Ecological Archives **E094-149-D1**

Sofia Sal, Angel Lopez-Urrutia, Xabier Irigoien, Derek S. Harbour, and Roger P. Harris. 2013. Marine microplankton diversity database. *Ecology* 94:1658. http://dx.doi.org/10.1890/13-0236.1

Introduction

The high diversity of phytoplankton has fascinated ecologists since the early works of Hutchinson (1961). Many theories have been developed to explain the factors regulating marine phytoplankton diversity patterns. Some suggest that species coexistence is enhanced at equilibrium conditions when competition for resources such as nutrients or light is high (Barton et al. 2010). However, some authors showed that diversity can even increase when fluctuations take place (Connell 1978; Sommer 1985; Floder and Sommer 1999; Huisman 2010). Other theories relate phytoplankton diversity to energy availability as photosynthetically active radiation (PAR) or temperature (Wright 1983). Phytoplankton diversity is also correlated to standing stock biomass, with higher diversity found at intermediate productivity levels (Irigoien et al. 2004; Stomp et al. 2011).

However, analyzing the relative importance of these theories in natural systems is very difficult: experimental work is very complex at such broad scales. To test these theories there is a need for global databases with sufficient gradients in the proposed explanatory variables. Such diversity data sets with extensive geographical coverage exist for terrestrial plants. For example, *The Alwyn H. Gentry Forest Transect Data Set* (Gentry 1988; Phillips and Miller 2002) has been succesfully used to test several macroecological theories (Clinebell et al. 1995; Enquist and Niklas 2001; Simova et al. 2011). For marine ecosystems, such global databases are starting to be compiled. Most of these data sets are focused on the compilation of distribution maps like the *NMFS-COPEPOD*: *the global plankton database* (O'Brien 2007) for marine copepods or the *World Modern Foraminifera Database* (Hayward et al. 2011), as part of the World Register of Marine Species (WoRMS). For marine phytoplankton, the *World Ocean Atlas of Plankton Functional Types* is being created from the compilation of data sets for different functional types. Some examples are the databases for picophytoplankton (Buitenhuis et al. 2012) or for diatoms (Leblanc et al. 2012). Although these databases are fairly complete including abundance, biovolume and carbon biomass, they lack environmental data. Furthermore, they are not suitable for diversity calculations. To provide a reliable measure of species diversity, the taxonomic identification should be carried out by the same taxonomist over the whole data set, or at best some standarization protocols need to be applied.

Identification of phytoplankton to the species level is often quite challenging, even for taxonomic experts. Consequently, many large phytoplankton databases are not internally consistent, because changes in personnel handling the taxonomic analyses have led to changes in species identification. In fact, this problem can be so severe that in several studies the observed changes in phytoplankton community structure have been attributed to changes in personnel or laboratory (Wiltshire and Durselen 2004; Peperzak 2010; Straile et al. 2013), rather than to environmental variation. Such major inconsistencies were avoided here.

In this work we compiled a data set of marine microplankton species abundances (cells/mL), together with estimates of biomass and cell biovolume. These data were collected at 788 stations on a number of oceanographic cruises between 1992 and 2002. The compilation covers a wide range of marine ecosystems, ranging from coastal to open ocean. Environmental information has also been compiled for different oceanographic parameters (chlorophyll, temperature, PAR, nutrients, mixed layer depth) for each station. These data allow the study area to be characterized and can be used in studies on the environmental and biological controls of marine biodiversity. Most importantly, all species identification were made by the same taxonomist (Derek S. Harbour), which provides greater strength to the collection and ensures that estimates of species diversity are reliable. To our knowledge, this dataset is unique in marine phytoplankton diversity studies. We know of no other study which compiles abundance, biomass and biovolume for such a great number of species which have been identified by the same taxonomist and which also includes environmental data.

To date, some data included in this work have been used previously to identify global patterns of marine phytoplankton biodiversity (Irigoien et al. 2004) and also in studies relating speciess richness or phytoplankton abundance to cell size (Cermeño et al. 2006). In addition, parts of this global dataset have been used to study temporal variability (Rodríguez et al. 2000), seasonal succession (Marañón et al. 1996) or species distribution (Tyrrell et al. 2003). It is important to remark that species names have not been standarized until now, this means that the same species could be named differently in each subset of the global database. This has hindered the use of the database for studies involving distribution patterns at the species level. The main feature of this new compilation is the inclusion of environmental data, which were scarce previously. This database aims to complete these studies and to enhance the development of new ones. In this way we hope it will contribute to a better understanding of the processes of diversification in the ocean. Understanding and assessing diversity will be essential to understand and predict the impact of environmental forcing on this major compartment (Simon et al. 2009).

Metadata

Class I. Data set descriptors

A. Data set title: Database of abundance for 736 microplankton taxa across 788 stations with corresponding environmental variables.

B. Data set identification code: To be determined

C. Data set updates: The data set is complete and no updates are planned.

D. Principal investigators: Same as authors.

E. Abstract: Many macroecological theories have been developed to study the diversity on our planet. All these theories require the existence of consistent databases to test their predictions. In this work, we compiled a data set of marine microplankton species abundances at 788 stations with an extensive geographical coverage. Data were collected on different oceanographic cruises between 1992 and 2002. This database consists of abundances (cells/mL) for each species at each station and depth, together with estimates of the biomass and biovolume for each species. One of the key strengths in this database is that species identifications were made by the same taxonomist, which provides greater strength to the collection and ensures that estimates of species diversity are reliable. Environmental information has also been compiled at each station (chlorophyll, temperature, photosynthetically active radiation (PAR), nutrients) in order to have a characterization of the study area and to be used in studies on the environmental and biological controls of marine biodiversity.

F. *Key words*: *abundance; chlorophyll; diversity; microplankton; nutrients; photosynthetically active radiation; phytoplankton; temperature.*

Class II. Research origin descriptors

A. Overall project description

Identity: Database of abundance for 736 microplankton taxa across 788 stations with corresponding environmental variables.

Objectives: The main objective of this work is to compile a data set of marine microplankton species abundances which have been identified by the same taxonomist. We provide abundances (cells mL^{-1}) data, together with estimates of biomass, cell biovolume and environmental data (chlorophyll, temperature, nutrients, PAR, mixed layer depth) for each site.

Originators: Data contained in this database were originally collected by Dr. Xabier Irigoien and Dr. Roger P. Harris. Derek S. Harbour was responsible for all sample analysis.

Period of Study: October 1992 to May 2002.

Sources of funding: Data compilation was supported by project METabolic OCean Analysis (METOCA) funded by Spanish National Investigation+Development+Innovation (I+D+I) Plan. S.S. was funded by a Formaciön de Personal Universitario (FPU) grant from the Spanish Ministry of Education. *This study is a contribution to the international IMBER project. AMT sample collection and analysis was supported by the UK Natural Environment Research Council National Capability funding to Plymouth Marine Laboratory and the National Oceanography Centre, Southampton.This is contribution number 233 of the AMT programme*. The L4 programme is funded under the UK NERC Oceans 2025 programme as part of Theme 10, Sustained Observations.

B. Specific subproject description

Study region. Data were compiled for 788 stations during different oceanographic cruises in temperate, polar and subtropical regions. Stations sampled cover a wide range of marine ecosystems, ranging from coastal to open ocean. North Atlantic Ocean samples include the Irminger Sea, Norwegian Sea, North Sea, and Iceland Basin. Samples were also collected on cruises along the South Atlantic Ocean (mainly Atlantic Meridional Transect cruises), Benguela current, Indian Ocean, and West Coast of the North Pacific Ocean. One of the experiments, "Bergen", took place in open-air mesocosms at the Espegrend Marine Biological Station (University of Bergen).

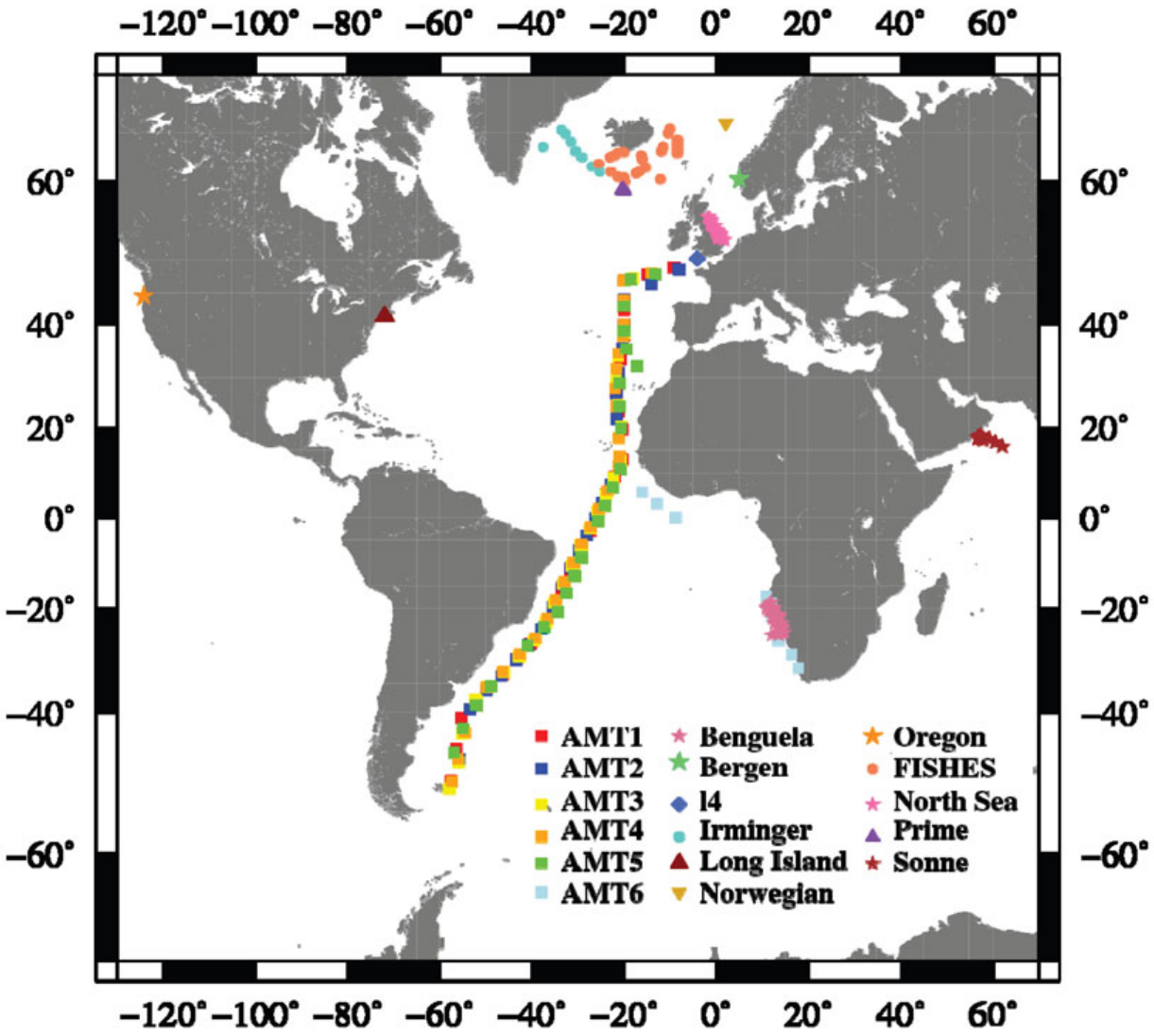

FIG. 1. Map showing the different stations sampled in the study. Each symbol and color represents a cruise.

Experimental or sampling design. Data were obtained from many experiments and observations made in the oceanographic cruises listed above. Species taxonomic identification and cell counts were all made by Derek S. Harbour. See Research Methods below.

Research Methods:

1. Sampling methods:

Microplankton abundance

Data analysed were collected from 1992 to 2002 at 788 sites. See Fig. 1 and Table 1 for a detailed site description. Seawater samples were collected from different depths (most of them in surface waters) from CTD Niskin bottles. For later microplankton cell counts, it is very important to handle seawater with care, as some organisms are very sensitive to turbulence (Gifford and Caron 2000). Water samples were taken from the Niskin bottle and immediately preserved with 1–5 % acid-Lugol's iodine solution (Throndsen 1978). Samples were labelled and stored in cold, dark conditions during transportation to the laboratory.

Nutrients

We only have in situ nutrients data for AMT cruises. Samples were taken from the underway pumping system between stations, from vertical profiles at each station, or both. However, we only included samples obtained during the daily CTD casts coincident with the microplankton sampling. Water samples from the CTD/Rosette system (SeaBird) were sub-sampled into clean Nalgene bottles. Sample analysis was completed within 3 h of sampling, so no samples were stored.

Other variables

For Chlorophyll, between 200 and 300 mL of sea water from each depth in the water column were sequentially filtered through 0.2 µm, 2 µm and 20 µm polycarbonate filters. Chl *a* was extracted from filters in 90% acetone at 20°C for 12 to 24 hours. Samples were measured on a Turner 10-AU fluorometer calibrated with pure Chl *a*.

Temperature and PAR were obtained either from CTD data or underway records from the ship. For those stations where it was impossible to obtain data, these were retrieved from satellite data.

2. Analysis

Microplankton abundance

Microplankton identification and cell counts was carried out by Derek S. Harbour at the Plymouth Marine Laboratory using inverted microscopy following the Utermöhl technique (Utermöhl 1958). The "Water quality - Guidance standard for routine microscopic surveys of phytoplankton using Utermöhl technique" (BS EN 15204:2006) was followed:

Microplankton samples, preserved in Lugol's iodine and formalin, were settled in sedimentation chambers while acclimatized to room temperature, to ensure a random distribution of cells. After this, sample bottles were rotated to help re-suspension and separation. Sub-samples with volumes between 10 and 256 mL were later transferred to plankton settling chambers. A variable area of the chamber bottom was counted under the microscope. The size of that area varies with species and abundance and under some circunstances different species were counted in different settled volumes to obtain consistency and reproducibility in the counts. At least 100 cells of each of the more abundant species were counted. Settlement duration varied between 4h cm^{-1} for Lugol's iodine and 16 h cm^{-1} for formaldehyde samples.

Once the settling process finished, cells were identified, where possible, to species/genus level and assigned to different functional groups: Flagellates, Heterotrophic flagellates, Diatoms, Coccolithophores, Dinoflagellates, Heterotrophic dinoflagellates, and Ciliates. It should be noted that heterotrophic refers to organisms that do not contain pigments.

Abundance data for each species at each station was calculated in cells per mL. Dimensions of individual species were measured in µm units using digital measurements and calibrated against an ocular micrometer. Using the corresponding geometric shapes, these measurements were converted to volume using the (Kovala and Larrance 1966) methodology. Once this was done, cell volumes were converted to carbon (pg $cell^{-1}$) using the formulae of Menden-Deuer and Lessard (2000).

Since all the plankton counts were obtained by light inverted microscopy they do not include pico-cyanobacteria, like *Prochlorococcus* and *Synechococcus*. The database adequately samples the microplankton size range and part of the nanoplankton abundance, small eukaryotes are also too small to be identified to the species level by light-microscopy. The Utermöhl technique is restricted to cells larger than 10 µm (within the nanoplankton size range). Smaller cells do not settle quantitatively even after Lugol's iodine addition and cells are too small to classify to the species level.

Nutrients

To analyse nutrients, a Technicon AAII (four-five channel depending on the cruise) segmented-flow auto-analyser was used. Protocols used were different for each nutrient: phosphate and silicate were analysed as described by Kirkwood (1989). Nitrate and nitrite was analysed using a modified version of Grasshoff's method (Grasshoff 1976), as described by Brewer and Riley (1965). These were measured as nirate plus nitrite, since the nitrate was determined as nitrite using a copper-cadmium reduction column to reduce it to nitrite. We later calculated nitrate as the difference between the nitrite measure and the nitrite plus nitrate measure. Ammonium was measured only in cruise AMT6. The chemical methodology used was the described by (Mantoura and Woodward 1983). All results are presented as µmol L^{-1} of the elements nitrogen, phosphorus and silica.

Environmental data

When in situ enviromental data were not available they were extracted from satellite data or global distribution maps. For Chl, Surface PAR and Diffuse attenuation coefficient at 490 nm (Kd490), we used SeaWIFS L3 datasets with 9km (1 pixel = 9 km) spatial resolution. We used SeaDAS (SeaWiFS Data Analysis System) to locate the closest pixel to the sampled location in the satellite image (radius of 0). Because sometimes this exact pixel contained a missing value we used the data of adjacent pixels using different search radius (from high to low accuracy), starting at 1 (radius of 1 pixel). When satellite data for the same day was not available we used the satellite image for the corresponding month and, ultimately, the monthly climatological data from the Ocean Color site (http://oceandata.sci.gsfc.nasa.gov/SeaWiFS/Mapped/).

For each variable a vector attached indicates the data quality flag (QF), starting at 0 when data is in situ, and decreasing in precision going from data extracted from daily maps to data extracted from monthly climatologies.

QF are: 0 (real data), 1 (daily satellite data (DS), radius = 0), 2 (DS, radius = 1), 3 (DS, radius = 3), 4 (DS, radius = 5), 5 (DS, radius = 10), 6 (DS, radius = 20), 7 (monthly satellite data (MS), radius = 0), 8 (MS, radius = 1), 9 (MS, radius = 3), 10 (MS, radius = 5), 11 (MS, radius = 10),12 (MS, radius = 20), 13 (monthly climatology satellite data (CS), radius = 0), 14 (CS, radius = 1), 15 (CS, radius = 3), 16 (CS, radius = 5), 17 (CS, radius = 10).

PAR at the sampled depth (PARz) was calculated using the Surface PAR and the Kd490. Mixed layer depth (MLD) data were extracted from the Ocean Productivity site (http://orca.science.oregonstate.edu/1080.by.2160.monthly.hdf.mld.merge.php). Data are stored in maps on a monthly basis at 1080 by 2160 resolution. We used SeaDAS to extract the whole image for each month. Then we located the MLD value for each coordinate value. For those points where there were not data, we calculated an annual climatology based on the monthly data set: We first interpolated maps to a lower resolution (360 by 180) and then calculated the mean for each month.

QF are defined as follows: 0 (in situ data), 1 (monthly satellite data (MS)), 2 (monthly climatology satellite data (CS)). The use of a search radius is not needed because images are the output of a model and do not have missing values.

To obtain an estimate of temperature for samples collected at depths below the MLD and for nutrients, we compiled data from the annual climatologies from the World Ocean Atlas 09 (WOA09) database at one degree resolution and 10 depth

levels (0, 10, 20, 30, 50, 75, 100, 125, 150, 200 meters) (http://www.nodc.noaa.gov/OC5/WOA09/woa09data.html). We extracted the value in the range of one degree around the specified coordinate.

QF are defined as follows: 0 (in-situ data), 1 (WOA data).

When the sample was collected at a depth shallower than the MLD, temperature was obtained from the Sea Surface Temperature (SST) data from the AVHRR satellite. We compiled daily datasets with 4km (1 pixel = 4 km) resolution from the NOAA site (ftp://podaac-ftp.jpl.nasa.gov/allData/avhrr/L3/pathfinder_v5/daily/night/04km/).

QF are defined as follows: 2 (daily satellite data (DS), radius = 0), 3 (DS, radius = 1), 4 (DS,radius = 3).

Figure 2 shows the relationship between the in situ data and estimated data for the different variables. Although for most of them, satellite can be a good estimation source, this does not occur for Chl and Silicate, where the correlation coefficient is too low.

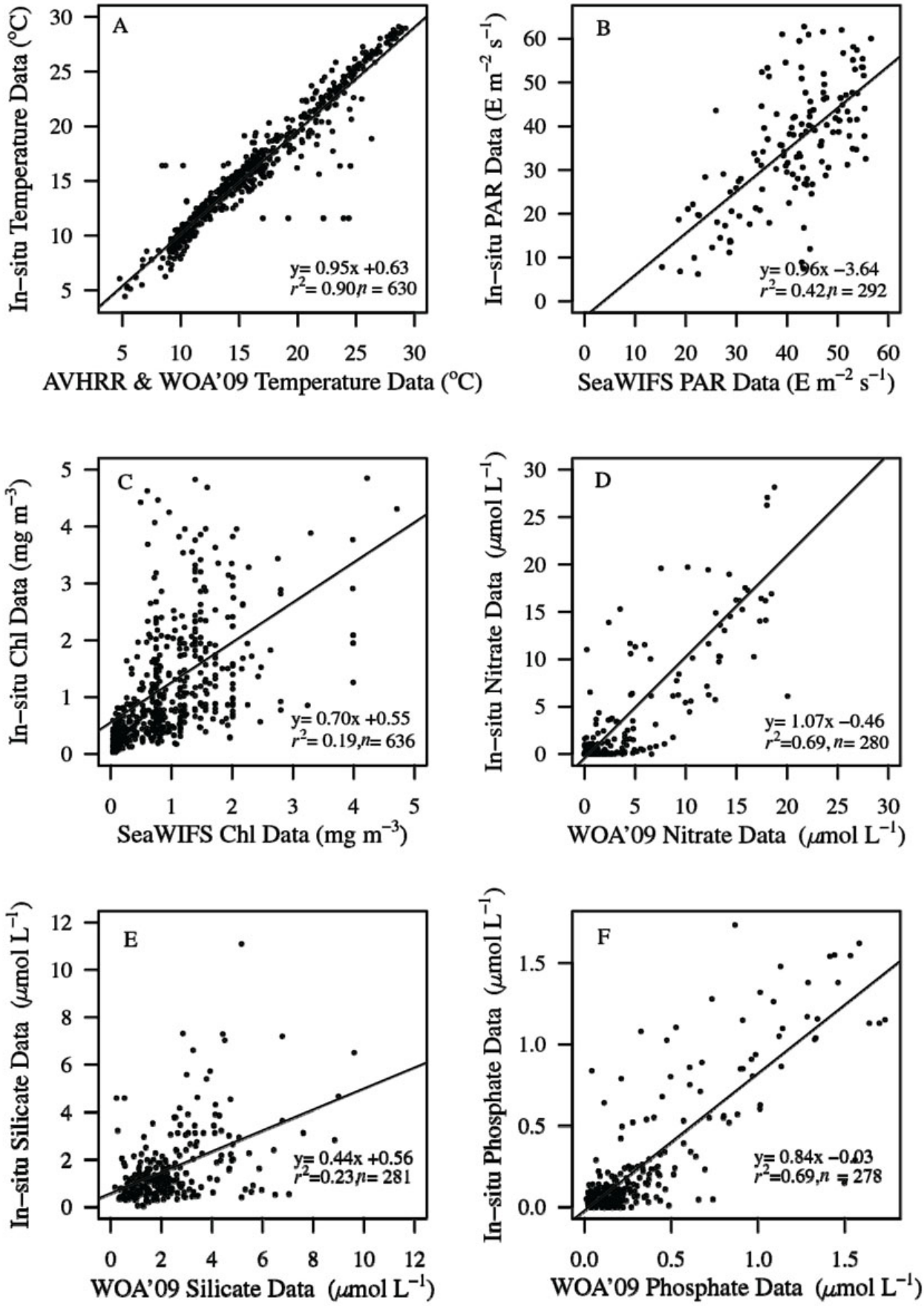

FIG. 2. Relationship between in situ data and estimated data for all variables: (A) Temperature, (B) PAR, (C) Chlorophyll, (D) Nitrate, (E) Silicate and (F) Phosphate. In each case, plotted points show only stations in which in situ data is available.

3. Taxonomy and systematics

Taxonomic names were checked against the World Register of Marine Species (WoRMS). Names not matched within WoRMS were checked against various other taxonomic references (e.g., ITIS, algaebase). A column with author comments is attached for those species which were not matched to any taxonomic references.

Project personnel: Same as authors

Class III. Data set status and accessibility

A. Status

Latest update: 2013

Latest Archive date: 2013

Metadata status: Metadata are complete for this period and are stored with the data.

B. Accessibility

Storage location and medium: The Ecological Society of America's *Ecological Archives*.

Contact persons:

Xabier Irigoien, King Abdullah University of Science and Technology. Red Sea Research Center, Building 2, Thuwal 23955-6900, Kingdom of Saudi Arabia.

Roger P. Harris, Plymouth Marine Laboratory, Prospect Place, Plymouth, Devon PL1 3DH, United Kingdom.

Derek S. Harbour, Plymouth Marine Laboratory, Prospect Place, Plymouth, Devon PL1 3DH, United Kingdom.

ángel Löpez-Urrutia, Centro Oceanográfico de Gijön, Instituto Español de Oceanografía, Avda Principe de Asturias 70bis, 33212, Gijön, Asturias, Spain.

Sofía Sal, Centro Oceanográfico de Gijön, Instituto Español de Oceanografía, Avda Principe de Asturias 70bis, 33212, Gijön, Asturias, Spain.

Copyright restrictions: None.

Class IV. Data structural descriptors

A. Data Set File

Identity: Data set is downloadable as a single archive, PhytoDataBase.zip (215.5 KB), which contains the following *.csv data files:

Table 1: Stations and cast description, including date, location and data for oceanographic variables such as nutrients or temperature.
Table 2: Species identification for the whole data set, including phylogenetic classification, author comments and carbon and biovolume for each species. Each row corresponds to each column in Table 3.
Table 3: Abundance for each species (by columns) at each station (by rows). Species carbon content can vary from one station to another, for those cases the species is repeated each column representing a different carbon content as specified in Table 2. For this reason we have more columns than species total number.

Size:

Table 1: 237.5 KB, 1043 rows and 30 columns.
Table 2: 222.6 KB, 1335 rows and 14 columns.
Table 3: 2.8 MB, 1043 rows and 1335 columns.

Format and storage mode:CSV text, comma delimited. Special characters/fields: All missing values are denoted as "NA".

B. Variable definitions:

Table 1:

Column name	Variable definition	Units	Storage type	Range numeric values	Missing value codes
SampleID	Sample identification code	text	string	N/A	NA
Cruise	Cruise name	text	string	N/A	NA

Date	Date	date	string	N/A	NA
Original SampleNo	Original cruise sample number	count	integer	1 to 14084	NA
Original StationNo	Original cruise station number	count	integer	1 to 35575	NA
Depth	Depth	m	integer	1 to 160	NA
Lat	Latitude	degrees	integer	-51.9314 to 66.0000	NA
Lon	Longitude	degrees	integer	-124.167 to 62.000	NA
Daylength	Daylength	hours	integer	8.0366 to 22.2324	NA
Chl	Chlorophyll concentration	mg m^{-3}	integer	0.03 to 27.4966	NA
QFChl	Chlorophyll quality flag	count	integer	0 to 17	NA
Temperature	Temperature	celsius	integer	2.7 to 29.117	NA
QFTemp	Temperature quality flag	count	integer	0 to 4	NA
SurfacePAR	Surface photosynthetically active radiation	mol photons m^{-2} d^{-1}	integer	3.664 to 64.0054	NA
QFPAR	Surface photosynthetically active radiation quality flag	count	integer	0 to 14	NA
Kd490	Diffuse attenuation coefficient at 490 nm	m^{-1}	integer	0.0224 to 6.2144	NA
QFKd490	Diffuse attenuation coefficient quality flag	count	integer	1 to 17	NA
PARz	Depth photosynthetically active radiation	mol photons m^{-2} d^{-1}	integer	0 to 52.2669	NA
Nitrate	Nitrate concentration	µmol L^{-1}	integer	0 to 37.7919	NA
QFNO3	Nitrate quality flag	count	integer	0 to 1	NA
Nitrite	Nitrite concentration	µmol L^{-1}	integer	0 to 0.72	NA
QFNO2	Nitrite quality flag	count	integer	0	NA
Ammonium	Ammonium concentration	µmol L^{-1}	integer	0.62 to 3.13	NA
QFNH4	Ammonium quality flag	count	integer	0	NA
Phosphate	Phosphate concentration	µmol L^{-1}	integer	0 to 2.1075	NA

QFPO4	Phosphate quality flag	count	integer	0 to 1	NA
Silicate	Silicate concentration	µmol L^{-1}	integer	0.04 to 22.5392	NA
QFSil	Silicate quality flag	count	integer	0 to 1	NA
MLD	Mixed layer depth	m	integer	10.7578 to 400	NA
QFMLD	Mixed layer depth quality flag	count	integer	1 to 2	NA

Table 2:

Column name	**Variable definition**	**Units**	**Storage type**	**Range numeric values**	**Missing value codes**
Group	Functional group	text	string	N/A	NA
Kingdom	Taxonomic kingdom	text	string	N/A	NA
Phylum	Taxonomic phylum	text	string	N/A	NA
Class	Taxonomic class	text	string	N/A	NA
Order	Taxonomic order	text	string	N/A	NA
Family	Taxonomic family	text	string	N/A	NA
Genus	Taxonomic genus	text	string	N/A	NA
Species	Taxonomic species	text	string	N/A	NA
Forma	Taxonomic forma	text	string	N/A	NA
Author Comments	Author specific comments about name, size or forma. Most times when species is difficult to indentify.	text	string	N/A	NA
Author	Taxonomist name	text	string	N/A	NA
SpeciesID	Identification code for unique species	count	integer	1 to 736	NA
Carbon	Carbon content	pg $cell^{-1}$	integer	0.0 to 143194.7	NA
Biovolume	Cell volume	µm $cell^{-1}$	integer	0 to 17671459	NA

Table 3:

Column name	Variable definition	Units	Storage type	Range numeric values	Missing value codes
N/A	Sample identification code	text	string	N/A	NA
Species name	Species abundance	cell ml^{-1}	integer	0.0 to 59763.5	NA

Acknowledgments

Data compilation was supported by project METabolic OCean Analysis (METOCA) funded by Spanish National Investigation+Development+Innovation (I+D+I) Plan. S.S. was funded by a Formaciön de Personal Universitario (FPU) grant from the Spanish Ministry of Education. This study is a contribution to the international IMBER project. AMT sample collection and analysis was supported by the UK Natural Environment Research Council National Capability funding to Plymouth Marine Laboratory and the National Oceanography Centre, Southampton. This is contribution number 233 of the AMT programme. The L4 programme is funded under the UK NERC Oceans 2025 programme as part of Theme 10, Sustained Observations.

Literature cited

Barton, A. D., S. Dutkiewicz, G. Flierl, J. Bragg, and M. J. Follows. 2010. Patterns of Diversity in Marine Phytoplankton. Science 327:1509–1511.

Brewer, P., and J. Riley. 1965. The automatic determination of nitrate in seawater. Deep Sea Research 12:765–72.

Buitenhuis, E. T., W. K. W. Li, D. Vaulot, M. W. Lomas, M. R. Landry, F. Partensky, D. M. Karl, O. Ulloa, L. Campbell, S. Jacquet, F. Lantoine, F. Chavez, D. Macias, M. Gosselin, and G.B. McManus. 2012. Picophytoplankton biomass distribution in the global ocean. Earth System Science Data 4:37–46.

Cermeño, P., E. Marañön, D. Harbour, and R. P. Harris. 2006. Invariant scaling of phytoplankton abundance and cell size in contrasting marine environments. Ecology Letters 9:1210–1215.

Clinebell, R. R., O. L. Phillips, A. H. Gentry, N. Stark, and H. Zuuring. 1995. Prediction of Neotropical Tree and Liana Species Richness From Soil and Climatic Data. Biodiversity and Conservation 4: 56–90.

Connell, J. H. 1978. Diversity In Tropical Rain Forests and Coral Reefs - High Diversity of Trees and Corals Is Maintained Only In A Non-equilibrium State. Science 199:1302–1310.

Enquist, B. J., and K. J. Niklas. 2001. Invariant scaling relations across tree-dominated communities. Nature 410: 655–660.

Floder, S., and U. Sommer. 1999. Diversity in planktonic communities: An experimental test of the intermediate disturbance hypothesis. Limnology and Oceanography 44:1114–1119.

Gentry, A. 1988. Changes in plant community diversity and floristic composition on environmental and geographic gradients. Annals of the Missouri Botanical Garden 75:1–34.

Gifford, D., and D. Caron. 2000. Sampling, preservation, enumeration and biomass of marine protozooplankton. In: Harris R.P. et al. (eds) ICES Zooplankton Methodology Manual. Academic Press, London pages 193–221.

Grasshoff, K. 1976. Methods of seawater analysis. Verlag Chemie, Weinheim and New York page 317pp.

Hayward, B., T. Cedhagen, M. Kaminski, and O. Gross. 2011. World Modern Foraminifera database. Available online at http://www.marinespecies.org/foraminifera. pages Consulted on 2013–01–22.

Huisman, J. 2010. Comment on ”Patterns of Diversity in Marine Phytoplankton”. Science 329:512.

Hutchinson, G. E. 1961. The Paradox of the Plankton. American Naturalist 95: 137–145.

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

Kirkwood, D. 1989. Simultaneous determination of selected nutrients in seawater. ICES CM **C:**29.

Kovala, P. E., and J. D. Larrance. 1966. Computation of phytoplankton cell numbers, cell volume, cell surface and plasma volumne per litre, from microscopical counts. Department of Oceanography. University of Washington. Special Report 38.

Leblanc, K., J. Arístegui, L. Armand, P. Assmy, B. Beker, A. Bode, E. Breton, V. Cornet, J. Gibson, M. Gosselin, E. Kopczynska, H. Marshall, J. Peloquin, S. Piontkovski, A. Poulton, B. Quéguiner, R. Schiebel, R. Shipe, J. Stefels, M. van Leeuwe, M. Varela, C. Widdicombe, and M. Yallop. 2012. A global diatom database - abundance, biovolume and biomass in the world ocean. Earth System Science Data 4:149–165.

Mantoura, R. F. C., and E. M. S. Woodward. 1983. Optimization of the Indophenol Blue Method For the Automated-determination of Ammonia In Estuarine Waters. Estuarine Coastal and Shelf Science 17:219–224.

Marañön, E., E. Fernández, R. Harris, and S. D. Harbour. 1996. Effects of the diatom-Emiliania huxleyi succession on photosynthesis, calcification and carbon metabolism by size-fractionated phytoplankton. Hydrobiologia 317:189–199.

Menden-Deuer, S., and E. J. Lessard. 2000. Carbon to volume relationships for dinoflagellates, diatoms, and other protist plankton. Limnology and Oceanography 45:569–579.

O'Brien, T. 2007. COPEPOD: The Global Plankton Database. A review of the 2007 database contents and new quality control methodology. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-F/ST-34 page 28p.

Peperzak, L. 2010. An objective procedure to remove observer-bias from phytoplankton time-series. Journal of Sea Research 63:152–156.

Phillips, O., and J. Miller. 2002. Global Patterns of Plant Diversity: Alwyn H. Gentry Forest Transect Data Set. Monogr. Syst. Bot. Missouri Bot. Gard. 89.

Rodríguez, F., E. Fernández, R. N. Head, D. S. Harbour, G. Bratbak, M. Heldal, and R. P. Harris. 2000. Temporal variability of viruses, bacteria, phytoplankton and zooplankton in the western English Channel off Plymouth. Journal of the Marine Biological Association of the United Kingdom 80:575–586.

Simon, N., A.-L. Cras, E. Foulon, and R. Lemee. 2009. Diversity and evolution of marine phytoplankton. Comptes Rendus Biologies 332:159–170.

Simova, I., D. Storch, P. Keil, B. Boyle, O. L. Phillips, and B. J. Enquist. 2011. Global species-energy relationship in forest plots: role of abundance, temperature and species climatic tolerances. Global Ecology and Biogeography 20:842–856.

Sommer, U. 1985. Comparison Between Steady-state and Non-steady State Competition - Experiments With Natural Phytoplankton. Limnology and Oceanography 30:335–346.

Stomp, M., J. Huisman, G. G. Mittelbach, E. Litchman, and C. A. Klausmeier. 2011. Large-scale biodiversity patterns in freshwater phytoplankton. Ecology 92:2096–2107.

Straile, D., M. C. Jochimsen, and R. Kümmerlin. 2013. The use of long-term monitoring data for studies of planktonic diversity: a cautionary tale from two Swiss lakes. Freshwater Biology (in press; early online available on the journal's website): doi: 10.1111/fwb.12118.

Throndsen, J. 1978. Preservation and storage. In: Sournia A (ed) Phytoplankton manual. UNESCO Paris, pages 69–74.

Tyrrell, T., E. Marañön, A. J. Poulton, A. R. Bowie, D. S. Harbour, and E. M. S. Woodward. 2003. Large-scale latitudinal distribution of Trichodesmium spp. in the Atlantic Ocean. Journal of Plankton Research 25: 405–416.

Utermöhl, H. 1958. Zur Vervolkommung der Quantitativen Phytoplankton-methodik. Mitt. Int. Ver. Limnol. 9: 1–38.

Wiltshire, K. H., and C. D. Durselen. 2004. Revision and quality analyses of the Helgoland Reede long-term phytoplankton data archive. Helgoland Marine Research 58:252–268.

Wright, D. H. 1983. Species-energy Theory - An Extension of Species-area Theory. Oikos 41:496–506.

[Back to E094-149]