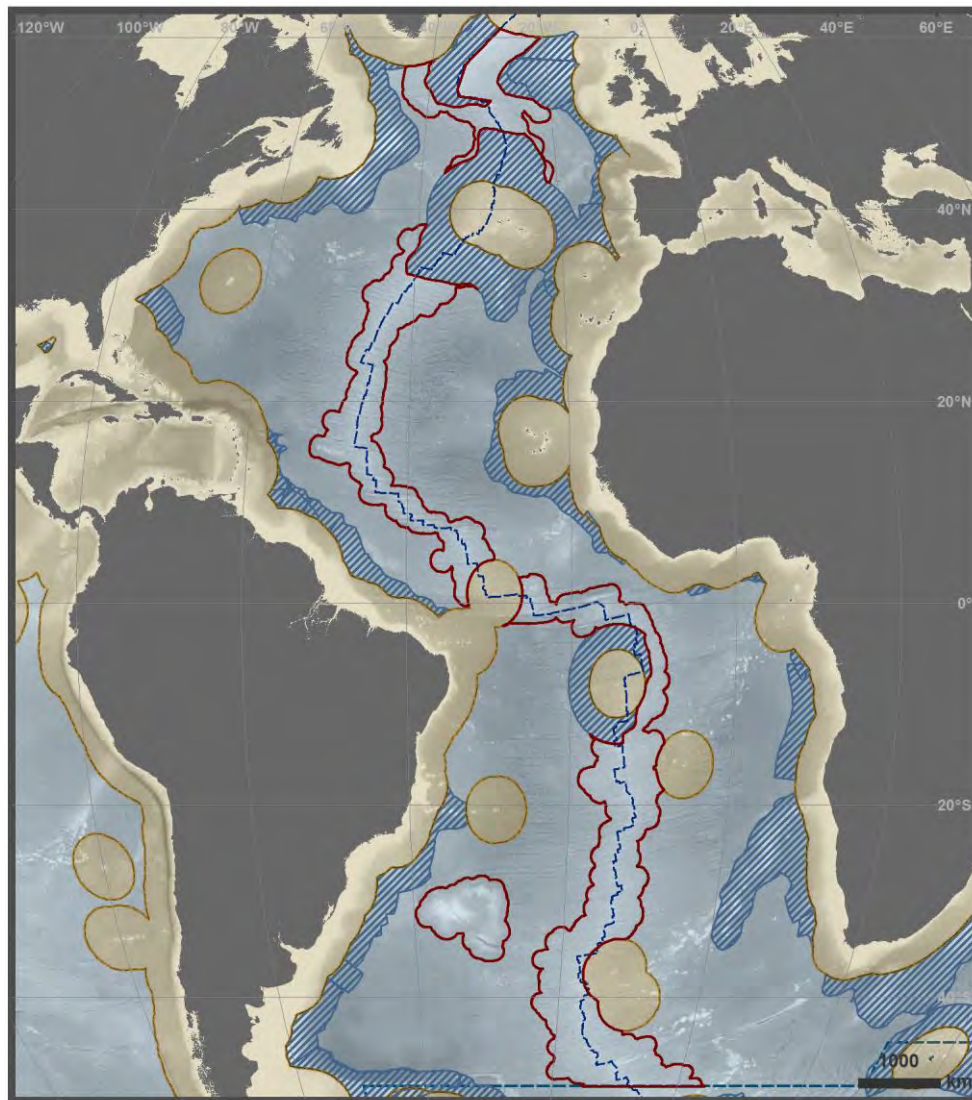
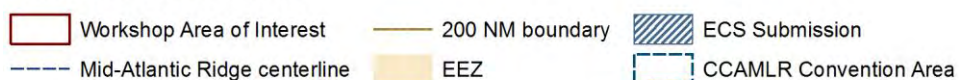


Data report: Towards development of a Strategic Environmental Management Plan for deep seabed mineral exploitation in the Atlantic basin

Pre-Workshop Data Report



Marine Boundaries



1-3 June 2015, Horta, Azores, Portugal

Telmo Morato, Jesse Cleary, Gerald H. Taranto, Frederic Vandeperre, Christopher K. Pham, Daniel C. Dunn, Ana Colaço, Patrick N. Halpin

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Data report to inform the workshop Towards development of a strategic Environmental Management Plan for deep seabed mineral exploitation in the Atlantic basin, prepared by IMAR Instituto do Mar and the Marine Geospatial Ecology Lab, Duke University.

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Pre-Workshop Data Report

1-3 June 2015, Horta, Azores, Portugal

Departamento de Oceanografia e Pescas, Universidade dos Açores

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Foreword

Drafting an effective Strategic Environment Management Plan (SEMP) for mining in areas beyond national jurisdiction in the Atlantic Basin is a major challenge, but one that must be met if seabed mining activities are to be managed consistent with the obligations of States under international law.

The Environment Management Plan for the Clarion Clipperton Zone (CCZ) adopted by the International Seabed Authority (ISA), was based on a recommendation of the ISA's Legal and Technical Commission which elaborated a set of 'guiding principles' for the development of the plan, including the precautionary approach, protection and preservation of the marine environment, prior environmental impact assessment, conservation and sustainable use of marine biodiversity, and transparency. These should be built upon and be effectively operationalized in the design and implementation of an SEMP for the Atlantic Basin.

The importance of having a SEMP in place before commercial mining occurs is clear. For example, we can only know how to manage the potential impacts of mining operations on source populations of key deep-sea species, species connectivity, or ecosystem functions through a broad, bioregional review of the species, ecosystems and ecosystem functions in an area. This is important for determining the size, locations and numbers of areas that should be set aside to ensure continued ecosystem function and viability. Moreover, a SEMP is a necessary framework for evaluating environment impact assessments and establishing management plans for individual sites, determining the number of individual sites that can or should potentially be authorized for mining (the carrying capacity of the area or region), and is a critical mechanism for assessing potential and actual cumulative impacts at appropriate bioregional scales, not only those arising from seabed mining activities but from other activities as well, for example deep-sea fishing, including over the long term.

Drawing on provisions of the UN Convention on the Law of the Sea (UNCLOS), a SEMP provides an important means to meet the obligation in Article 194 of the convention to "preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species". A well designed SEMP should also be robust to scientific uncertainty, in particular where information is unreliable or inadequate, as a precaution against significant, serious or irreversible harm to the marine environment. Further, a well designed SEMP should also set standards for the extent and quality of baseline information needed and for the validation of modeling at bioregional scales in order to ensure with a reasonable degree of confidence that conservation objectives will be met if and as commercial mining is permitted to occur.

Finally a SEMP should not be a one-off exercise but be periodically updated and improved as new scientific information becomes available from contractors and by other means, as is recognized by the International Seabed Authority in the CCZ Environment Management Plan. This in turn should be built into the overall management regime for seabed mining. The scientific and management challenges are clear but not insurmountable and the importance of adopting and implementing an effective Strategic Environmental Management Plan before mining occurs should be recognized as being of paramount importance to ensure the protection and preservation of the marine environment, an obligation well established under international law.

Matthew Gianni

Co-founder, Political and Policy Advisor
Deep Sea Conservation Coalition

Executive Summary

Deep-sea and open ocean waters are probably the largest environments on Earth but still some of the least understood. These ecosystems provide important direct and indirect goods and services such as food resources, oil and gas, and climate regulation. There is currently a great interest in different types of metal-rich deposits found in the deep-sea. Even though no exploitation has yet started, deep-sea mining activities may impact deep-sea biodiversity and consequently ecosystem functioning. Along the Mid-Atlantic Ridge (MAR) south of the Azores, the International Seabed Authority (ISA) has signed two exploration contracts for massive sulfide deposits with Russia and France, while Brazil's application for exploration for cobalt-rich ferromanganese crusts on the Rio Grande Rise was approved by the ISA Council in 2014. Growing pressure on deep-sea minerals prompted the Legal and Technical Commission of the ISA to adopt an Environmental Management Plan (EMP) for the Clarion-Clipperton Zone, but no such plan has been formulated for the Atlantic Ocean and particularly the Mid-Atlantic Ridge. The United Nations General Assembly requested the ISA 'to consider developing and approving environmental management plans in other international seabed area zones, in particular where there are currently exploration contracts'. Therefore a 'road map' for the development of a SEMP for the Mid-Atlantic Ridge in the international seabed area (from now on called the Area of Interest – AOI) is necessary.

The critical question for the process of developing a SEMP for the Atlantic is what data exist to support such a plan? In this data report, we have assembled a large amount of information originating from available publications, biogeographic databases, experts, online libraries and habitat suitability models, and have identified gaps in the baseline information. The biological data we collected come from two main sources: The Ocean Biogeographic Information System (OBIS) (www.iobis.org) and a comprehensive revision of the published literature. A total of 315,000 OBIS records counting circa 2,500 species fell within the MAR and RGR areas. Most of these records clustered north and south of the Azores EEZ and were generally concentrated in the North Atlantic, with less than 3% of the total data describing lower bathyal provinces (800-3000m). Remarkably, almost no benthic information existed in OBIS for the RGR. Although we may have overlooked some published information, a total of 125 scientific cruises, 235 articles and 410 unique sampling sites were identified for the Area of Interest. With the exception of a minor fraction of the ridge area, the MAR and the RGR remain poorly described in the literature. Away from vent sites, two international projects (MAR-ECO and ECOMAR) were responsible for nearly 65% of all the biological publications available for the northern-MAR. Although most of the MAR-ECO project data is readily available through OBIS, the ECOMAR and South Atlantic MAR-ECO data are not yet available for the workshop. Similarly, the Japanese expedition Quest for the Limit of Life that in 2013 explored the deep-sea habitats of the RGR is absent from OBIS.

Chapter 1. Introduction

1.1 Setting the Context

Deep-sea and open ocean waters are probably the largest environments on Earth but still some of the least understood (Ramirez-Llodra et al., 2010). These ecosystems provide important direct and indirect goods and services such as food resources, oil and gas, and climate regulation (UNEP, 2007). In the last decades, the human pressure on these systems has sharply increased (Roberts, 2002; Morato et al., 2006). In fact, the increase in demand for natural and mineral resources coupled with a rapid technological development that now allows the exploitation of formerly inaccessible areas has caused a constant expansion of human-related activities toward deeper waters and more distant areas (Halpern et al., 2008; Ramirez-Llodra et al., 2011; Watson and Morato, 2013; Merrie et al., 2014).

There is a growing interest in deep seabed mining. Different types of metal-rich deposits can be found in the deep-sea of which polymetallic nodules, Fe-Mn crusts and massive polymetallic sulphides are of highest commercial interest (Halfar and Fujita, 2007; Hein et al., 2010). Even though no substantive exploitation has yet started, with the exception of few exploratory surveys, mining activities on submarine features are likely to threaten deep-sea biodiversity and consequently ecosystem functioning (Halfar and Fujita, 2007, Danovaro et al., 2008, He et al., 2011). Deep-sea mining is expected to target mineral resources from distinct environments and, consequently, to have varying impacts on their ecosystems. Massive sulfide mining may directly or indirectly impact active hydrothermal vents that support rich chemosynthetic ecosystems. Many species are endemic to vents and for many their distribution is thought to be restricted to the Mid-Atlantic Ridge, which forms a consistent biogeographic unit (e. g. Desbruyères et al., 2001). In 2010, the Dinard Workshop initiated a discussion on the need for protective networks of chemosynthetic ecosystems (Van Dover et al., 2011). However, initially massive sulfide mining is likely to impact inactive vents. Benthic communities at inactive vents and seamount cobalt crusts remain poorly understood. They are possibly as diverse as active vents and may well host vulnerable, structure-forming taxa such as deep-sea corals, sponges or xenophyophores. The distribution of the species inhabiting inactive vents and cobalt crusts is not expected to be restricted to these areas but habitat fragmentation is likely to influence recovery potential after mining. The current state of knowledge of the species composition and the biogeography of these species are mostly unknown. Consequently rehabilitation and recovery rates are yet to be established.

Therefore, there is an urgent need for science and management plans aiming at assessing impacts of deep-sea mining on deep-sea, seamounts and pelagic ecosystems to mitigate the impacts of such new activities (Van Dover et al., 2011; ISA, 2012; Collins et al., 2013).

Along the Mid-Atlantic Ridge south of the Azores, the International Seabed Authority (ISA) has signed two exploration contracts for massive sulfide deposits to Russia and France. Brazil has applied for an exploration contract for cobalt crusts on the Rio Grande Rise and is also prospecting for deep-sea minerals within its EEZ. Other States have conducted marine scientific research to inform on the potential prospection for minerals in the relevant area. In the Azores waters, including the extended continental shelf, private companies have applied for exploration contracts for massive sulfide deposits. North of the Azores, massive sulfide deposits are also known to occur and Norway is undertaking an assessment of areas with potential for mineral exploration within its EEZ.

In 2013 and again in 2014, the United Nations General Assembly (UNGA) requested the ISA 'to consider developing and approving environmental management plans in other international seabed

area zones, in particular where there are currently exploration contracts' (UNGA Resolution 68/70 §51 and A.69/L.28, §51). At the twentieth session of ISA in 2014, the Assembly took note of the invitation by the UNGA and noted the importance of giving priority to the development of such environmental management plans within the work programme of ISA.

While growing pressure on deep-sea minerals and their associated ecosystems prompted the Council of the ISA in 2012 to adopt a Strategic Environmental Management Plan (SEMP) for the Clarion-Clipperton Zone (ISBA/18/C/22), no such plan has been formulated for the Atlantic Ocean and particularly the Mid-Atlantic Ridge. The lack of a SEMP for the Atlantic leaves open the prospect of exploitation of the deep-seabed without appropriate conservation measures being in place.

Therefore a stakeholder workshop promoting the discussion on a 'road map' for the development of a SEMP for the Mid-Atlantic Ridge in the international seabed area (from now on called the Area of Interest) is necessary. The primary drivers underlying the development of a SEMP are the fragility and vulnerability of species and habitats. Fragility and vulnerability may be assessed by, inter alia, data on the distribution of species, habitats, and stressors or proxies for future stressors (e.g., the presence of commercially valuable minerals). The critical question at this juncture for the process of developing a SEMP for the Atlantic is what data exist to support such a plan?

1.2 Objectives

Considering the ecosystems at stake and ongoing activities in the Atlantic, a Strategic Environmental Management Plan (SEMP) for mineral mining will need to consider the current legal and management regimes as well as the effects and intensity of cumulative impacts of planned and existing activities. It could assist in the planning of future seabed mining activities in the context of past, present and future impacts of human activities, including climate change, by gathering information needed to inform any future Strategic Environmental Assessment or Environmental Impact Assessments. To develop this SEMP, we convened a workshop in Horta, Azores (Portugal), between the 1st and 3rd of June 2015 to identify elements for a SEMP for deep seabed mineral exploration and exploitation in the Atlantic in areas beyond national jurisdiction (known as the Area). Special focus was placed on the Mid-Atlantic Ridge (MAR) and the Rio Grande Rise (RGR) (Areas of Interest) since these are the areas where mineral extraction in the Atlantic is expected to start.

The main objectives of the workshop are:

- Gather and review the adequacy of available baseline information on the marine environment including the location of sensitive deep-sea habitats and ecosystems;
- Identifying gaps in the baseline information and discuss how to fill them;
- Identify related policy and legislation at international, regional and national levels;
- Identify the nature, distribution and intensity of pressures and impacts associated with mining and how they interact with other anthropogenic activities and stresses;
- Agree upon a 'road map' for the development of a SEMP for the Atlantic in the Area of Interest, and the strategic aims and goals of such a plan.
- In addition to the core outcomes identified above, the workshop will provide a valuable template for environmental planning with respect to deep-ocean activities that cross sectors in the Area of Interest. We anticipate such a template to be useful in other regions in the future.

1.3 Geographical area to be addressed in the report

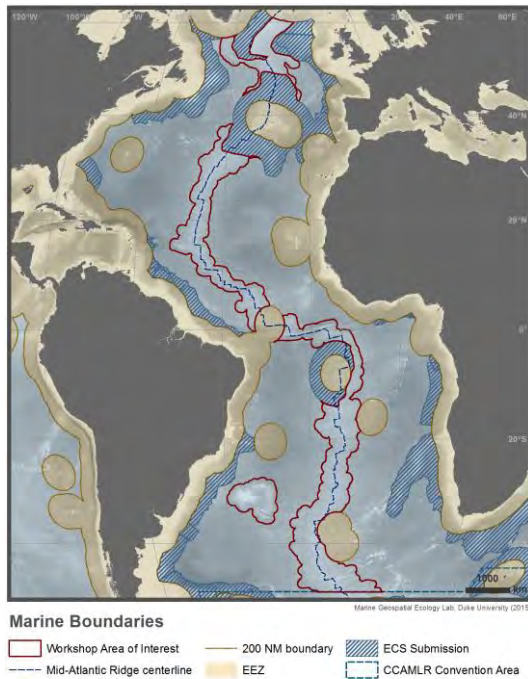


Figure 1. Workshop areas of interest

Mid-Atlantic Ridge

The Mid-Atlantic Ridge (MAR) extends right from the Arctic Ocean to beyond South Africa. In many parts it rises to less than 1000 m depth and reaches the 2000 m depth contour nearly everywhere (Tomczak and Godfrey, 1994). For the purposes of this report the MAR was defined by: (1) Creating a 500km buffer around the MAR; (2) removing areas falling in the GOODS Abyssal provinces (> 3500m) (UNESCO, 2009); (3) removing areas inside EEZs, extended continental shelf submissions, and the CCAMLR convention area (Figure 1).

Rio Grande Rise

The Rio Grande Rise RGR is an immense ridge that rises more than 5000 m above the ocean floor in the South Atlantic. Together with the Walvis Ridge it constitutes one of the most prominent bathymetric features in the South Atlantic Basin (Figure 1).

1.4 Baseline data mining

A comprehensive understanding of the physical, chemical, and biological environment provides the foundation for a well-executed SEMP. An effective SEMP should consider present and future human uses and the current legal and management regimes. The next chapters provide a thorough overview of such information available for the Area, with the exception of biological data that mostly concerned the Mid-Atlantic Ridge (MAR) and Rio Grande Rise (RGR) areas – the Area of Interest.

Particular emphasis was given to the synthesis of ecological information for the MAR and RGR. Biogeographic databases, experts, online libraries and habitat suitability models were consulted to review the adequacy of available data for the Area of Interest – including the location of sensitive deep-sea ecosystems – and to identify gaps in the baseline information. All the major repositories for biological data in the Atlantic (OBIS, Pangaea and EMODnet) appeared to be interrelated. In particular, the Ocean Biogeographic Information System (OBIS) (IOC, 2015) harvests data from other portals on a regular basis and was therefore chosen as a reference to identify data



Figure 2. OBIS records in the Area of Interest

gaps, possible vulnerable marine ecosystems and zones of enhanced diversity. Within the Area of Interest data were extremely patchy and unevenly distributed along latitudinal and depth gradients (Figure 2 and 23).

A total of about 315,000 OBIS records counting circa 2,500 species fell within the MAR and RGR areas. Most of these records clustered north and south of the Azores EEZ, were generally concentrated in the North Atlantic, and less than 3% of the total data described lower bathyal provinces (800-3000m). Remarkably, almost no benthic information existed in OBIS for the RGR. In an attempt to fill current gaps, over 30 scientists involved in deep-sea research on the MAR or RGR were contacted. With few exceptions, data openness and formatting constraints generally limited their contribution. Nevertheless future collaborations and different data policies may change this situation. In particular, colleagues from the Russian Academy of Sciences and from the University of Aberdeen were generously keen to provide new biological data.

A third and novel approach to investigate the adequacy of baseline information was the creation of a Geo-Referenced Library (GRL) where peer-reviewed articles were assigned to one or more 1x1 degree cells based on the location of their sampling sites (Figure 3). Each article was then further classified into different categories: realm (benthic, benthopelagic, bathypelagic, and pelagic); main taxonomic group; indicator of vulnerable marine ecosystem. As a result different queries could be performed to explore spatial patterns in published papers (Figure 4) or to synthesise the information available for each cell. Online libraries represented the main data source – Cambridge Journals, Oxford Journals, Science Direct, Springer Link, Wiley Online Library and Web of Knowledge. The criteria to identify articles of interest were to search for ‘Mid-Atlantic Ridge’ or ‘Rio Grande Rise’ in title, abstract or keywords and then filter for articles published in life sciences journals. Although these criteria may have overlooked large-scale reviews and fishery information, they still provide a reliable overview of scientific surveys and articles for which the MAR and RGR played central role. At the moment, a total of 125 scientific cruises, 235 articles and 410 unique sampling sites were identified. By broadening the search criteria and by completing the list of biological cruises that took place in the Area of Interest it will be possible to map all the sampling sites along the MAR and on the RGR, highlight those sites that produced scientific outcomes and those that did not and immediately visualize gap areas. Another advantage of this approach was to link scientists and study areas giving the possibility to have contact lists of researchers for each zone.

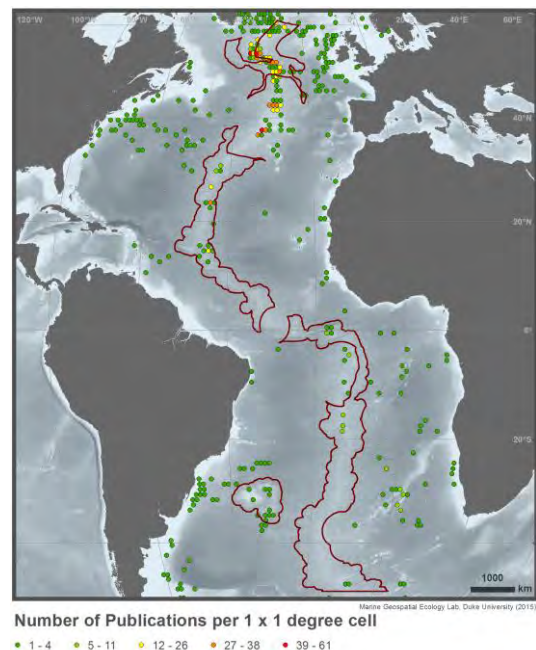


Figure 3. Publications referring to MAR or RGR

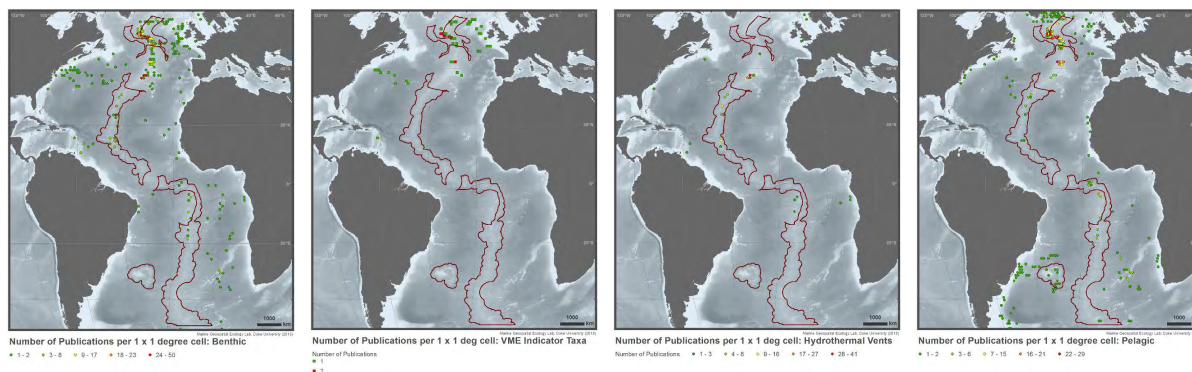


Figure 4. Publications referring to MAR or RGR divided by different categories

With the exception of a minor fraction of the ridge area, the MAR and the RGR remain poorly represented in the literature. Of the 217 articles that could be geo-referenced less than 10% described the biology of southern-MAR (Latitude $< 0^\circ$) and RGR and even less (ca. 5%) concerned the benthic environments of these areas (Figure 4). Greater scientific efforts were spent on the northern portion of the MAR, but they were generally limited to very specific areas. In fact, in recent decades most of deep-sea research on the MAR mirrored the location of hydrothermal vents, focusing therefore on very peculiar ecosystems and spatially limited areas (Van Dover, 2000; Desbruyères et al., 2001). Publications related to hydrothermal vents represented almost 35% of the total (Figure 4). But the most surprising finding was that moving away from vent sites less than 10 scientific cruises are responsible for about 65% of all the biological publications available for the northern-MAR.

Two international projects conducted these cruises, MAR-ECO (Patterns and processes of the ecosystems of the northern Mid-Atlantic) (Bergstad and Godø, 2002) and its spin-off project ECOMAR (Ecosystem of the Mid-Atlantic Ridge at the sub-polar front and Charlie-Gibbs Fracture Zone) (Priede et al., 2013). Particular emphasis should be given to the ECOMAR project that besides its contribution in terms of scientific production, still presents few data accessible through OBIS. A second spin-off project of MAR-ECO was the South Atlantic MAR-ECO, a project that aimed at better defining the ecosystem of the southern MAR and the overall biogeography of the lower bathyal provinces in the Atlantic Ocean (Perez et al., 2012). Unfortunately this project is still in an early stage and counts only one preliminary cruise conducted in 2009 in the southern Atlantic as its outcome. With a single exception (Parin et al., 1995), virtually no publication targeted the benthic environment of the RGR. New data are expected from the Japanese expedition QUELLE 2013 (Quest for the Limit of Life) that explored the deep-sea habitats of the RGR in 2013. However the information collected has not been fully analyzed yet. Some information was available for the pelagic waters above the RGR. It consisted of fisheries data on the bycatch of sharks, seabirds and sea turtles (e.g. Sales et al., 2008; Jiménez et al., 2010; Frédou et al., 2015) and population studies regarding seabirds and sea turtles (Reid et al., 2013; Prosdocimi et al., 2015).

Chapter 2. Environmental Data

2.1 Bathymetry and Seafloor Slope

The GEBCO 2014 Grid (http://www.gebco.net/data_and_products/gridded_bathymetry_data/) is a global 30 arc-second interval grid largely generated by combining quality controlled ship depth soundings with interpolation between sounding points guided by satellite derived gravity data. However, in areas where they improve on the existing GEBCO_2014 grid, data sets generated by other methods have been included. Land data are largely based on the Shuttle Radar Topography Mission (SRTM30) gridded digital elevation model. GEBCO bathymetry can also be used to calculate different descriptors of the seafloor (Dunn and Halpin, 2009) such as seafloor slope and slope of the slope (a proxy for rugosity).

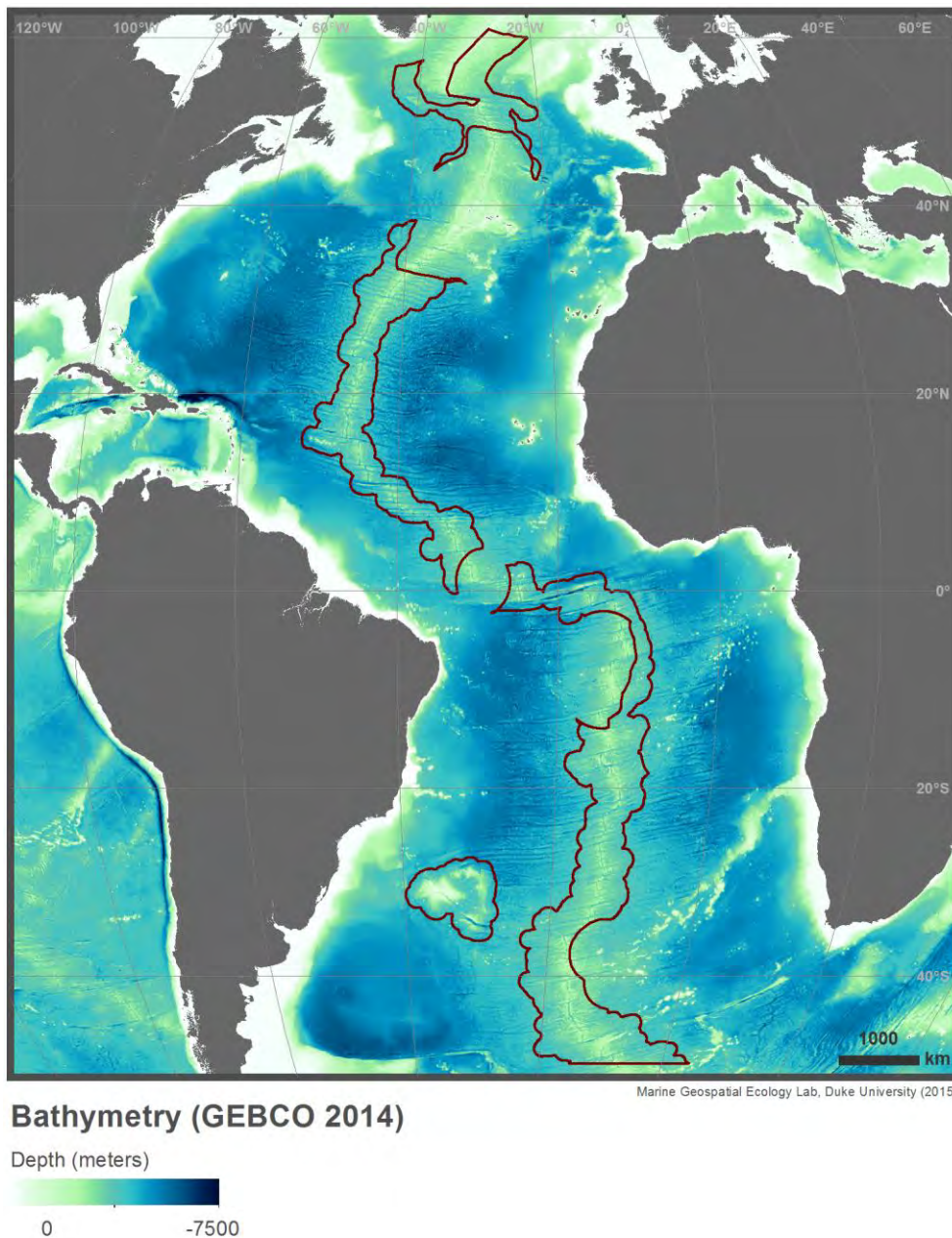
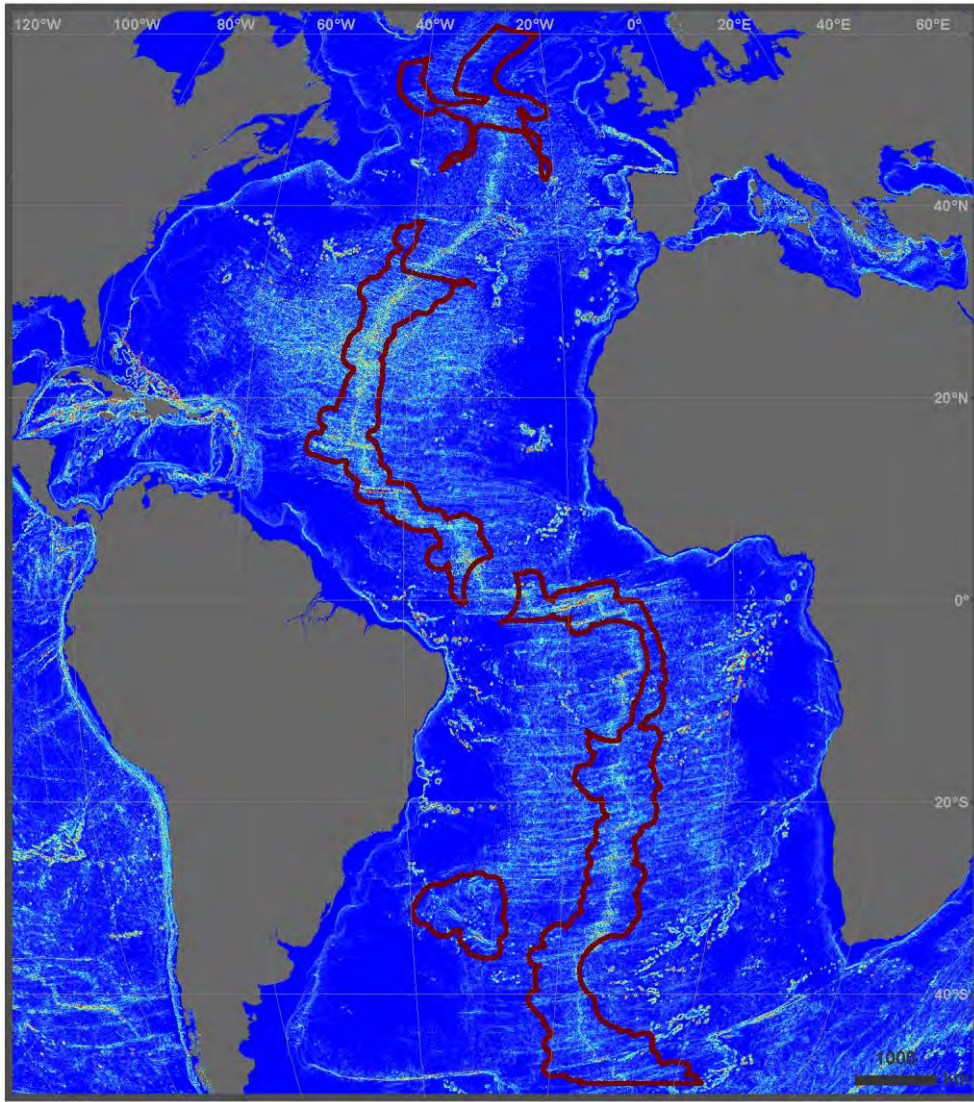


Figure 5. Bathymetry of the Atlantic Ocean, GEBCO 2014 30 arc sec interval grid.



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Seafloor Slope (derived from GEBCO 2014)

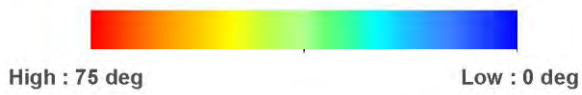
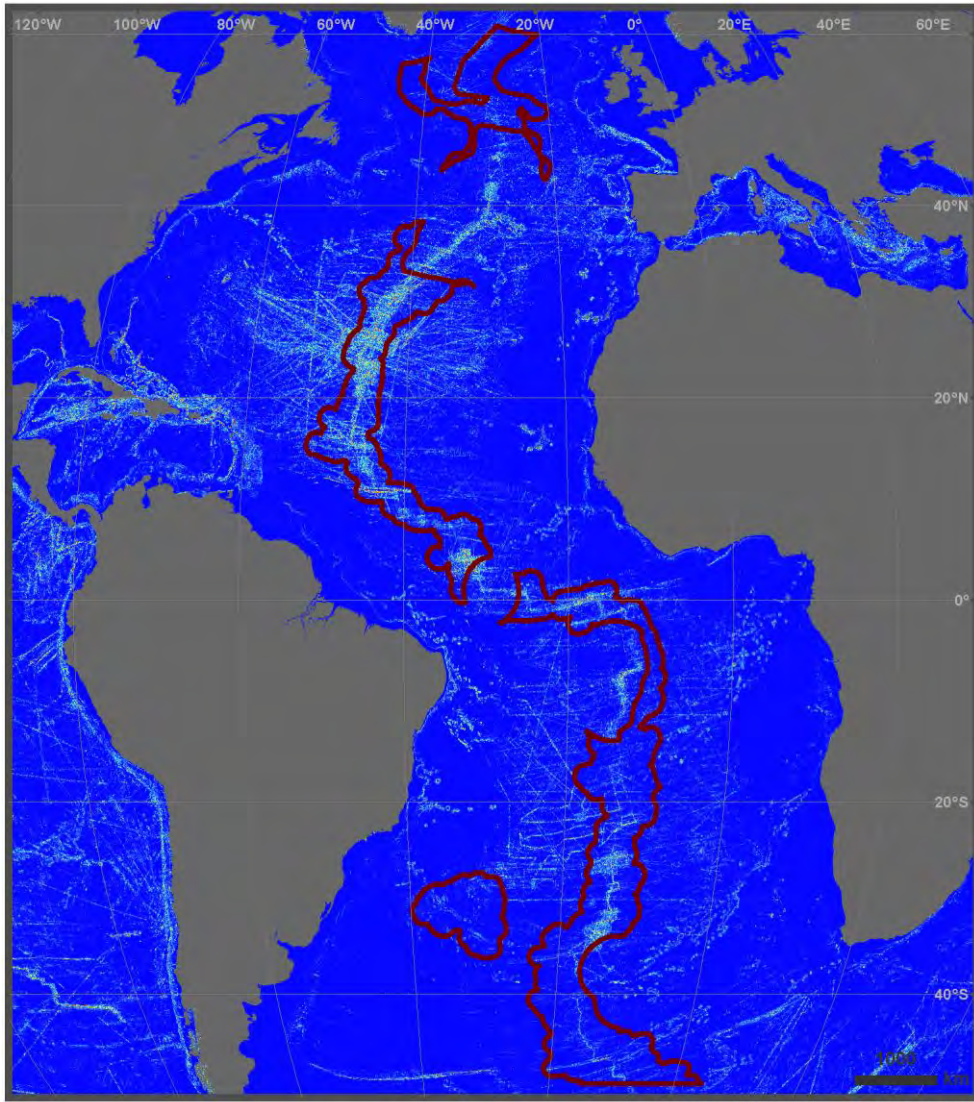


Figure 6. Seafloor slope, GEBCO 2014 30 arc sec interval grid.



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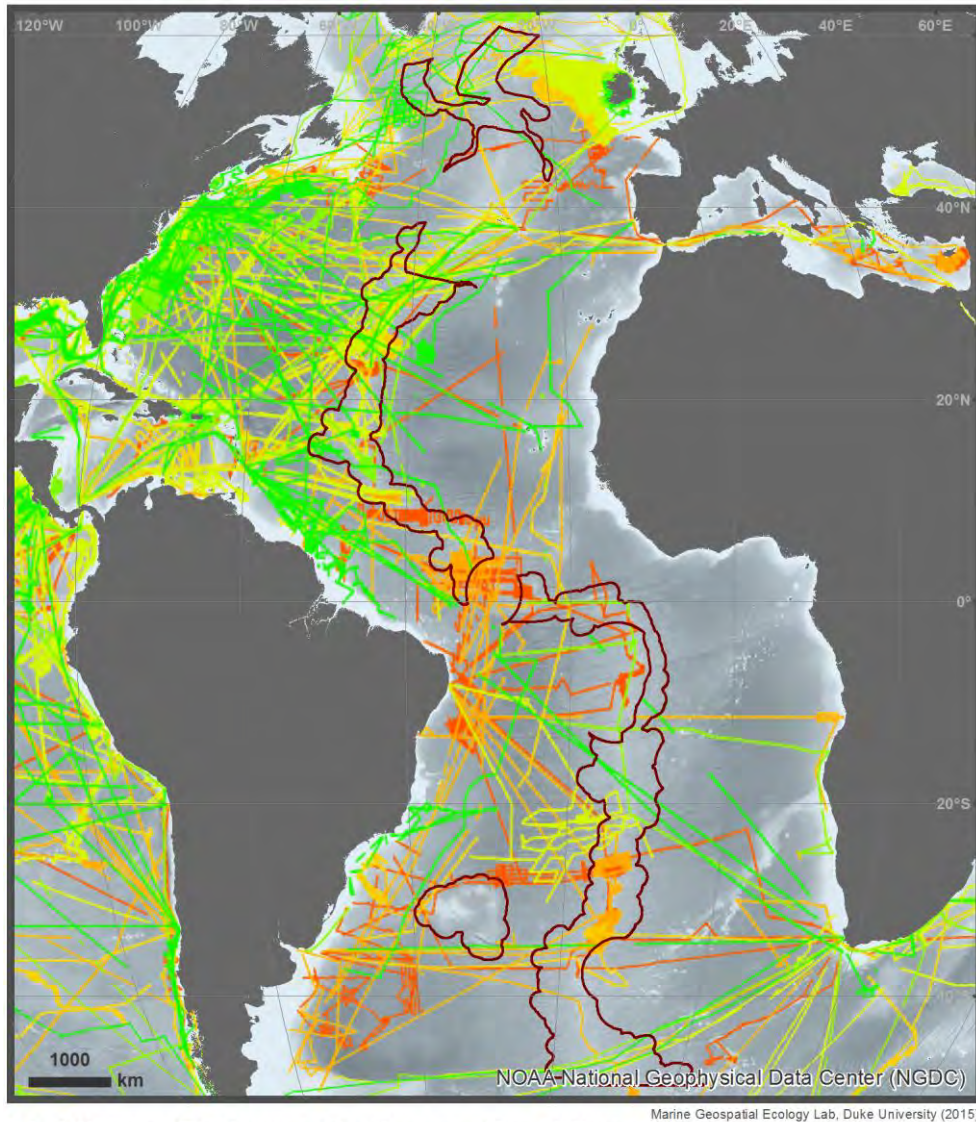
Acceleration of Seafloor Slope (derived from GEBCO 2014)



Figure 7. Slope of the slope derived from GEBCO 2014 (proxy for rugosity).

2.2 Fine-scale Bathymetry

NGDC is the US national archive for multibeam bathymetric data and presently holds over 15.7 million nautical miles of ship tracklines (1187 surveys) received from sources worldwide (<http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html>). In addition to deepwater data, the multibeam database also includes hydrographic multibeam survey data from NOAA's National Ocean Service (NOS). Here we show the ship track lines of multibeam bathymetric data for the Atlantic.



Multibeam Bathymetric Survey Tracklines

Survey Year	1995 - 1999	2005 - 2009
1980 - 1989	2000 - 2004	2010 - Present
1990 - 1994		

Figure 8. Multibeam bathymetric survey tracks.

2.3 AVHRR SST climatology

The 4k Advanced Very High Resolution Radiometer (AVHRR) Pathfinder dataset (Casey et al., 2010), published by the NOAA National Oceanographic Data Center (NODC), provides a global, long-term, high-resolution record of sea surface temperature (SST) using data collected by NOAA's Polar-orbiting Operational Environmental Satellites (POES). For this effort, a cumulative climatology (1982 - 2009) was created using the “Create Climatological Rasters for AVHRR Pathfinder V5 SST” tool in the Marine Geospatial Ecology Tools (MGET) for ArcGIS (Roberts et al., 2010).

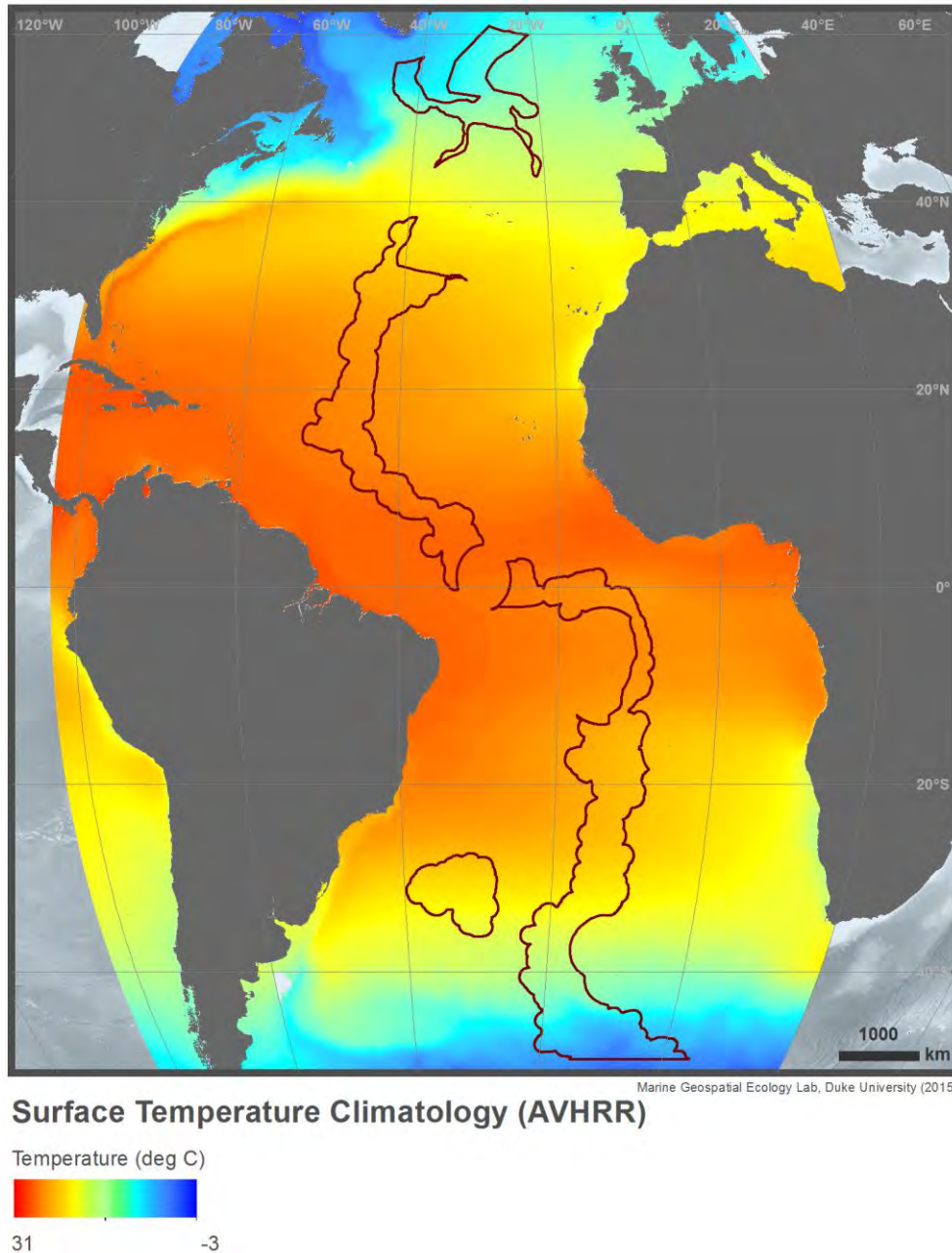
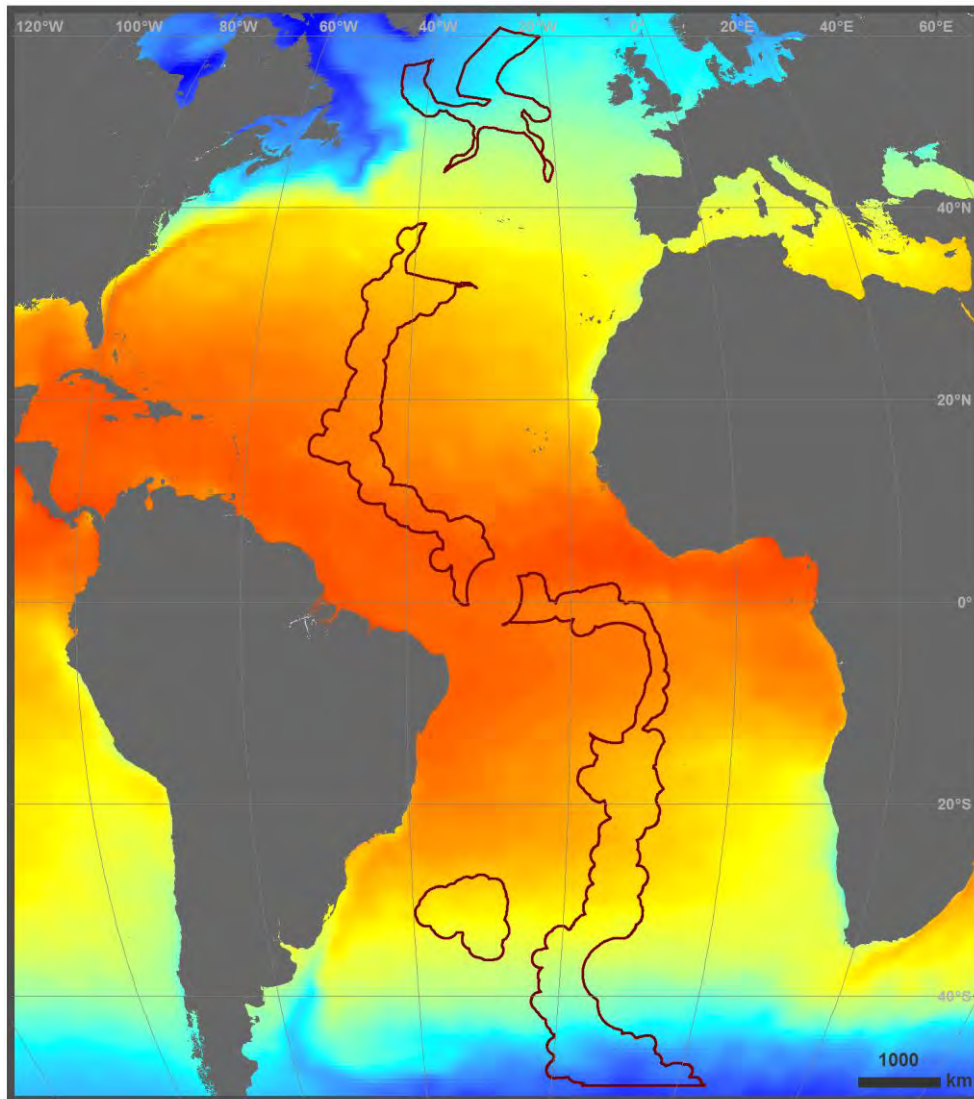


Figure 9. SST climatology (1982 - 2009) created using the Advanced Very High Resolution Radiometer (AVHRR) Pathfinder dataset (Casey et al., 2010).

2.4 Physical Oceans Climatologies from CARS

For this section data were downloaded and processed from the CSIRO Atlas of Regional Seas (CARS) (Ridgway, et al., 2002; <http://www.marine.csiro.au/~dunn/cars2009/>). CARS is a digital climatology, or atlas of seasonal ocean water properties. It comprises gridded fields of mean ocean properties over the period of modern ocean measurement, and average seasonal cycles for that period. It is derived from a quality-controlled archive of all available historical subsurface ocean property measurements - primarily research vessel instrument profiles and autonomous profiling buoys. As data availability has enormously increased in recent years, the CARS mean values are inevitably biased towards the recent ocean state. A number of global ocean climatologies are presently available. CARS is different as it employs extra stages of in-house quality control of input data, and uses an adaptive-lengthscale loess mapper to maximise resolution in data-rich regions, and the mapper's "BAR" algorithm takes account of topographic barriers (Dunn and Ridgway, 2002; Condie and Dunn, 2006). The result is excellent definition of oceanic structures and accuracy of point values.



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Surface Temperature Climatology (CARS 2009)

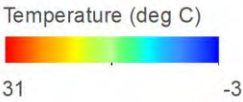
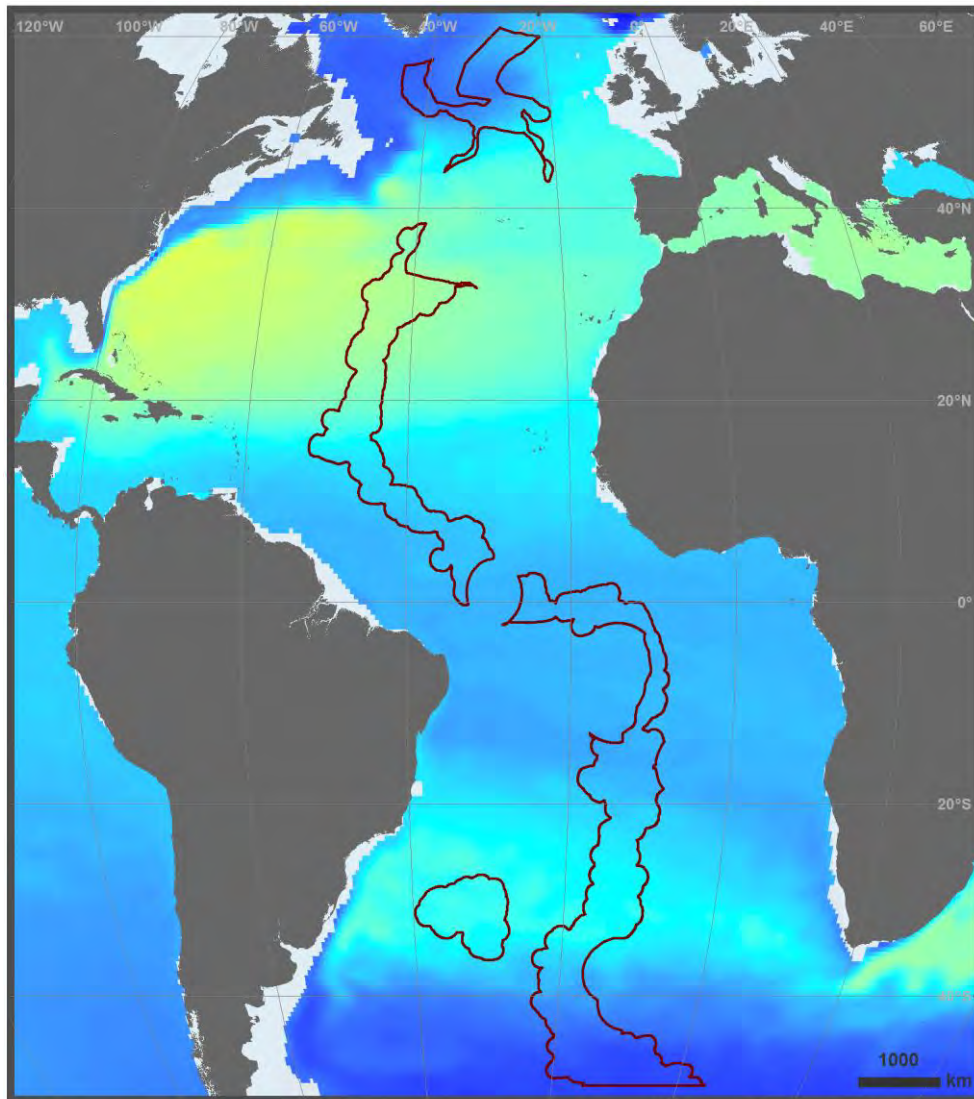


Figure 10. Surface temperature (2009), data from CSIRO Atlas of Regional Seas (CARS) (Ridgway, et al., 2002).



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500m Temperature Climatology (CARS 2009)

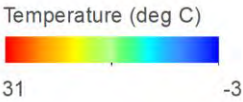
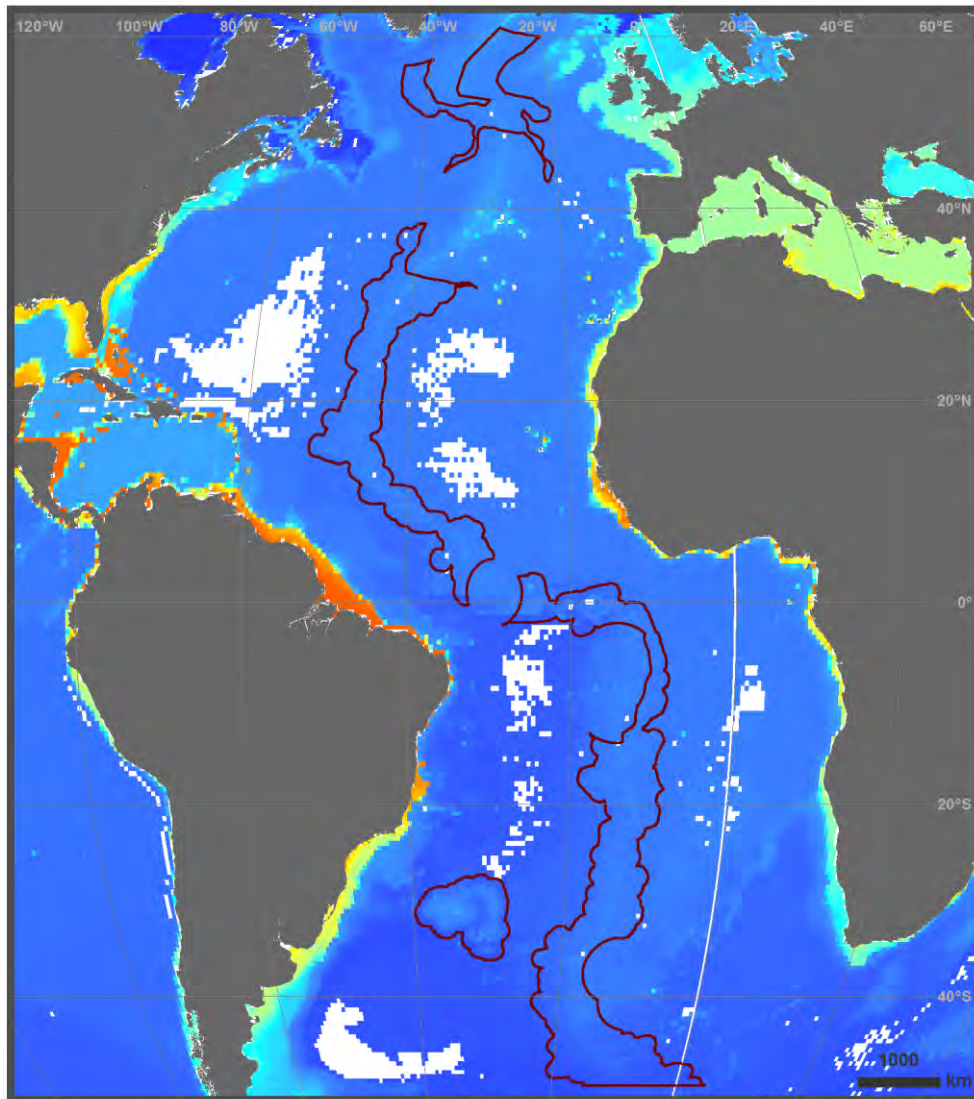


Figure 11. 500 m temperature (2009), data from CSIRO Atlas of Regional Seas (CARS) (Ridgway, et al., 2002).



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Bottom Temperature Climatology (CARS 2009)

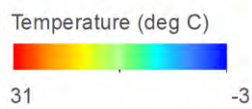
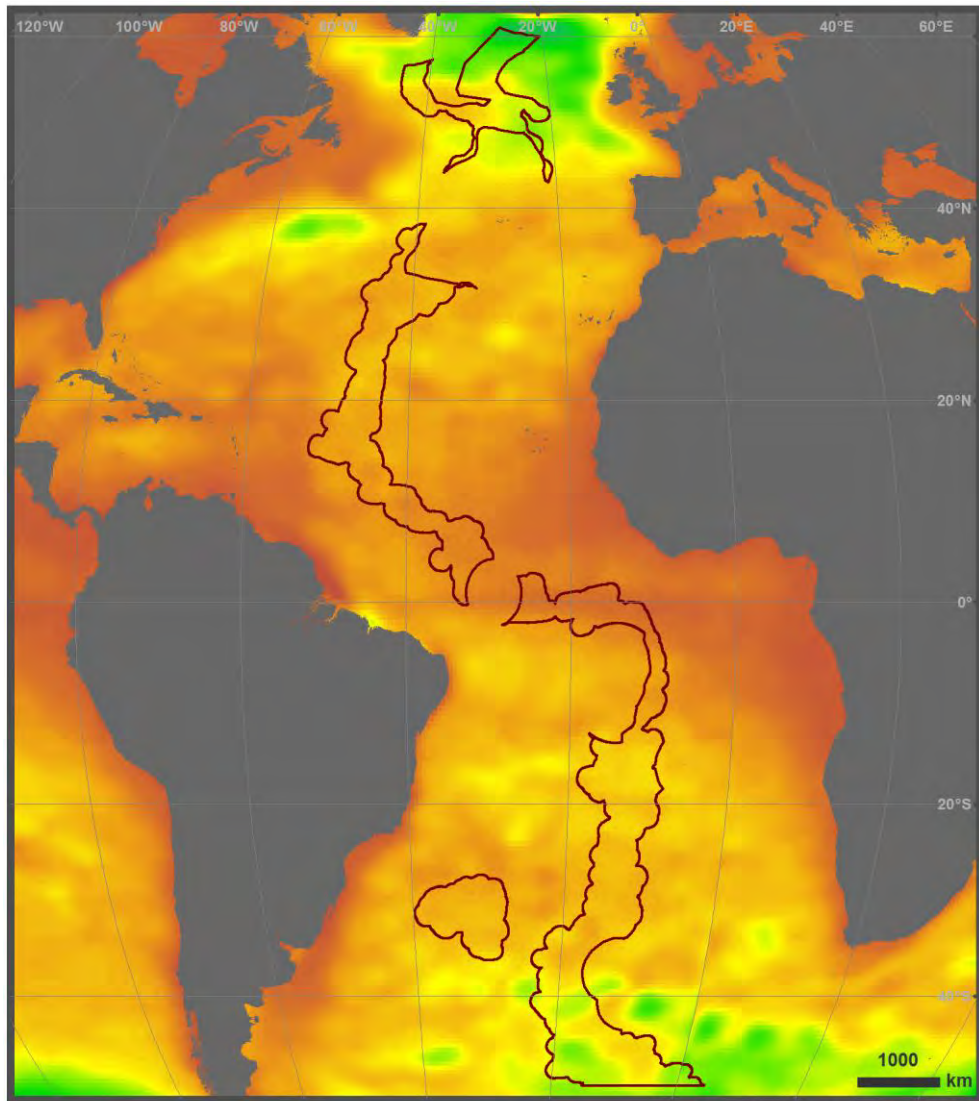


Figure 12. Bottom temperature (2009), data from CSIRO Atlas of Regional Seas (CARS) (Ridgway, et al., 2002).



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Mixed Layer Depth Climatology (CARS 2009)

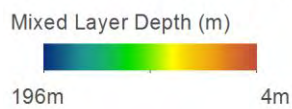
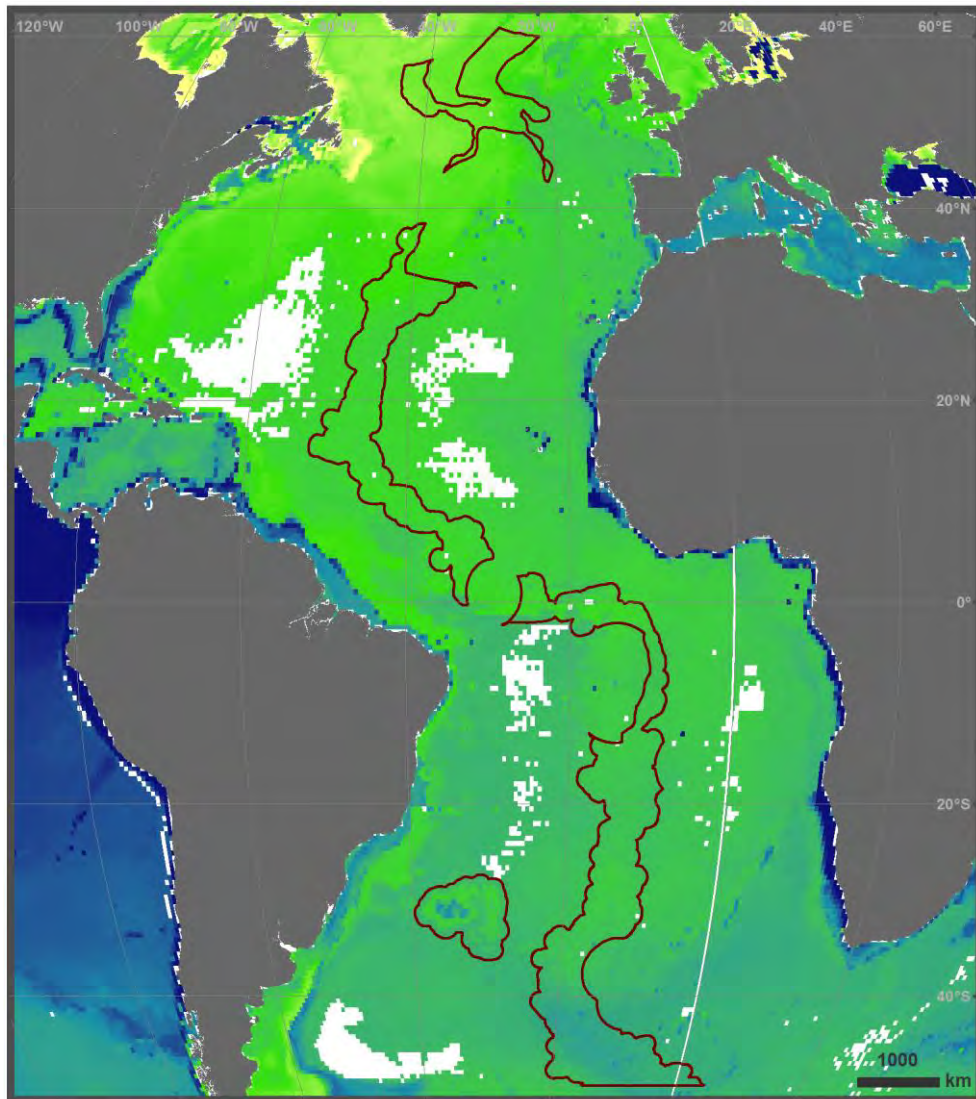


Figure 13. Mixed layer depth (2009), data from CSIRO Atlas of Regional Seas (CARS) (Ridgway, et al., 2002).



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Bottom Oxygen Climatology (CARS 2009)

Mean (ml/l)



H: 8.7 L: -0.0006

Figure 14. Bottom oxygen climatology (2009), data from CSIRO Atlas of Regional Seas (CARS) (Ridgway, et al., 2002).

2.5 Particulate Organic Carbon (POC) flux

Abstract (Lutz et al. 2007): We investigate the functioning of the ocean's biological pump by analyzing the vertical transfer efficiency of particulate organic carbon (POC). Data evaluated include globally distributed time series of sediment trap POC flux, and remotely sensed estimates of net primary production (NPP) and sea surface temperature (SST). Mathematical techniques are developed to compare these temporally discordant time series using NPP and POC flux climatologies. The seasonal variation of NPP is mapped and shows regional- and basin-scale biogeographic patterns reflecting solar, climatic, and oceanographic controls. Patterns of flux are similar, with more high-frequency variability and a subtropical-subpolar pattern of maximum flux delayed by about 5 days per degree latitude increase, coherent across multiple sediment trap time series. Seasonal production-to-flux analyses indicate during intervals of bloom production, the sinking fraction of NPP is typically half that of other seasons. This globally synchronous pattern may result from seasonally varying biodegradability or multiseasonal retention of POC. The relationship between NPP variability and flux variability reverses with latitude, and may reflect dominance by the large-amplitude seasonal NPP signal at higher latitudes. We construct algorithms describing labile and refractory flux components as a function of remotely sensed NPP rates, NPP variability, and SST, which predict POC flux with accuracies greater than equations typically employed by global climate models. Globally mapped predictions of POC export, flux to depth, and sedimentation are supplied. Results indicate improved ocean carbon cycle forecasts may be obtained by combining satellite-based observations and more mechanistic representations taking into account factors such as mineral ballasting and ecosystem structure.

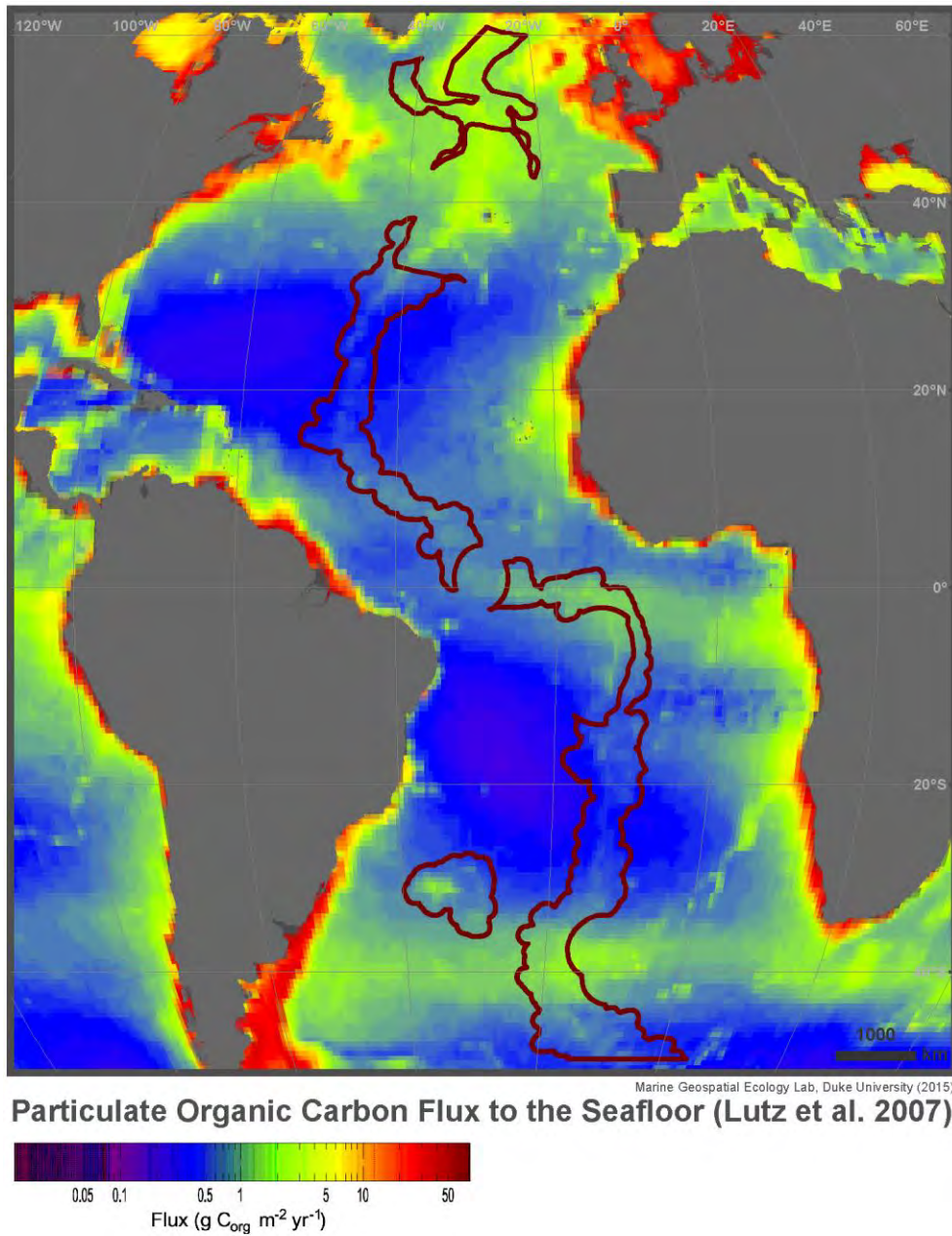
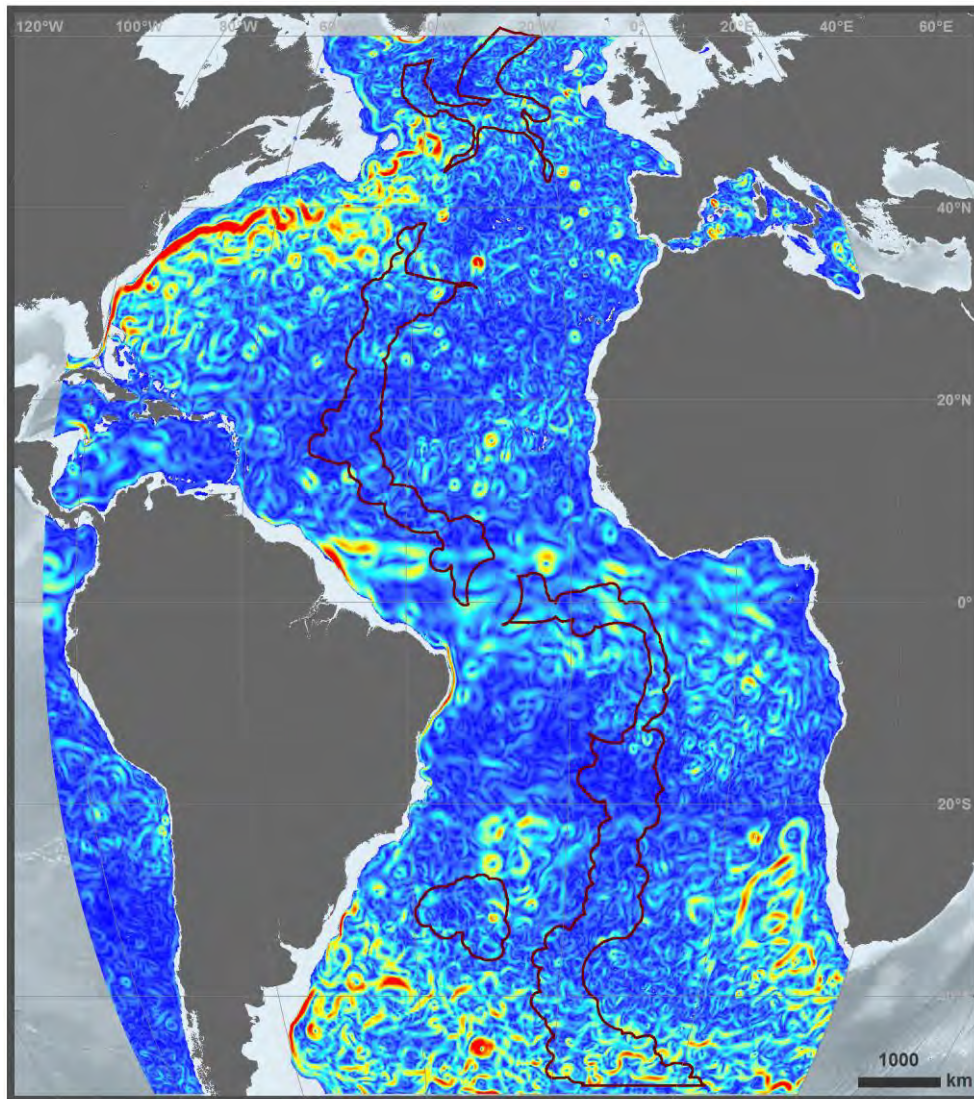


Figure 15. Forecast of annual average POC flux to the seafloor.

2.6 HYbrid Coordinate Ocean Model (HYCOM)

The HYCOM consortium (<https://hycom.org/about>) is a multi-institutional effort sponsored by the National Ocean Partnership Program (NOPP), as part of the U.S. Global Ocean Data Assimilation Experiment (GODAE), to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model (called HYbrid Coordinate Ocean Model or HYCOM). Here, climatologies of the 500 m current velocity and bottom temperature (Figures 11 and 12) were created using the “Create Climatological Rasters for HYCOM GLBa0.08 Equatorial 4D Variable” tool in the Marine Geospatial Ecology Tools (MGET) for ArcGIS (Roberts et al., 2010). This tool uses data from the Hybrid Coordinate Ocean Model (HYCOM) model GLBa0.08 (Chassignet et al. 2009). This tool produces rasters showing the climatological average value (or other statistic) of a HYCOM GLBa0.08 4D variable. Given a desired variable, a statistic, and a climatological bin definition, this tool downloads daily images for each depth layer of the variable, classifies them into bins, and produces a single raster for each bin. Each cell of the raster is produced by calculating the statistic on the values of that cell extracted from all of the rasters in the bin. This tool accesses the "All Experiments (Aggregated)" dataset of the HYCOM + NCOA Global 1/12 Degree Analysis (GLBa0.08) using the OPeNDAP protocol.



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500m Current Velocity (HYCOM, January 2014)

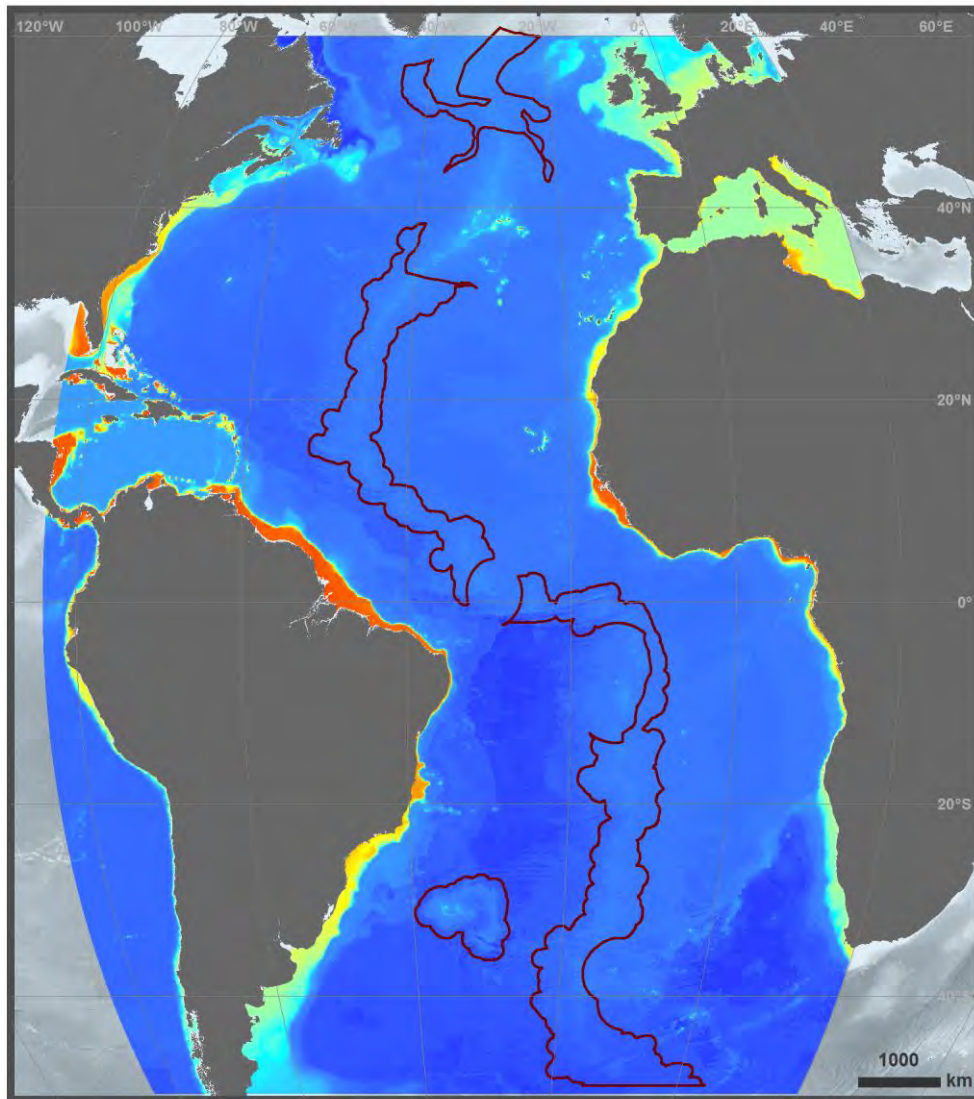
Velocity (m/s)



H: 0.9

L: 0.0004

Figure 16. 500 m current velocity (January 2014), generated using the Hybrid Coordinate Ocean Model (HYCOM) (Chassignet et al. 2009).



Marine Geospatial Ecology Lab, Duke University (2015)

Bottom Temperature Climatology (HYCOM 2014)

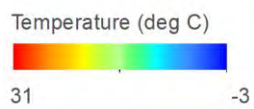


Figure 17. Bottom temperature (2014), generated using the Hybrid Coordinate Ocean Model (HYCOM) (Chassignet et al. 2009).

2.7 Seasonal thermal front variability observed using microwave and infrared satellite data

An oceanic front is a narrow zone of enhanced horizontal gradients of water properties (temperature, salinity, nutrients, etc.) that separates broader areas with different water masses or different vertical structure (stratification) (Belkin et al., 2009). They may anticipate both surface and bottom structures such as jet currents, ridges or fracture zones (Miller et al., 2013) and may throughout influence marine ecosystems over large scales (Scales et al., 2014). Since high-resolution infrared measurements – Advanced Very High Resolution Radiometer (AVHRR) – are limited by cloud cover, Miller et al. (2013) analyzed thermal front variability along the North Atlantic Current (NAC) combining fine-scale infrared data with coarser microwave data that can estimate sea surface temperature through clouds. Their study focused on the region south and north of the Charlie Gibbs Fracture Zone (CGFZ) (52°N). Thermal fronts resulted aligned with the major branching of the NAC and their presence and persistence were influenced by bottom features located several thousand metres below. In particular, while shallower portions of the MAR (e.g., Reykjanes Ridge) acted like a barrier to water movements, deep west-to-east fracture zones (e.g., CGFZ) seemed to guide the spatial and temporal distribution of thermal fronts and water masses. Mid-ocean bathymetrically-induced frontal zones may exert a strong influence on the distribution of marine organisms (Scales et al., 2014). The topographic structures associated with them, such as shallow portions of the MAR and deep fracture zones, may represent areas of particular interest in a strategic environmental management plan.

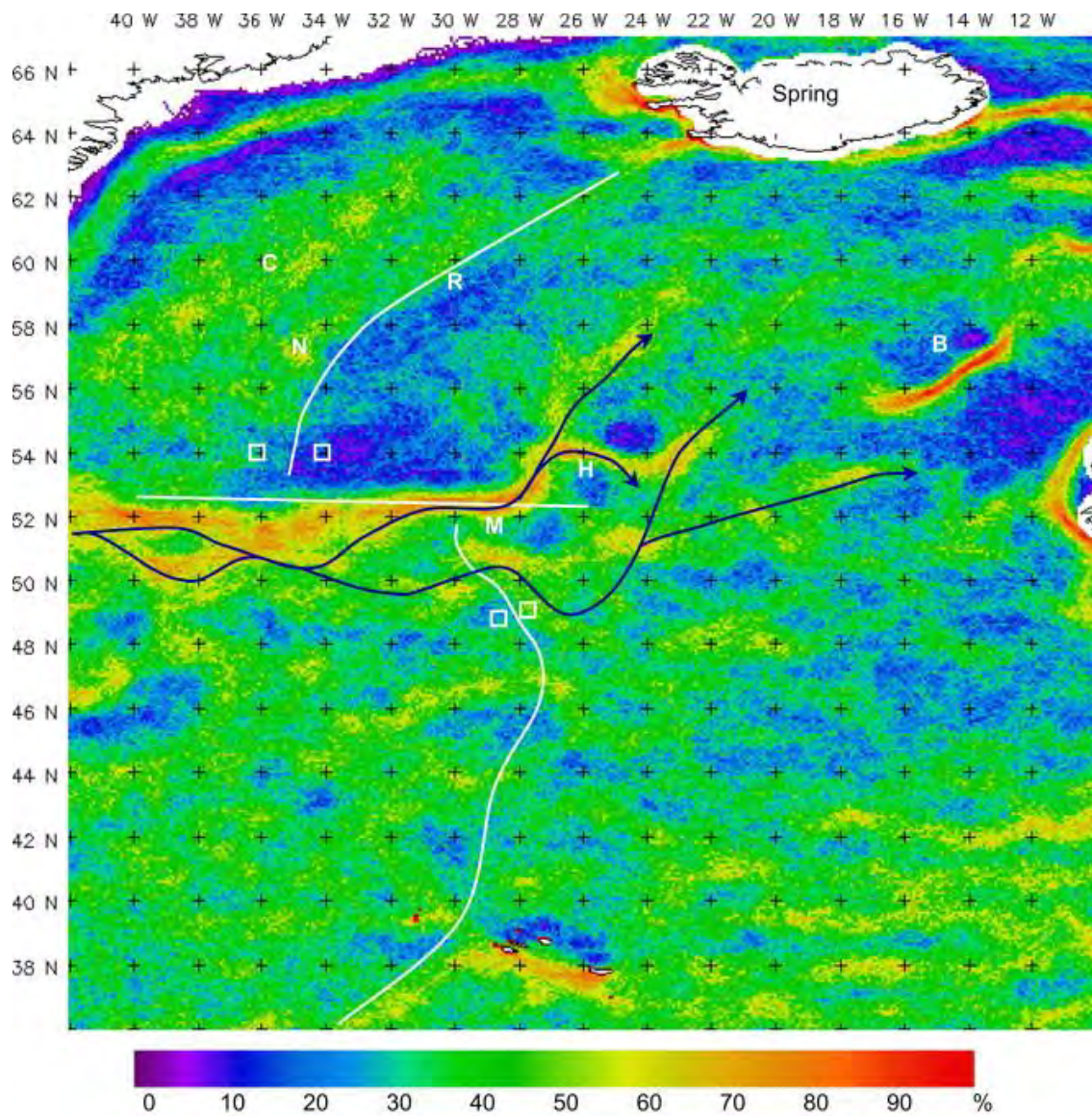


Figure 18. Spring oceanic front frequency.

Figure 4 in Miller et al. (2013): Seasonal oceanic front frequency map indicating the percentage of time a strong front was observed at each location during spring (March–May), derived from merged microwave and infrared SST data, 2006–2011. ECOMAR mooring stations are marked by white squares, blue arrow is inferred path of NAC, and letters are explained in text: B=Rockall Bank, M=Meander, R=Reykjanes Ridge, N=Irminger Current, C=Central Irminger Basin, H=Seabed trough.

2.8 Chlorophyll A Climatology

For this effort, a cumulative climatology (1998-2009) was created using the “Create Climatological Rasters for the NASA OceanColor L3 SMI Product” tool in the Marine Geospatial Ecology Tools (MGET) for ArcGIS (Roberts et al., 2010).

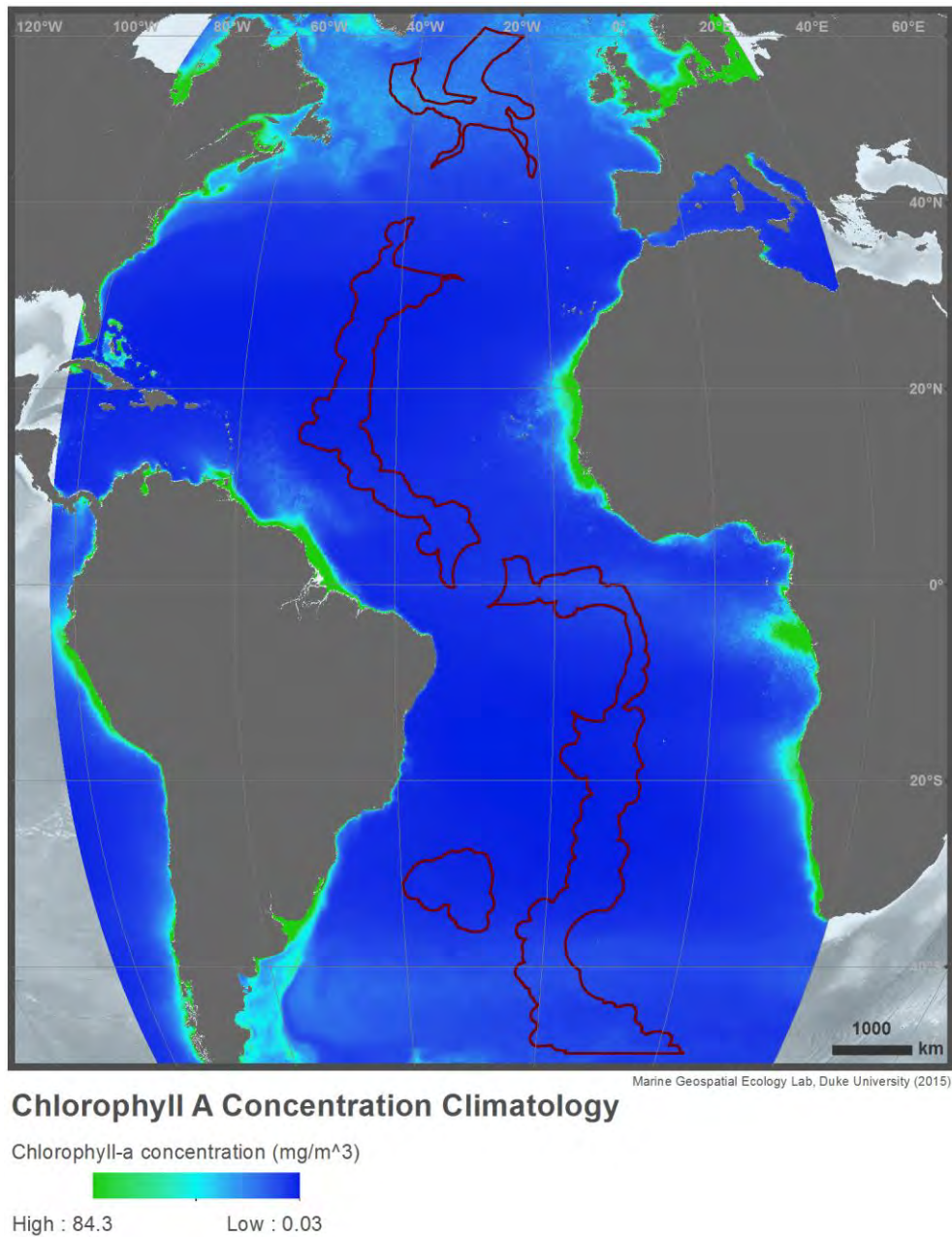


Figure 19. Chlorophyll A climatology (1998-2009), NASA OceanColor L3 SMI Product.

2.9 VGPM Primary Productivity

Standard Ocean Productivity Products (<http://www.science.oregonstate.edu/ocean.productivity/standard.product.php>) are based on the original description of the Vertically Generalized Production Model (VGPM) (Behrenfeld & Falkowski 1997), MODIS surface chlorophyll concentrations (Chl_{sat}), MODIS sea surface temperature data (SST), and MODIS cloud-corrected incident daily photosynthetically active radiation (PAR). Euphotic depths are calculated from Chl_{sat} following Morel and Berthon (1989). For this effort, a cumulative climatology was created from Standard VGPM data derived from MODIS AQUA data from 2003-2007.

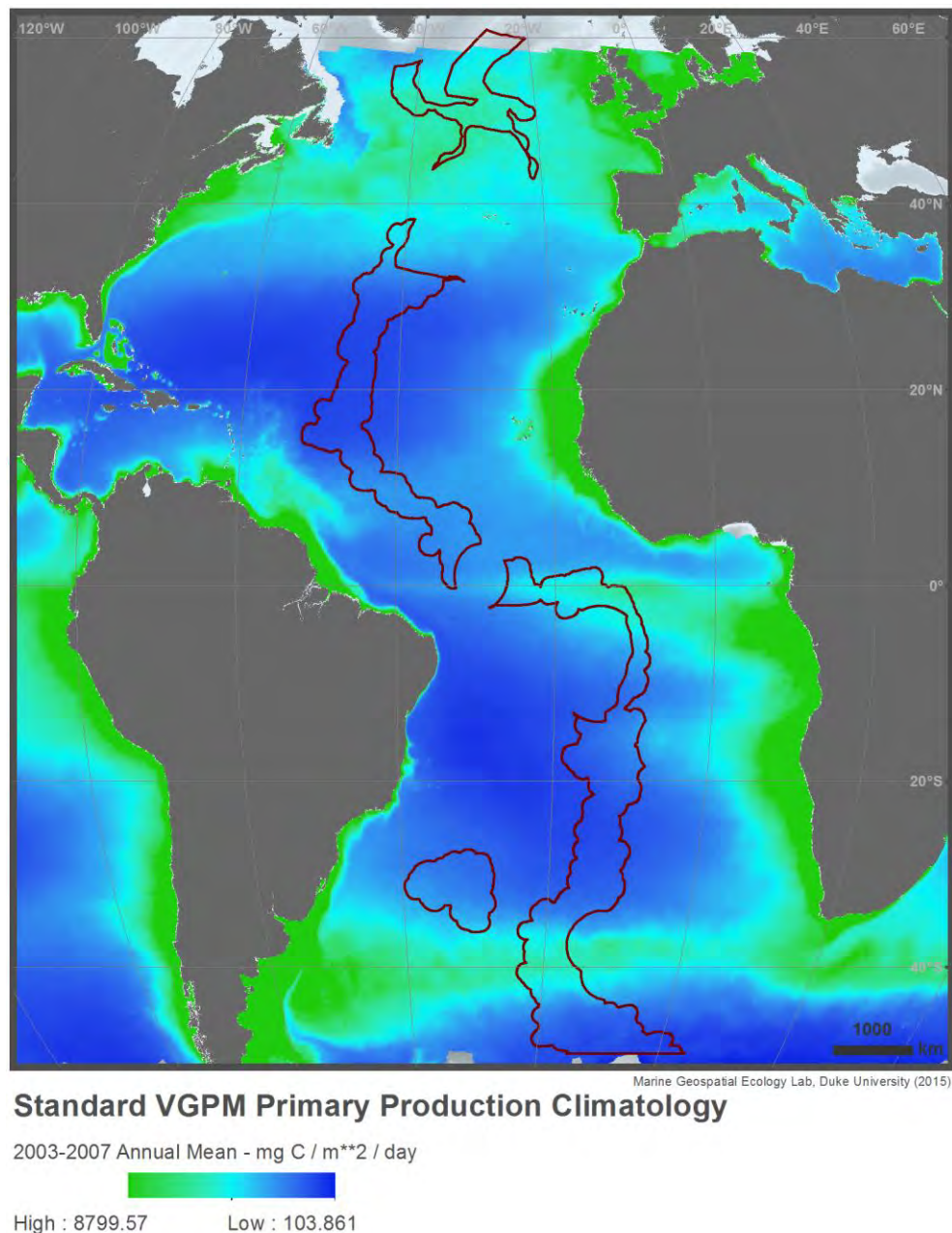
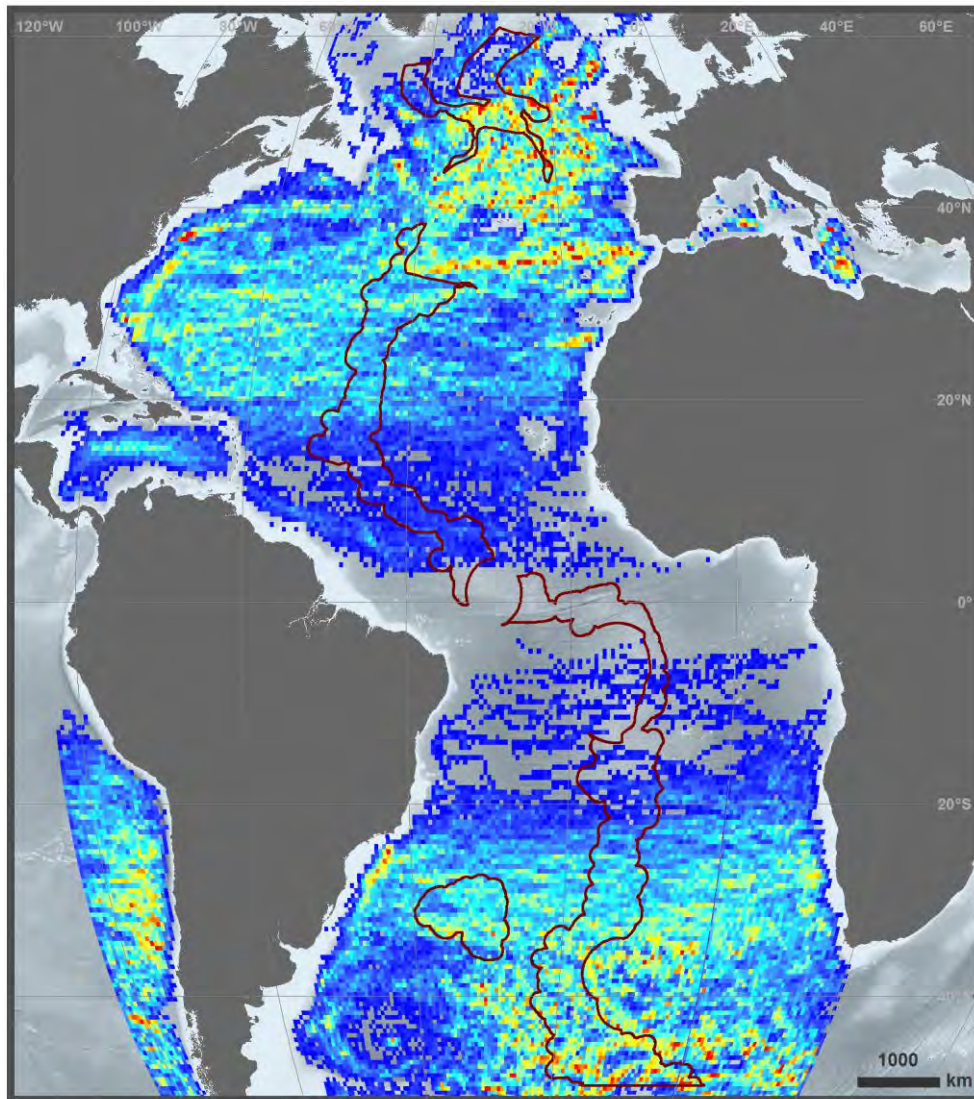


Figure 20. Vertically Generalized Production Model (VGPM) primary productivity climatology derived from MODIS AQUA data from 2003-2007.

2.10 Mesoscale eddy climatology

Dudley B. Chelton and Michael G. Schlax maintain a database of trajectories of mesoscale eddies for the 18-year period October 1992 - January 2011. Eddies are based on the SSH fields in Version 3 of the AVISO Reference Series. Only eddies with lifetimes of 4 weeks or longer are retained; the trajectories are available at 7-day time steps. A density raster of eddy centroids was created from the Chelton database (Chelton et al., 2011; <http://cioss.coas.oregonstate.edu/eddies/>). First, the NetCDF file was converted to a SpatiaLite database using the MGET tool (Roberts et al., 2010) 'Convert Mesoscale Eddies NetCDF to SpatiaLite'. Next, the 'Extract Mesoscale Eddy Centroids from SpatiaLite' and 'Extract Mesoscale Eddy Tracklines from SpatiaLite' tools were run specifying the date range (1993 - 2010) and the region of interest. For the tracks, only eddies that persisted at least 17 weeks were selected. By joining the centroids and tracks features, we obtained all centroids for eddies that persisted at least 17 weeks. The density raster was created from the Point Density ArcMap tool using 0.5 degree cell size and 0.5 x 0.5 rectangular windows.



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Mesoscale Eddy Density

Eddy density, 0.5 degree cells



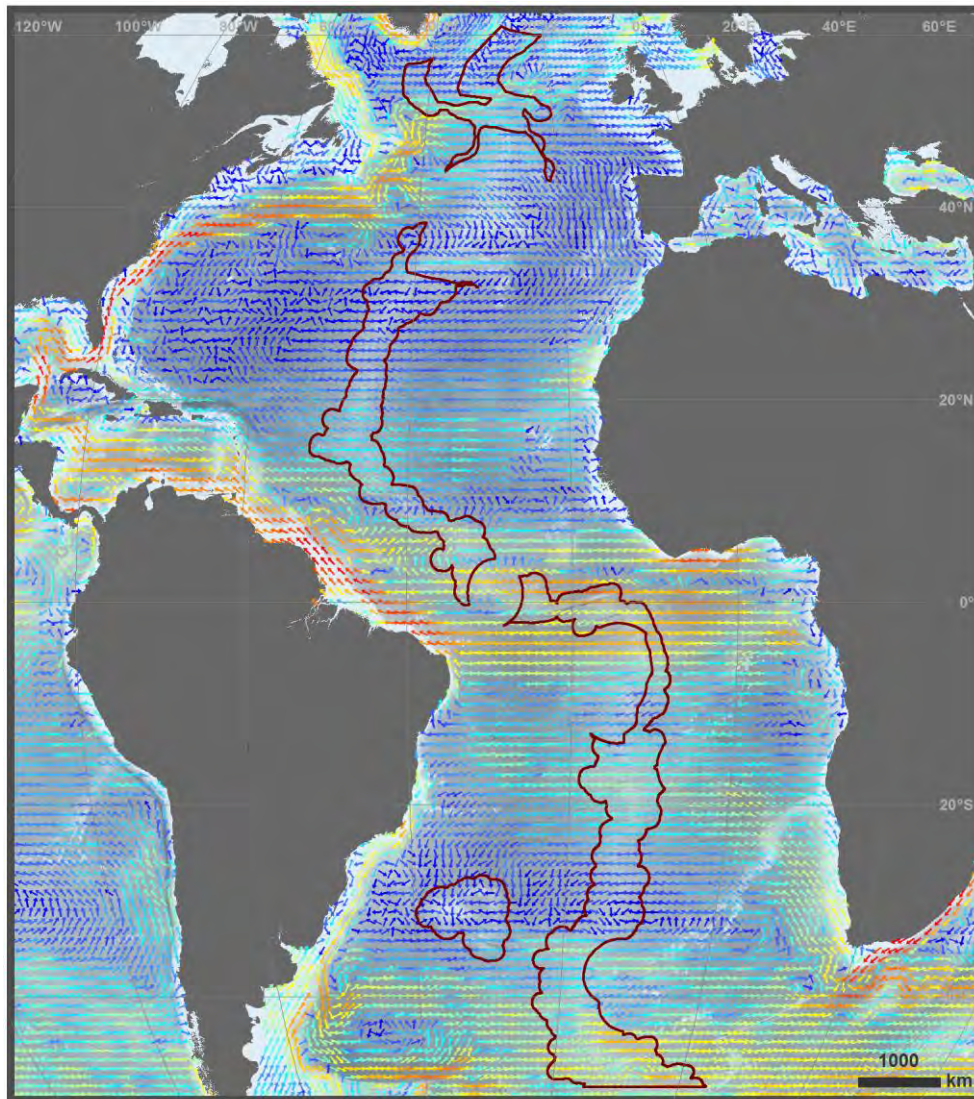
High : 452

Low : 0

Figure 21. Eddy density climatology (1993 - 2010) for eddies that persisted at least 17 weeks, created from the Chelton database (Chelton et al., 2011).

2.11 Drifter Climatology of Near-Surface Currents

Satellite-tracked SVP drifting buoys (Sybrandy and Niiler, 1991; Niiler, 2001) provide observations of near-surface circulation at unprecedented resolution. In September 2005, the Global Drifter Array became the first fully realized component of the Global Ocean Observing System when it reached an array size of 1250 drifters. A drifter is composed of a surface float which includes a transmitter to relay data, a thermometer which reads temperature a few centimeters below the air/sea interface, and a submergence sensor used to detect when/if the drogue is lost. The surface float is tethered to a subsurface float which minimizes rectification of surface wave motion (Niiler et al., 1987; Niiler et al., 1995). This in turn is tethered to a holey sock drogue, centered at 15 m depth. The drifter follows the flow integrated over the drogue depth, although some slip with respect to this motion is associated with direct wind forcing (Niiler and Paduan, 1995). This slip is greatly enhanced in drifters which have lost their drogues (Pazan and Niiler, 2001). Drifter velocities are derived from finite differencing their raw position fixes. These velocities, and the concurrent SST measurements, are archived at AOML's Drifting Buoy Data Assembly Center where the data are quality controlled and interpolated to 1/4-day intervals (Hansen and Herman, 1989; Hansen and Poulain, 1996). Here, we include climatology of near-surface currents for the world, at one degree resolution, derived from satellite-tracked surface drifting buoy observations (Lumpkin and Garraffo, 2005).



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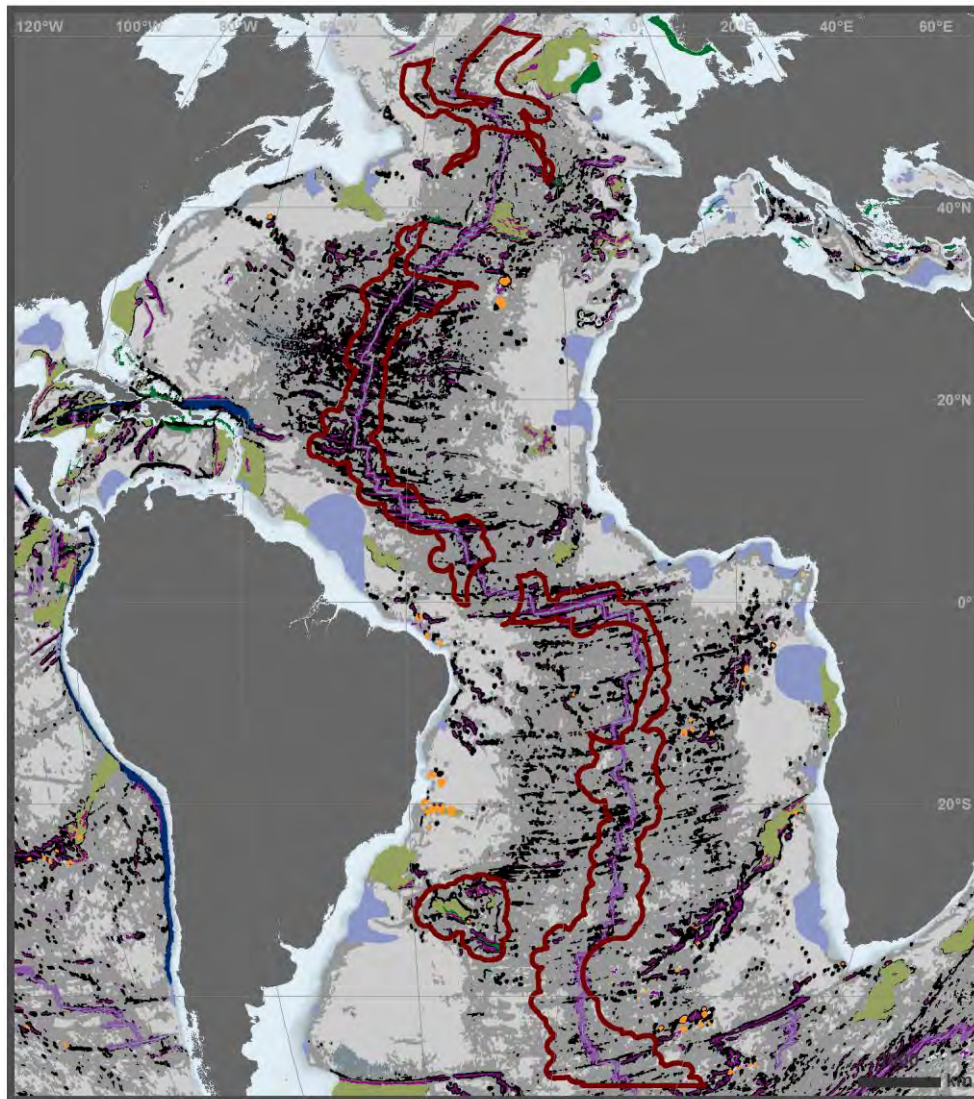
Drifter-Derived Climatology of Near-Surface Currents

Surface Current Velocity (m/s)	↑ 0.114 - 0.174	↑ 0.337 - 0.477
↑ 0.000 - 0.062	↑ 0.175 - 0.244	↑ 0.478 - 0.705
↑ 0.063 - 0.113	↑ 0.245 - 0.336	↑ 0.706 - 1.221

Figure 22. Drifter-derived climatology of near-surface currents from drifting buoy data (Lumpkin and Garraffo, 2005).

2.12 Global seafloor geomorphic features

Harris et al. (2014) presented the most updated global map of seafloor physiography based on interpretation of the Shuttle Radar Topography Mapping (SRTM30_plus) global bathymetry grid (30 arc sec resolution ~ 1 km) (Becker et al., 2009). Each of the major ocean regions (IHO, 1953) was divided into shelf, slope, abyss and hadal zones; shelf and abyss zones were further subdivided into classification layers based on roughness. In particular the abyssal classification layers were abyssal plains (< 300 m relief), abyssal hills (300–1000 m relief) and abyssal mountains (> 1000 m relief). For each of these base layers different geomorphic features were identified. The total abyssal area (from depths below the foot of the continental slope to 6000 m) constituted the 75% of the North Atlantic Ocean and more than the 90% of the South Atlantic Ocean. Abyssal hills dominated the landscapes of the abyss in both the North and South Atlantic comprising, respectively, the 49% and the 53% of the total abyssal area. Of the geomorphic features identified, we show spreading ridge, rift valley, sill, guyots, ridge, troughs, trenches, bridges, fans, and plateaus. The Mid-Atlantic Ridge occupy circa 0.7 million km² in the North Atlantic ($\sim 2\%$ of the ocean basin) and 1.2 million km² in the South Atlantic Ocean ($\sim 3\%$ of the ocean basin). Descriptive statistics of the other seafloor geomorphic features are available in Harris et al. (2014). Information on the spatial distribution of topographic features is of particular importance and represents one of the requirements to prepare and implement strategic environmental management plans (e.g., Johnson et al., 2014; Levin et al. 2014).



Global Seafloor Geomorphic Features (Harris et al. 2014)

- | | | | | | |
|---|--|---|---|--|--|
| ■ Guyot | ■ Rift valley | ■ Spreading ridge | ■ Plateau | Abyssal Classification | |
| ■ Bridge | ■ Trough | ■ Fan/Apron | | ■ Mountains | |
| ■ Sill | ■ Ridge | ■ Trench | | ■ Hills | |
| | | | | ■ Plains | |

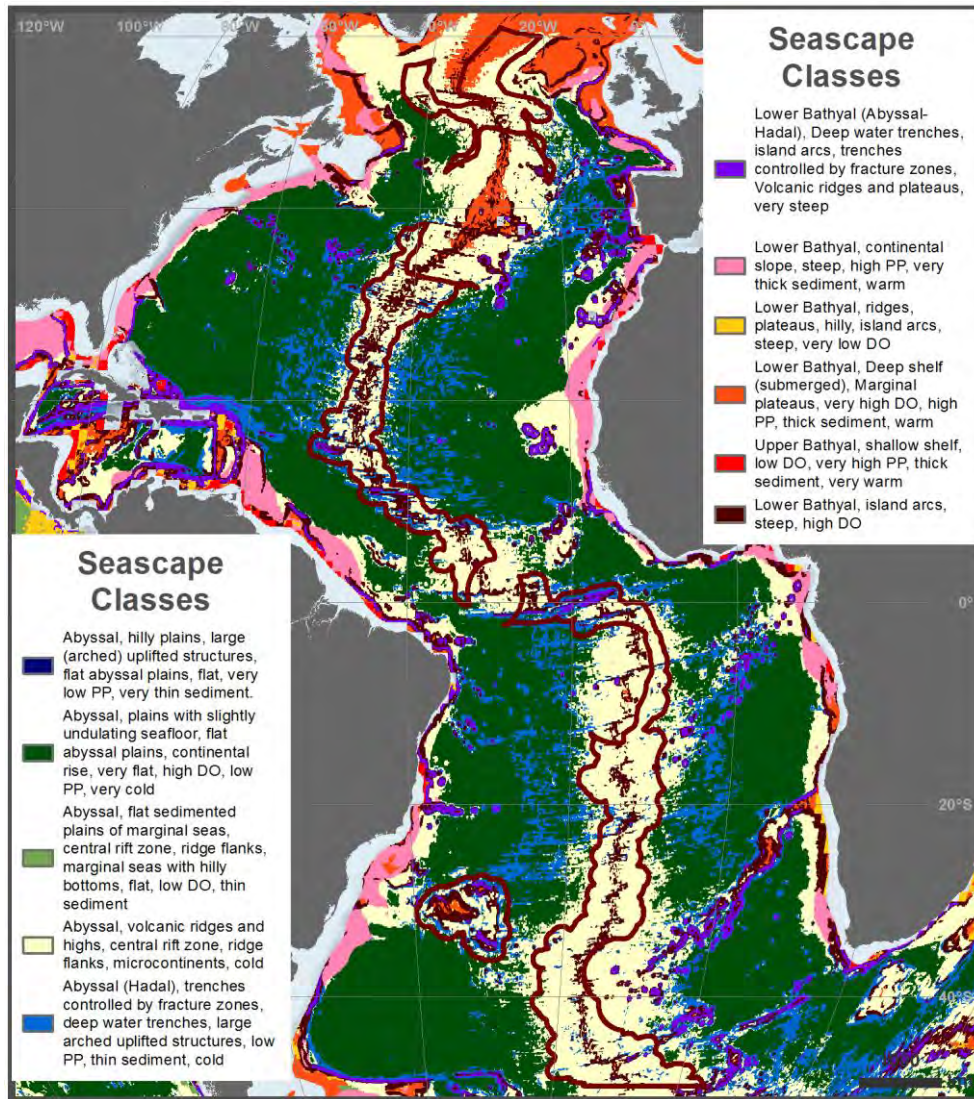
Figure 23. Seafloor geomorphic features, adapted from Harris et al. (2014).

2.13 Global Seascapes

Harris and Whiteway (2009) produced a ‘seascape’ map of the world’s oceans based on (1) ocean water depth, (2) seafloor slope, (3) net ocean primary productivity, (4) total sediment thickness, (5) bottom water temperature, (6) ocean bottom water dissolved oxygen. The authors followed two primary criteria to choose these biophysical parameters: they had to exert control on or be a surrogate for the occurrence of species; sufficient data to allow for extrapolations on a global scale had to be available for each parameter. Eleven seabed categories or ‘seascapes’ were identified (Table 1).

Table 1. List and description of seascapes, their mean depth and geomorphic associations (adapted from Harris and Whiteway, 2009).

Seascape	Description	Mean depth	Geomorphic associations
1	Warmest, highest primary productivity, smallest, continental margin sediments	Upper bathyal	Shallow shelf (22%)
2	Highest dissolved oxygen, second highest primary productivity, third thickest sediment, third warmest, continental margin sediments.	Lower bathyal	Deep submerged shelf (66%), marginal plateaus (27%)
3	Lowest dissolved oxygen, continental margin sediments.	Lower bathyal	Ridges and plateaus (44%), marginal seas with hilly bottom (25%)
4	Thickest sediment, third highest primary production, second warmest, second smallest, terrigenous sediments.	Lower bathyal	Continental slope (15%)
5	Second highest slope and second highest dissolved oxygen, continental margin and glacial sediments.	Lower bathyal	Island arcs (19%)
6	Steepest slope, continental margin sediments	Lower bathyal	Trenches (39%), island arcs (34%), volcanic ridges and plateaus (31%), trenches controlled by fracture zones (23%).
7	Second coldest, glacial, calcareous and siliceous sediments.	Abyssal	Volcanic ridges and highs (84%), central rift zone (39%), ridge flanks (33%), microcontinents (29%), continental rise (22%).
8	Third lowest slope, third lowest dissolved oxygen, third lowest sediment thickness, calcareous and terrigenous sediments.	Abyssal	Sedimented plains of marginal seas (34%), central rift zone (29%), ridge flanks (27%), marginal seas with hilly bottoms (25%).
9	Second lowest primary production, second thinnest sediment, third coldest, mostly red clay and siliceous sediments.	Abyssal	Trenches controlled by fracture zones (39%), deep water trenches (31%), large arched uplifted structures (24%)
10	Lowest slope, coldest, third highest dissolved oxygen, largest, mostly glacial, red clay and siliceous sediments	Abyssal	Plains with slightly undulating seafloor (83%), flat abyssal plains (53%), continental rise (33%).
11	Thinnest sediment, lowest primary production, second lowest slope, second largest, mostly red clay and siliceous sediments.	Abyssal	Hilly plains (38%), large arched uplifted structures (28%) flat abyssal plains (26%).



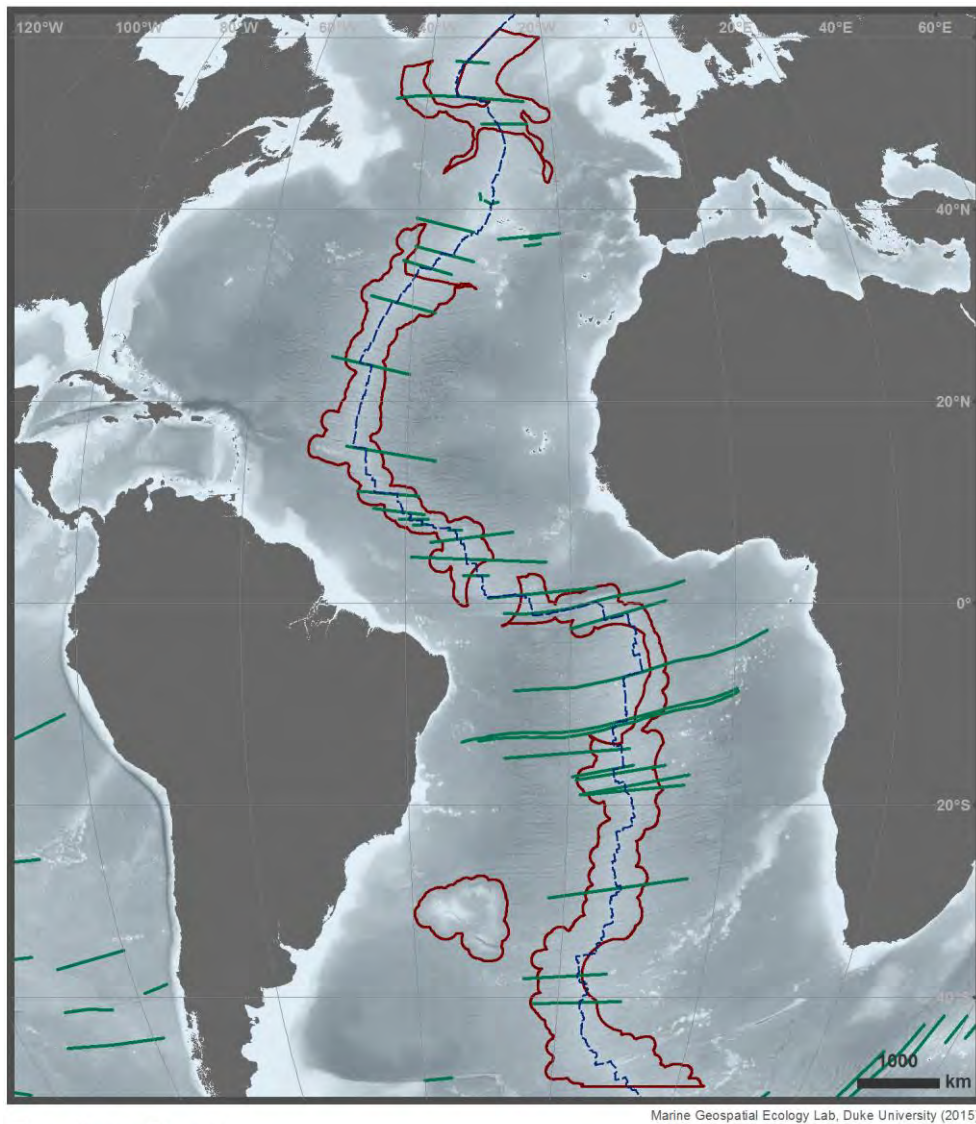
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**Global Seascapes
(Harris & Whiteway 2009)**

Figure 24. Global seascapes (seabed categories), adapted from Harris and Whiteway (2009).

2.14 Fracture Zones

The following figure shows the fracture zones in the Atlantic included in the IHO-IOC GEBCO Gazetteer of Undersea Features Names. The GEBCO Sub-Committee on Undersea Feature Names (SCUFN) maintains and makes available a digital gazetteer of the names, generic feature type and geographic position of features on the sea floor (last updated in August 2011).



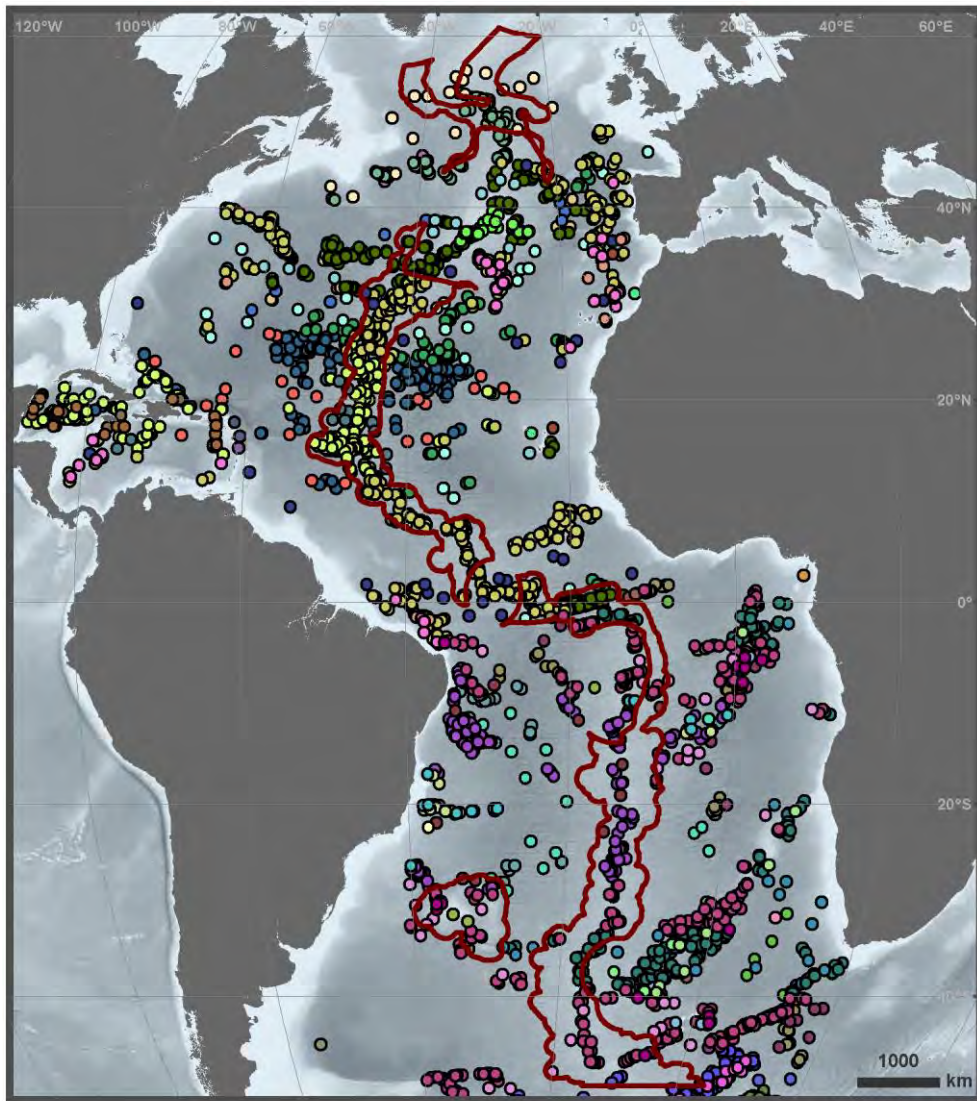
Fracture Zones

- Mid-Atlantic Ridge centerline
- Fracture Zone

Figure 25. Atlantic fracture zones (IHO-IOC GEBCO Gazetteer of Undersea Features Names).

2.15 Seamount Classification

Abstract (Clark et al., 2011): Seamounts are prominent features of the world's seafloor, and are the target of deep-sea commercial fisheries, and of interest for minerals exploitation. They can host vulnerable benthic communities, which can be rapidly and severely impacted by human activities. There have been recent calls to establish networks of marine protected areas on the High Seas, including seamounts. However, there is little biological information on the benthic communities on seamounts, and this has limited the ability of scientists to inform managers about seamounts that should be protected as part of a network. In this paper we present a seamount classification based on "biologically meaningful" physical variables for which global-scale data are available. The approach involves the use of a general biogeographic classification for the bathyal depth zone (near-surface to 3500 m), and then uses four key environmental variables (overlying export production, summit depth, oxygen levels, and seamount proximity) to group seamounts with similar characteristics. This procedure is done in a simple hierarchical manner, which results in 194 seamount classes throughout the world's oceans. The method was compared against a multivariate approach, and ground-truthed against octocoral data for the North Atlantic. We believe it gives biologically realistic groupings, in a transparent process that can be used to either directly select, or aid selection of, seamounts to be protected.



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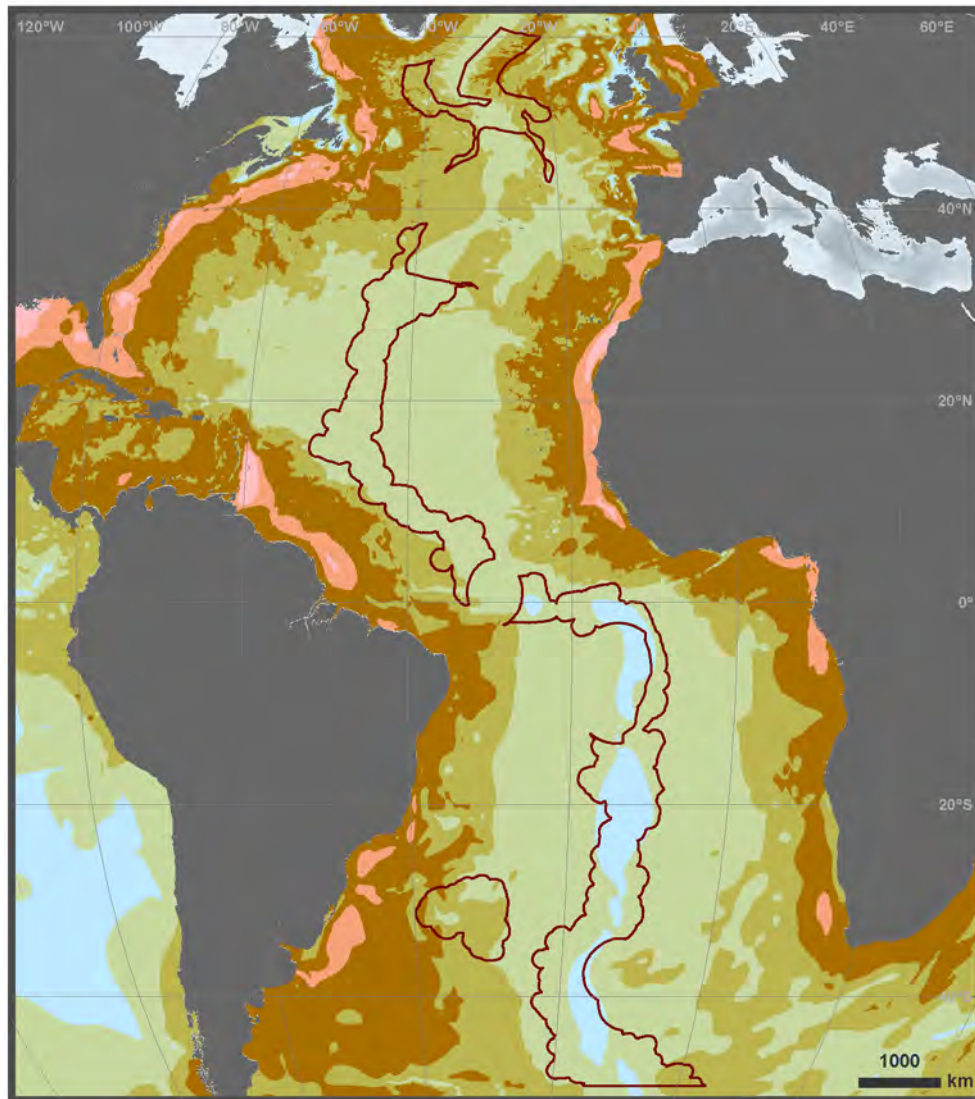
Global Seamount Classification (Clark et al. 2011)

Figure 26. Global seamount classification (Clark et al. 2011 for more details).

2.16 Total Sediment Thickness of the World's Oceans & Marginal Seas

A digital total-sediment-thickness database for the world's oceans and marginal seas has been compiled (<http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html>) by the NOAA National Geophysical Data Center (NGDC). The data were gridded with a grid spacing of 5 arc-minutes by 5 arc-minutes. Sediment-thickness data were compiled from three principle sources: (i) previously published isopach maps including Ludwig and Houtz (1979), Matthias et al. (1988), Divins and Rabinowitz (1990), Hayes and LaBrecque (1991), and Divins (2003); (ii) ocean drilling results, both from the Ocean Drilling Program (ODP) and the Deep Sea Drilling Project (DSDP); and (iii) seismic reflection profiles archived at NGDC as well as seismic data and isopach maps available as part of the IOC's International Geological-Geophysical Atlas of the Pacific Ocean (Udinstev, 2003). The distribution of sediments in the oceans is controlled by five primary factors: 1) age of the underlying crust, 2) tectonic history of the ocean crust, 3) structural trends in basement, 4) nature and location of sediment source, and 5) nature of the sedimentary processes delivering sediments to depocenters. The sediment isopach contour maps for the Pacific were digitized by Greg Cole of Los Alamos National Laboratory, for the Indian Ocean by Carol Stein of Northwestern University, and the South Atlantic and Southern Ocean by Dennis Hayes of Lamont-Doherty Earth Observatory. The digitized data were then gridded at NGDC using the algorithm for 'Gridding with Continuous Curvature Splines in Tension' of Smith and Wessel (1990).

The data values are in meters and represent the depth to acoustic basement. It should be noted that acoustic basement may not actually represent the base of the sediments. These data are intended to provide a minimum value for the thickness of the sediment in a particular geographic region.



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**Sediment Thickness of the Worlds Oceans & Marginal Seas
(Whittaker et al. 2013; Retrieved from NGDC)**

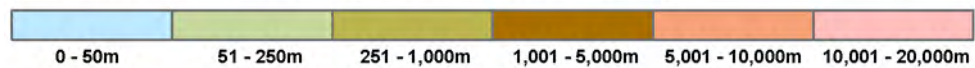


Figure 27. Sediment thickness, data from the NOAA National Geophysical Data Center (NGDC).

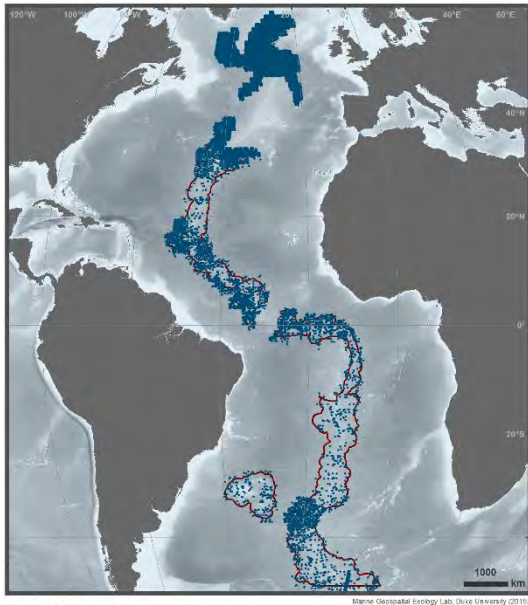
Chapter 3. Biological Data

3.1 General Ocean Biogeographic Information System (OBIS)

The Ocean Biogeographic information System (OBIS) (IOC, 2015) (<http://www.iobis.org/about/index>) seeks to absorb, integrate, and assess isolated datasets into a larger, more comprehensive picture of life in our oceans. The system hopes to stimulate research about our oceans to generate new hypotheses concerning evolutionary processes, species distributions, and roles of organisms in marine systems on a global scale. OBIS generate maps that contribute to the ‘big picture’ of our oceans: a comprehensive, collaborative, worldwide view of our oceans.

OBIS provides a portal or gateway to many datasets containing information on where and when marine species have been recorded. The datasets are integrated so you can search them all seamlessly by species name, higher taxonomic level, geographic area, depth, and time; and then map and find environmental data related to the locations.

The maps provided in this report are based on available OBIS records for the Mid-Atlantic Ridge (MAR) and the Rio Grande Rise (RGR) – the area of interest. The figures include all records, records for deep-water species (>200 m of water depth or lower half of the water column) and shallow-water species (upper half of the water column). Records below 200 m depth represented only 7% of the total number of records present in the workshop’s area of interest. Species Richness and Hurlbert’s Index (ES[50]) (Hurlbert, 1971) data summaries for 1 degree grids are provided for all species and deep species (lower half of the water column). Data gaps do exist in OBIS and thus these summaries are not exhaustive.



OBIS Records: Area of Interest

- OBIS record (all, ~316K)



OBIS Records: Below 200m

- OBIS record (below 200m, ~22K)

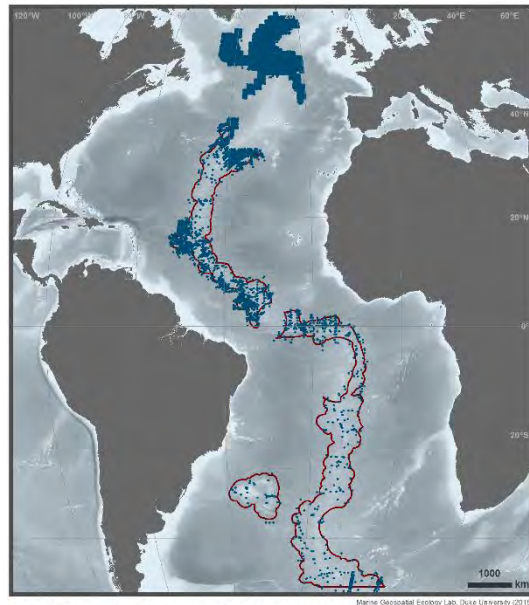
Figure 28. All OBIS records for the area of interest.

Figure 29. All OBIS records below 200 m for the area of interest.



OBIS Records: Lower Half of Water Column

- OBIS record (lower half water column, ~5K)

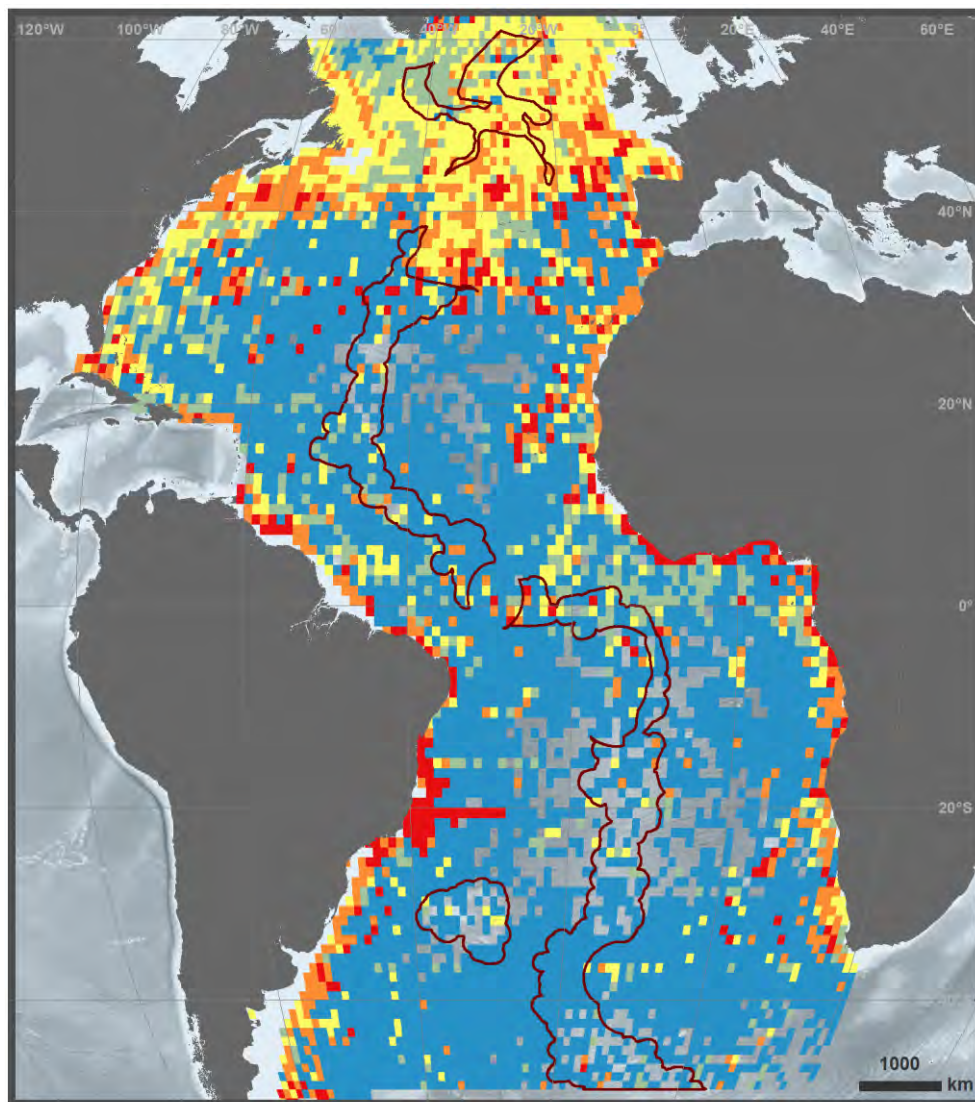


OBIS Records: Upper Half of Water Column

- OBIS record (upper half water column, ~283K)

Figure 30. All OBIS records of the lower half of the water column for the area of interest.

Figure 31. All OBIS records of the upper half of the water column for the area of interest.

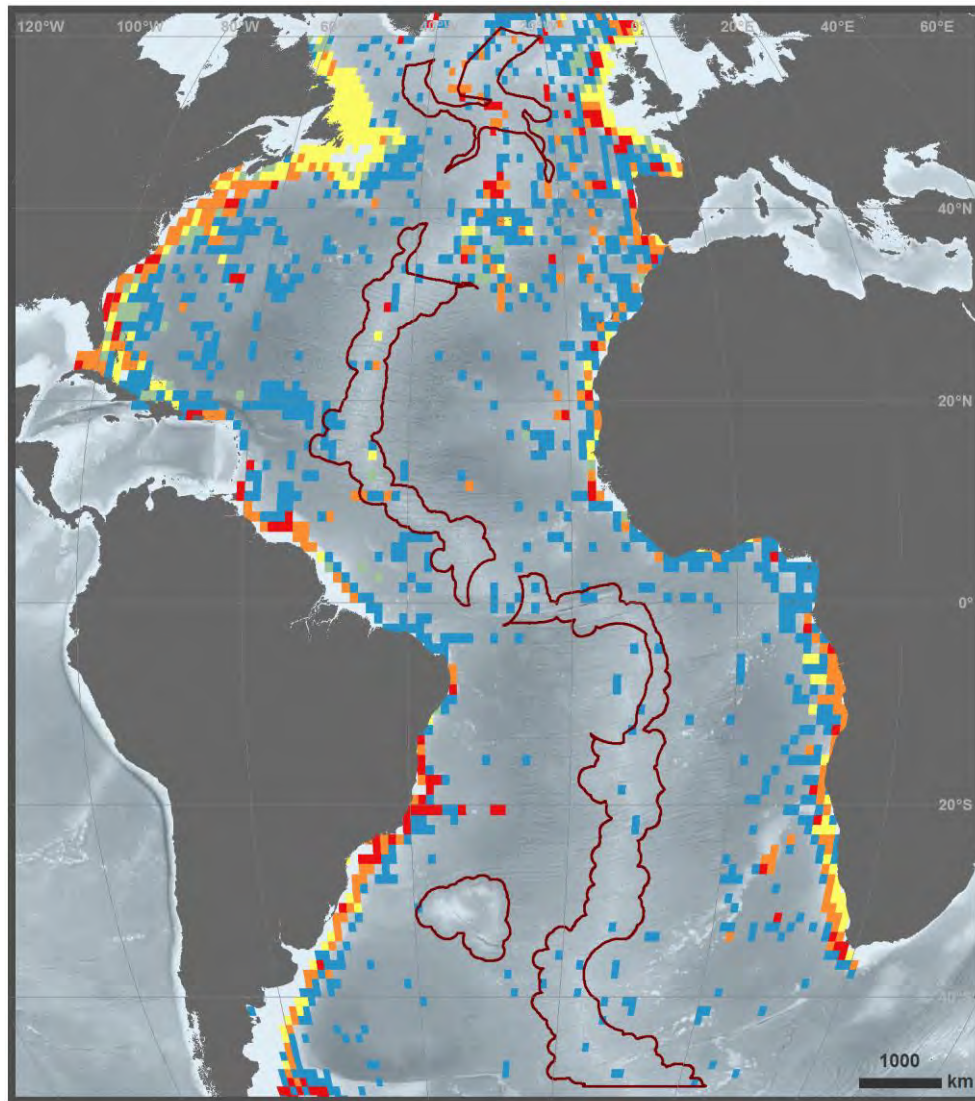


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OBIS Biodiversity: all records



Figure 32. Hurlbert's Index (ES[50]) for all taxa.



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OBIS Biodiversity: records from lower water column



Figure 33. Hurlbert's Index (ES[50]) for all taxa of the lower half of the water column.

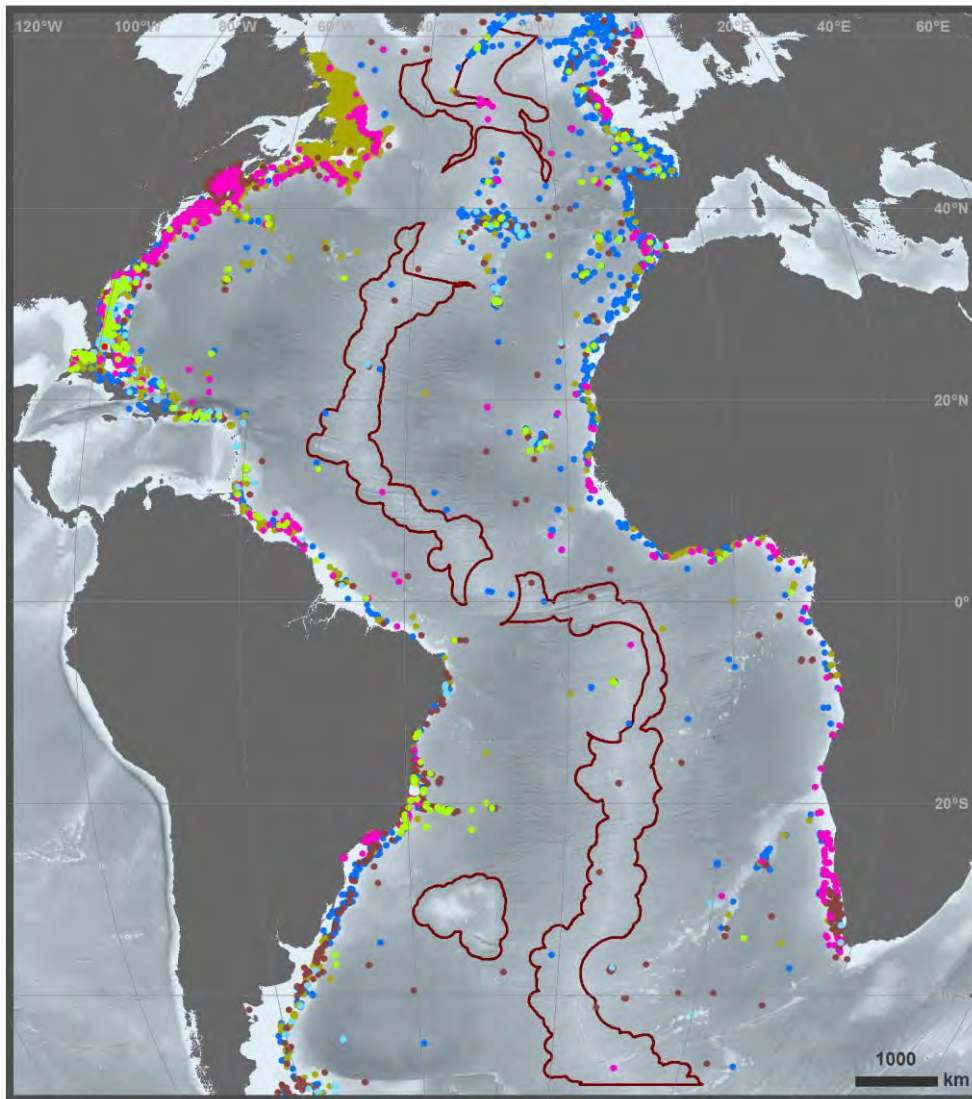
3.2 Vulnerable Marine Ecosystems (VMEs) Indicator Taxa

The Food and Agriculture Organization (FAO) of the United Nations International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2009) provide general tools and considerations for the identification of vulnerable marine ecosystems (VMEs). They include a set of criteria that should be used, individually or in combination, for the identification process. Specifically: Uniqueness or rareness, functional significance of the habitat, fragility, life-history of species that make recovery difficult and structural complexity.

Although many taxa, including mobile organisms such as fishes and elasmobranchs could potentially qualify under the FAO criteria (Ardron et al. 2014), the most commonly identified VME taxa are cold-water corals and sponges and are the ones considered in this report (Table 2). However, at least concerning fisheries management, the range of taxa considered VME indicator species goes beyond corals and sponges and new species may be considered in future works (e.g., NEAFC recommendation 19:2014 as amended by recommendation 09:2015). Hydrothermal vents and cold seeps are also considered to be VMEs but they are treated in a separate section of this report.

Table 2. Number of records of VME indicator taxa in the Mid Atlantic Ridge (MAR) and in the wider Atlantic (ATL) Region

Common name	Scientific name	Taxonomical level	OBIS Record Count (MAR; ATL region)
Stony coral	Scleractinia	Order	139; 36614
Sponge	Porifera	Phylum	22; 6889
Black coral	Antipatharia	Order	8; 559
Lace coral	Stylasteridae	Family	2; 811
Gorgonian	Alcyonacea	Order	10; 10529
Sea-pen	Pennatulacea	Order	15; 1821
Blue coral	Helioporacea	Order	0; 1

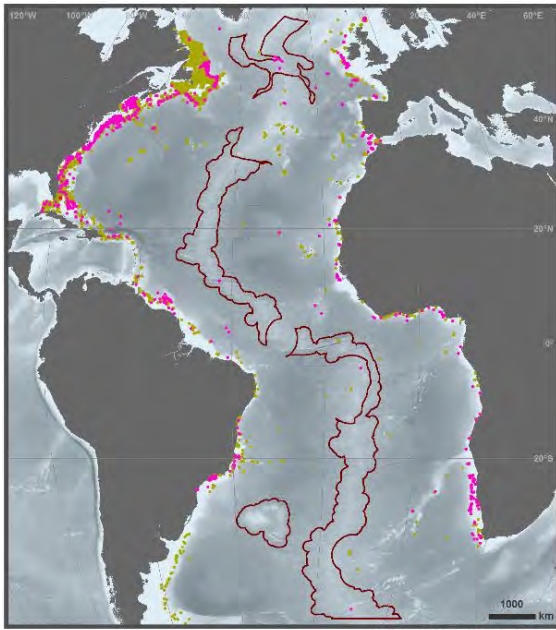


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OBIS Records: VME Taxa

- Order Helioporacea (n=1)
- Order Pennatulacea (n=1821)
- Order Scleractinia (n=36614)
- Order Antipatharia (n=559)
- Phylum Porifera (n=6889)
- Family Stylasteridae (n=811)
- Order Alcyonacea (n=10529)

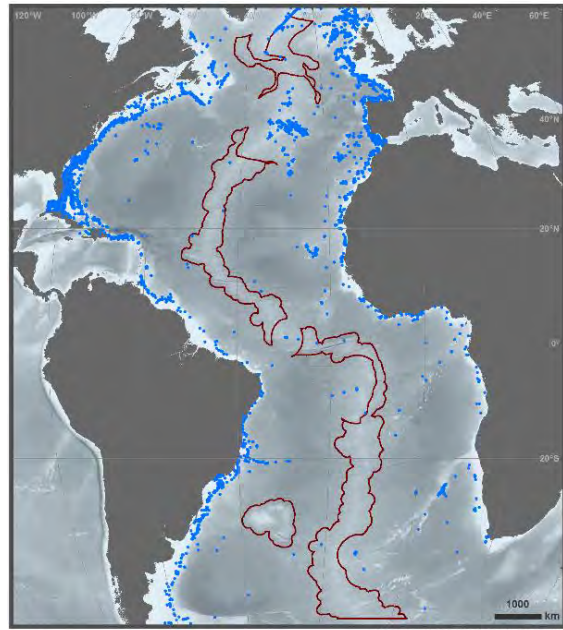
Figure 34. OBIS records of all VME indicator taxa considered (see Table 2).



OBIS Records: Octocorals

- Order Helioporacea (n=1)
- Order Pennatulacea (n=1821)
- Order Alcyonacea (n=10529)

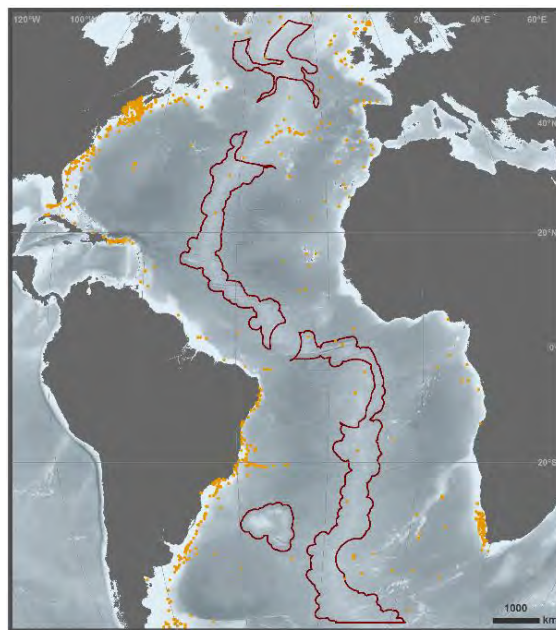
Figure 35. OBIS records of Octocorals.



OBIS Records: Order Scleractinia

- Order Scleractinia (n=36614)

Figure 36. OBIS records of Scleractinia.



OBIS Records: Sponges

- Phylum Porifera (n=6889)

Figure 37. OBIS records of sponges.

3.3 Geo-Referenced Library

A Geo-Referenced Library (GRL) of peer-reviewed articles about the MAR or RGR assigned to 1x1 degree cells based on the location of their sampling sites was created. Each article was classified into different categories: realm (benthic, benthopelagic, bathypelagic, or pelagic); main taxonomic group; indicator of vulnerable marine ecosystem.

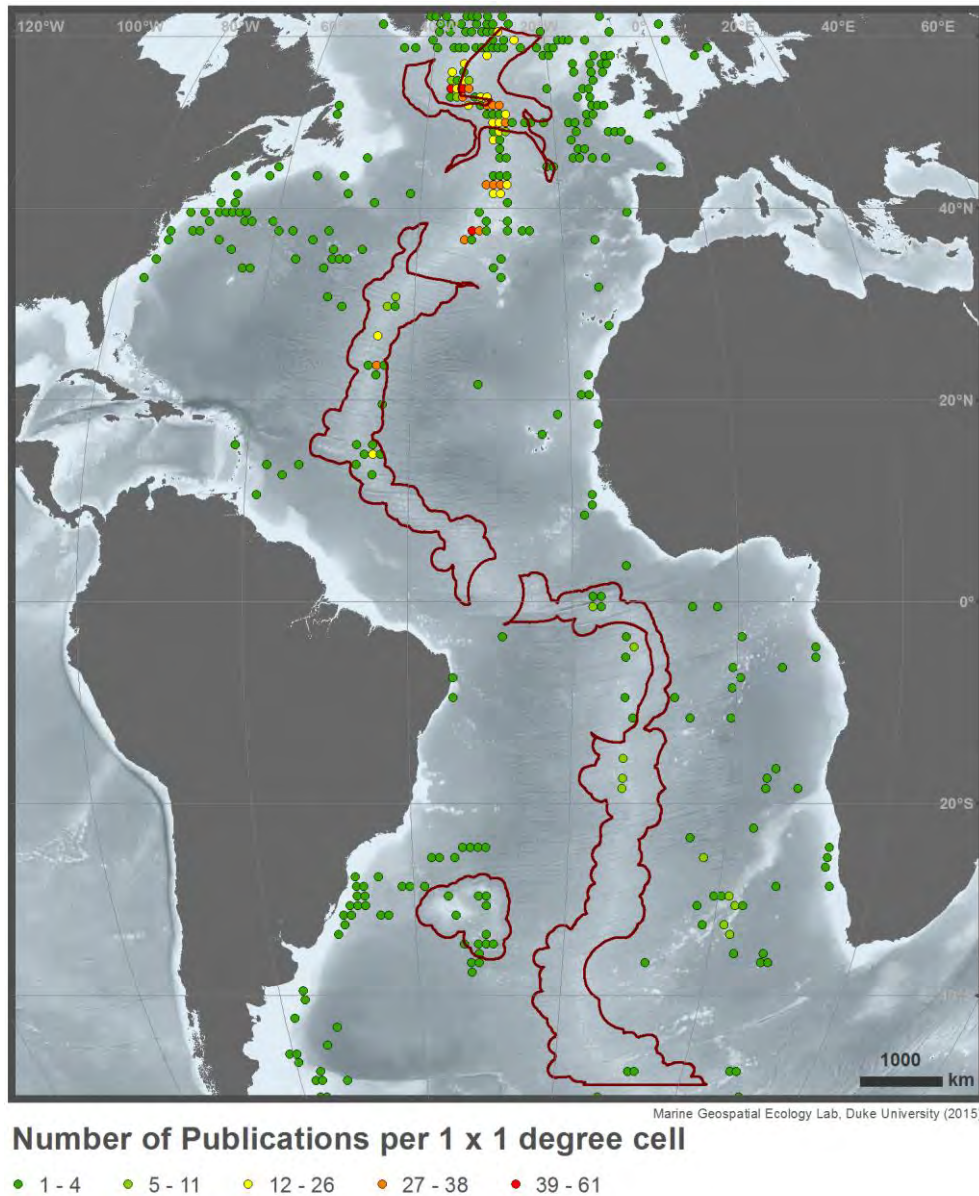
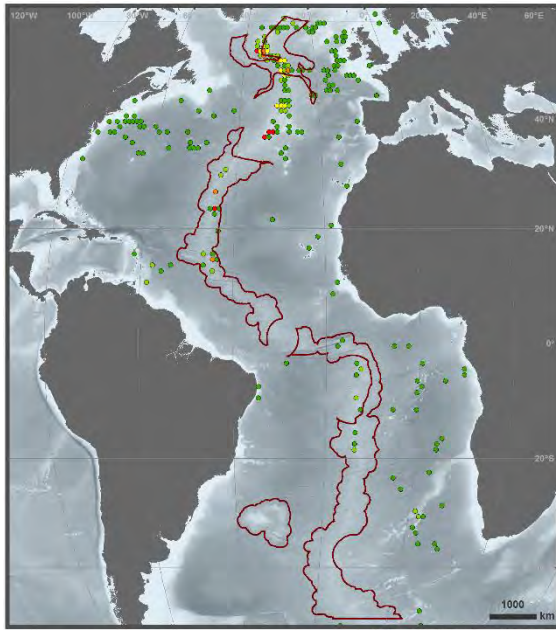
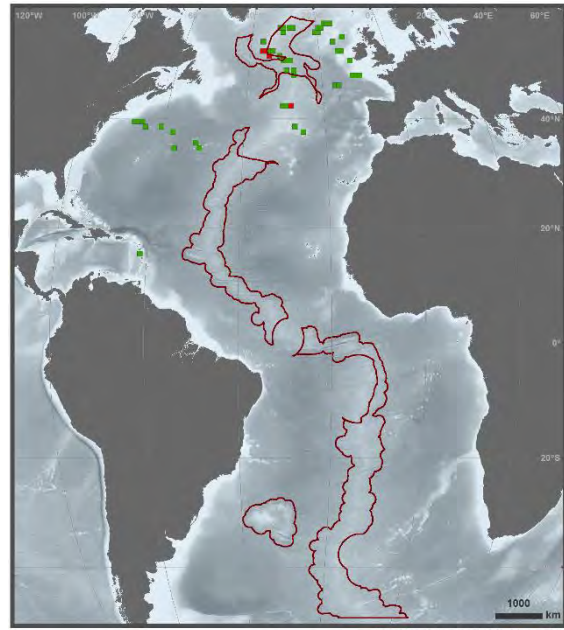


Figure 38. Total number of publications assigned to 1x1 degree cells based on the location of their sampling sites.



Number of Publications per 1 x 1 degree cell: Benthic

Number of Publications
 ● 1 - 2 ● 3 - 8 ● 9 - 17 ● 18 - 23 ● 24 - 50

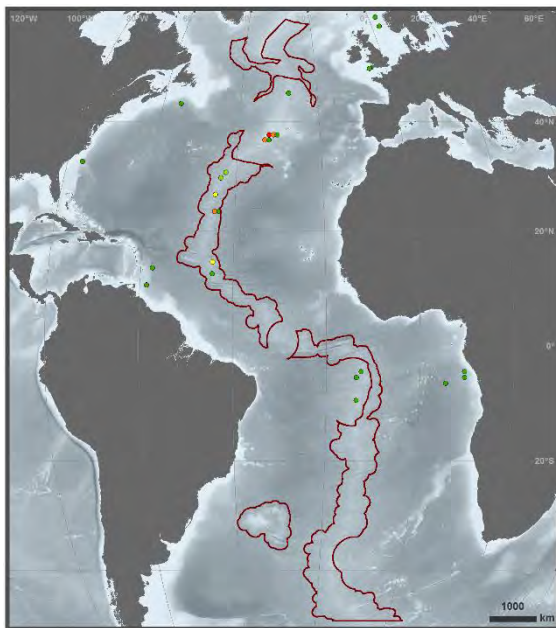


Number of Publications per 1 x 1 deg cell: VME Indicator Taxa

Number of Publications
 ■ 1 ■ 2

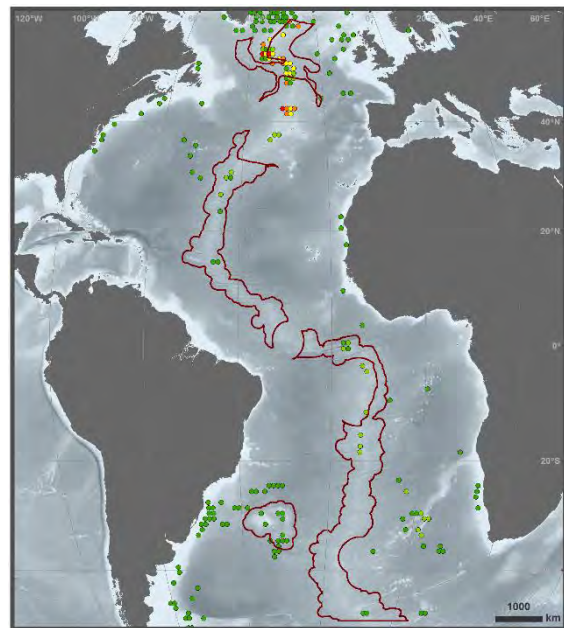
Figure 39. Total number of publications – benthic.

Figure 40. Total number of publications – VME indicator taxa.



Number of Publications per 1 x 1 deg cell: Hydrothermal Vents

Number of Publications
 ● 1 - 3 ● 4 - 8 ● 9 - 16 ● 17 - 27 ● 28 - 41



Number of Publications per 1 x 1 degree cell: Pelagic

Number of Publications
 ● 1 - 2 ● 3 - 6 ● 7 - 15 ● 16 - 21 ● 22 - 29

Figure 41. Total number of publications – Hydrothermal vents and cold seeps type.

Figure 42. Total number of publications – pelagic.

3.4 Predictions of Vulnerable Marine Ecosystems (VMEs) Indicator Taxa

Octocorallia

Abstract (Yesson, et al., 2012): Three-quarters of Octocorallia species are found in deep waters. These cold-water octocoral colonies can form a major constituent of structurally complex habitats. The global distribution and the habitat requirements of deep-sea octocorals are poorly understood given the expense and difficulties of sampling at depth. Habitat suitability models are useful tools to extrapolate distributions and provide an understanding of ecological requirements. Here, we present global habitat suitability models and distribution maps for seven suborders of Octocorallia: Alcyoniina, Calcaxonia, Holaxonia, Scleraxonia, Sessiliflorae, Stolonifera and Subselliiflorae.

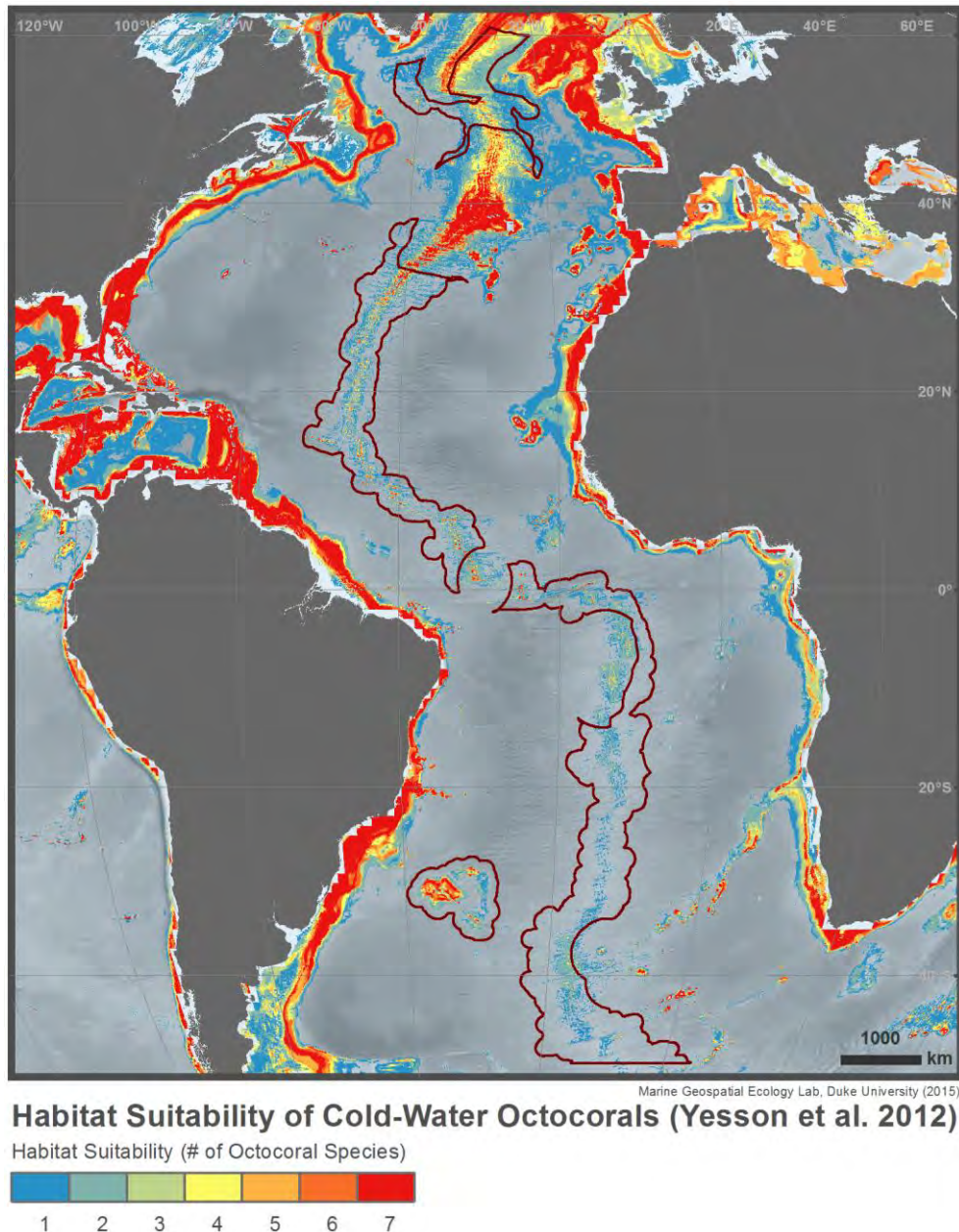
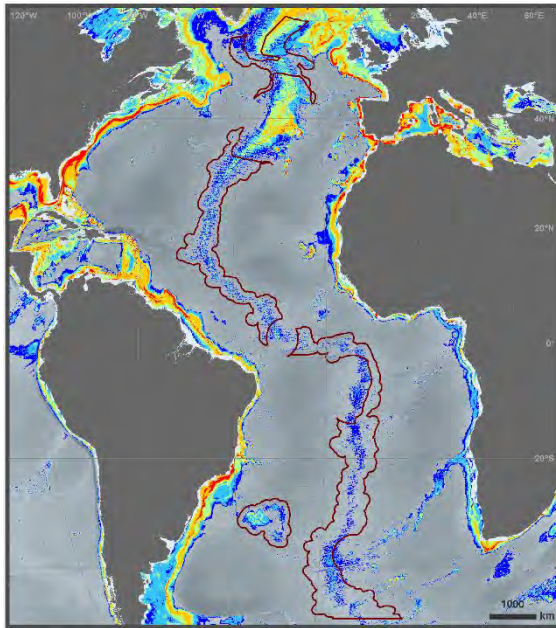


Figure 43. Deep-Sea Octocoral Habitat Suitability – Consensus.



Habitat Suitability of the Cold-Water Octocoral Alcyoniina (Yesson et al. 2012)

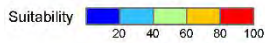
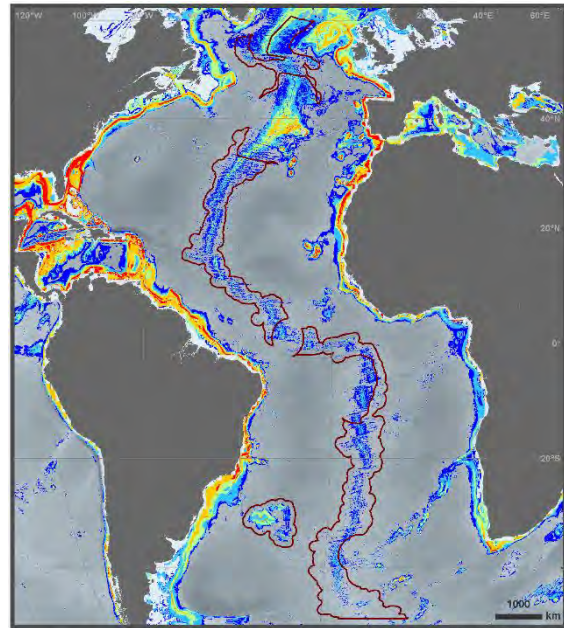


Figure 44. Deep-Sea Octocoral Habitat Suitability – Alcyoniina.



Habitat Suitability of the Cold-Water Octocoral Holaxonia (Yesson et al. 2012)

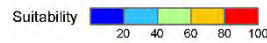
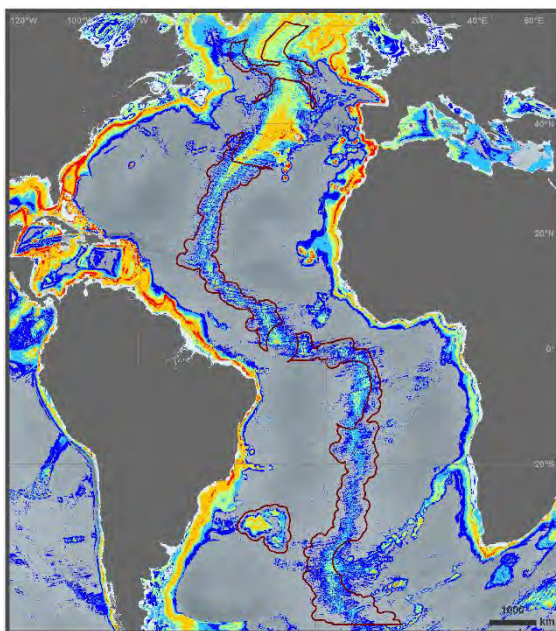


Figure 45. Deep-Sea Octocoral Habitat Suitability – Holaxonia.



Habitat Suitability of the Cold-Water Octocoral Calcaxonia (Yesson et al. 2012)

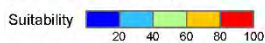
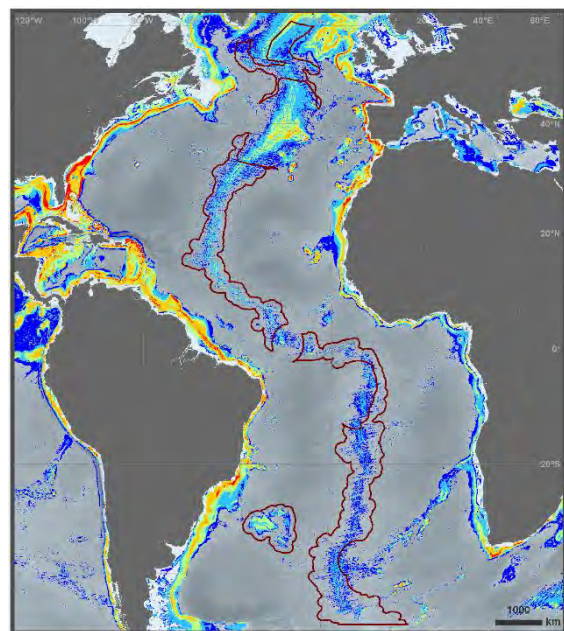


Figure 46. Deep-Sea Octocoral Habitat Suitability – Calcaxonia.



Habitat Suitability of the Cold-Water Octocoral Scleraxonia (Yesson et al. 2012)

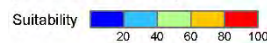
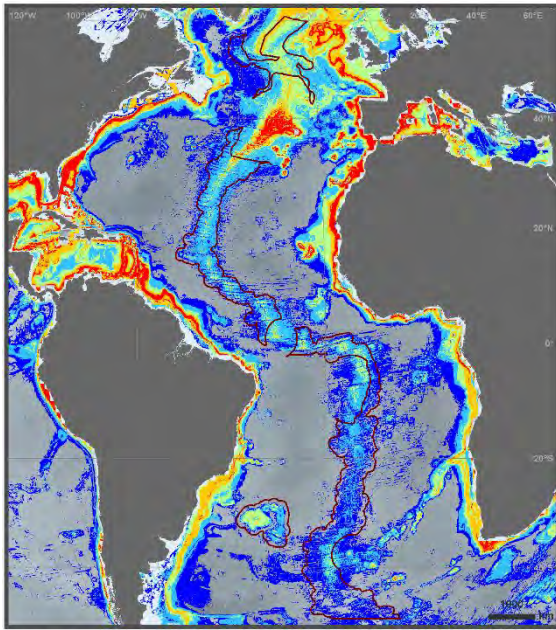


Figure 47. Deep-Sea Octocoral Habitat Suitability – Scleraxonia.



Habitat Suitability of the Cold-Water Octocoral Sessiliflorae (Yesson et al. 2012)

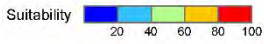
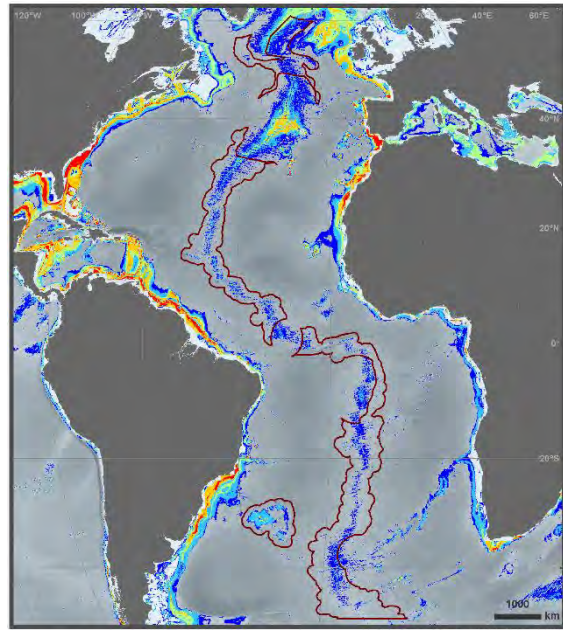


Figure 48. Deep-Sea Octocoral Habitat Suitability – Sessiliflorae.



Habitat Suitability of the Cold-Water Octocoral Stolonifera (Yesson et al. 2012)

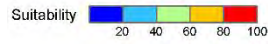
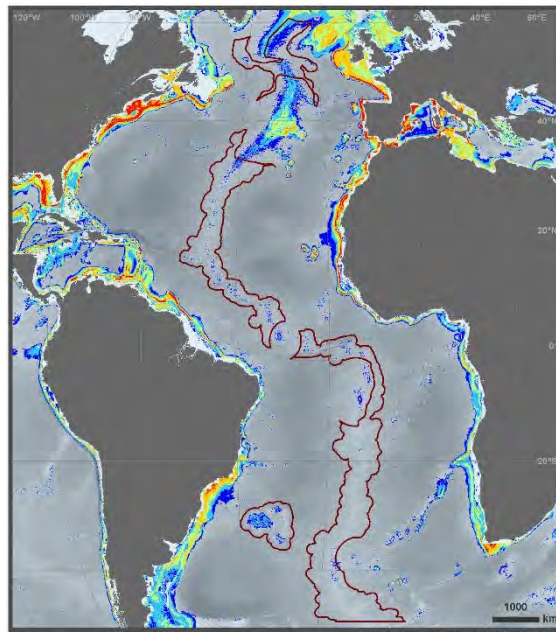


Figure 49. Deep-Sea Octocoral Habitat Suitability – Stolonifera.



Habitat Suitability of the Cold-Water Octocoral Subselliflorae (Yesson et al. 2012)

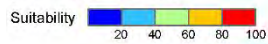
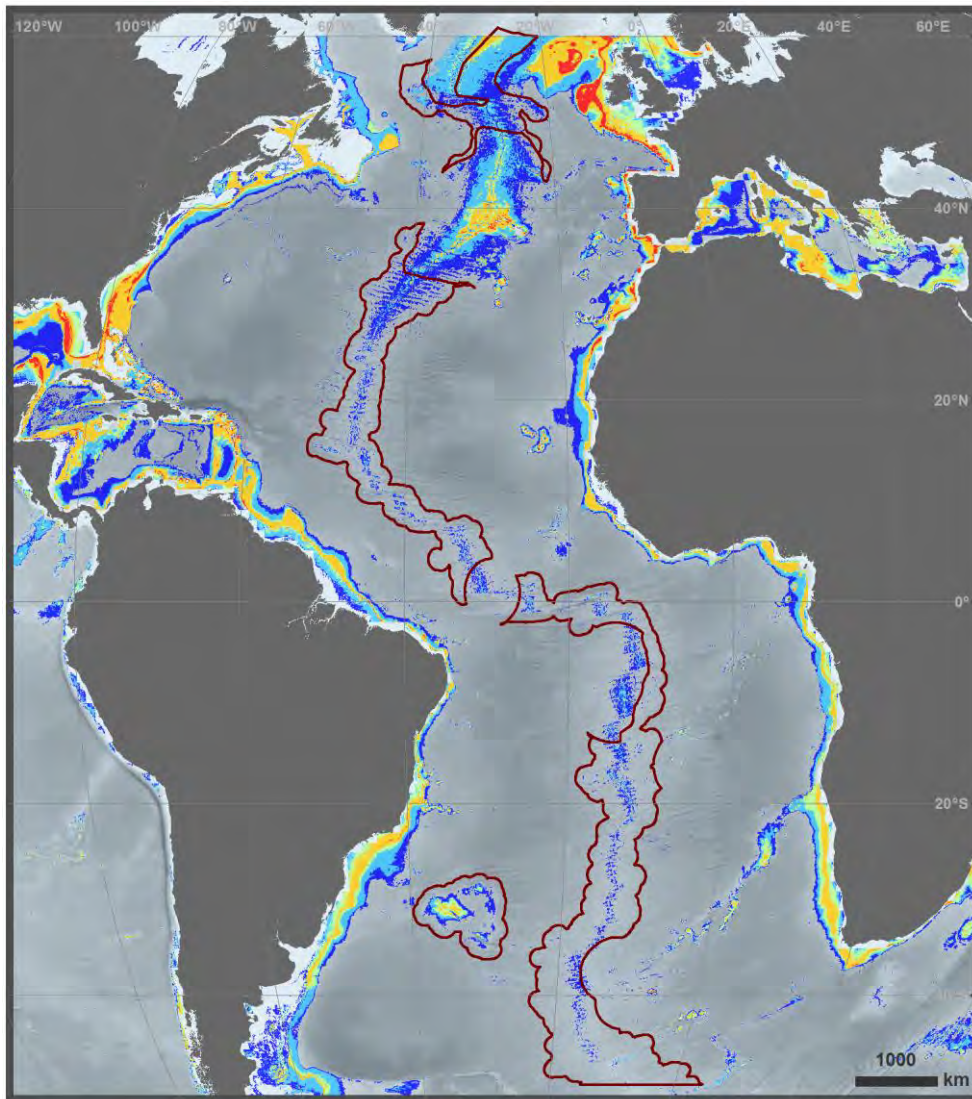


Figure 50. Deep-Sea Octocoral Habitat Suitability – Subselliflorae.

Scleractinia

Abstract (Davies and Guinotte, 2011): Predictive habitat models are increasingly being used by conservationists, researchers and governmental bodies to identify vulnerable ecosystems and species' distributions in areas that have not been sampled. However, in the deep sea, several limitations have restricted the widespread utilisation of this approach. These range from issues with the accuracy of species presences, the lack of reliable absence data and the limited spatial resolution of environmental factors known or thought to control deep-sea species' distributions. To address these problems, global habitat suitability models have been generated for five species of framework-forming scleractinian corals by taking the best available data and using a novel approach to generate high resolution maps of seafloor conditions. High-resolution global bathymetry was used to resample gridded data from sources such as World Ocean Atlas to produce continuous 30-arc second (1 km²) global grids for environmental, chemical and physical data of the world's oceans. The increased area and resolution of the environmental variables resulted in a greater number of coral presence records being incorporated into habitat models and higher accuracy of model predictions. The most important factors in determining cold-water coral habitat suitability were depth, temperature, aragonite saturation state and salinity. Model outputs indicated the majority of suitable coral habitat is likely to occur on the continental shelves and slopes of the Atlantic, South Pacific and Indian Oceans. The North Pacific has very little suitable scleractinian coral habitat. Numerous small scale features (i.e., seamounts), which have not been sampled or identified as having a high probability of supporting cold-water coral habitat were identified in all ocean basins. Field validation of newly identified areas is needed to determine the accuracy of model results, assess the utility of modeling efforts to identify vulnerable marine ecosystems for inclusion in future marine protected areas and reduce coral bycatch by commercial fisheries.



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Habitat Suitability of Scleractinia (Davies and Guinotte 2011)

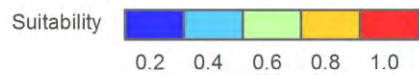
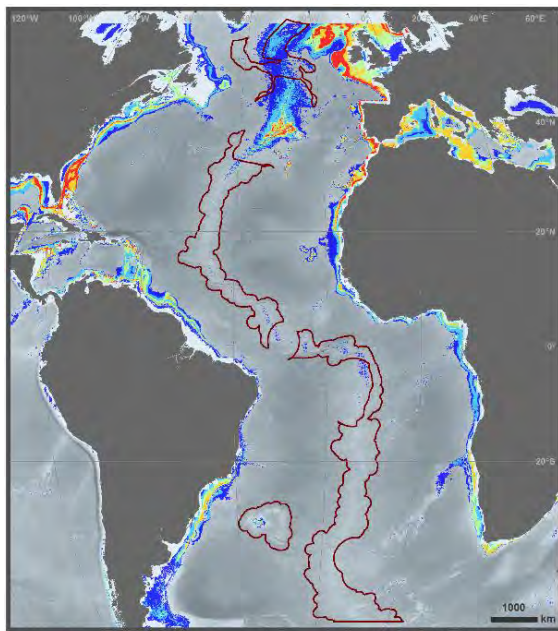
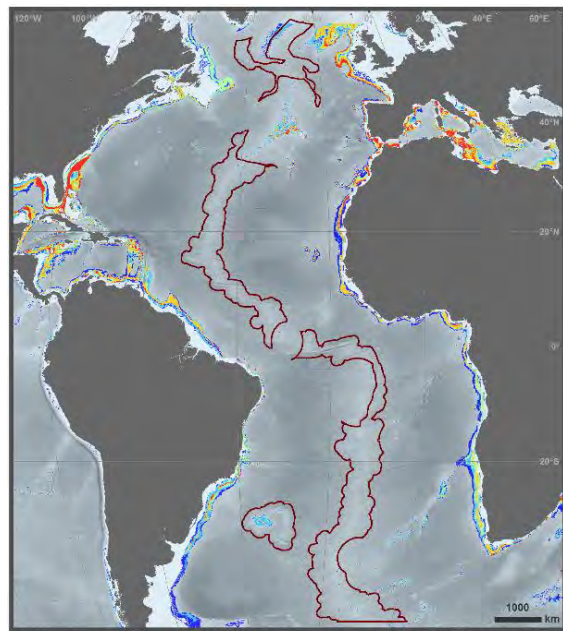


Figure 51. Deep-Sea Scleractinia Habitat Suitability – All five framework forming species.



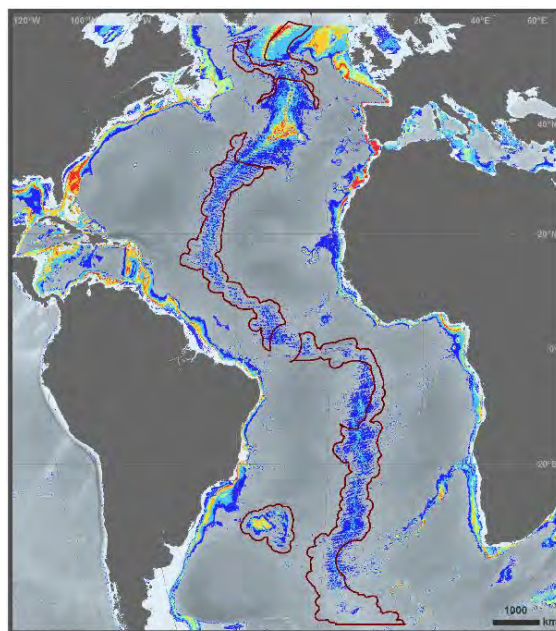
Habitat Suitability of *Lophelia pertusa* (Davies & Guinotte 2011)
 Suitability 0.2 0.4 0.6 0.8 1.0

Figure 52. Deep-Sea Scleractinia Habitat Suitability – *Lophelia pertusa*.



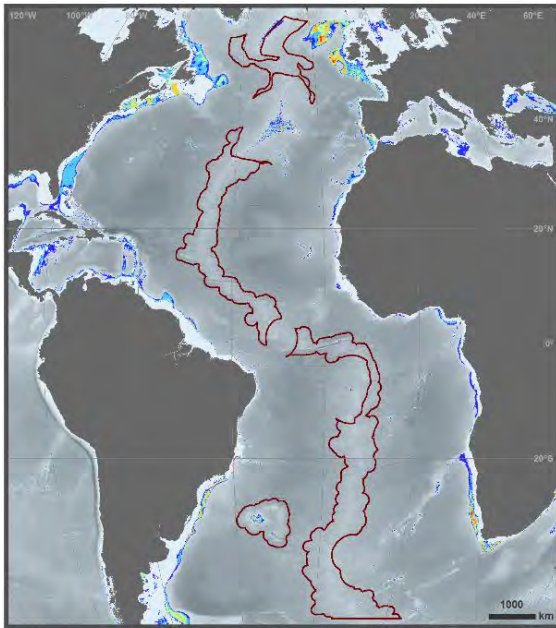
Habitat Suitability of *M. oculata* (Davies & Guinotte 2011)
 Suitability 0.2 0.4 0.6 0.8 1.0

Figure 53. Deep-Sea Scleractinia Habitat Suitability – *Madrepora oculata*.



Habitat Suitability of *S. variabilis* (Davies & Guinotte 2011)
 Suitability 0.2 0.4 0.6 0.8 1.0

Figure 54. Deep-Sea Scleractinia Habitat Suitability – *Solenosmilia variabilis*.



Habitat Suitability of *G. dumosa* (Davies & Guinotte 2011)

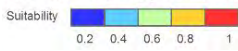
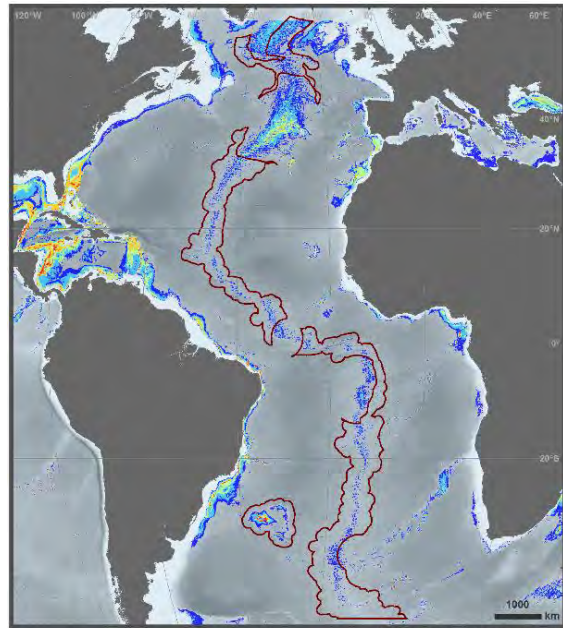


Figure 55. Deep-Sea Scleractinia Habitat Suitability – *Goniocorella dumosa*.



Habitat Suitability of *E. rostrata* (Davies and Guinotte 2011)

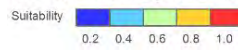


Figure 56. Deep-Sea Scleractinia Habitat Suitability – *Enallopsammia rostrata*.

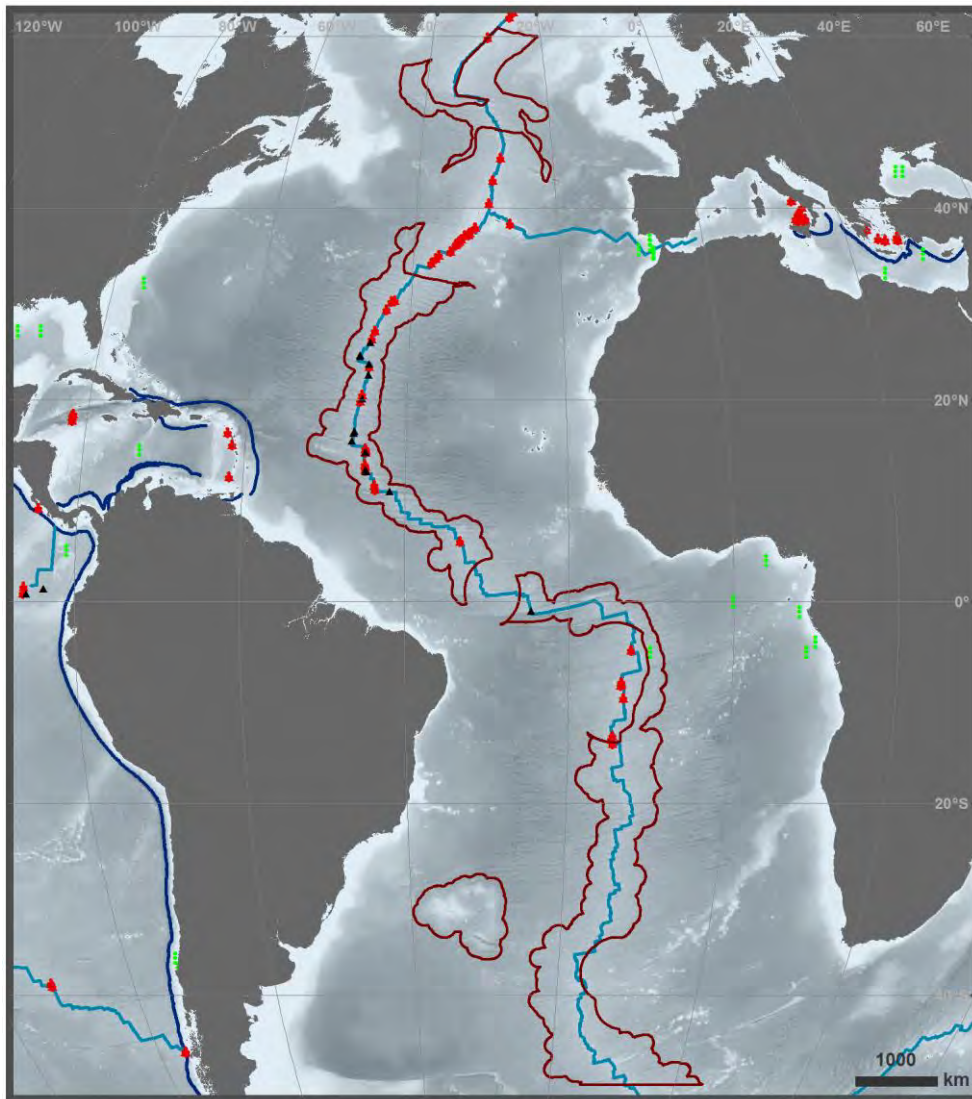
3.5 Hydrothermal vents and cold seeps

ChEss (Chemosynthetic Ecosystem Science; <http://www.noc.soton.ac.uk/chess/>) was a field project of the Census of Marine Life programme (CoML). The main aim of ChEss was to determine the biogeography of deep-water chemosynthetic ecosystems at a global scale and to understand the processes driving these ecosystems. ChEss addressed the main questions of CoML on diversity, abundance and distribution of marine species, focusing on deep-water reducing environments such as hydrothermal vents, cold seeps, whale falls, sunken wood and areas of low oxygen that intersect with continental margins and seamounts. ChEssBase is a dynamic relational database available online since December 2004. The aim of ChEssBase is to provide taxonomical, biological, ecological and distributional data of all species described from deep-water chemosynthetic ecosystems, as well as bibliography and information on the habitats. These habitats include hydrothermal vents, cold seeps, whale falls, sunken wood and areas of minimum oxygen that intersect with the continental margin or seamounts.

Since the discovery of hydrothermal vents in 1977 and of cold seep communities in 1984, over 500 species from vents and over 200 species from seeps have been described (Van Dover et al., 2002). The discovery of chemosynthetically fuelled communities on benthic OMZs and large organic falls to the deep-sea such as whales and wood have increased the number of habitats and fauna for investigation. New species are continuously being discovered and described from sampling programmes around the globe.

ChEssBase: http://www.noc.soton.ac.uk/chess/database/db_home.php

InterRidge: <http://www.interridge.org/irvents/maps>



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Hydrothermal Vents and Cold Seeps

- | | | |
|--------------------------------------|----------------------|----------|
| Hydrothermal Vents (InterRidge 2011) | █ Cold Seeps (CHESS) | — Ridge |
| ▲ Active | | — Trench |
| ▲ Inactive | | |

Figure 57. Hydrothermal vents and cold seeps, data from InterRidge and CHESS databases.

3.6 Landings of pelagic commercial species

The landings of commercial tuna and swordfish presented here were obtained from the CATDIS (<https://www.iccat.int/en/accesingdb.htm>) database made available by the International Commission for the Conservation of Atlantic Tunas (ICCAT). CATDIS is basically an estimate of Task-1 nominal catches (T1NC) for the nine major tuna and tuna like species of ICCAT, stratified in time (trimester) and space (5x5 degree squares). It assumes that, time/space distribution of Task II partial catch data (obtained from catch and effort reports) is representative of T1NC overall annual catches dispersion in time and space. The catches for the main pelagic sharks were obtained from Task II Catch and Effort (T2CE) database from the International Commission for the Conservation of Atlantic Tunas (ICCAT). T2CE are basically data obtained from sampling a portion of the individual fishing operations of a given fishery in a specified period of time.



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**Aggregated Landings of Tuna between 2005 and 2009
(thousands of kg; source: ICCAT)**

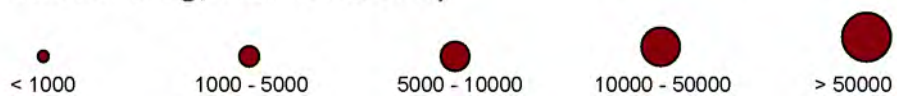
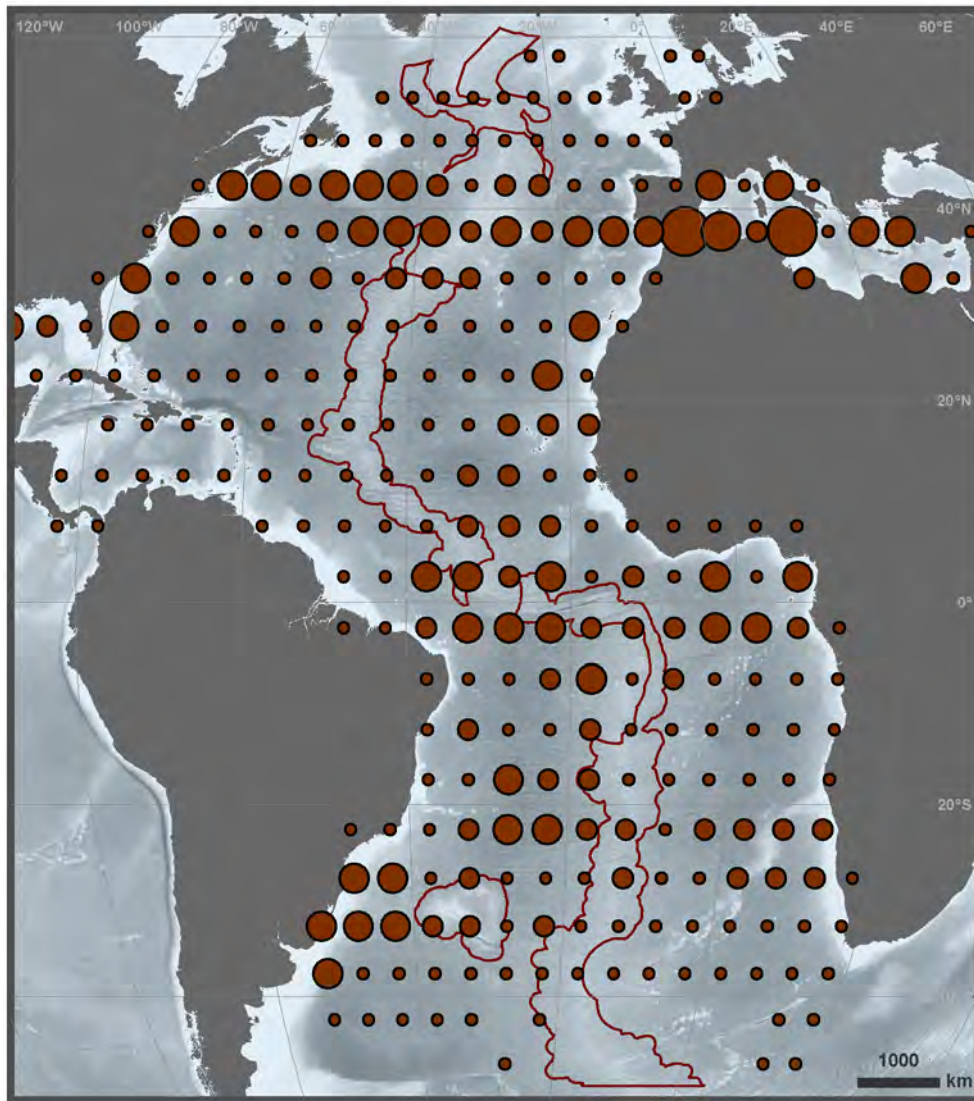


Figure 58. Aggregated landings for the five main tuna species (Atlantic bluefin tuna, yellowfin tuna, albacore, bigeye tuna and skipjack tuna), data from CATDIS database (ICCAT).

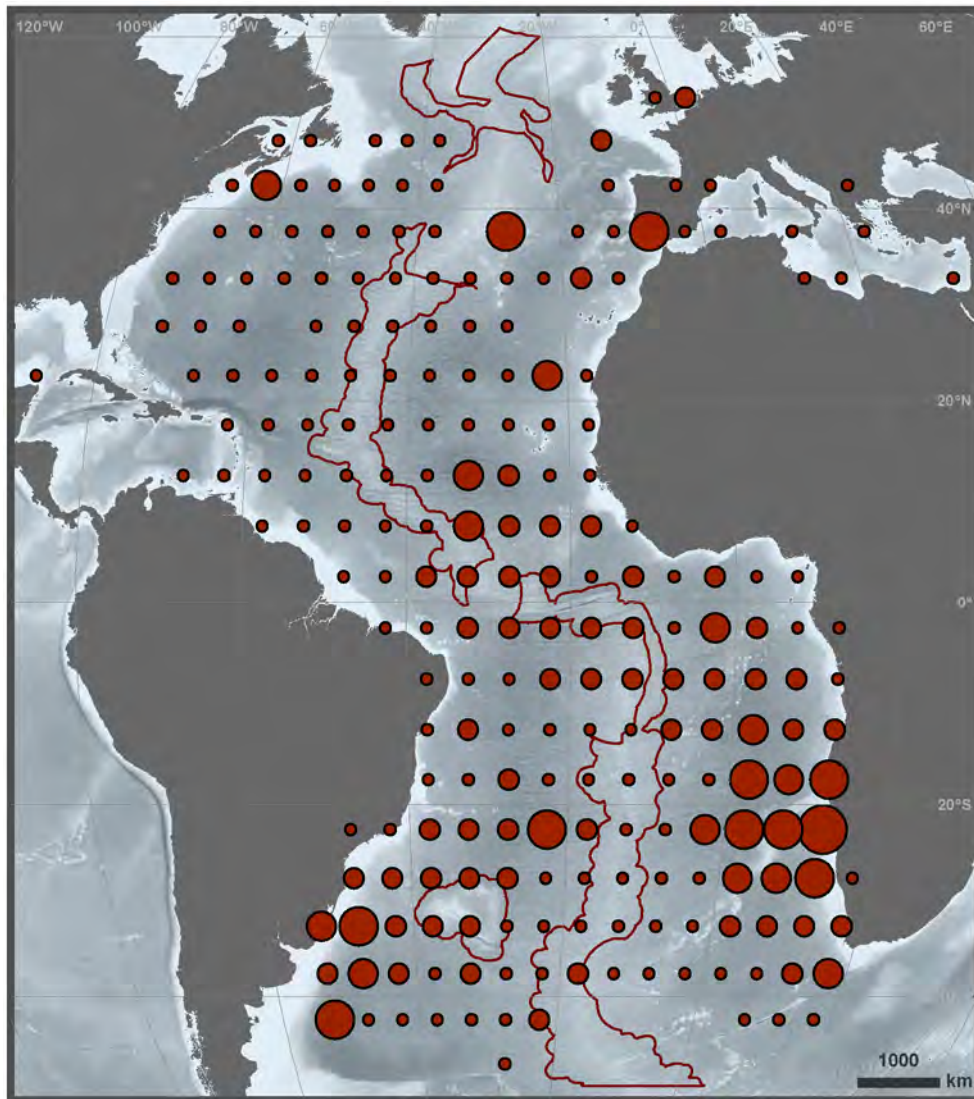


Marine Geospatial Ecology Lab, Duke University (2015)

**Aggregated Landings of Swordfish between 2005 and 2009
(kg; source: ICCAT)**



Figure 59. Aggregated landings for swordfish, data from CATDIS database (ICCAT).



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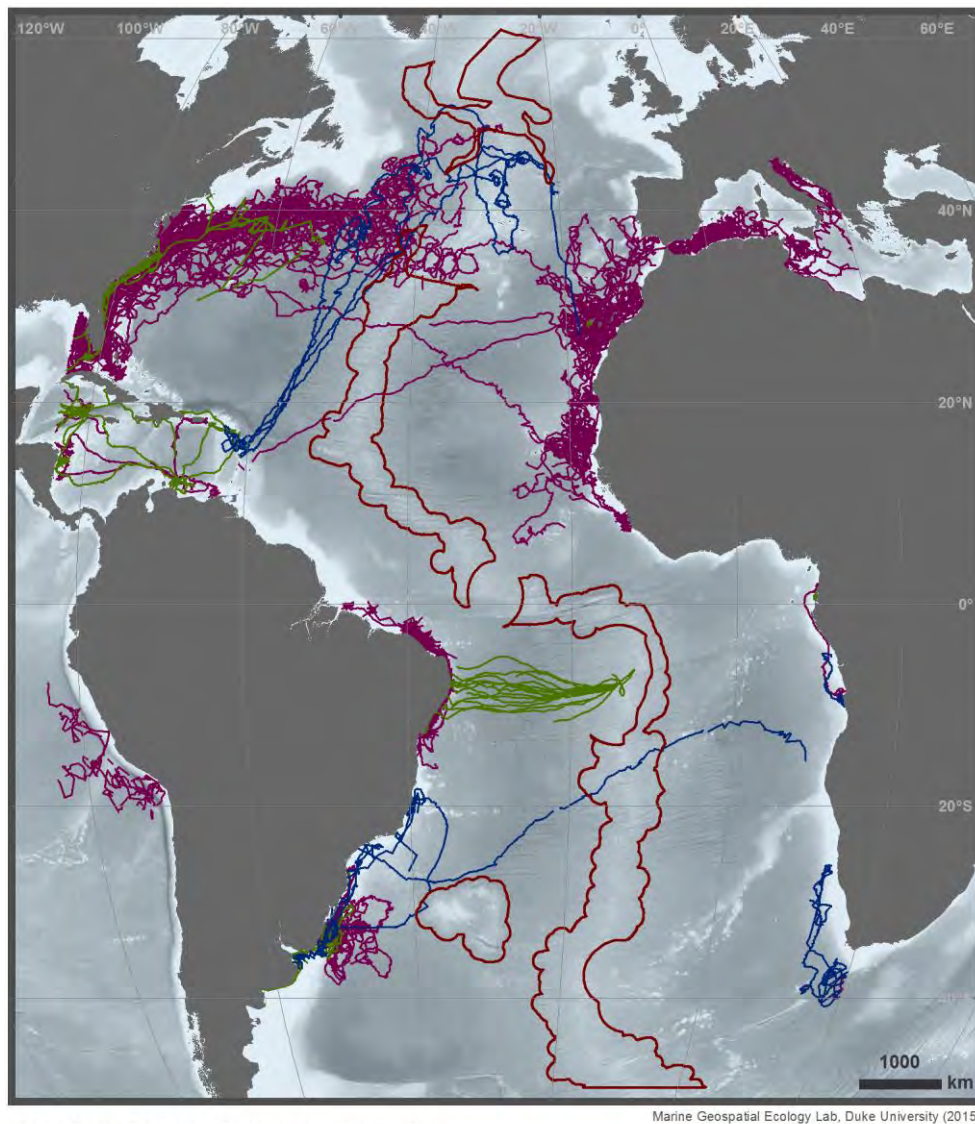
**Aggregated Catches of Sharks between 2005 and 2009
(kg; source: ICCAT)**



Figure 60. Aggregated catches for the 3 main shark species (shortfin mako, porbeagle, blue shark), data from ICCAT.

3.7 Turtle tagging data aggregated by OBIS-SEAMAP

OBIS-SEAMAP (<http://seamap.env.duke.edu/>), Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations, is a spatially referenced online database, aggregating marine mammal, seabird and sea turtle observation data from across the globe. Data from several turtle tracking efforts were extracted from OBIS-SEAMAP data center for the study area and displayed on a per species basis.



OBIS-SEAMAP Turtle Tracks

- Leatherback turtle track (17 individual tracks shown)
- Green turtle track (115 individual tracks shown)
- Loggerhead turtle tracks (441 individual tracks shown)

Figure 61. Turtle telemetry (Leatherback, Green Turtle and Loggerhead), data from OBIS-SEAMAP.

3.8 Leatherback Turtle Telemetry and Density

Abstract (Fossette et al., 2014): Large oceanic migrants play important roles in ecosystems, yet many species are of conservation concern as a result of anthropogenic threats, of which incidental capture by fisheries is frequently identified. The last large populations of the leatherback turtle, *Dermochelys coriacea*, occur in the Atlantic Ocean, but interactions with industrial fisheries could jeopardize recent positive population trends, making bycatch mitigation a priority. Here, we perform the first pan-Atlantic analysis of spatio-temporal distribution of the leatherback turtle and ascertain overlap with longline fishing effort. Data suggest that the Atlantic probably consists of two regional management units: northern and southern (the latter including turtles breeding in South Africa). Although turtles and fisheries show highly diverse distributions, we highlight nine areas of high susceptibility to potential bycatch (four in the northern Atlantic and five in the southern/equatorial Atlantic) that are worthy of further targeted investigation and mitigation. These are reinforced by reports of leatherback bycatch at eight of these sites. International collaborative efforts are needed, especially from nations hosting regions where susceptibility to bycatch is likely to be high within their exclusive economic zone (northern Atlantic: Cape Verde, Gambia, Guinea Bissau, Mauritania, Senegal, Spain, USA and Western Sahara; southern Atlantic: Angola, Brazil, Namibia and UK) and from nations fishing in these high-susceptibility areas, including those located in international waters.

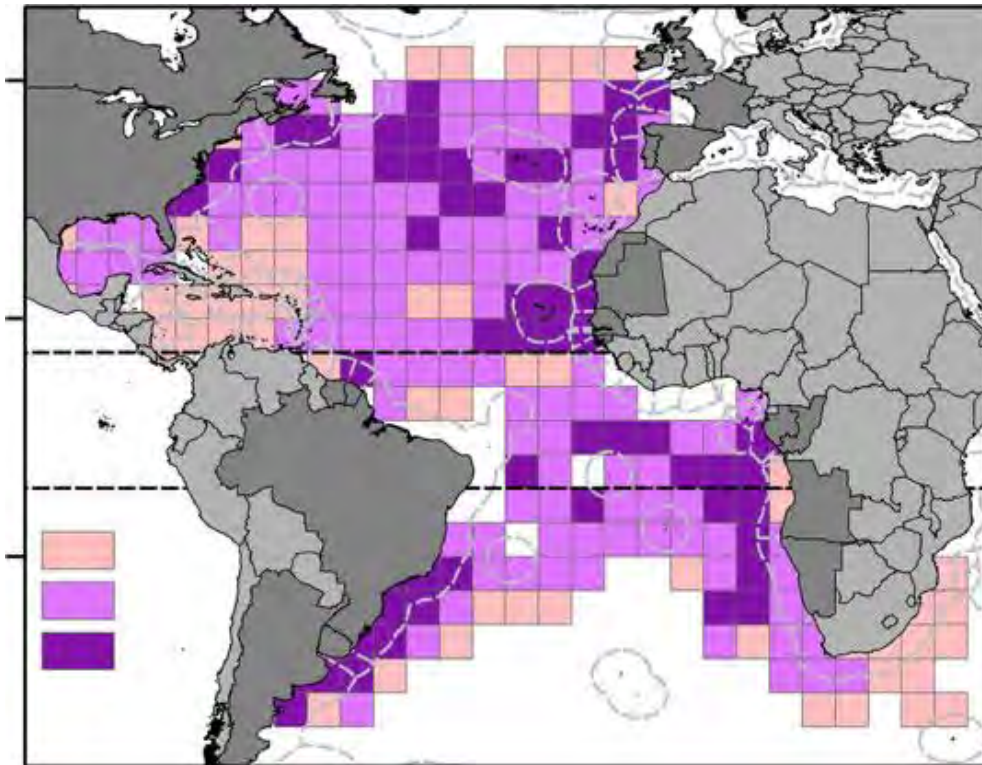


Figure 62. Density distribution of satellite-tracked leatherbacks in the Atlantic Ocean.

Figure 1b from Fossette et al. (2014): Density of leatherback daily locations (locations were time-weighted and population-size normalized). Three density classes were defined: low, medium and high use. White pixels represent areas from which tracking data were not received. High-use areas occurred both in international waters and within the EEZs of 20 countries (in dark grey) fringing the northern Atlantic (Canada, Cape Verde, Gambia, Guinea Bissau, France/French Guiana, Mauritania, Portugal/Azores, Senegal, Spain/Canaries, Suriname, United States of America, Western Sahara) or the southern Atlantic (Angola, Argentina, Brazil, Congo, Gabon, Namibia, United Kingdom/Ascension Island and Uruguay). Dashed grey lines represent the limits of national EEZs.

3.9 Global patterns of marine turtle bycatch

Abstract (Wallace et al., 2010): Fisheries bycatch is a primary driver of population declines in several species of marine megafauna (e.g., elasmobranchs, mammals, seabirds, turtles). Characterizing the global bycatch seascape using data on bycatch rates across fisheries is essential for highlighting conservation priorities. We compiled a comprehensive database of reported data on marine turtle bycatch in gillnet, longline, and trawl fisheries worldwide from 1990 to 2008. The total reported global marine turtle bycatch was ~85,000 turtles, but due to the small percentage of fishing effort observed and reported (typically <1% of total fleets), and to a global lack of bycatch information from small-scale fisheries, this likely underestimates the true total by at least two orders of magnitude. Our synthesis also highlights an apparently universal pattern across fishing gears and regions where high bycatch rates were associated with low observed effort, which emphasizes the need for strategic bycatch data collection and reporting. This study provides the first global perspective of fisheries bycatch for marine turtles and highlights region–gear combinations that warrant urgent conservation action (e.g., gillnets, longlines, and trawls in the Mediterranean Sea and eastern Pacific Ocean) and region–gear combinations in need of enhanced observation and reporting efforts (e.g., eastern Indian Ocean gillnets, West African trawls).

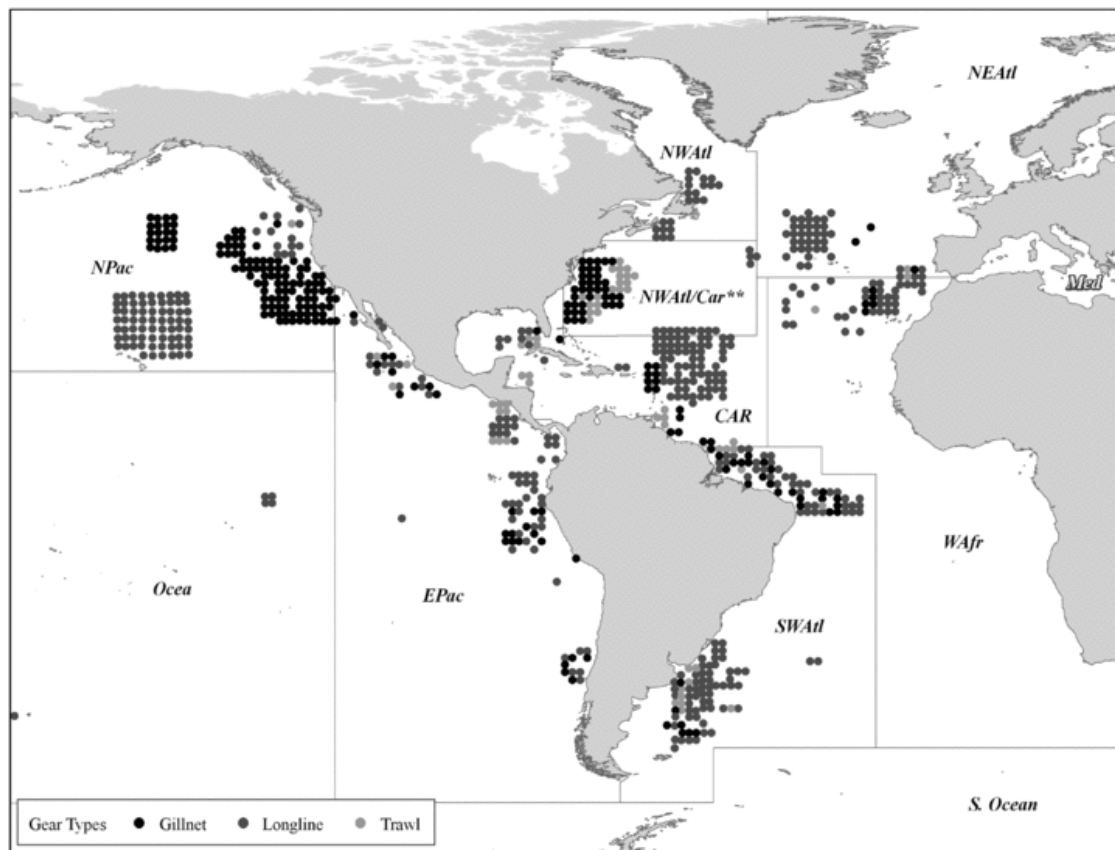


Figure 63. Overview of sea turtle bycatch data.

First panel of figure 1 from Wallace et al. (2010): Geographic delineation of regions and putative distribution of marine turtle bycatch records for gillnets, longlines, and trawls. Points represent all records we compiled in our database ($n= 993$), including those we used in analyses ($n= 700$). Locations were plotted according to reported geographic coordinates, or when coordinates were not available, based on region-specific descriptions of each fishing gear. Map was split into two panels to facilitate visual assessment of distribution of bycatch studies. Although some regions appear in both panels, data are only displayed once. NPac: North Pacific Ocean; EPac: eastern Pacific Ocean; Ocea: Oceania; NWAtl: Northwest Atlantic Ocean; Car: Caribbean; **NWAtl/Car: area of overlap between those two regions for longlines only (some bycatch records originated could not be assigned to one region); NEAtl: northeast Atlantic Ocean; WAfr: West Africa; Med: Mediterranean; WInd: western Indian Ocean; EInd: eastern Indian Ocean.

3.10 Sharks caught by the Brazilian tuna longline fleet

Abstract (Frédou et al., 2015): Large pelagic sharks are distributed throughout all of the oceans and are caught as bycatch in pelagic longline fisheries worldwide. In the southern Atlantic Ocean, more than a dozen shark species are caught by the Brazilian tuna longline fleet. This study compiles information of the main shark species caught by the Brazilian tuna longline fishery in the southwestern and equatorial Atlantic Ocean. Catch and effort data of 14,860 longline sets from the Brazilian chartered tuna longline fleet, between 2004 and 2010, were analyzed. The blue shark *Prionace glauca* was the main shark species captured by this fishery. Shark catches showed contrasting trends during the study period: the silky (*Carcharhinus falciformis*) and the oceanic whitetip (*C. longimanus*) sharks catch increased up to 2008 and then declined, while mako sharks (*Isurus* spp.) showed an opposite trend. Effort for the Brazilian longline fishery had a higher concentration from 10°N to 30°S and from 20°W to 40°W. High values of catch per unit effort of southwestern and equatorial Atlantic Ocean sharks were heterogeneously distributed and, although elasmobranchs were caught over most of the longline fishing range, only blue sharks were caught in all areas. In the southern Atlantic Ocean, high fishing effort zones overlap significantly with some nursery areas, especially for the oceanic whitetip shark, indicating that these areas are at a direct risk from the industrial longline fishery.

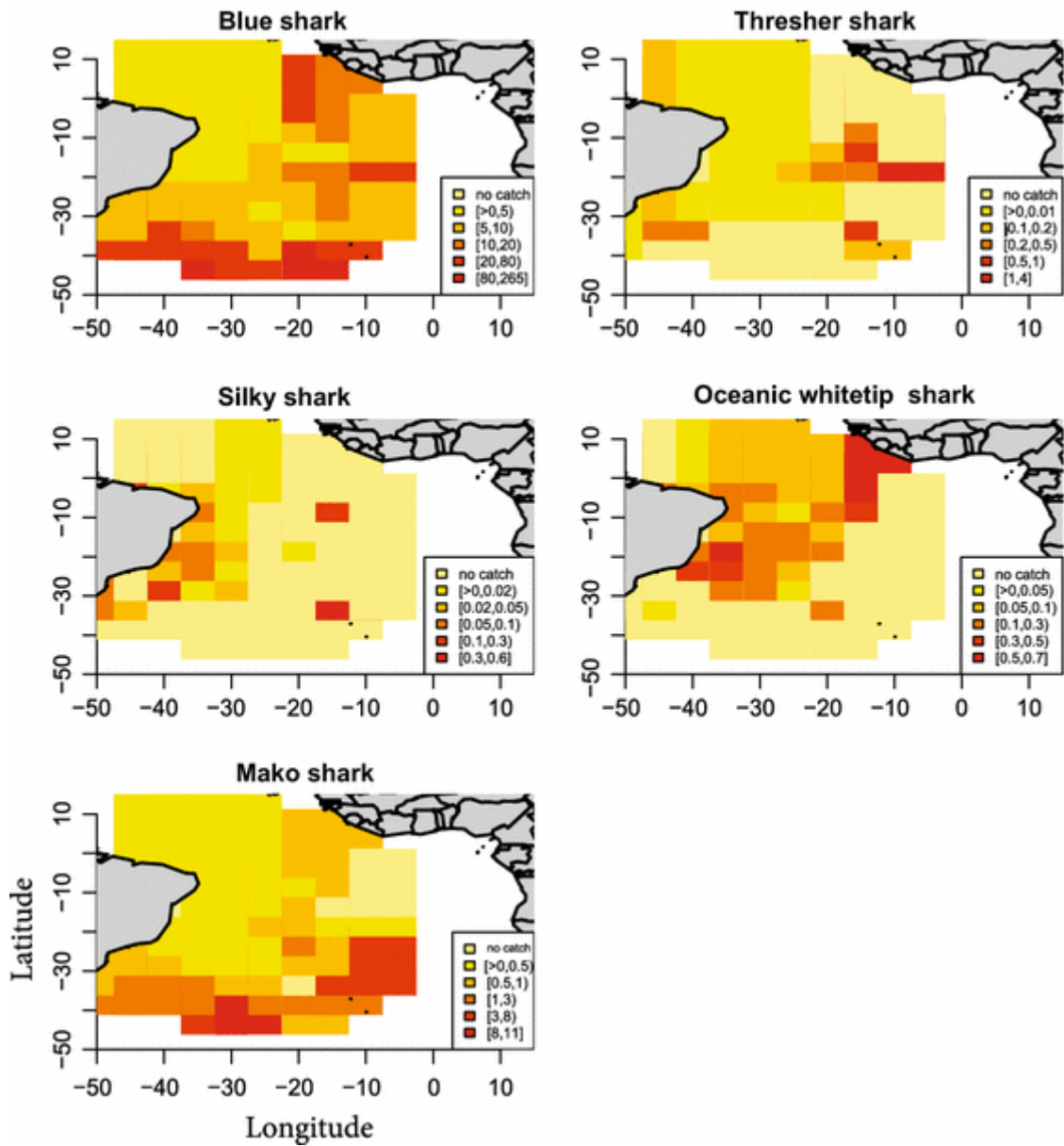


Figure 64. Catch rates of pelagic sharks.

Figure 5 from Frédou (2015): Longline catch per unit effort (CPUE individuals per 1,000 hooks) of the Brazilian chartered tuna longline fleet for the main elasmobranch species: blue shark (BSH), thresher shark (THR), silky shark (FAL), oceanic whitetip shark (OCS), mako shark (MAK). Note the different legends for each panel.

3.11 Blue shark telemetry

Abstract (Vandeperre et al., 2014): Spatial structuring and segregation by sex and size is considered to be an intrinsic attribute of shark populations. These spatial patterns remain poorly understood, particularly for oceanic species such as blue shark (*Prionace glauca*), despite its importance for the management and conservation of this highly migratory species. This study presents the results of a long-term electronic tagging experiment to investigate the migratory patterns of blue shark, to elucidate how these patterns change across its life history and to assess the existence of a nursery area in the central North Atlantic. Blue sharks belonging to different life stages (n = 34) were tracked for periods up to 952 days during which they moved extensively (up to an estimated 28.139 km), occupying large parts of the oceanic basin. Notwithstanding a large individual variability, there were pronounced differences in movements and space use across the species' life history. The study provides strong evidence for the existence of a discrete central North Atlantic nursery, where juveniles can reside for up to at least 2 years. In contrast with previously described nurseries of coastal and semi-pelagic sharks, this oceanic nursery is comparatively vast and open suggesting that shelter from predators is not its main function. Subsequently, male and female blue sharks spatially segregate. Females engage in seasonal latitudinal migrations until approaching maturity, when they undergo an ontogenic habitat shift towards tropical latitudes. In contrast, juvenile males generally expanded their range southward and apparently displayed a higher degree of behavioural polymorphism. These results provide important insights into the spatial ecology of pelagic sharks, with implications for the sustainable management of this heavily exploited shark, especially in the central North Atlantic where the presence of a nursery and the seasonal overlap and alternation of different life stages coincides with a high fishing mortality.

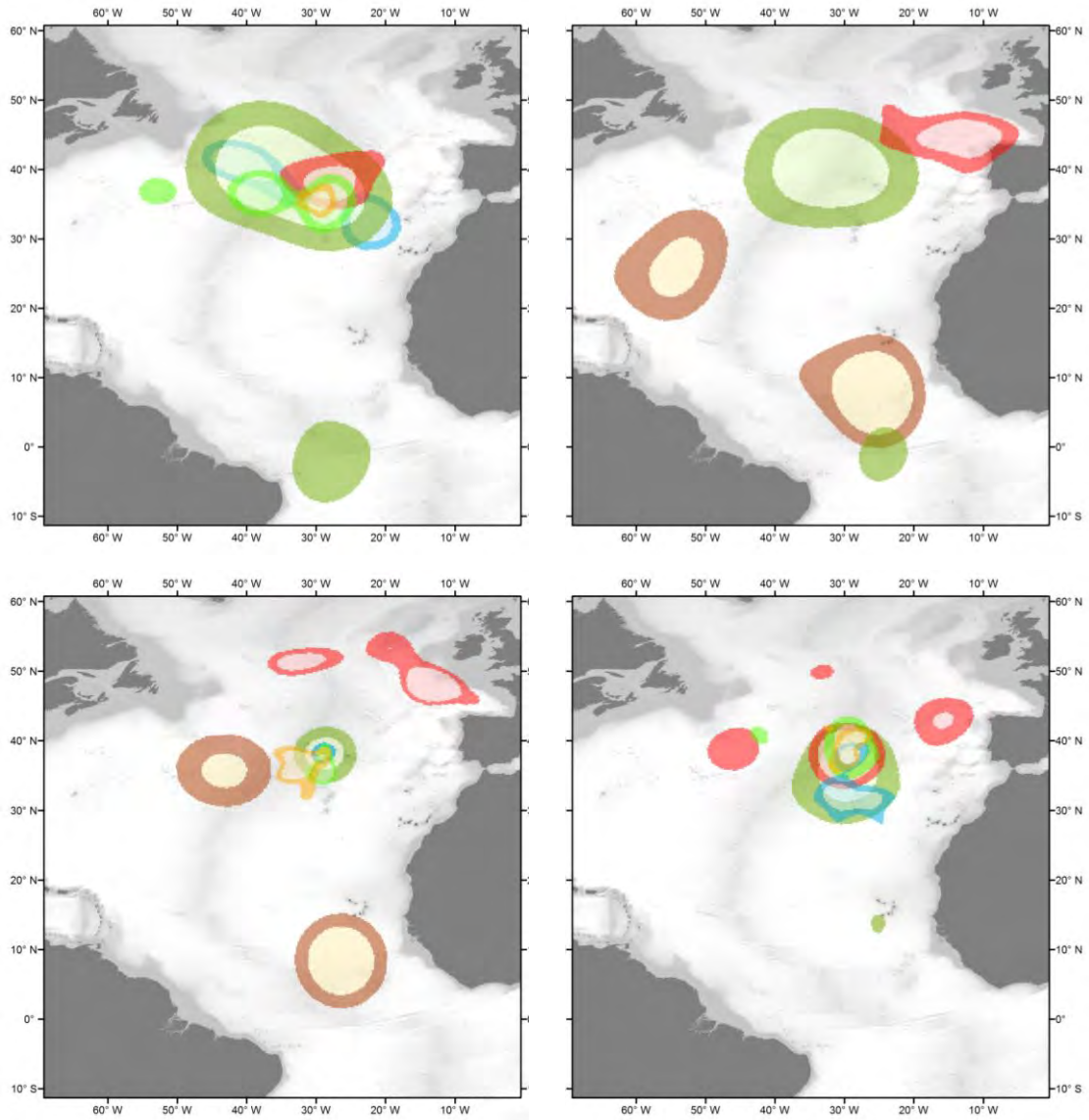


Figure 65. Seasonal blue shark utilisation distributions.

Figure 8 from Vandeperre et al. (2014): Quarterly 25% and 50% Kernel Utilisation Distributions (KUD) for the different life stages of blue sharks tagged in the Azores. Orange – Small Juvenile (SJ) females; Green – SJ males; Red – Large Juvenile and Sub-adult females; Dark green - Large Juvenile (LJ) males; Brown – Adult (AD) females; Blue – AD males.

3.12 Blue and fin whales telemetry

Abstract (Silva et al., 2013): The need to balance energy reserves during migration is a critical factor for most long-distance migrants and an important determinant of migratory strategies in birds, insects and land mammals. Large baleen whales migrate annually between foraging and breeding sites, crossing vast ocean areas where food is seldom abundant. How whales respond to the demands and constraints of such long migrations remains unknown. We applied a behaviour discriminating hierarchical state-space model to the satellite tracking data of 12 fin whales and 3 blue whales tagged off the Azores, to investigate their movements, behaviour (transiting and area-restricted search, ARS) and daily activity cycles during the spring migration. Fin and blue whales remained at middle latitudes for prolonged periods, spending most of their time there in ARS behaviour. While near the Azores, fin whale ARS behaviour occurred within a restricted area, with a high degree of overlap among whales. There were noticeable behavioural differences along the migratory pathway of fin whales tracked to higher latitudes: ARS occurred only in the Azores and north of 56°N, whereas in between these areas whales travelled at higher overall speeds while maintaining a nearly direct trajectory. This suggests fin whales may alternate periods of active migration with periods of extended use of specific habitats along the migratory route. ARS behaviour in blue whales occurred over a much wider area as whales slowly progressed northwards. The tracks of these whales terminated still at middle latitudes, before any behavioural switch was detected. Fin whales exhibited behavioural-specific diel rhythms in swimming speed but these varied significantly between geographic areas, possibly due to differences in the day-night cycle across areas. Finally, we show a link between fin whales seen in the Azores and those summering in eastern Greenland-western Iceland along a migratory corridor located in central Atlantic waters.

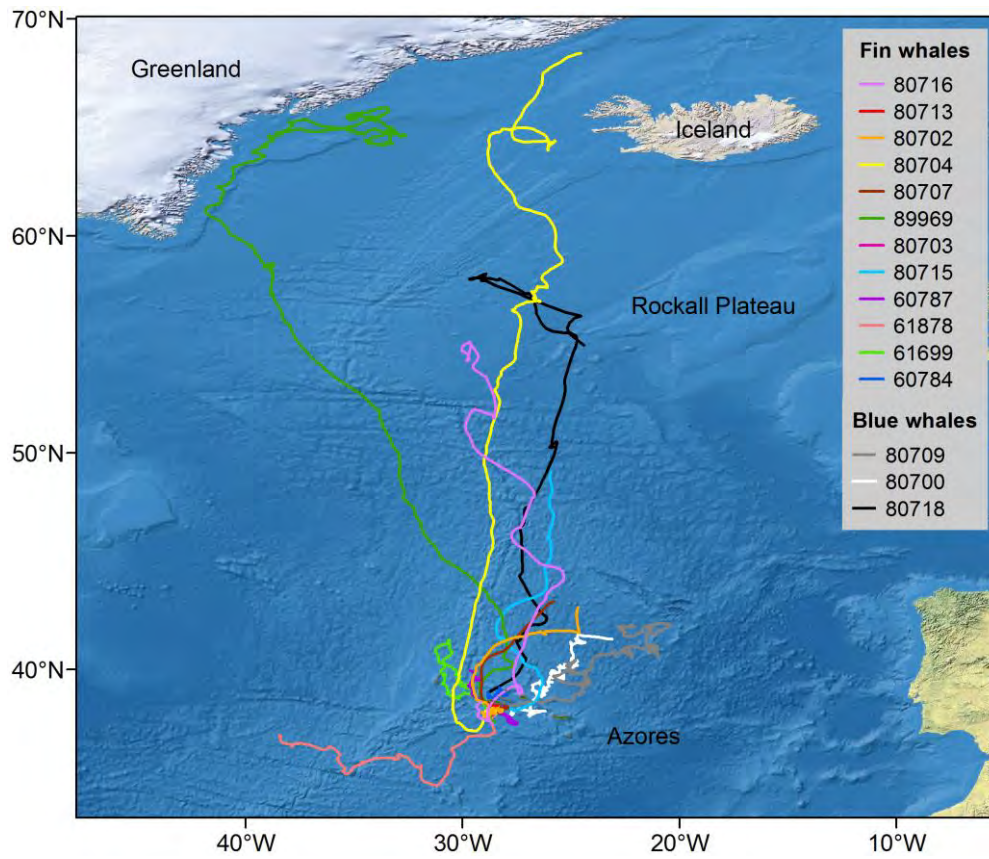


Figure 66. Blue and fin whale telemetry.

Figure 1 from (Silva et al. 2013): Hierarchical switching state-space model derived tracks of 12 fin whales and 3 blue whales.

3.13 Bluefin tuna telemetry

Abstract (Block et al. 2005): Electronic tags that archive or transmit stored data to satellites have advanced the mapping of habitats used by highly migratory fish in pelagic ecosystems. Here we report on the electronic tagging of 772 Atlantic bluefin tuna in the western Atlantic Ocean in an effort to identify population structure. Reporting electronic tags provided accurate location data that show the extensive migrations of individual fish ($n = 330$). Geoposition data delineate two populations, one using spawning grounds in the Gulf of Mexico and another from the Mediterranean Sea. Transatlantic movements of western-tagged bluefin tuna reveal site fidelity to known spawning areas in the Mediterranean Sea. Bluefin tuna that occupy western spawning grounds move to central and eastern Atlantic foraging grounds. Our results are consistent with two populations of bluefin tuna with distinct spawning areas that overlap on North Atlantic foraging grounds. Electronic tagging locations, when combined with US pelagic longline observer and logbook catch data, identify hot spots for spawning bluefin tuna in the northern slope waters of the Gulf of Mexico. Restrictions on the time and area where longlining occurs would reduce incidental catch mortalities on western spawning grounds.

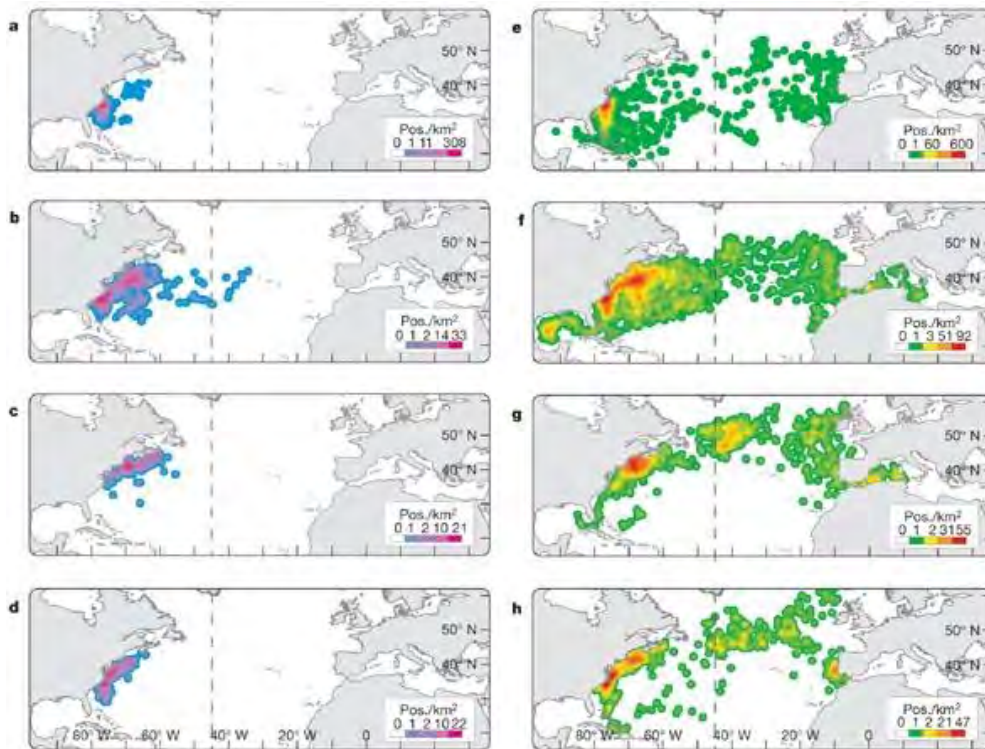


Figure 67. Seasonal hot spots where western-tagged Atlantic bluefin tuna spent the majority of time from 1996 to 2004.

Figure 4 from Block et al. (2005): a–d, Less than 200 cm CFL. a, Winter; b, spring; c, summer; d, autumn. e–h, Greater than or equal to 200 cm CFL. e, Winter; f, spring; g, summer; h, autumn. The dashed line in each panel indicates the current ICCAT management boundary (45° W meridian). High kernel densities²⁹ indicate seasonal hot spots where western-tagged Atlantic bluefin tuna spent the majority of time from 1996 to 2004. Only fish that were measured were used in this analysis. A western²⁰ or eastern²⁴ growth model was applied to obtain daily length after tagging. a, $n = 101$, mean size at release 192.9 cm CFL. b, $n = 56$, 192.6 cm CFL. c, $n = 22$, 192.7 cm CFL. d, $n = 13$, 187.8 cm CFL. e, $n = 162$, 219.14 cm CFL. f, $n = 167$, 220.13 cm CFL. g, $n = 97$, 225.15 cm CFL. h, $n = 49$, 227.15 cm CFL. Pos., positions.

3.14 Seabirds in the central North Atlantic

Abstract (Boertmann 2011): From 12 to 17 September 2006 a “snapshot” of seabird densities in the northern Atlantic between Greenland and the Azores was obtained using the strip-transect method. Relatively high densities of seabirds in the Greenland shelf and subpolar waters as well as very low densities in the oceanic subtropical waters, described by early authors, were confirmed. Highest oceanic densities (average 21 individuals/km² per subtransect) were observed on 15 September approximately 200 km south of the subpolar front at about 50°N and approximately 600 km west of the Mid-Atlantic Ridge. Most numerous in this area were Leach’s Storm-Petrel (552 on-transect), Great Shearwater (317 on-transect) and Cory’s Shearwater (125 on-transect), and noteworthy were small numbers of Arctic Terns and Long-tailed Skuas. This high-density site was located in the centre of the stopover site/foraging area recently discovered by tracking Arctic Terns, Long-tailed Skuas, Sooty Shearwaters and Cory’s Shearwaters. This combined aggregation area seems to be associated with the subpolar front between the Grand Banks and the Charlie–Gibbs fracture zone.

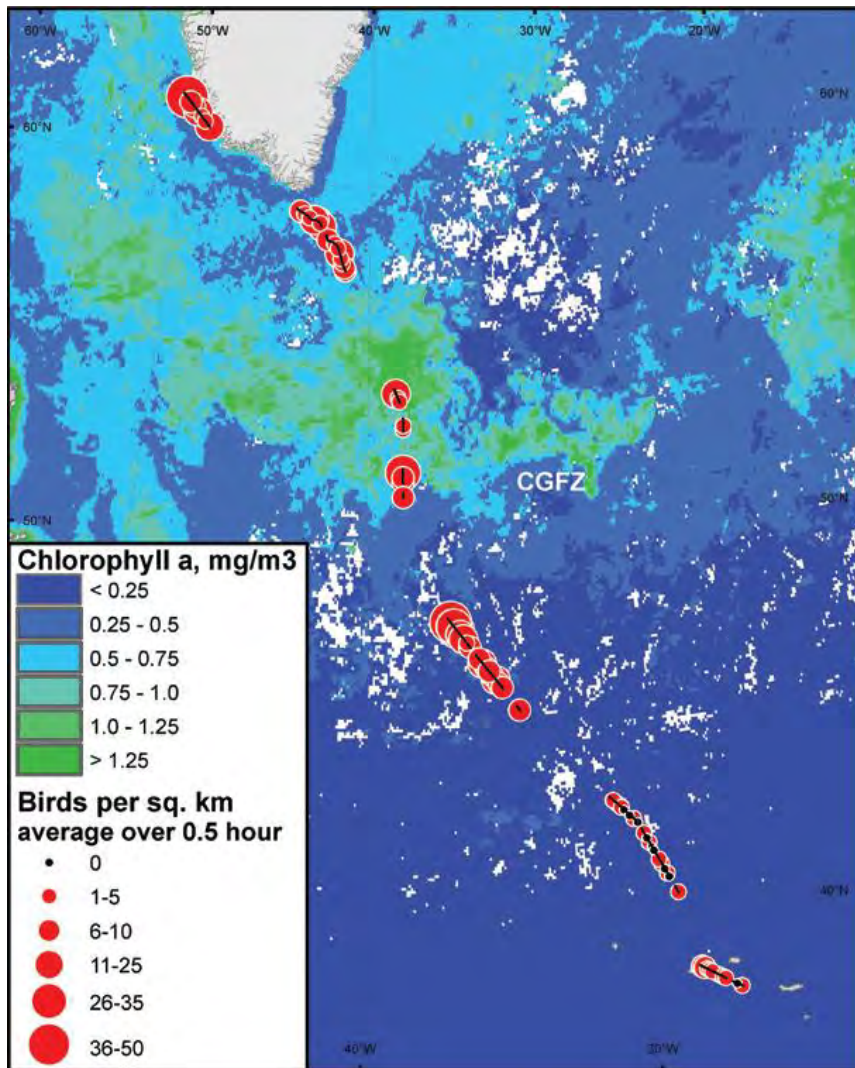
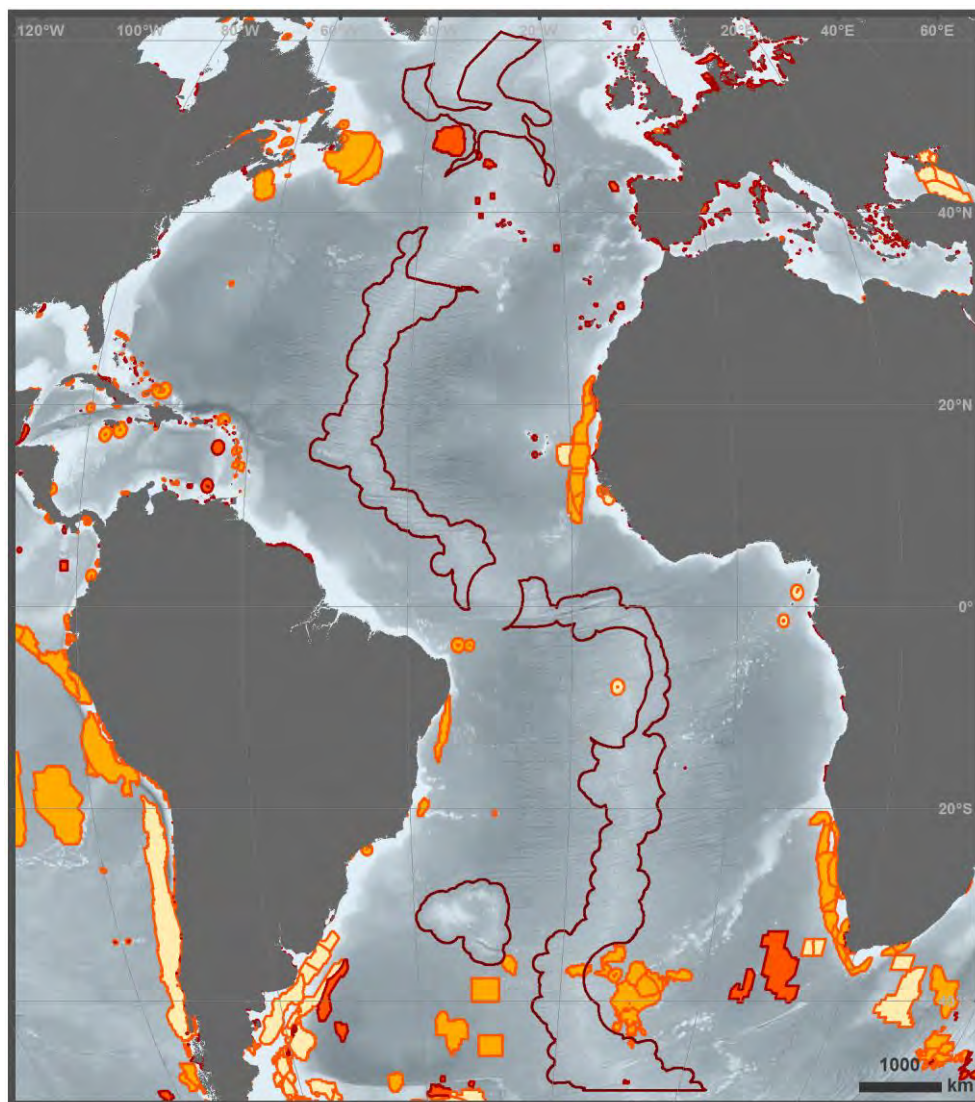


Figure 68. Seabird densities.

Figure 2 from Boertmann (2011): Densities of seabirds (all species on-transect combined) along the transect in September 2006. Densities are aggregated over 30 min periods, to provide a better overview. Background is a synoptic Aqua Modis composite image of chlorophyll a in surface waters. CGFZ is the Charlie–Gibbs fracture zone.

3.15 Important Bird Areas (IBAs)

BirdLife Important Bird Areas (IBAs) have been identified using several data sources: 1) terrestrial seabird breeding sites are shown with point locality and species that qualifies at the IBA (<http://www.birdlife.org/datazone/site/search>), 2) marine areas around breeding colonies have been identified based on literature review where possible to guide the distance required by each species; where literature is sparse or lacking, extensions have been applied on a precautionary basis (<http://seabird.wikispaces.com/>), and 3) sites identified by satellite tracking data via kernel density analysis, first passage time analysis and bootstrapping approaches (www.seabirdtracking.org). Together these IBAs form a network of sites of importance to coastal, pelagic, resident and or migratory species.



Marine Important Bird Areas (Bird Life)

- IBAs
- Confirmed
 - Proposed
 - Candidate

Figure 69. Important Bird Areas (BirdLife).

Chapter 4. Biogeographic Classification

4.1 Global Open Ocean and Deep Seabed (GOODS) biogeographic classification

GOODS is the first attempt at comprehensively classifying the open-ocean and deep seafloor into distinct biogeographic regions (UNESCO, 2009). The classification was produced by an international and multidisciplinary group of experts under the auspices of a number of international and intergovernmental organizations as well as governments, and under the ultimate umbrella of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and its Intergovernmental Oceanographic Commission (IOC). The maps showed below include the updates made by Watling et al. (2013).

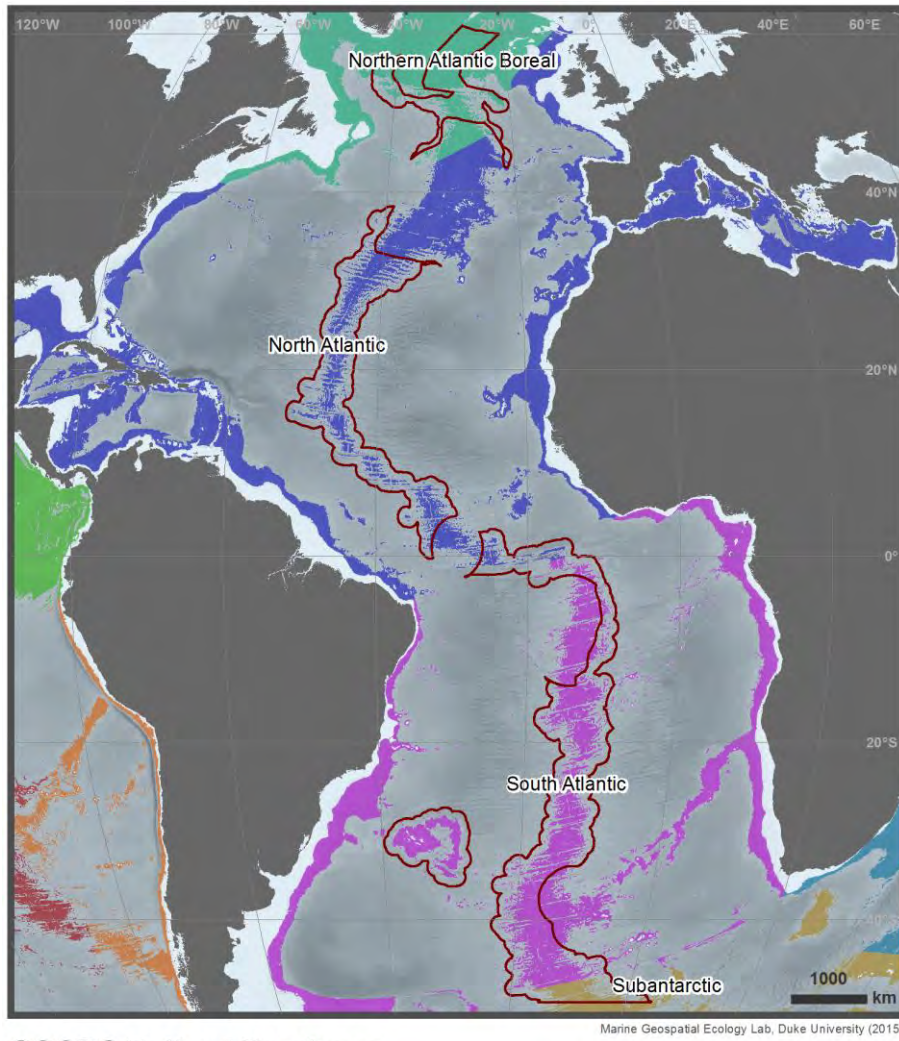
The biogeographic classification classifies specific ocean regions using environmental features and – to the extent data are available – their species composition. GOODS is hypothesis-driven and still preliminary, and will thus require further refinement and peer review in the future. However, parts of it have already been published (e.g. pelagic provinces; Spalding et al. 2012). Watling et al. (2013) tried to refine the GOODS bathyal and abyssal provinces including some new variables. Physical and chemical proxies thought to be good predictors of the distributions of organisms at the deep-sea floor, and thus used for the definition of biogeographic provinces, were: depth, temperature (T), salinity (S), dissolved oxygen (O), and particulate organic carbon flux (POC) to the sea- floor.

The major open ocean pelagic and deep sea benthic zones presented by the GOODS report and by Watling et al. (2013) are considered by their authors a reasonable basis for advancing efforts towards the conservation and sustainable use of biodiversity in marine areas beyond the limits of national jurisdiction in line with a precautionary approach.



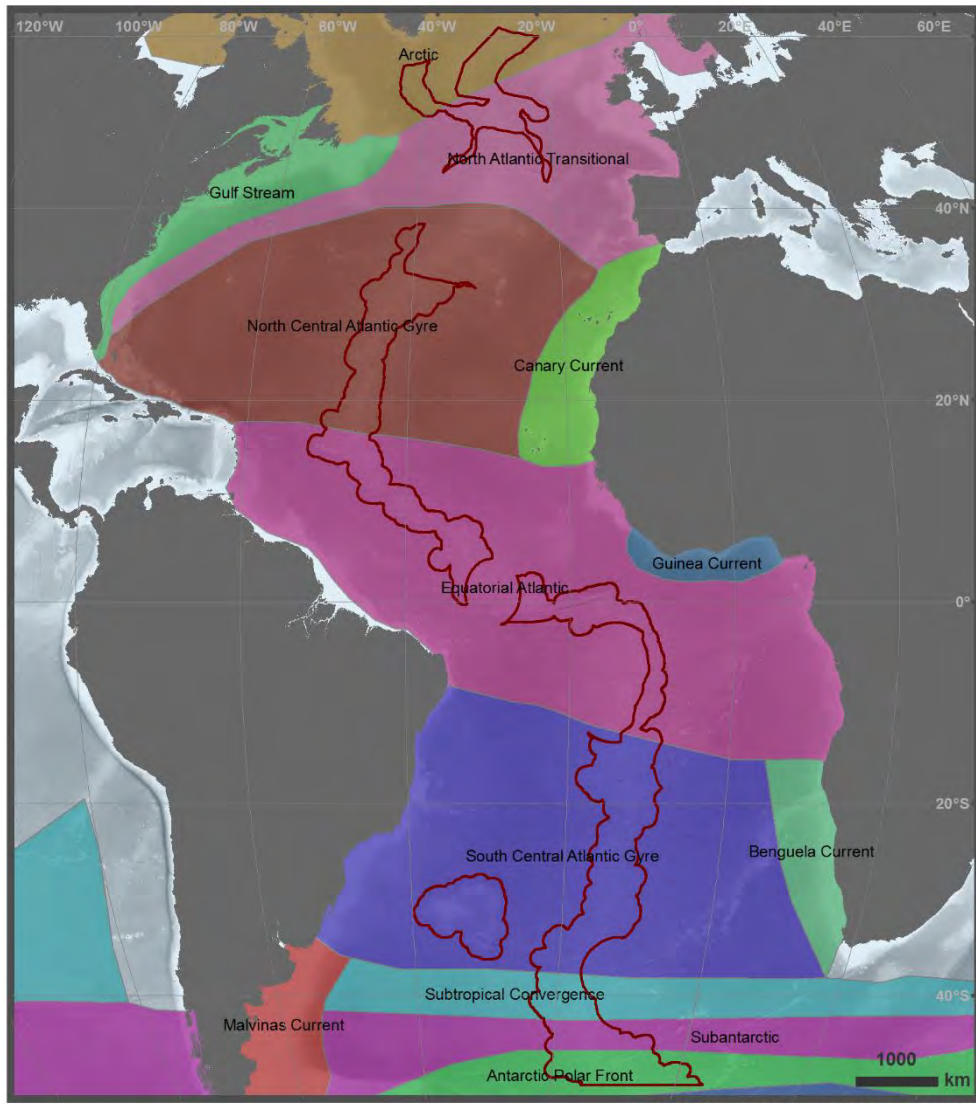
GOODS Abyssal Provinces

Figure 70. GOODS abyssal provinces. Depth range 3500 to 6500 m – as updated by Watling et al. (2013).



GOODS Bathyal Provinces

Figure 71. GOODS lower bathyal provinces. Depth range 800 to 3500 m – as updated by Watling et al. (2013).



GOODS Pelagic Provinces

Figure 72. GOODS pelagic provinces.

4.2 Mesopelagic provinces

Abstract (Sutton et al., in review): We have developed a global biogeographic classification of the mesopelagic zone (200–1000 m), presented to reflect the regional scales over which the deep-pelagic ocean varies in terms of biodiversity and function, and thereby inform global ocean conservation and management efforts. An integrated approach was necessary given the gaps in data and/or non-standardized sampling methods for the deep-pelagic biome globally. A panel combining expertise in oceanography, geospatial mapping, ecology, organism ecology, and mesopelagic taxonomy across a broad spectrum of taxa (e.g., gelatinous, molluscan and crustacean zooplankton; chaetognaths; cephalopods; larger decapod Crustacea; and fishes) convened to collate expert opinion on distributional patterns of pelagic fauna in combination with environmental data felt to be useful biological “proxies.” The latter proxies (annual means for temperature, salinity, and dissolved oxygen at 200, 500, 750, and 1000 m depths) were mapped as raster outputs using the Iso Cluster and Maximum Likelihood Classification tools in ArcGIS. Existing water mass classifications were referenced when interpreting cluster results. An iterative, modified Delphi process integrating additional physical (e.g., topography) and biological data (e.g., surface water productivity; abrupt species replacements) was used to refine cluster outputs (i.e., provinces) and to identify the probable location of province boundaries. A total of 33 global mesopelagic provinces are classified here. Of these, 13 are oceanic while 20 are ‘distant neritic.’ While each is driven by a complex of controlling factors, an (equivocal) attempt was made to identify the primary driver of each province: fifteen provinces appear to be maintained primarily via water mass homogeneity, six by upwelling processes, six by topography, three by surface primary productivity, and three by low dissolved oxygen, though the latter two drivers are correlated, with the first inducing the second. While work remains to be done to produce a truly three-dimensional and dynamic mesopelagic biogeography, we believe that the classification set forth in this study will prove to be a useful and timely input to policy planning and management for conservation and sustainable use of the diverse deep-pelagic marine resources. In particular, it gives an indication of the spatial scale at which faunal communities are expected to be broadly similar in composition, and hence can inform application of ecosystem-based management approaches, marine spatial planning and the distribution and spacing of systems of representative protected areas.

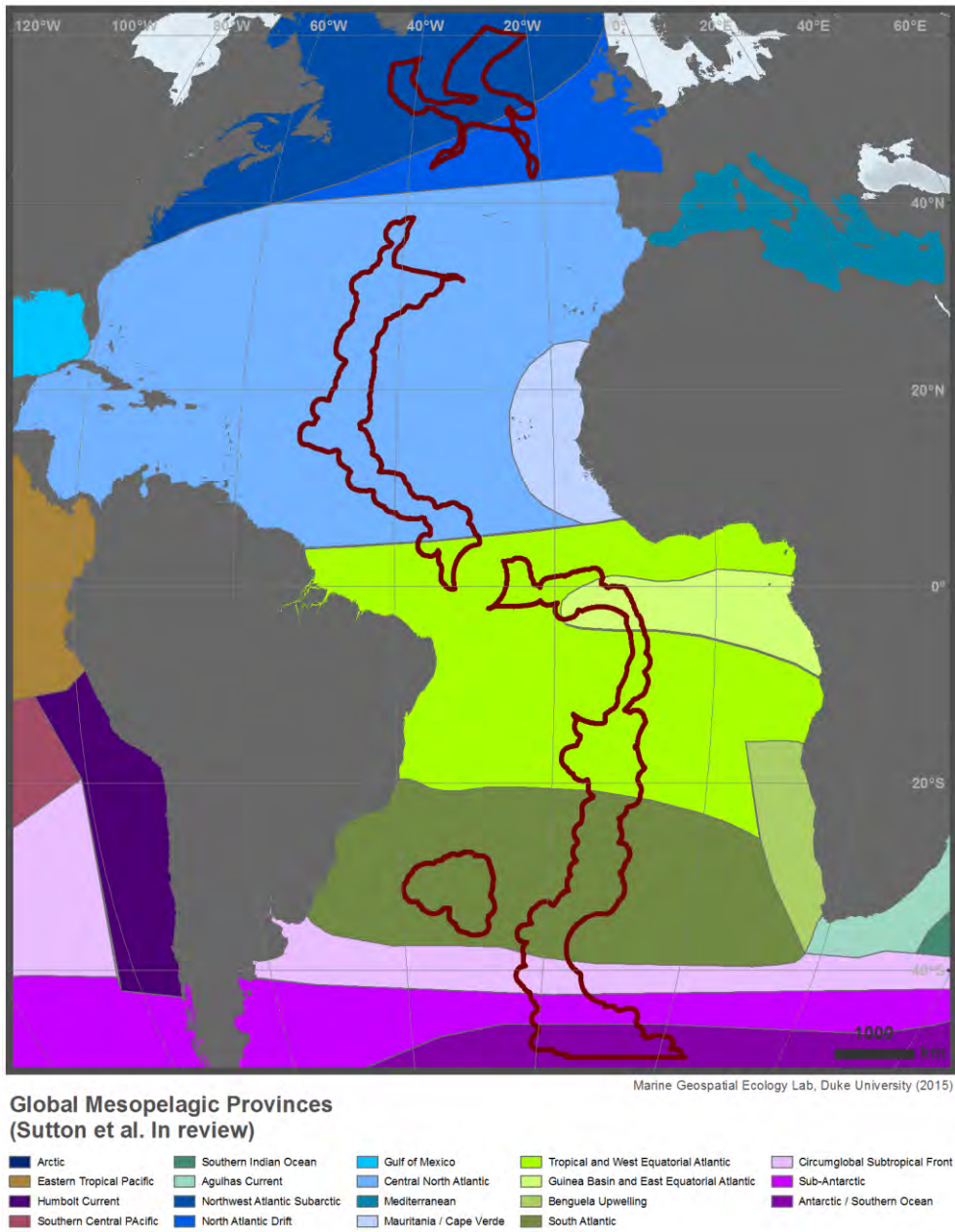


Figure 73. Mesopelagic provinces, adapted from Sutton et al. (in review).

4.3 Longhurst Marine Provinces

This dataset represents a partition of the world oceans into provinces as defined by Longhurst (2006), and are based on the prevailing role of physical forcing as a regulator of phytoplankton distribution. The dataset represents the initial static boundaries developed at the Bedford Institute of Oceanography, Canada. Note that the boundaries of these provinces are not fixed in time and space, but are dynamic and move under seasonal and interannual changes in physical forcing. At the first level of reduction, Longhurst recognized four principal biomes (also referred to as domains in earlier publications): the Polar Biome, the Westerlies Biome, the Trade-Winds Biome, and the Coastal Boundary Zone Biome. These four Biomes are recognizable in every major ocean basin. At the next level of reduction, the ocean basins are partitioned into provinces, roughly ten for each basin. These partitions provide a template for data analysis or for making parameter assignments on a global scale. This layer was downloaded from VLIZ (<http://www.marineregions.org/>).



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Longhurst Marine Provinces

Figure 74. Longhurst marine provinces, layer downloaded from VLIZ (www.marineregions.org/).

4.4 Biogeography of hydrothermal vents

Abstract (German et al., 2011): The ChEss project of the Census of Marine Life (2002–2010) helped foster internationally-coordinated studies worldwide focusing on exploration for, and characterization of new deep-sea chemosynthetic ecosystem sites. This work has advanced our understanding of the nature and factors controlling the biogeography and biodiversity of these ecosystems in four geographic locations: the Atlantic Equatorial Belt (AEB), the New Zealand region, the Arctic and Antarctic and the SE Pacific off Chile. In the AEB, major discoveries include hydrothermal seeps on the Costa Rica margin, deepest vents found on the Mid-Cayman Rise and the hottest vents found on the Southern Mid-Atlantic Ridge. It was also shown that the major fracture zones on the MAR do not create barriers for the dispersal but may act as trans-Atlantic conduits for larvae. In New Zealand, investigations of a newly found large cold-seep area suggest that this region may be a new biogeographic province. In the Arctic, the newly discovered sites on the Mohs Ridge (71°N) showed extensive mats of sulfur-oxidising bacteria, but only one gastropod potentially bears chemosynthetic symbionts, while cold seeps on the Haakon Mossby Mud Volcano (72°N) are dominated by siboglinid worms. In the Antarctic region, the first hydrothermal vents south of the Polar Front were located and biological results indicate that they may represent a new biogeographic province. The recent exploration of the South Pacific region has provided evidence for a sediment hosted hydrothermal source near a methane-rich cold-seep area. Based on our 8 years of investigations of deep-water chemosynthetic ecosystems worldwide, we suggest highest priorities for future research: (i) continued exploration of the deep-ocean ridge-crest; (ii) increased focus on anthropogenic impacts; (iii) concerted effort to coordinate a major investigation of the deep South Pacific Ocean – the largest contiguous habitat for life within Earth's biosphere, but also the world's least investigated deep-ocean basin.

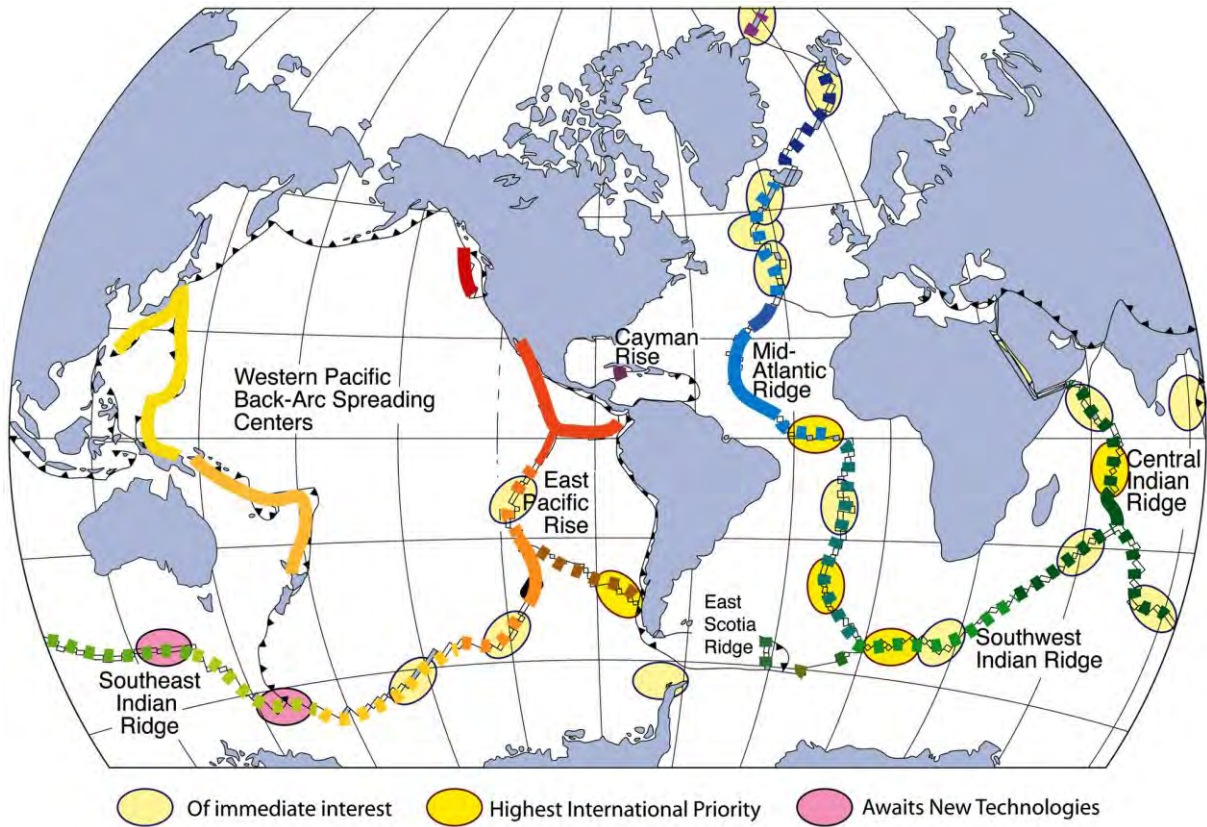


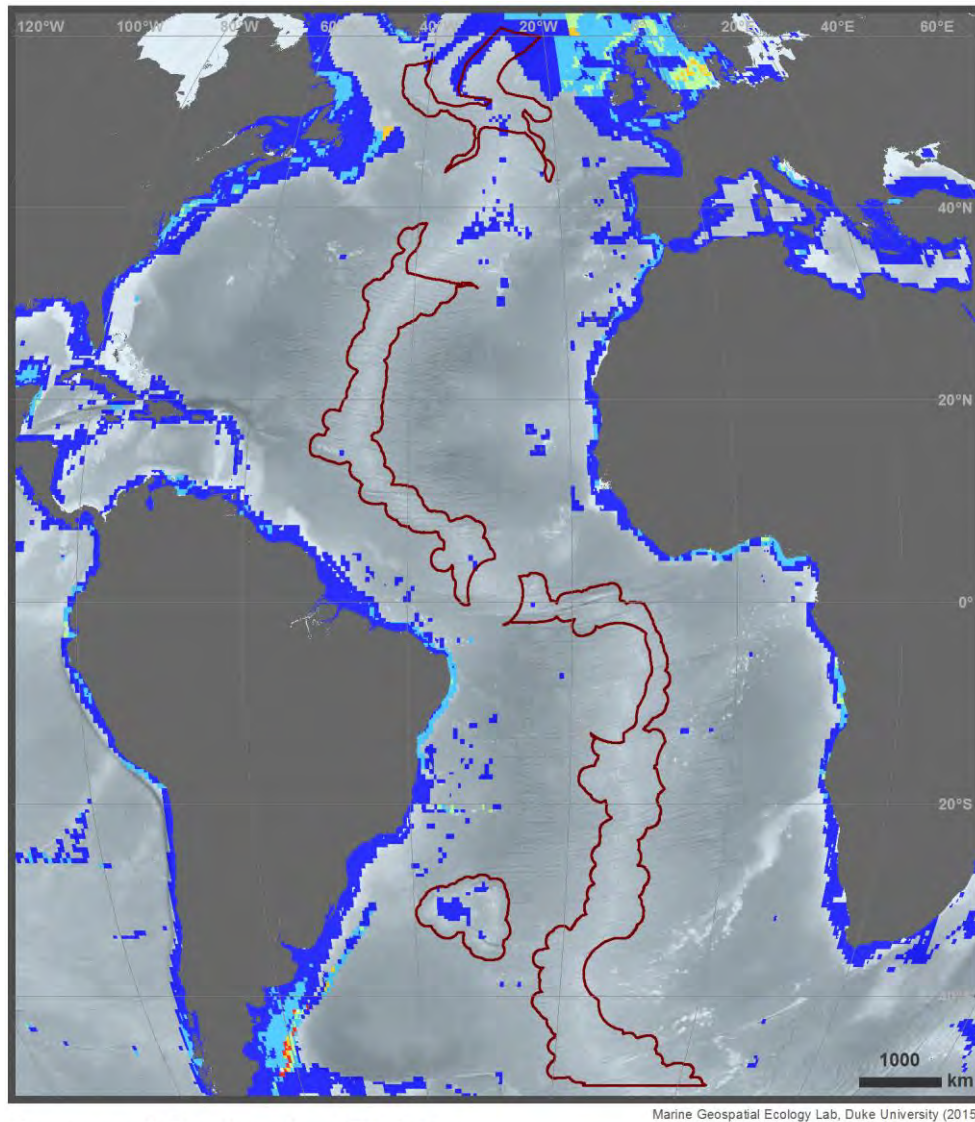
Figure 75. A model of biogeographic differentiation of invertebrate species associated with hydrothermal vents and regions of international interest for ridge-crest exploration.

Figure 4 from German et al. (2011): Annotated map (after Van Dover, 2010) of the global ridge crest, illustrating both a model of the global biogeographic differentiation of invertebrate species associated with hydrothermal vents and regions recently identified by the international community as being of continuing importance for future ridge-crest exploration.

Chapter 5. Human Uses

5.1 Demersal fishing

Here we include a map of demersal destructive fishing from Halpern et al. (2008) that was created as an input for his analysis of the global impact of human uses on the marine ecosystem. More information on the methods used to produce this map can be found as online supporting material (http://www.sciencemag.org/content/suppl/2008/02/12/319.5865.948.DC1/Halpern_SOM.pdf).



Demersal Destructive Fishing

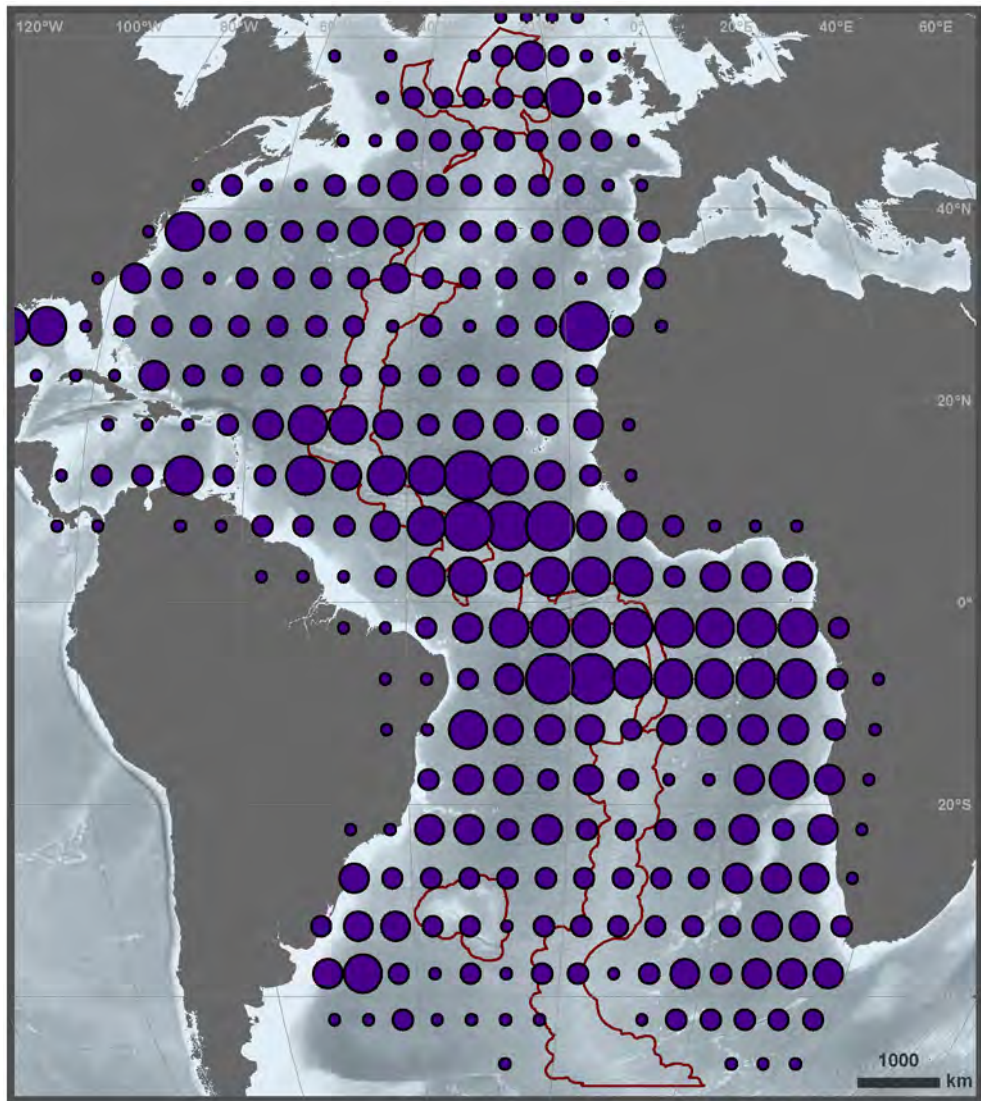
Demersal Destructive Fishing (input to Halpern et al. 2008)



Figure 76. Demersal fishing, adapted from Halpern et al. (2008).

5.2 Longline fishing effort

This data product provided by ICCAT is an estimation of the total longline fishing effort (number of hooks), distributed by major flag, month and 5 by 5 degree squares, between 2005 and 2009 for the entire ICCAT convention area (Palma and Gallego, 2010; de Bruyn et al., 2014). The nine major ICCAT tuna and tuna-like species were used to obtain Task I global nominal catches (in weight) and CPUEs from partial catch and effort (Task II) statistics. The model basic assumption considers that catch rates are equivalent at the partial and global level.



Marine Geospatial Ecology Lab, Duke University (2015)

**Aggregated Longline Effort between 2005 and 2009
(thousands of hooks; source: ICCAT)**

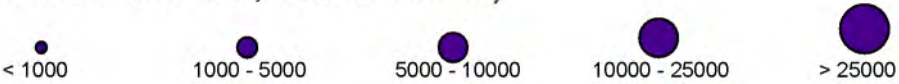
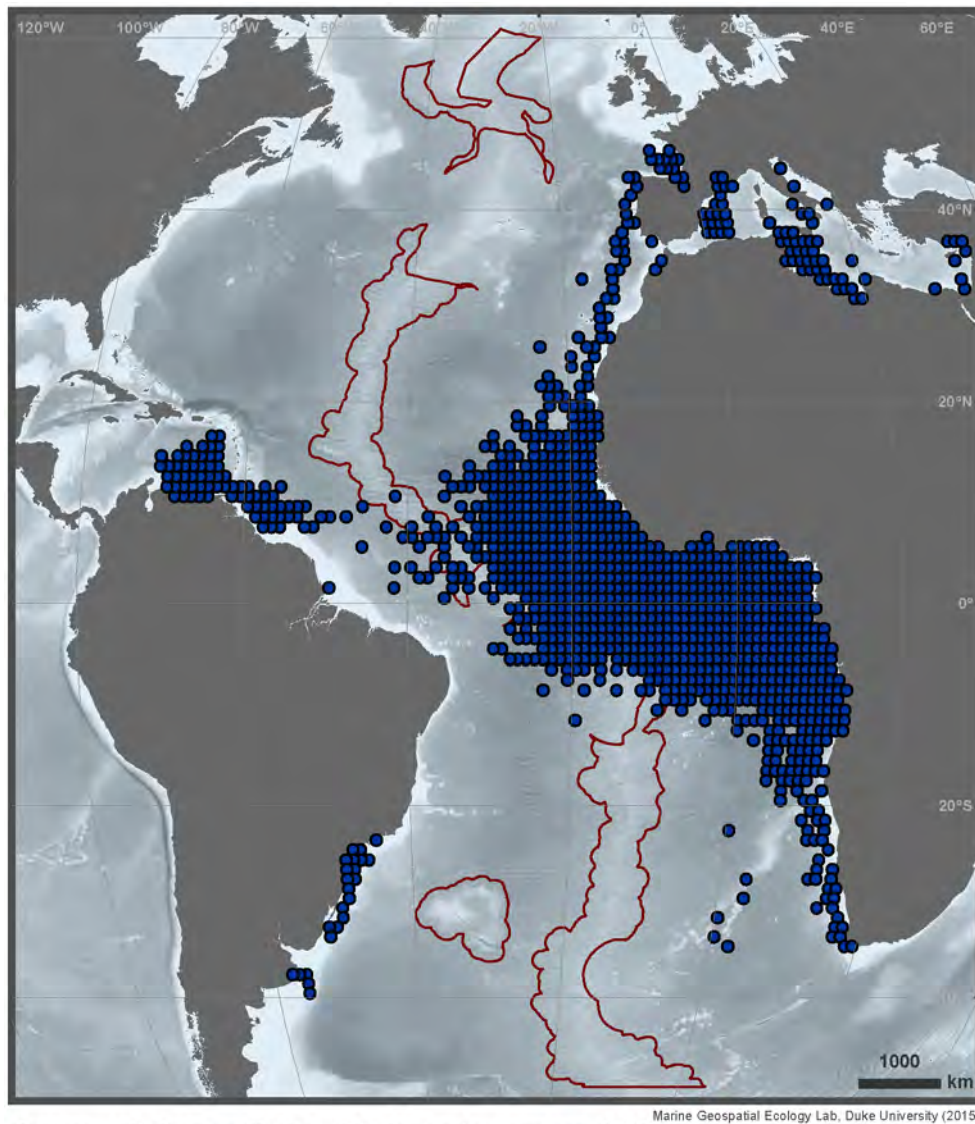


Figure 77. Aggregated longline fishing effort for all flags, data from ICCAT.

5.3 Areas of purse seine fishing

Here areas by 5 x 5 degrees cells are shown where purse seine fishing occurred during the period 2005-2009, irrespective of the flag, as reported to the Task II Catch and Effort (T2CE) database from the International Commission for the Conservation of Atlantic Tunas (ICCAT). T2CE are basically data obtained from sampling a portion of the individual fishing operations of a given fishery in a specified period of time. This approach was chosen as no universal measure of effort is adopted for this fishery for reporting to ICCAT.



Areas of Purse Seine Fishing between 2005 and 2009
(source: ICCAT)

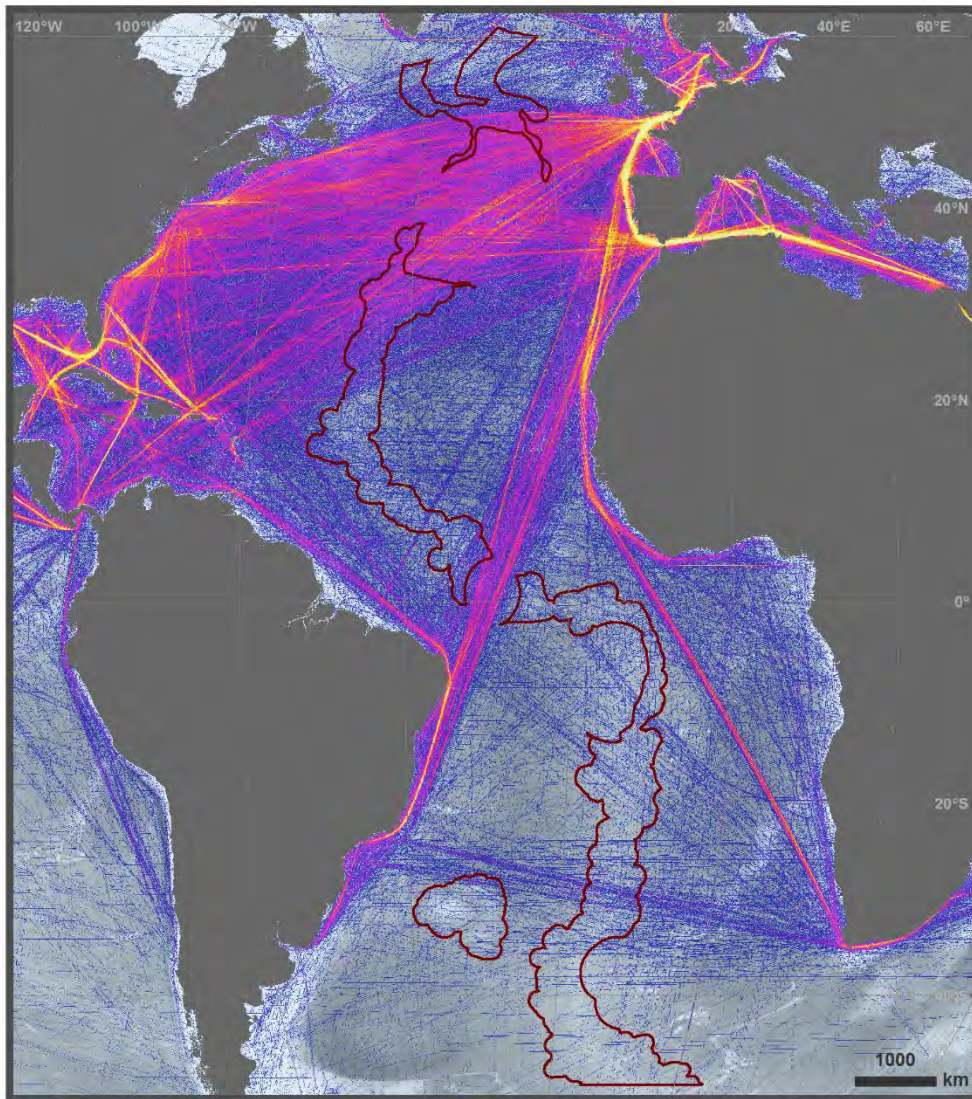
- Areas of ICCAT Purse Seine Fishing

Figure 78. Occurrence of purse seine fishing for all flags, data from ICCAT (2005-2009).

5.4 Shipping

Here we include a map of commercial shipping from Halpern et al. (2008) that was created as an input for his analysis of the global impact of human uses on the marine ecosystem.

Supplementary Material (Halpern et al., 2008): Ships from many countries voluntarily participate in collecting meteorological data globally, and therefore also report the location of the ship. We used data collected from 12 months beginning October 2004 (collected as part of the World Meteorological Organization Voluntary Observing Ships Scheme; http://www.vos.noaa.gov/vos_scheme.shtml) as this year had the most ships with vetted protocols and so provides the most representative estimate of global ship locations. The data include unique identifier codes for ships (mobile or a single datum) and stationary buoys and oil platforms (multiple data at a fixed location); we removed all stationary and single point ship data, leaving 1,189,127 mobile ship data points from a total of 3,374 commercial and research vessels, representing roughly 11% of the 30,851 merchant ships >1000 gross tonnage at sea in 2005 (S14). We then connected all mobile ship data to create ship tracks, under the assumption that ships travel in straight lines (a reasonable assumption since ships minimize travel distance in an effort to minimize fuel costs). Finally, we removed any tracks that crossed land (e.g. a single ship that records its location in the Atlantic and the Pacific would have a track connected across North America), buffered the remaining 799,853 line segments to be 1km wide to account for the width of shipping lanes, summed all buffered line segments to account for overlapping ship tracks, and converted summed ship tracks to raster data. This produced 1 km² raster cells with values ranging from 0 to 1,158, the maximum number of ship tracks recorded in a single 1 km² cell. Because the VOS program is voluntary, much commercial shipping traffic is not captured by these data. Therefore our estimates of the impact of shipping are biased (in an unknown way) to locations and types of ships engaged in the program. In particular, high traffic locations may be strongly underestimated, although the relative impact on these areas versus low-traffic areas appears to be well-captured by the available data, and areas identified as without shipping may actually have low levels of ship traffic. Furthermore, because ships report their location with varying distance between signals, ship tracks are estimates of the actual shipping route taken.



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Commercial Shipping

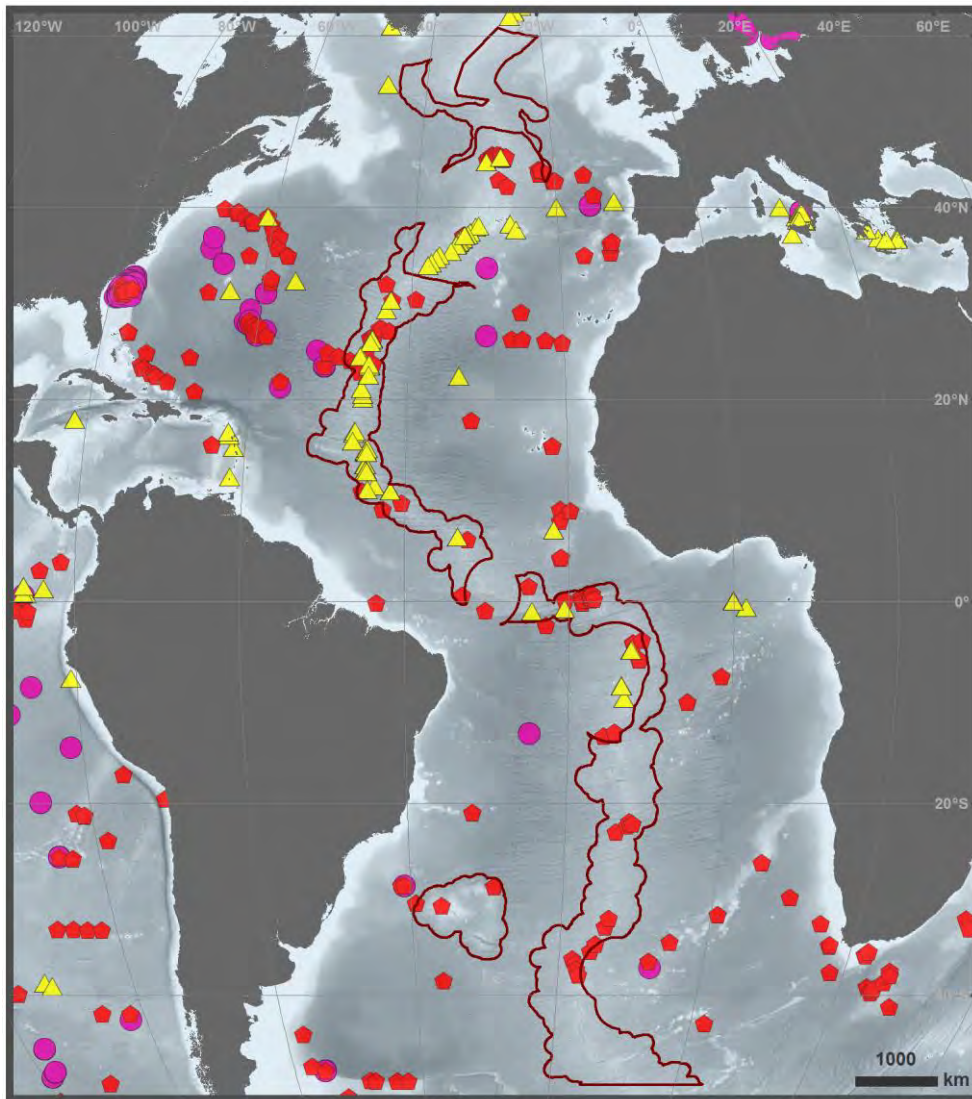
Ship Traffic (Halpern et al. 2008)



Figure 79. Commercial shipping, adapted from Halpern et al. (2008).

5.5 Deep-sea Mining

The International Seabed Authority (ISA; <https://www.isa.org.jm/>) provides the localization of all potential mineral resources (polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts) across the world's oceans. ISA has entered into 15-year contracts for exploration of mineral resources in the deep seabed with twenty-one contractors. Fourteen of these contracts are for exploration for polymetallic nodules in the Clarion-Clipperton Fracture Zone (13) and Central Indian Ocean Basin (1). There are five contracts for exploration for polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and three contracts for exploration for cobalt-rich crusts in the Western Pacific Ocean. The current areas of exploration are as per the following maps produced by the Authority (<http://mapserver.isa.org.jm/GIS/>).

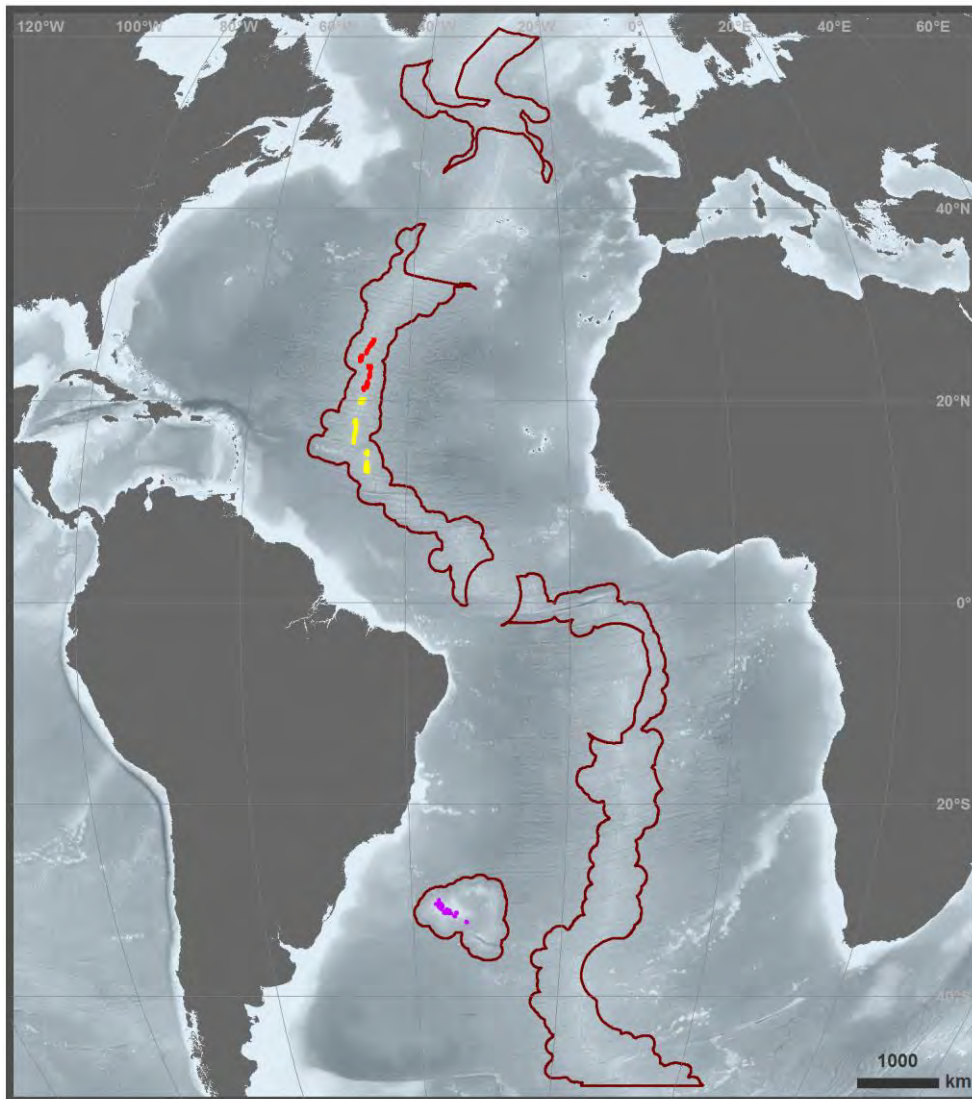


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ISA Resource Distribution

- ▲ Polymetallic Sulphides
- ◆ Cobalt-Rich Ferromanganese Crusts
- Polymetallic Nodules

Figure 80. ISA resource distribution (polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts).



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Exploration Areas

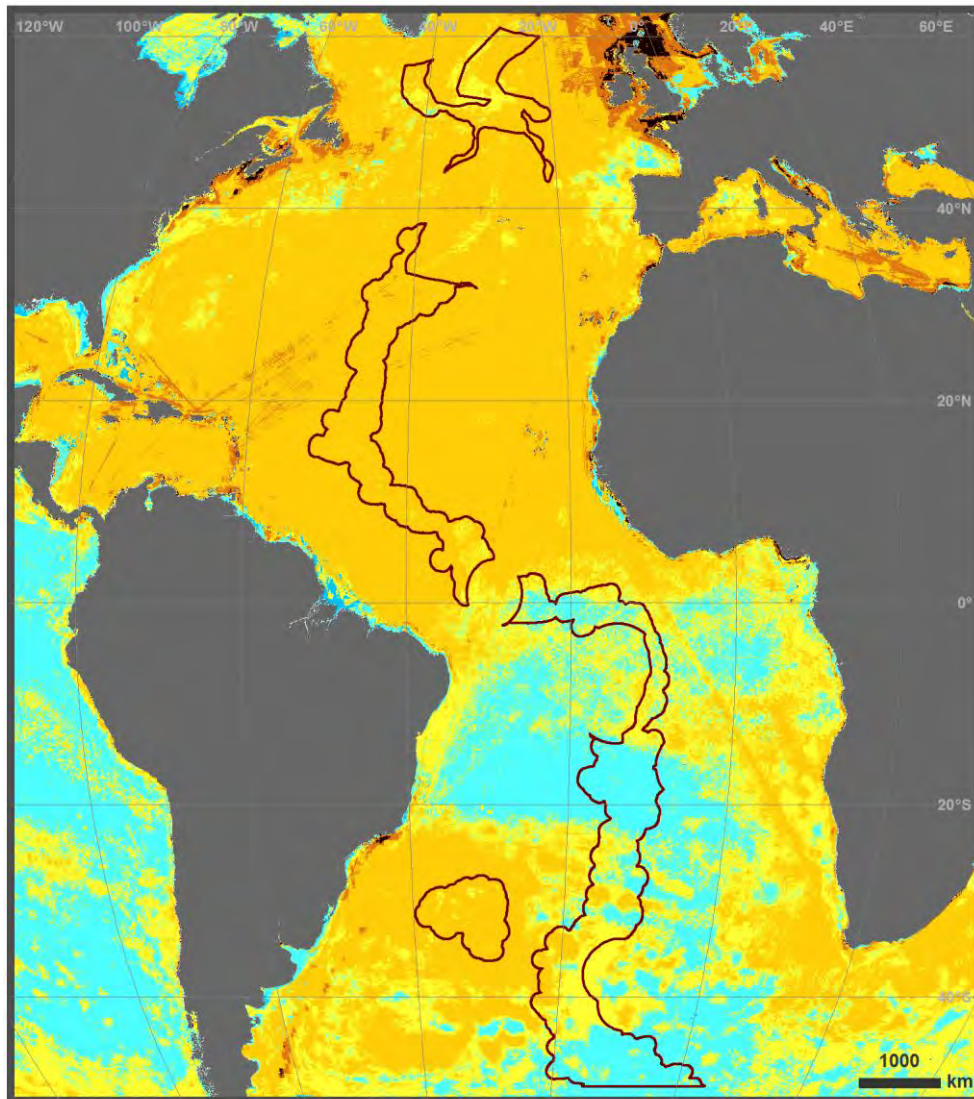
- ISA: France
- ISA: Russian Federation
- ISA: Brazil

Figure 81. Exploration areas: France and Russia massive sulfide deposits on the Mid-Atlantic Ridge; Brazil cobalt crusts on the Rio Grande Rise.

5.6 Cumulative impacts

Here we include a map of cumulative anthropogenic impacts from Halpern et al. (2008).

Abstract (Halpern et al., 2008): The management and conservation of the world's oceans require synthesis of spatial data on the distribution and intensity of human activities and the overlap of their impacts on marine ecosystems. We developed an ecosystem-specific, multiscale spatial model to synthesize 17 global data sets of anthropogenic drivers of ecological change for 20 marine ecosystems. Our analysis indicates that no area is unaffected by human influence and that a large fraction (41%) is strongly affected by multiple drivers. However, large areas of relatively little human impact remain, particularly near the poles. The analytical process and resulting maps provide flexible tools for regional and global efforts to allocate conservation resources; to implement ecosystem-based management; and to inform marine spatial planning, education, and basic research.



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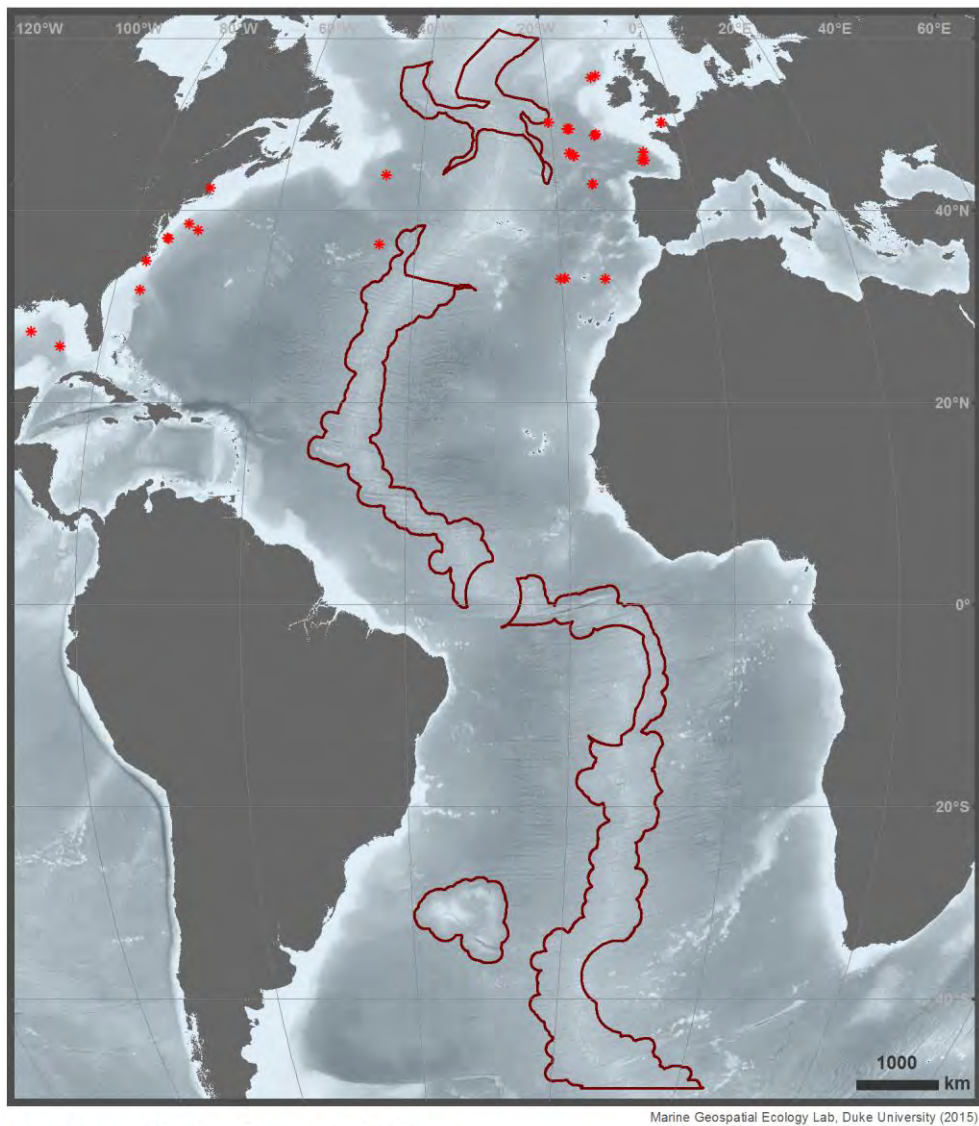
**Cumulative Human Impact
(Halpern et al. 2008)**

- | | | |
|------------------------|------------------------------|---------------------------|
| Very Low Impact (<1.4) | Medium Impact (4.95–8.47) | High Impact (12–15.52) |
| Low Impact (1.4–4.95) | Medium High Impact (8.47–12) | Very High Impact (>15.52) |

Figure 82. Cumulative human impact, adapted from Halpern et al. (2008).

5.7 Inventory of radioactive waste disposal at sea

The following map shows the location of radioactive waste disposal sites in the Atlantic Ocean. These data were extracted from the International Atomic Energy Agency (IAEA) report (IAEA, 1999).



Nuclear Waste Disposal Sites

* Nuclear Waste Disposal Site

Figure 83. Nuclear waste disposal at sea (IAEA, 1999).

5.8 Transatlantic slave trade

This map from the *Atlas of the Transatlantic Slave Trade* (Eltis and Richardson, 2010, Yale University Press) summarizes and combines the many different paths by which captives left Africa and reached the Americas. While there were strong connections between particular embarkation and disembarkation regions, it was also the case that captives from any of the major regions of Africa could disembark in almost any of the major regions of the Americas. Even captives leaving Southeast Africa, the region most remote from the Americas, could disembark in mainland North America, as well as the Caribbean and South America. The data in this map are based on estimates of the total slave trade rather than documented departures and arrivals (source: <http://www.slavevoyages.org/tast/assessment/intro-maps.faces>).

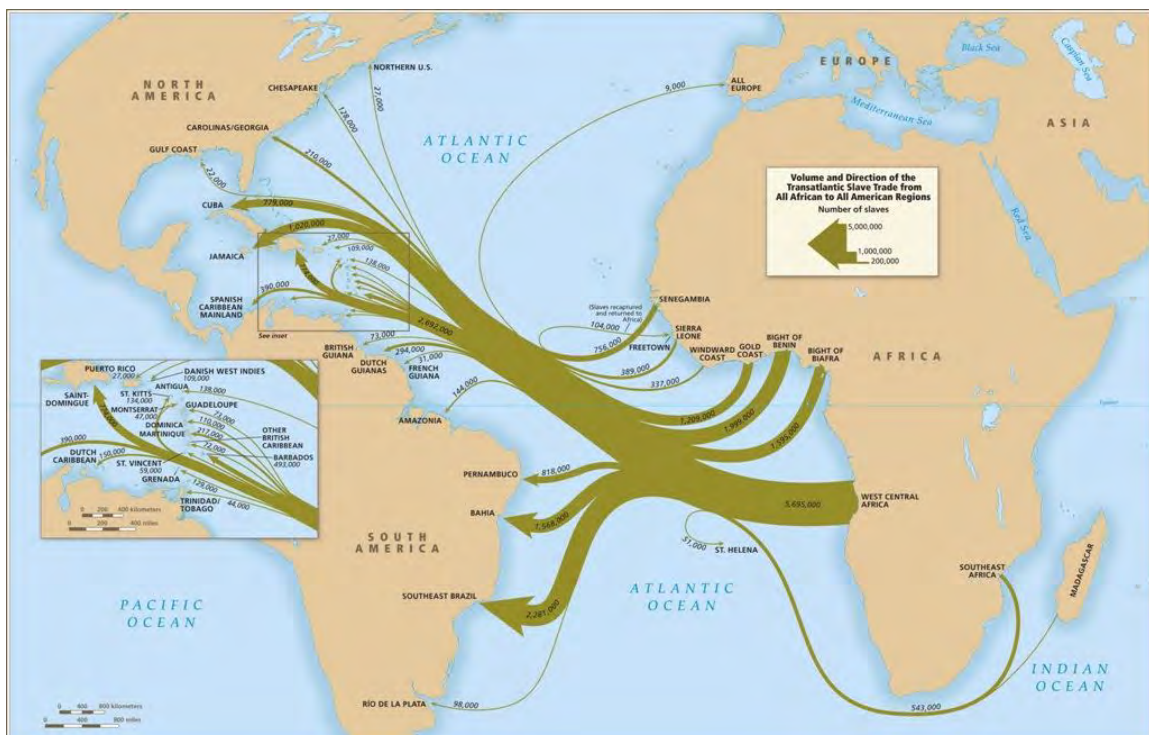
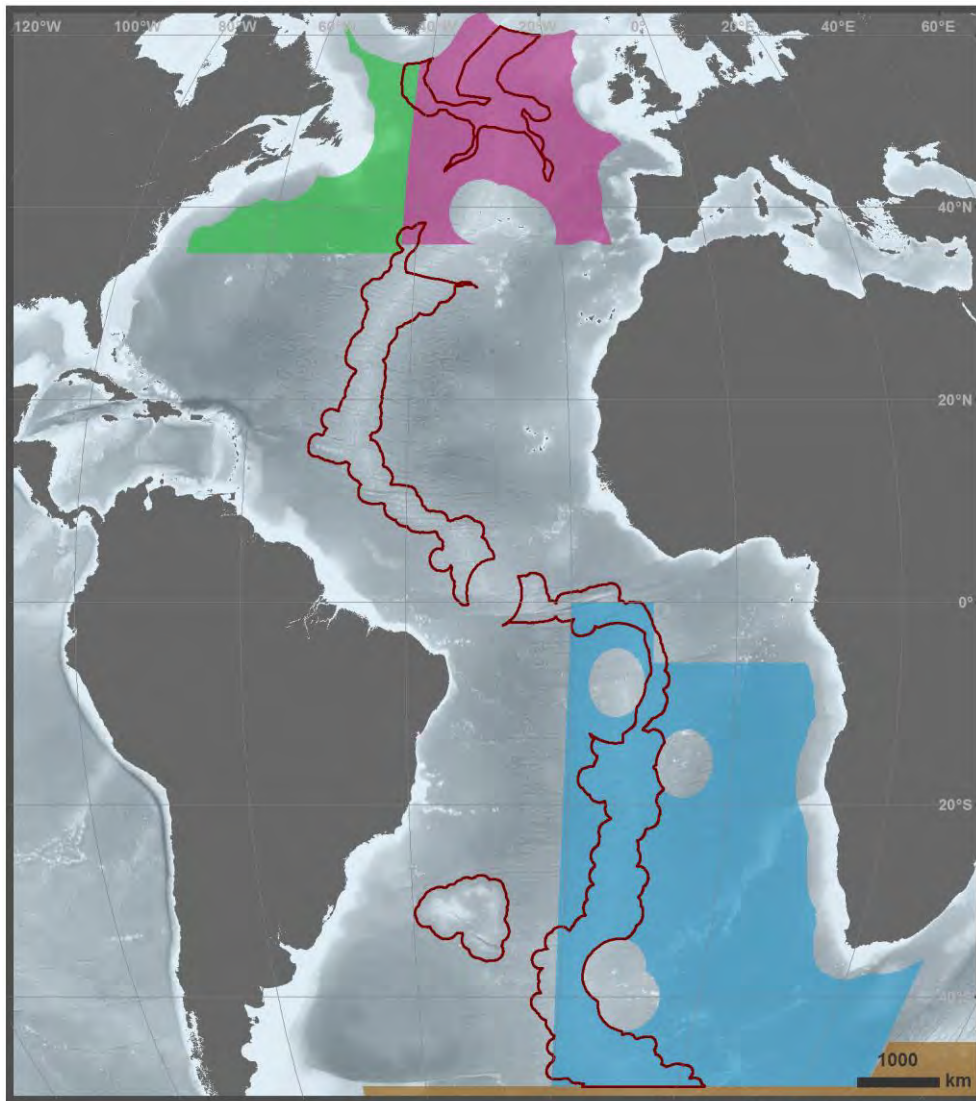


Figure 84. Volume and direction of the trans-Atlantic slave trade from all African to all American regions (www.slavevoyages.org).

Chapter 6. Management and Conservation

6.1 Regional Fisheries Bodies (RFB)

Regional Fishery Bodies (RFBs) are a mechanism through which States or organizations that are parties to an international fishery agreement or arrangement work together towards the conservation, management and/or development of fisheries (<http://www.fao.org/fishery/topic/16800/en>). The mandates of RFBs vary. Some RFBs have an advisory mandate, and provide advice, decisions or coordinating mechanisms that are not binding on their members. Some RFBs have a management mandate – these are called Regional Fisheries Management Organizations (RFMOs). They adopt fisheries conservation and management measures that are binding on their members. Regional Fishery Bodies (RFB) include the Fishery Committee for the Eastern Central Atlantic (CECAF) and the Western Central Atlantic Fishery Commission (WECAFC). The RFMOs having mandate to regulate deep-sea fisheries in the high seas include the Northwest Atlantic Fisheries Organization (NAFO), North East Atlantic Fisheries Commission (NEAFC) and the South East Atlantic Fisheries Organization (SEAFO). The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is a special management body established by multilateral treaty, which has a wider mandate than the management of fisheries only. The objective of the CCAMLR is the conservation of Antarctic marine living resources, including their rational use. Other important RFMOs in the Atlantic are oriented towards managing pelagic species or species groups and include the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) and the International Whaling Commission (IWC).



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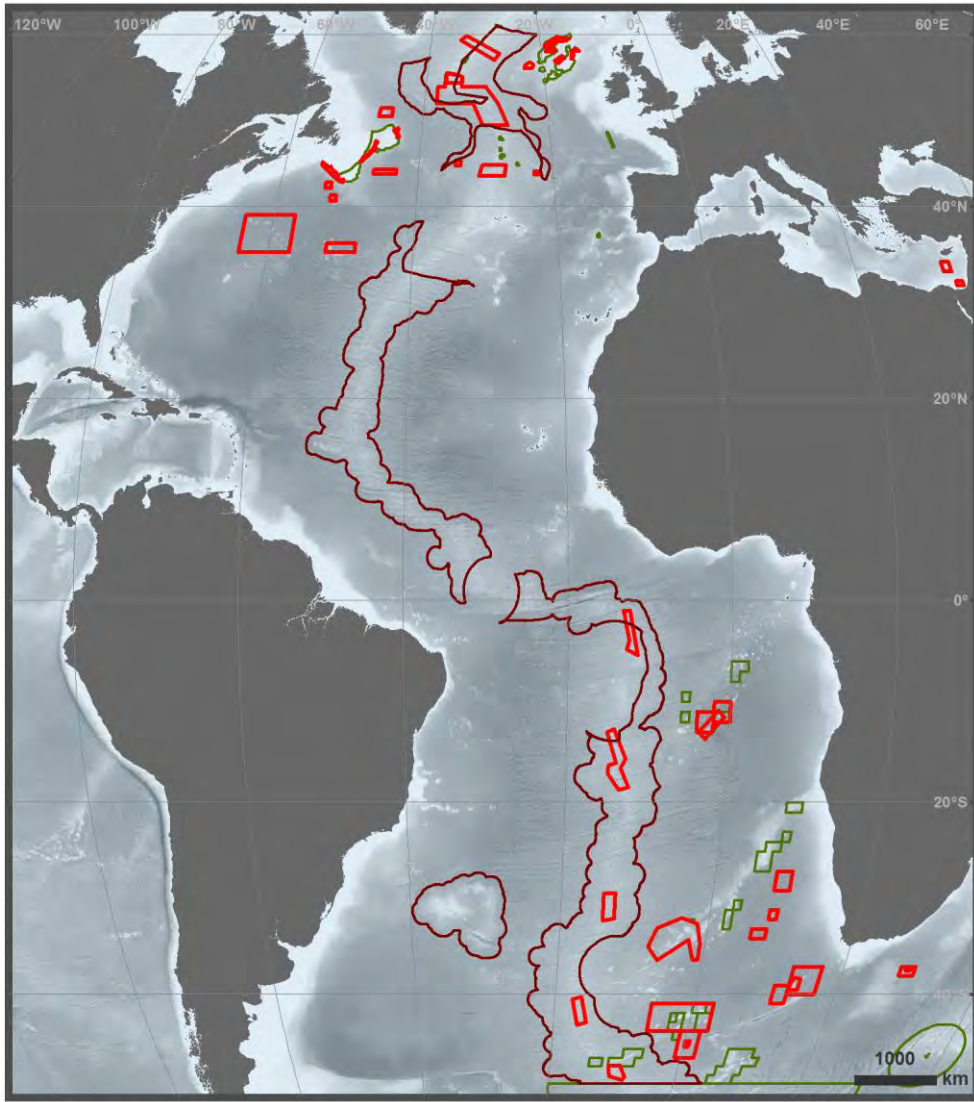
Regional Fisheries Organizations

- | | |
|---|---|
| ■ NAFO | ■ SEAFO |
| ■ NEAFC | ■ CCAMLR |

Figure 85. Relevant Regional Fisheries Management Organizations (RFMOs).

6.2 RFMO spatially managed areas

NAFO, NEAFC and SEAFO have closed areas to bottom fishing activities (NAFO, 2010; SEAFO, 2010; NEAFC, 2014). Although the exact definition for such protection zones varies between RFMOs, they have been implemented to ensure the protection of VMEs. Bottom fishing areas are basically portions of Regional Fisheries Management Organisations (RFMO) convention areas where bottom fishing has historically occurred, even though their exact definition might somewhat vary (<http://www.fao.org/in-action/vulnerable-marine-ecosystems/definitions/en/>). Exploratory fishing and fishing outside existing bottom fishing areas is dependent upon a previous assessment of the potential adverse impacts of the proposed activity on VMEs by the relevant RFMO (for more information [NEAFC recommendation 19:2014](#); [NAFO Conservation and Enforcement Measures NAFO/FC doc. 12/1](#); [SEAFO conservation measure 26/13](#)).



RFMO Managed Areas

- Bottom Fishing Area
- VME Closed Area

Figure 86. RFMO spatially managed areas for bottom fisheries.

6.3 Marine protected areas

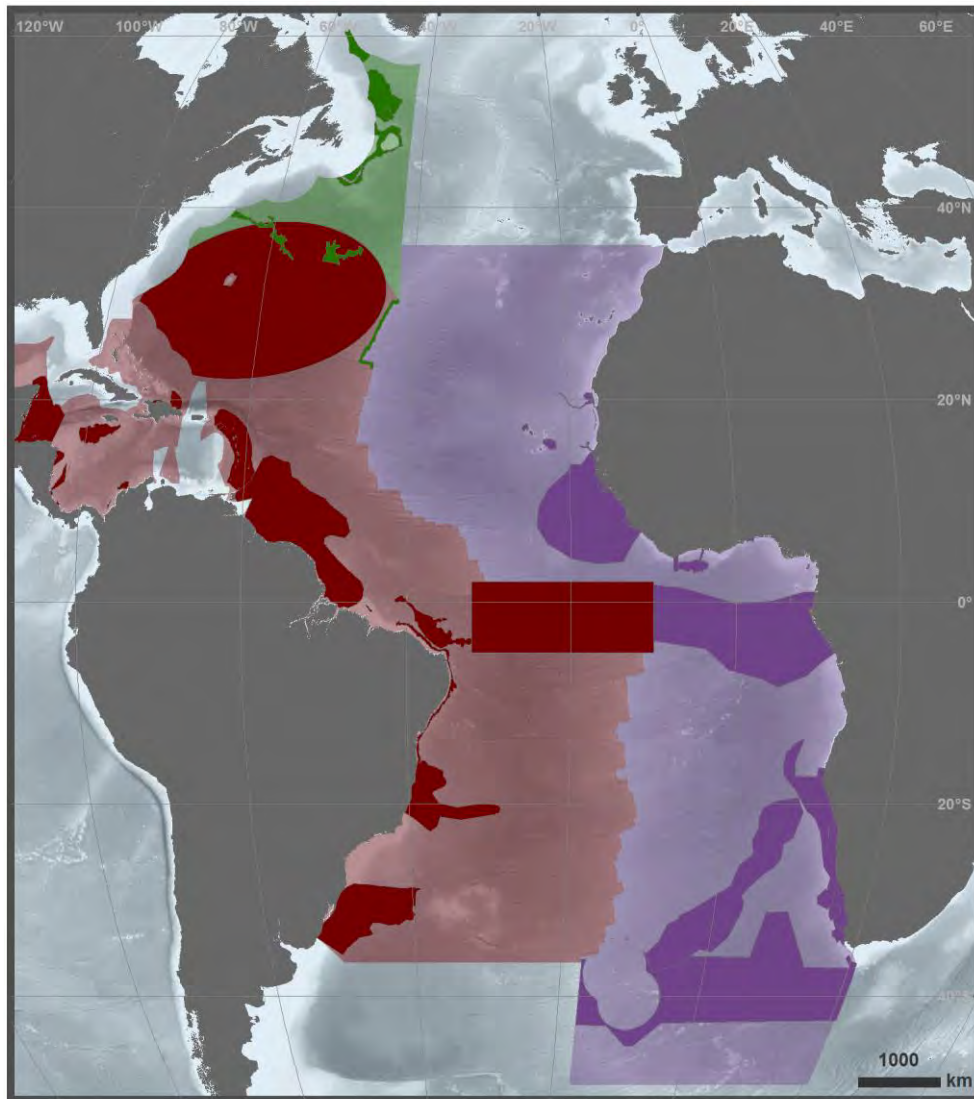
The World Database on Protected Areas (WDPA; https://www.iucn.org/about/work/programmes/gpap_home/gpap_biodiversity/gpap_wdpa/) is the most comprehensive global spatial dataset on marine and terrestrial protected areas available. Protected areas are internationally recognised as major tools in conserving species and ecosystems. Up to date information on protected areas is essential to enable a wide range of conservation and development activities. Since 1981 UNEP-WCMC, through its Protected Areas Programme, has been compiling this information and making it available to the global community. The WDPA is a joint project of UNEP and IUCN, produced by UNEP-WCMC and the IUCN World Commission on Protected Areas working with governments and collaborating NGOs.



Figure 87. Marine Protected Areas in the Atlantic Ocean as in WDPA.

6.4 Convention on Biological Diversity Ecologically or Biologically Significant Areas

In 2008, the ninth meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 9) adopted the following scientific criteria for identifying ecologically or biologically significant marine areas (EBSAs) in need of protection in open-ocean waters and deep-sea habitats. For more details on the EBSA criteria, please see: www.cbd.int/doc/meetings/mar/ebaws-2014-01/other/ebaws-2014-01-azores-brochure-en.pdf. CBD scientific criteria for ecologically or biologically significant areas (EBSAs) (annex I, decision IX/20) includes: Uniqueness or Rarity, Special importance for life history stages of species, Importance for threatened, endangered or declining species and/or habitats, Vulnerability, Fragility, Sensitivity, or Slow recovery, Biological Productivity, Biological Diversity, Naturalness. From 2011 to 2014, the CBD convened nine regional workshops involving experts from 92 countries and 79 regional or international bodies. These workshops covering 250 million km², (two-thirds of the world ocean area), identified over 200 areas meeting the internationally agreed criteria for Ecologically and Biologically Significant Areas (EBSAs).



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CBD Ecologically or Biologically Significant Areas (EBSA)

Workshop Boundary

North West Atlantic

South East Atlantic

Wider Caribbean and Western Mid-Atlantic

Described EBSA

NWA EBSA

SEA EBSA

WC and WMA EBSA

Figure 88. Convention on Biological Diversity's Ecologically or Biologically Significant Areas.

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