogen-to-phosphorus stoichiometry of phytoplankton, Nature, 429, 171 – 74, 2004.

Kostadinov, T.S., D.A. Siegel, and S. Maritorena, Retrieval of the particle size distribution from satellite ocean color observations. Journal of Geophysical Research, 114, C09015, 10.1029/2009JC005303, 2009.

Kostadinov, T.S., D.A. Siegel, S. Maritorena, Global variability of phytoplankton functional types from space: assessment via the particle size distribution, Biogeosciences, 7, 3239-3257, 2010.

Lana, A., T. G. Bell, R. Simó, S. M. Vallina, J. Ballabrera-Poy, A. J. Kettle, et al., An updated climatology of surface dimethlysulfide concentrations and emission fluxes in the global ocean, Global Biogeochemical Cycles, 25, doi:10.1029/2010GB003850, 2011.

Landschützer, P., N. Gruber, D. C. E. Bakker, U. Schuster, S. Nakaoka, M. R. Payne, T. Sasse, and J. Zeng, A Neural Network-based Estimate of the Seasonal to Inter-annual Variability of the Atlantic Ocean Carbon Sink, Biogeosciences Discussions, bg-2013-215, 2013.

Leblanc, K., J. Arístegui, L. Armand, P. Assmy, B. Beker, A. Bode, et al., A global diatom database – abundance, biovolume and biomass in the world ocean, Earth System Science Data, 5, 147 – 185, 2012.

Le Quéré, C., S. Harrison, I. C. Prentice, E. T. Buitenhuis, O. Aumont, and L. Bopp, Ecosystem dynamics based on plankton functional types for global ocean biogeochemistry models, Global Change Biology, 11, 2016 – 2040, 2005.

Litchman, E. and C. Klausmeier, Trait-Based Community Ecology of Phytoplankton, Annual Review of Ecology, Evolution and Systematics, 39, 615 – 639, 2008.

Longhurst, A., Ecological Geography of the Sea, 2nd Edition, Academic Press: San Diego, 527 pp., 2010.

Luo, Y.-W., Doney, S. C. et al., Database of diazotrophs in global ocean: abundance, biomass and nitrogen fixation rates, Earth System Science Data, 4, 47-73, 2012.

Luo, Y.-W., Lima, I. D., Karl, D. M., and Doney, S. C., Data-based assessment of environmental controls on global marine nitrogen fixation, Biogeosciences Discussions, 10, 7367-7412, 2013.

Martiny, A. C., Pham, C. T. A., Primeau, F. W., Vrugt, J A., Moore, J. K., Levin, S. A., and Lomas, M. W., Strong latitudinal patterns in the elemental ratios of marine plankton and organic matter, Nature Geoscience, 6, 279-283, doi: 10.1038/NGEO1757, 2013.

Moriarty, R. and T. D. O'Brien, Distribution of mesozooplankton biomass in the global ocean, Earth System Science Data, 5, 893 – 919, 2012.

Moriarty, R., E. T. Buitenhuis, C. Le Quéré, and M.-P. Gosselin, Distribution of known macrozooplankton abundance and biomass in the global ocean, Earth System Science Data, 5, 187 – 220, 2012.

O'Brien, C., Vogt, M., N. Gruber, K. Leblanc, 'Latitudinal diversity gradients in coccolithophore and diatom assemblages', *in preparation*.

O'Brien, C. & Peloquin, J., Vogt, M., Heinle, M., Gruber, N., Ajani, P., Andruleit, H., Aristegui, J., Beaufort, L., Estrada, M., Karentz, D., Kopczynska, E., Lee, R., Pritchard, T., Widdicombe, C., 'Global Plankton Functional Type Biomass Distributions: Coccolithophores', Earth System Science Data Discussions, 5, 491-520, 2012; doi:10.5194/essdd-5-491-2012.

Oguz, T., Gilbert, D., Abrupt transitions of the top-down controlled Black Sea pelagic ecosystem during 1960–2000: evidence for regime-shifts under strong fishery exploitation and nutrient enrichment modulated by climate-induced variations. Deep-Sea Research I, 54, 220–242, 2007.

Peloquin, J., Swan, C., Gruber, N., Vogt, M., Claustre, H., Ras, J., Uitz, J. et al., The MAREDAT global database of high performance liquid chromatography marine pigment measurements, Earth System Science Data, 5, 1179-1214, doi:10.5194/essdd-5-1179-2012, 2013.

Polovina J. J., E. A. Howell, and M. Abecassis, Ocean's least productive waters are expanding, Geophysical Research Letters, 35, L03618, doi:10.1029/2007GL031745, 2008.

Randerson, J. T., F. M. Hoffman, P. E. Thornton, N. M. Mahowald, K. Lindsay, Y.-H. Lee, C.D. Nevison, S. C. Doney, G. Bonan, R. Stöckli, C. Covey, S. W. Running, and I. Y. Fung, Systematic assessment of terrestrial biogeochemistry in coupled climate-carbon models, Global Change Biology, 15, 2462-2484, 2009.

Reid, P. C., M. de Fatima Borges, E. Svendsen, A regime shift in the North Sea circa 1988 linked to changes in the North Sea horse mackerel fishery, Fisheries Research, 50, 153 – 171, 2001.

Rutherford, S., S. D'Hondt, and W. Prell, Environmental controls on the geographic distribution of zooplankton diversity, Nature, 400, 749–753, 1999.

Sailley, S., Vogt, M., Doney, S. C., Aita, M. N., Bopp, L., Buitenhuis, E. T., Hashioka, T., Lima, I., Le Quéré, C., Yamanaka, Y. Comparing food web structures and dynamics across a suite of global marine ecosystem models, Ecological Modelling, *accepted*.

Sarmiento, J. L. S., and N. Gruber, Ocean Biogeochemical Dynamics, 503 pp., Princeton University Press, Princeton, N. J., 2006.

Schiebel, R. and A. Movellan, First-order estimate of the planktic foraminifer biomass in the modern global oceans, Earth System Science Data, 5, 243 – 280, 2012.

Schoemann, V., Becquevort, S., Stefels, J., Rousseau, V., and Lancelot, C., Phaeocystis blooms in the global ocean and their controlling mechanisms: a review, Journal of Sea Research, 53, 43-66, 2005.

Steinacher, M., Joos, F., Frölicher, T. L., Bopp, L., Cadule, P., Cocco, V., Doney, S. C., Gehlen, M., Lindsay, K., Moore, J. M., Schneider, B., and Segschneider, J., Projected 21st century decrease in marine productivity: a multi-model analysis, Biogeosciences, 7, 979–1005, 2010.

Thomas, M. K., C. T. Kremer, C. A. Klausmeier, and E. Litchman, A global pattern of thermal adaptation in marine phytoplankton, Science, 338, 1085 – 1088, 2012.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, E. Siemann, The influence of functional diversity and composition on ecosystem processes, Science, 277, 1300 – 1302, 1997.

Vogt, M., O'Brien, C., Peloquin, J., Schoemann, V., Breton, E., Estrada, M., Gibson, J., Karentz, D., Van Leeuwe, M. A., Stefels, J., Widdicombe, C., Peperzak, L., 'Global Plankton Functional Type Biomass Distributions: *Phaeocystis* spp', Earth System Science Data, 4, 107-120, doi:10.5194/essd-4-107-2012, 2012.

Vogt, M., Hashioka, T., Payne, M. R., Alvain, S., Bopp, L., Buitenhuis, E. T., Doney, S. C., Le Quéré, C., Lima, I., Aita, M. N., Yamanaka, Y. 'MARine Ecosystem Model Inter-comparison Project (MAREMIP): The distribution, dominance patterns and ecological niches of plankton functional groups in different Dynamic Green Ocean Models', *submitted.*

Worm, B., E. B. Barbier, N. Beaumont, J. E. Duffy, C. Folke, B. S. Halpern, J. B. C. Jackson, H. K. Lotze, F. Micheli, S. R. Palumbi, E. Sala, K. A. Selkoe, J. J. Stachowicz, and R. Watson, Recent biodiversity loss undermines ocean ecosystem services at all scales, Science, 314: 787–790, 2006.