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# GLOBAL OPEN OCEANS AND DEEP SEABED (GOODS) BIOGEOGRAPHIC CLASSIFICATION

*Note by the Executive Secretary*

1. In paragraph 1 (c) of recommendation XIII/3, the Subsidiary Body on Scientific, Technical and Technological Advice, at its thirteenth meeting, took note of the draft report on Global Open Oceans and Deep Sea-habitats (GOODS) Biogeographic Classification (UNEP/CBD/SBSTTA/13/1NF/19) compiled by an expert group drawing mainly from the results of the Scientific Experts Workshop on Biogeographic Classification Systems in Open Ocean and Deep Seabed Areas Beyond National Jurisdiction, held in Mexico City, from 22 to 24 January 2007.

2. In the same recommendation, the Subsidiary Body encouraged Parties to contribute to the peer review of the above draft report, and requested the Executive Secretary to make available the final report for the information of participants in the ninth meeting of the Conference of the Parties, and further forward it to the fourteenth meeting of the Subsidiary Body.

3. In accordance with the above-mentioned recommendation, the Executive Secretary is circulating herewith, for the information of participants in the ninth meeting of the Conference of the Parties, a report on “Global Open Oceans and Deep Seabed (GOODS) Biogeographic Classification”.

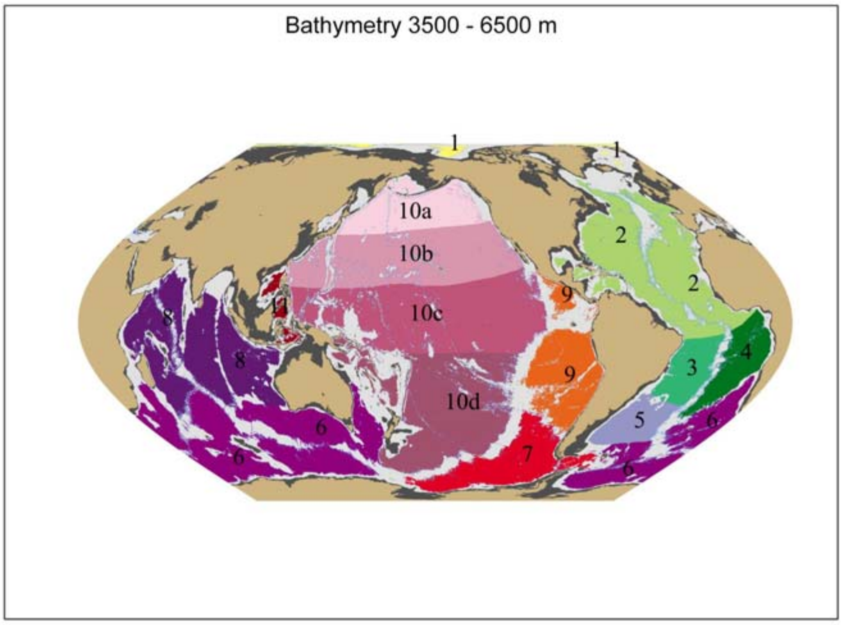
4. The document is circulated in the form and language in which it was received by the Secretariat.

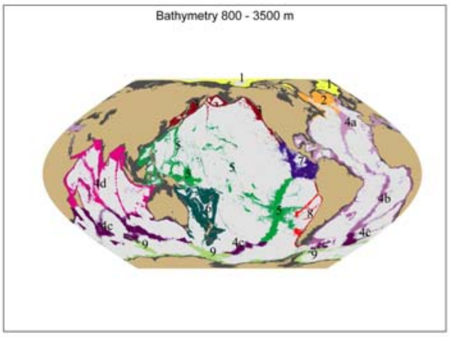
* UNEP/CBD/COP/9/1.

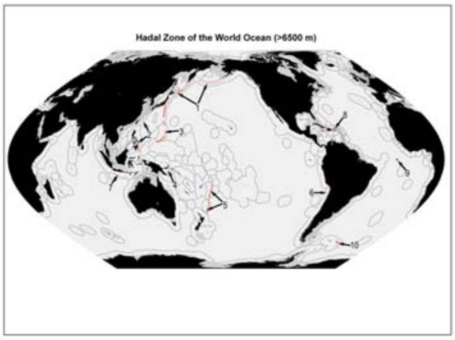
**Revised Report**

# Global Open Oceans and Deep Seabed (GOODS) biogeographic classification


**Edited by:** Marjo Vierros (UNU-IAS), Ian Cresswell (Australia), Elva Escobar Briones (Mexico), Jake Rice (Canada), and Jeff Ardron (Germany)


May 2008

# Global Open Oceans and Deep Seabed (GOODS) biogeographic classification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## Disclaimer

## Foreword

This report presents a revised biogeographic classification for global open ocean and deep sea areas. It has been compiled by an international expert group initiated at a workshop held in Mexico City, Mexico, in January 2007, and is based on the input of many scientists and managers. It has been made available to the Conference of the Parties of the Convention on Biological Diversity at the request of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA).

The draft version of the attached document was initially presented to the 13th meeting of the CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) in February 2008 as information document UNEP/CBD/SBSTTA/13/1NF/19. In the resulting recommendation XIII/3, SBSTTA took note of the draft report; encouraged Parties to contribute to its peer-review; and requested the Executive Secretary to make available the report for the information of participants in the ninth meeting of the Conference of the Parties.

In accordance with the request of SBSTTA, the present document incorporates peer review comments received from Parties and other governments, as well as from scientific experts associated with various research institutions. The list of reviewers can be found in the acknowledgements section of this report. In addition, the document incorporates comments received during a side event held to present the biogeographic classification at the 2nd meeting of the Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction (New York, 28 April – 2 May 2008).

Many governments in several policy fora have requested this bioregionalization to assist their governments in further identifying ways to safeguard marine biodiversity in marine areas beyond national jurisdiction and in support of ocean management measures, including marine protected areas. This biogeographic classification can provide a planning tool to assimilate multiple layers of information and extrapolation of existing data into large “bioregions” or provinces (assemblages of flora, fauna and the supporting environmental factors contained within distinct but dynamic spatial boundaries).

It should be noted that the boundaries of the biogeographic classification could be further refined as improved data, particularly biological data, become available. However, the major open ocean pelagic and deep sea benthic zones presented in this report are considered a reasonable basis for progressing efforts towards the conservation and sustainable use of biodiversity in marine areas beyond the limits of national jurisdiction in line with a precautionary approach.

It is hoped that the document will meet the information needs of the Convention and other relevant fora.

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## Glossary

**Abyssal** — Between 3500 m and 6500 m depth.

**Abyssal Plain** — A large area of almost flat or gently sloping ocean floor just offshore from a continent and usually at depths between 2000 and 4000 m. The abyssal plain begins where the continental margin and slope end.

**Bathyal** — Between 300 m and 3500 m depth

**Bathymetry** – Water depth relative to sea level.

**Benthic** — Of, or relating to, or living on or in the bottom of a body of water or the seafloor.

**Biodiversity** — the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

**Biogeographic** — Relating to the geographic occurrence of life forms (fauna and flora) at the scale of large regions with distinct landscapes/seascapes, flora and fauna.

**Bioregion** — Assemblages of flora, fauna and the supporting environmental factors contained within distinct but dynamic spatial boundaries. Biogeographic regions vary in size, with larger regions often found where areas have more subdued environmental gradients. These are defined and delineated at the meso-scale.

**Bioregionalisation** — A regionalisation that includes biological as well as physical data in analyses to define regions for administrative purposes. Classifying large areas by their defined environmental features and their unique species composition.

**Biome** — A major regional ecological community of plants and animals extending over large natural areas. In the sea, these equate to geological units or hydrographic features such as coastal, demersal, shelf and slope, abyssal, neritic, epipelagic, mesopelagic and bathypelagic.

**Biotone** — Zones of transition between core provinces.

**Circulation regime** — Areas within water masses that have differing circulations and resulting in differing retention, mixing and transport of water properties and biological processes and organisms.

**Continental margin** — The submerged prolongation of a land mass from the coastline, which consists of seabed and subsoil of the continental shelf, slope and rise, but not the deep ocean floor.

**Continental rise** — The sloping part of the ocean floor at depths about 2000-4000 m, between the continental slope and the abyssal plain.

**Continental shelf** — The shelf-like part of the ocean floor extending from the continental coasts to a depth of about 200 m. The shelf is divided into inner-shelf (the area closes to the coastline), outer-shelf (the area adjacent to the shelf break) and mid-shelf (the region between the inner and outer shelf).

**Continental slope** — The sloping, relatively steep, part of the ocean floor bordering the continental shelf and extending to a depth of about 2000 m; divided into the upper slope (200-700 m) which is adjacent to the shelf break, mid-slope (700-1400 m) and lower slope (1400-2000 m).

**Deep seabed** – Deep seabed is a non-legal term commonly understood by scientists to refer to the seafloor below 200 – 300 m. In other words, it is non-shelf area.

**Demersal** — Occurring or living on or near the bottom of an aquatic environment. Generally used in reference to mobile fish and crustaceans whose life history is related to seafloor processes.

**Ecologically sustainable development** — Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained and/or improved.

**Ecosystem** — A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. In practice, ecosystems are mapped and described using biophysical data.

**Ecosystem approach** — A strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (CBD decision V/6).

**Ecosystem-based management (EBM)** — Management that recognises that maintaining the structure and function of ecosystems is vital, and that human uses and ecosystem health are interdependent. EBM considers ecological, social and cultural objectives for an ecosystem, but makes ecological sustainability the primary goal of management.

**Endemic —** Native to, or confined to a certain region.

**Evolutionarily Significant Unit (ESU) —** A population of organisms that is considered distinct for purposes of conservation. Delineating ESUs is important when considering conservation action.

**Exclusive Economic Zone (EEZ)** — Ocean areas from the coast to usually 200 nautical miles offshore, where the adjacent nation has exclusive economic rights and the rights and freedoms of other states are governed by the relevant positions of the United Nations Convention on the Law of the Sea.

**Geomorphic feature** —Major element of the seabed such as a seamount, canyon, basin, reef or plateau distinguished by its shape.

**Geomorphic unit** — Group of geomorphic features that represent areas of similar geomorphology.

**Geomorphology** – The study of the shape of the earth's surface and how it changes through time.

**Hadal –** the region of the sea at depths greater than 6500 m.

**Habitat** — A geographic area that can provide for the key activities of life – the place or type of site in which an organism naturally occurs.

**Lower bathyal** — Between 800 m and 3500 m depth

**Meso-scale region** — Large spatial unit (hundreds or thousands of kilometres in length).

**Mixed layer** — The layer between the ocean surface and a depth usually ranging between 25 and 200 m, where the density is about the same as at the surface. The water conditions in the mixed layer are homogeneous due to wind mixing.

**Nautical mile** – Distance measure used at sea equal to 1.852 kilometres or approximately 1.1508 statute miles. It is also equal to 1 minute of latitude.

**Oceanic feature** — Structure within a circulation regime that can be characterised by differing energy. Distinct major element of the upper water column, such as anticyclonic and cyclonic gyres, fronts and upwelling.

**Offshore** — The area of the Exclusive Economic Zone extending seaward from 3 nautical miles.

**Open ocean** — Open ocean is a non-legal term commonly understood by scientists to refer to the water column beyond the continental shelf, in other words, non-coastal. Open ocean may occur in areas within national jurisdiction in States with a narrow continental shelf.

**Pelagic** — Of, relating to, or living in the water column of the open oceans or seas.

**Province** — A large-scale biogeographic unit derived from evolutionary processes containing a suite of endemic species.

**Regionalisation** — The process and output of identifying and mapping broad spatial patterns based on physical and/or biological attributes through classification methods used for planning and management purposes.

**Shelf break** — The abrupt change in seabed gradient that occurs at the boundary between the outer continental shelf and the upper continental slope, usually at about 200 metres water depth.

**Surrogate** — One that takes the place of another; a substitute. For example, physical characteristics of the seabed (eg geomorphic features or sediment types) can be used to determine bioregions in place of biological information. (Synonym: proxy.)

**Transition** — A zone of overlap between provinces. The transitions are not simply 'fuzzy' boundaries but are areas that represent unique communities and ecological processes that can be richer than the provinces.

**Ultra-abyssal** — a term often used in place of hadal

**Upper bathyal** — Between 300 m and 800 m depth

# Global Open Oceans and Deep Seabed (GOODS) biogeographic classification

## Executive summary

This document presents the Global Open Oceans and Deep Seabed (GOODS) biogeographic classification. This classification has been produced by a multidisciplinary scientific expert group, who started this task at the workshop in Mexico City in January 2007.

The pelagic and benthic biogeographic classifications presented in this report represent the first attempt at comprehensively classifying the open ocean and deep seafloor into distinct biogeographic regions. This biogeographic classification is based on a physiognomic approach, which uses environmental characteristics of the benthic and pelagic environments to select homogeneous regions of similar habitat and associated biological community characteristics. In other words, it classifies specific ocean regions by their defined environmental features (structural features of habitat, or ecological functions and processes) and – to the extent data are available-- their species composition. This work is hypothesis-driven and still preliminary, and will thus require further refinement and peer review in the future. However, in its present format it provides a basis for discussions that can assist policy development and implementation in the context of the Convention on Biological Diversity (CBD) and other fora.

As discussed in this report, biogeographic classification is an important tool that will help us understand the distribution of species and habitats for the purposes of scientific research, conservation and management, and is therefore of importance to policy. A biogeographic classification will assist us in understanding the scales for ecosystem-based management and in identifying areas representative of major ecosystems. While clearly needing further refinement, the major open ocean pelagic and deep sea benthic zones presented in this report are considered 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. The authors of this report believe that any further refinement to biogeographical provinces need not delay action to be undertaken towards this end, and that such action be supported by the best available scientific information.

### Scope of the work

This classification covers open oceans and deep seabed with an emphasis on areas beyond national jurisdiction. Open ocean and deep seabed are non-legal terms commonly understood by scientists to refer to the water column and seabed beyond the continental shelf.

Open ocean and deep seabed habitats may occur in areas within national jurisdiction in States with a narrow continental shelf, or the continental shelf is intersected by underwater canyons. The term was chosen to convey that the ocean does not respect manmade boundaries but rather the processes and influences are interlinked. It also was chosen to complement the MEOW (Marine Ecoregions of the World) global marine biogeographic regionalization which currently is limited to coastal waters and continental shelf systems.

In the pelagic environment, large-scale oceanographic features that strongly influence species assemblages are inherently dynamic, with boundaries whose positions change over time. As a

result, some of these features commonly extend from the open ocean onto continental shelves and into national jurisdictions, and the pelagic provinces include these areas when it is biologically appropriate to do so.

The focus on open ocean and deep seabed, and the fact that the maps do cover some areas within national jurisdiction, is not intended to infringe on the national sovereignty and jurisdiction of coastal nations over these waters and continental shelves, but rather to enhance understanding and inform management.

### Methodology and principles

As a first step, the expert group considered existing global and regional biogeographic classifications of marine areas, with the understanding that their work should draw upon the considerable experience in biogeographic classification nationally, regionally and globally. The experts decided that the development of a biogeographic classification for deep and open ocean areas would need to start with the definition of a set of basic principles that included dealing with the pelagic and benthic environments separately due to their different characteristics, though the existing coupling between these two environments was acknowledged. The expert group also emphasised that a preferred system of classification should be consistent with available knowledge on taxonomy, physiognomy, palaeontology, oceanographic processes, geology and geomorphology, and that it would combine all these approaches and factors.

### Pelagic biogeographic classification

After reviewing a variety of proposed biogeographic models, including those developed for marine pelagic systems within national jurisdictions, the expert group concluded that the main large-scale physical features that a pelagic biogeographic classification system should capture included: i) core areas or gyres; ii) equatorial upwelling; iii) upwelling zones at basin edges; and iv) important transitional areas – including convergence and divergence areas.

Based on these criteria and a review of existing classifications, the expert group produced a map of pelagic biogeographic classes, which included 29 provinces. These provinces have unique environmental characteristics in regards to variables such as temperature, depth and primary productivity. The classification was later validated using a data-driven cluster analysis.

### Benthic biogeographic classification

At the Mexico workshop, the expert group produced a preliminary map of the distribution of organisms in the deep sea showing the locations of what were termed “the centers of distribution” of deep sea provinces at bathyal and abyssal depths. The expert group also recognized that for much of the deep sea there is very little information that can be used to delineate scientifically robust biogeographic units at the level of either province or region, though what information did exist was subsequently compiled using Geographic Information Systems (GIS) technology.

The benthic biogeographic units delineated by the expert group relied on previous work by a variety of researchers, with the proposed boundaries altered on the basis of more recent data, both published and unpublished. The proposed deep sea benthic classification encompasses three large depth zones: i) the lower bathyal (800-3500 m); ii) the abyssal (3500-6500 m); and iii) the hadal (depths greater than 6500 m, which includes primarily trenches). The bathyal classification was further broken down into nine biogeographic provinces, the abyssal into ten biogeographic provinces and the hadal into ten biogeographic provinces. Separate hydrothermal vent provinces were also delineated based on biological data and other records from field sampling and observation. It should be noted that as additional biological data are gathered, one or more of the bathyal and abyssal provinces may be further divided.

### Next steps

Scientifically, this biogeographic classification can provide a basis for hypotheses and further scientific studies on the origin and evolution of deep sea faunal assemblages, and the linkages between species communities and open ocean and deep seabed environments. From a policy perspective, such a classification is a necessary component when considering area-based management options, such as marine protected areas, particularly when assessing representativity of a potential network.

# 1. Background

## 1.1 The policy mandate

At the present time, the world's oceans have low levels of representation in protected areas, with only approximately 0.6% of the oceans and 6% of territorial seas protected. These protected areas cover only a small percentage of the different habitats within the marine domain. With few recent exceptions, marine protected areas are heavily concentrated along continental coastlines, providing relatively little protection to deep sea and open ocean habitats such as seamounts (~2% of total protected). In comparison, many coastal habitats, such as mangroves (~17% of total protected) are relatively better represented in global protected areas systems (CBD, 2006a). With the continuing decline in the status of marine resources and biodiversity, international policy has increasingly focused on calls to effectively protect a full spectrum of life on Earth, including in the world's oceans, and the services the oceans provide to mankind. This has resulted in the adoption of a number of targets relating to representative networks of marine protected areas. Notably, the Johannesburg Plan of Implementation of the World Summit on Sustainable Development (WSSD), in 2002, called for countries to:

*"Develop and facilitate the use of diverse approaches and tools, including the ecosystem approach, the elimination of destructive fishing practices, the establishment of marine protected areas consistent with international law and based on scientific information, including representative networks by 2012."*

Building on this, the Conference of the Parties to the Convention on Biological Diversity (CBD) adopted in 2004 a programme of work on protected areas with an overall objective to:

*"Establish and maintain, by 2010 for terrestrial areas and by 2012 for marine areas, comprehensive, effectively managed and ecologically representative systems of protected areas that, collectively, will significantly reduce the rate of loss of global biodiversity."*

Furthermore, individual nation States have established protected areas programs to protect their marine environments. Some recent examples include ambitious commitments such as the Micronesia and Caribbean Challenge, and progress made through the establishment of large marine protected areas, such as the Phoenix Islands Protected Area and the Papahanaumokuakea Marine National Monument in Northwestern Hawaiian Islands. Other commitments include the Natura 2000 network of the European Union and commitments of regional seas conventions.

To meet agreed-upon commitments, each of these global policy targets recognized the need to protect areas representative of the full range of biodiversity found in the world's oceans, as well as the services provided by this biodiversity, in the context of an ecosystem approach. However, our ability to undertake strategic action towards the conservation and sustainable use of biodiversity in deep and open ocean areas has been limited by our incomplete knowledge about how and where species and their habitats are distributed geographically, though this knowledge will likely be greatly enhanced by studies currently in progress. While it is important to protect some habitats and species because of their high diversity, rarity, endemism, threatened status, etc., efforts to protect a full range of marine biodiversity and ecosystem processes in a precautionary fashion requires inclusion of areas representative of major marine ecosystems in marine protected area networks. The identification of such representative areas, in turn requires knowledge of the spatial distribution of marine environments. A crucial tool to help begin this process is the development of a biogeographic classification system.

Realising the need to move forward on the conservation and sustainable use of underrepresented deep and open ocean areas, several international policy fora[1][2][3] requested further work aimed at developing criteria for selecting priority areas for protection and biogeographic classification systems. These requests led to the convening of an international workshop in Mexico City to initiate the development of a biogeographic classification system for deep and open oceans, which eventually resulted in the GOODS classification presented in this document.

## 1.2 The international response

The international workshop on biogeographic classification systems was convened in Mexico from 22 to 24 January 2007 at the Universidad Nacional Autónoma de Mexico (UNAM), Mexico City, Mexico. The workshop was coordinated by the Institute of Marine Sciences and Limnology (ICML) of UNAM, the National Commission for the Study and Utilization of Biodiversity (CONABIO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Union for Conservation of Nature (IUCN). The workshop was funded by Australia, Canada, Mexico and the J.M. Kaplan Fund under the co-sponsorship of the IOC of UNESCO. The workshop was titled the "Scientific Experts' Workshop on Biogeographic Classification Systems in Open Ocean and Deep Seabed Areas Beyond National Jurisdiction" (from here on referred to as the Mexico workshop). A list of participants is available in Annex E.

This workshop represents a major step in consolidating efforts at developing a comprehensive biogeographic classification of open ocean and deep seabed areas beyond national jurisdictions. The workshop built on existing relevant global and regional collaborative research programmes; the experience of coastal states and regional management bodies in developing representative classification systems; and the latest information made available from science experts. Following the workshop, a subgroup of the experts continued the work, eventually resulting in the Global Open Oceans and Deep Seabed (GOODS) classification presented in this document.

This report pulls together the information on biogeographic classifications collated at the workshop, as well as new information made available by experts following the work plans developed at the Mexico workshop, in order to report on the development of a global biogeographic classification of open ocean and deep seabed areas. This work is complementary to, but independent of, workshops conducted to review criteria for identifying ecologically or biologically significant areas in the deep sea and open ocean areas (Ottawa, Canada, 2005), and reviewing criteria for networks of marine protected areas (Azores, Portugal, 2007)

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[1] The CBD Ad Hoc Open-Ended Working Group on Protected Areas. Recommendation 1/1

[2] The CBD Conference of the Parties. Decision VIII/24

[3] The United Nations Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction. Document A/61/65. http://daccess-ods.un.org/TMP/7593736.html

# 2. Introduction

## 2.1 What is biogeographic classification and why is it important?

Biogeographic classification is a classification process that aims to partition a large area into distinct (geographical) regions that contain groups of plants and animals and physical features that are sufficiently distinct or unique from their surroundings at the chosen scale (UNEP-WCMC, 2007). Biogeographic classification systems are hypothesis-driven exercises that intend to reflect biological units with a degree of common history and coherent response to perturbations and management actions. Hence they are widely viewed as essential tools for oceans management in that they assist in understanding how and where taxa are distributed and in marking the boundaries between oceanographic regimes. They provide a basis by which the spectrum of life on Earth can be studied, conserved, and sustainably and equitably managed (UNICPOLOS, 2007).

Without a knowledge of the distribution of the elements of marine biodiversity, the associated environmental factors, and an agreed-upon a framework for classification of areas, it is difficult to assess how well our conservation efforts have achieved representation of biodiversity, and conversely to understand the negative impacts of human activities on our world oceans. Specifically, a global classification framework allows for the broad-scale evaluation of the status of our knowledge and an initial assessment of which habitats, communities and taxa may be subject to disproportionate impacts due to human activities. Such a framework can also highlight possibly fragmented marine habitats, as well as the relative rarity or limited extent of distribution of associated fauna. In short, the classification is a necessary precondition for identification of representative areas within each zone (UNICPOLOS, 2007), and will assist efforts to implement ecosystem-based management in open and deep oceans.

## 2.2 Biogeographic classification and representative networks of MPAs

An ecologically representative network of marine protected areas (MPAs) should incorporate the full range of known biodiversity in protected sites, including all habitat types, with the amount of each habitat type being sufficient to cover the variability within it, and to provide duplicates (as a minimum) so as to maximize potential connectivity and minimize the risk of impact from large-scale and long-term persistent effects (CBD, 2004). Taking into account connectivity between sites will require consideration of the scale at which populations are connected by adult and larval dispersal, as well as an understanding of differing dispersal mechanisms (or lack thereof) for different species within a given site. Ensuring that biogeographic units are well represented within a system of protected areas globally, helps ensure that the full range of marine biodiversity and ecosystem processes will also be protected, and is often the best that can be achieved with the current state of knowledge. Given these considerations, biogeographic classifications are central to the management and conservation of biodiversity in the oceans, including MPA network planning (UNEP-WCMC, 2007).

## 2.3 Towards a biogeographic classification of deep and open ocean areas

Although several research and management initiatives are currently underway, our knowledge of the deep and open oceans beyond the limits of national jurisdiction is limited. Consequently, no comprehensive and agreed upon biogeographic classification exists to date for all of the world's open ocean and deep seabed areas outside national jurisdiction, although some work towards this end has been undertaken in specific regions, and globally for certain ecosystems, such as back arc basins (Desbruyères et al 2007) and hydrothermal vents (Bachraty et al 2007). These and other biogeographic classifications are documented in section 3.1. The process towards biogeographic classification of these areas, initiated at the Mexico workshop, first defined a set of basic principles and a framework for the recognition and classification of coherent biogeographic regions in deep and open oceans. The basic principles allow scientists to spatially delineate into biogeographic provinces separate homogeneous areas that have recognizably different components. The available information presented herein has been processed using Geographic Information Systems (GIS) in order to gain an understanding of geophysical and hydrographic features that can help delineate preliminary biogeographic regions, and explain species distributions that contribute to defining such regions. These steps are presented in greater detail in the next chapters. Chapter 3 focuses on conceptual issues, including reviewing and extracting lessons learned from existing global and regional marine biogeographic classifications. Chapter 4 discusses available data. Chapter 5 focuses on the pelagic biogeographic classification, while chapter 6 discusses the benthic biogeographic classification. Chapter 7 considers strategies for nesting with other existing classification systems at different scales. Chapter 8 outlines gaps in scientific knowledge and further research needs, while chapter 9 discusses implications for policy. Chapter 10 presents the conclusions. The annex contains additional information, resources and a case study.

The primary focus of this report is to delineate major ecosystems in the open ocean and deep seabed area outside national exclusive economic zones (EEZ or comparable zone) and oceanward of continental shelves in those regions where continuity of the same ecosystem exists. Where clearly identifiable biogeographic zones continue inside EEZs, their biological contiguity within and outside the EEZ is probable, even if the governance systems for the different parts of the biogeographic zone may be different (UNICPOLOS, 2007).

# 3. Conceptual issues

## 3.1 Existing global and regional marine biogeographic classifications

In the deep and open ocean areas, biogeographic classification is far less developed than in terrestrial, coastal and continental shelf areas, where biogeographic maps and classifications of various kinds have long helped support ecosystem-based management. In the marine realm, there have been substantial efforts at biogeographic classification at the local, national and regional scales. There have been fewer such attempts to delineate marine bioregions globally, due mainly to the difficulties in acquiring data on this scale. In the pelagic environment, the only purely data-driven global marine biogeographic classification, the Longhurst classification (Longhurst, 1998), uses oceanographic rather than species data. In the benthic environment, hydrothermal vent species composition offers an interesting scientific example of a novel method for delineation of biogeographical regions globally (Bachraty et al 2007).

Of existing biogeographic classifications, the Large Marine Ecosystems (LMEs) are perhaps the most widely used for management purposes. The coverage of the 64 LMEs extends from river basins and estuaries to the seaward boundaries of continental shelves and the outer margins of the major current systems. Open ocean and deep sea areas beyond national jurisdiction are not covered, nor are many island systems. The boundaries of LMEs have been set by a combination of biological and geopolitical considerations. The more recent Marine Ecoregions of the World (MEOW) classification of the coastal ocean provides more comprehensive and finer scale coverage based solely on biodiversity criteria, and is a mosaic of existing, recognized spatial units. MEOW does not extend to the open ocean and deep sea areas beyond national jurisdiction, however (Figure ).

Regional classifications exist for almost all coastal and shelf waters, although many are only described in the gray literature. Areas with no known biogeographic classifications are the continental coasts of much of South, Southeast, and East Asia (Spalding et al, 2007). The table in Annex B, compiled and updated from Spalding et al, 2007, provides a list of selected regional biogeographic classifications. The Southern Ocean and the OSPAR maritime area provide examples of well-developed regional classifications (Dinter, 2001). The OSPAR case study can be found in Annex C.

A number of widely used key global biogeographic studies and systems, some of which are still in active use and/or being refined, are summarized in the box below.

## Selected global marine biogeographic classifications

*(Adapted from CBD 2006)*

**Zoogeography of the Sea (Ekman 1953)**
One of the first classic volumes originally published in German in 1935, this recognizes, but does not clearly map a number of “faunas”, “zoogeographic regions”, and “subregions”.

**Marine Biogeography (Hedgpeth 1957)**
This work points back to that of Ekman, but also reviews many other contributors and produces a first global map showing the distribution of the highest level “littoral provinces”.

**Marine Zoogeography (Briggs 1974)**
Perhaps the most thorough taxonomic-based classifications devised, this work still forms the basis for much ongoing biogeographic work. The work focuses on shelf areas and does not provide a biogeographic framework for the high seas. Briggs developed a system of regions and provinces, with the latter defined as areas having at least 10% endemism. These remain very broad-scale, with 53 Provinces in total.

**Classification of Coastal and Marine Environments (Hayden et al. 1984)**
An important attempt to devise a simple system of spatial units to inform conservation planning. The coastal units are closely allied to those proposed by Briggs.

**Large Marine Ecosystems (Sherman and Alexander 1989)**
One of the mostly widely used classifications, these are “relatively large regions on the order of 200,000 km2 or greater, characterized by distinct: (1) bathymetry, (2) hydrography, (3) productivity, and (4) trophically dependent populations”. They have been devised through expert consultation, taking account of governance regimes and management practicalities. At the present time the system is restricted to shelf areas and, in some cases, to adjacent major current systems and does not include all island systems. As shown by the definition these units are not defined by their constituent biotas: although in many cases there are close parallels due to the influence of the abiotic characters in driving biotas this is not always the case. There are 64 LMEs globally.

**A Global Representative System of Marine Protected Areas (Kelleher et al. 1995)**
Not strictly a classification, this is one of the few global efforts to look at global marine protected areas coverage. Contributing authors were asked to consider biogeographic representation in each of 18 areas and this volume provides important pointers to biogeographic literature and potential spatial units.

**Ecological Geography of the Sea (Longhurst 1998, 2007)**
This system of broad biomes and finescale “biogeochemical provinces” is centred on abiotic measures. The classification consists of 4 biomes and 57 biogeochemical provinces. They are largely determined by satellite-derived measures of surface productivity and refined by observed or inferred locations of change in other parameters (including mixing and the location of the nutricline). The direct “measurability” of this system has appealed to a number of authors. It would further appear that some of the divisions lie quite close to lines suggested by taxonomic biogeographers. At the same time it should be pointed out that this system does not strictly follow the surface circulation patterns in a number of areas. Some of his broader-scale biomes cut right across major ocean gyres, splitting in half some of the most reliable units of taxonomic integrity, while the finer-scale units would appear unlikely to capture true differences in taxa, but could perhaps be open to interpretation as finerscale ecoregions.

**Ecoregions: the ecosystem geography of the oceans and continents (Bailey 1998)**
Bailey has provided much of the critical input into the development of terrestrial biogeographic classification, but his work also provides a tiered scheme for the high seas. The higher level “domains” are based on latitudinal belts similar to Longhurst, while the finer-scale divisions are based patterns of ocean circulation.

**Marine Ecoregions of the World (MEOW) (Spalding et al 2006)**
This newest classification system is based on a review and synthesis of existing biogeographic boundaries (above) as well as expert consultation. It covers coastal areas and continental shelves, but not the deep and open oceans beyond national jurisdiction. The classification system includes 12 realms, 58 provinces and 229 ecoregions.

## 3.2 Summary of existing approaches to marine biogeographic classification and lessons learned

A preferred system of classification should be consistent with available knowledge on taxonomy, physiognomy, palaeontology, oceanographic processes and geomorphology. It should also draw upon the considerable experience in biogeographic classification nationally, regionally and globally.

A summary of the present approaches to classification of marine environments is given in

Table 1, illustrating that coastal, shelf and deep and open ocean areas can all be viewed from a variety of perspectives, and classified according to a variety of attributes - for a variety of purposes. The scientists undertaking the GOODS biogeographic classification reviewed the strengths and weaknesses of these methods of classification relative to their power to:

- describe how and suggest why species are distributed as they are in the oceans;
- provide a framework in which to explore how species aggregate to form characteristic ecosystems; and
- document the actual areas within which each characteristic ecosystem is expected to occur.

## Taxonomic methods

There is a long history of biogeography based on species ranges, and the broad global patterns of taxonomic distributions are well known, though subject to revision as new genetic methods are applied and bio-exploration of the seas continues (http://www.coml.org/). Taxonomic methods and surveys alone are however not sufficient at the present time to fully classify the biodiversity of the oceans. Although detailed information is available for some better known species groups in a few well-researched areas of the globe, for the vast majority of the oceans such information is sparse. At regional scales it is impossible to directly conduct comprehensive biological surveys. Instead, it is necessary to rely on extrapolations of relationships between biota and the physical environment – i.e. on physiognomic data.

## Physiognomic methods

In the pelagic realm, the broad scale distributions of ocean gyres, transition zones and coastal currents are well known. In the benthic environment, the geomorphology of the oceans is being mapped by a variety of technologies, but deep sea currents are less well documented. These environmental factors can adequately define habitat characteristics and associated biological community types at regional scales. Although aliasing of physical and biological data may be problematic, the major oceanographic processes of production, retention, and dispersal of larvae provide a process-based link between distinct regimes of ocean physics and distinct groups of species affected by or adapted to those processes (Bakun, 1998). In regions where the array of community types is already biogeographically defined, physical factors predict at least major community types fairly accurately (Kostylev, 2005, OSPAR, 2003). Physiognomic data can therefore provide a second level of calibration for mapping representative areas, and this general approach is now in widespread use in coastal and shelf waters.

**Table 1: A Summary of approaches to biogeography and mapping for the high seas (a classification of classifications) - some options**

| APPROACH | BASIS | | FACTORS |
|---|---|---|---|
| TAXONOMIC ('Conventional' biogeography) | Genetic differences | | Evolutionarily Significant Unit (ESU) |
| | Species - distributions and ranges | | Taxa themselves |
| | Genera – distributions and ranges | | Taxa themselves |
| | Families - ditto | | Taxa themselves |
| | Migrant/ Flagship species - distributions | | Feeding, breeding areas |
| | Community distributions and ranges | | Biocoenoces, biotopes |
| | Charismatic communities | | Vents, sponges |
| PHYSIOGNOMIC | Geophysical / environmental | Oceanographic properties | Temperature, salinity, water masses, nutrient regime, O2 min layer, lysocline |
| | | Physiographic | Depth and depth categories, substrate type, sediments |
| | Geomorphology | Topographic features | Ridges, seamounts, abyssal plains, continental slope etc. |
| ECOLOGICAL GEOGRAPHY | Combined Biological and Physical Factors | Biomes | Ocean basin, ocean gyres, water masses, sea colour (chlorophyll) productivity regimes, latitude, longitude, temperature regimes, community types |
| | | Ecosystems | Oceanographic features, gyres, boundary currents, convergence zones, divergences, ocean currents |
| | Geological History and Palaeontology | Evolution of Ecological Boundaries | Plate tectonics, ocean ridges |
| SOCIO-ECONOMICS | Ecosystem-based management | Fisheries Economics | Historical fishing areas, Catch quotas, productivity regime |
| | | Large Ocean Management Areas (LOMAs) | |
| | | Fishing Areas | |
| | Resource exploitation | Non-renewable resources | Distribution of major resources i.e. metals of interest to industry and economics of Nations, rare elements, energetics. |

## Ecological geography

Longhurst (1998, 2007) describes regions of the epipelagic oceans, based primarily on remotely observed temperature and ocean colour, and adds additional data to infer oceanographic and trophodynamic processes. However epipelagic boundaries and productivity regimes are only one aspect of the patterns of marine biodiversity, and cannot alone form the general basis for delineating marine ecozones. At the global level, predictions of biomes, ecosystems, or even community types from geophysical data do not ensure taxonomic identity within biomes nor taxonomic distinctness among biomes in different locations.

The concept of Large Marine Ecoystems (Sherman and Alexander, 1989) is intended to provide some consistency of scale of spatial ecological units, but has several drawbacks when considered as a global marine biogeographic classification. First, the boundaries of LMEs reflect a set of compromises among a variety of considerations and are at least partly determined by geopolitical considerations. Second, with a few exceptions, the concept has been restricted to shelf areas. Third, the concept of LMEs did not consistently incorporate physiognomy or global ecological geography, and the results do not consistently demonstrate a greater degree of homogeneity of biodiversity within LMEs than across adjacent ones.

#### Political or governance management regions

The boundaries used to delineate Regional Fisheries or Oceans Management Organizations are generally based on the distributions of fish stocks managed by the RFMOs/ROMOs, and/or the jurisdictions of the states participating in the RFMOs/ROMOs. Although they may be somewhat internally homogeneous in fauna, their boundaries cannot be counted on to coincide with any major discontinuities in species composition. Rather the boundaries reflect the limits of legal agreements and historic patterns of fisheries or other ocean uses. Hence the boundaries may be set rather arbitrarily compared to the full range of biodiversity, and coverage of deep and open ocean areas beyond the limits of national jurisdiction is far from complete.

### 3.3 Principles for a classification system for deep and open ocean areas

A science-based development of a biogeographic classification system requires definition of a set of basic principles and a framework for the recognition, and classification of coherent biogeographic regions of the high seas, where no such agreed system has been developed. These basic principles should allow us to spatially delineate separate areas that have recognizably different and predictable taxonomic compositions. Our confidence in the delineation of such areas will increase if it is possible to link them to oceanographic processes in the water column or geophysical structures in the seafloor that contribute to making them definably separate, and suggest evolutionary mechanisms by which their relative homogeneity could have arisen and diversity could be maintained. The same principles should be applicable to all high seas areas.

In their approach to developing a biogeographic classification system for deep and open ocean areas, the scientists involved in the GOODS biogeographic classification considered and rejected a number of properties, including:

- Distinctive areas (Roff and Evans, 2002),
- Hotspots (of whatever kind including areas of high species diversity),
- Ecologically and biologically significant areas, or
- The ‘naturalness’ of an area.

Such considerations, while important in marine planning, are not generally within the scope of representativity, and are primarily appropriate for targeted conservation measures at a finer scale and for delineations within a given representative area. Neither is the GOODS classification system based on any form of threats or risks to marine environments, habitats, or their communities, or any form of ‘end-uses’ of marine environments. It was felt that a biogeographic classification system should be useful for the management of threats, but not determined by them.

The Mexico workshop participants agreed on the following principles:

**1. Consider the pelagic and benthic environments separately**: To a first approximation the pelagic world is fully three dimensional, whereas the benthic world features two dimensional properties. The ecological scales and processes operating in the two systems are also fundamentally different. The pelagic system is dominated by oceanographic processes operating on large spatial scales but relatively shorter time scales. These processes are reflected strongly in the patterns of occurrence of many pelagic species. In contrast, the patterns of benthic species occurrences are strongly influenced by processes reflecting the depth, topography and substrates of the seafloor; processes that often have much finer spatial scales but persist on longer temporal scales. Although the expert group recognized that the two environments exchange energy and organisms, and are coupled, their complements of taxa, size-spectra of species, life-spans of species, and communities of organisms are largely different. The pelagic world is dynamic, with regions inter-connected at relatively short time-scales compared to the life-cycles and evolutionary changes of its species complements. Detailed locations of individual pelagic habitat features are predictable only on spatial scales of tens of kilometres or more and temporally on scales only up to a few weeks. In contrast, the benthic world appears to be more heterogeneous, less interconnected, with slower rates of dispersal and higher degrees of local endemism. Habitat features may be stable for years to centuries, down to scales of meters or less. Thus, it is reasonable to expect that different combinations of factors will need to be used to classify these two environments. However, when applying the biogeographic classification in management planning, it should be recognized that many uses and impacts carried out or occurring in one of the two realms affect both realms. In such cases, even if the biological communities may be different, it is necessary to consider their threats and responses to management interventions in an integrated manner.

**2. A classification of biogeographic regions for the selection of representative areas cannot be based upon unique characteristics of distinctive areas or upon individual focal species**. Conservation efforts may legitimately be directed towards protection of distinctive areas or species because of their unique value to biodiversity, but attention to such areas alone would not address patterns of species distribution in the great majority of the oceans.

**3. The classification system needs to reflect taxonomic identity, which is not addressed by ecological classification systems that focus on biomes**. Although geographically widely separated biomes may have similar physical environments, functions and *types* of communities, their community species compositions, and hence biogeography, can be distinctly different, and the benefits of protecting representative portions of one biome will not accrue to the different species found in other similar functional biomes.

A consequence of items 1-3 is that biogeographic classification of deep and open ocean areas must use the taxa themselves to delineate homogeneous areas and biogeographic provinces. The definition of areas by taxa inevitably becomes the first level of a classification for broad scale biogeographic boundaries in places of recognizable changes in species composition. Next, within such biogeographic areas – where the faunal and floral assemblages are already defined at some scale - physiognomic and other factors can be used to achieve finer scale classifications.

**4. The biogeographic classification system should emphasise generally recognizable communities of species, and not require presence of either a single diagnostic species**

**or abrupt changes in the whole species composition between regions.** Both endemic species and discontinuities in the ranges of many species may indeed occur within properly delimited biogeographic zones, but there will always be anomalies in distributions of individual species, and some species are cosmopolitan. What really matters is that the community structure changes in some marked and consistent way, such that the dominant species determining ecosystem structure and regulating ecosystem function have changed, whether the *types* of ecosystem characteristics of the zone or lists of species have changed greatly or not.

**5. A biogeographic classification must recognize the influences of both ecological structures and processes in defining habitats and their arrays of species, although the operative factors will be different in the pelagic and benthic worlds.** In the pelagic world, processes of ocean circulation dominate. These broadly correspond to biogeographic provinces and biomes, but their boundaries are dynamic and influenced by water motions in both vertical and horizontal planes. In the benthic world, geomorphological structures (seamounts, ridges, vents etc.), topography and physiography (scales of rugosity and complexity, and substrate composition) determine the type of benthic community and its characteristic species assemblages, and these structures are comparatively less dynamic than circulation features, resulting in more static biogeographical boundaries.

**6. A meaningful classification system should be hierarchical, based on appropriate scales of features, although the number of divisions required in a hierarchy is less clear**. Any factor used in a biogeographic classification system should enter the hierarchy at the scale at which it is judged to affect distributions (local, regional, global) - or to have done so historically. To do otherwise will produce neither a comprehensive hierarchy nor clear and inclusive categories within any level of the hierarchy. Thus for example, in the pelagic environment water masses of the ocean gyres and depth categories delimit species assemblages, while smaller scale features such as convergences and other frontal systems may serve to mark their boundaries or transitions. These large-scale oceanographic features that strongly influence the species assemblages are inherently dynamic, with boundaries whose positions change over time. As a result, some of these features commonly extend from the open ocean into national jurisdictions. Our biogeographic classification identified these features based on their presence in the open ocean, but the boundaries we present herein recognize the cases where the features extend into national jurisdictions. In the benthic environment, the largest scale biogeographic provinces will be determined by evolutionary history and plate tectonic movements of the basin. In addition, the local scale units would be determined by topography, geochemistry of the sediment-water interface and substrate characteristics. The location of these features is much more persistent over time, such that the boundaries of the benthic biogeographic provinces can be defined in close coordination with specific depth contours beyond the limits of national jurisdiction.

## 3.4 Practical issues to address

There are a number of practical issues to be addressed as part of a biogeographic classification process:

1. How to reconcile differences among biogeographic schemes, where they are based on community taxonomic composition. Information is not equally available on community taxonomic composition around the globe, such that different groups of experts, each using

the best information available in their area and discipline, may not draw the same maps. How can these be reconciled?

2. What level of taxonomy to use (species, genera, families)? Is there a biological reason to justify any one as more suitable than the others, and are there problems with using mixed levels in one classification? Much of the taxonomy of deep sea species is still unknown to the species level, and for some animal groups, many genera are wide-spread.

3. Regardless of level, which taxonomic groups to use (e.g. zooplankton, macrobenthos, fish)? Is there a better strategy than just using whatever is available?

4. How to deal with transition zones faunal breaks and other discontinuities, given that dynamic ocean processes suggest that abrupt community discontinuities will be rare.

5. How to deal with variability, especially seasonal and inter-annual, given that the same dynamic oceanographic processes suggest that boundaries of biogeographic zones are unlikely to be spatially very stable? Marine boundaries and conditions, particularly in the upper part of the water column, are variable in both space and time, and any mapping can only be one 'snapshot' of current and recent historical knowledge; thus it will only describe the biogeography of a quiescent ocean. Marine boundaries and species compositions vary over time scales from days (seasonal phytoplankton blooms), through decades (meteorological regime shifts, changes in fisheries and vent communities), to long-term climate change and global warming. Boundaries are especially likely to be 'fuzzy' in the pelagic environment, but boundaries in the benthic environment may need to be more fully reconstructed from palaeoecological data.

6. Regardless of the classification used, subsequent communications must state the principles and strategies clearly and explicitly. The information that used in applying the principles and strategies must be presented, so the subsequent communications have an identifiable and unambiguous starting point.

## 3.5 Conclusions

A final conclusion emerges from the principles and considerations above. To define and map biogeographic regions and select representative areas will require dealing with a 'mixed' system that combines taxonomic, ecological and physiographic approaches and factors. The observed distributions of organisms has resulted from series of interacting processes at different time scales including evolution, regional oceanographic processes of production, dispersal or retention, and local adaptation to oceanographic and substrate factors. It is therefore to be expected that large scale patterns in taxonomic occurrences, ecology, and physiognomy should all have some coherence. This may provide the foundation of a synthesis of factors needed to describe the planet-wide patterns of representative marine faunas and floras. However, the extent, nature and causal basis for the concordance of these patterns has not been well explored. As the data and patterns from each of these classification systems are explored and consistencies are identified, it should be possible to synthesize them into coherent descriptions of global biogeography. In the pelagic realm this appears to be an attainable goal in the near future, but in the benthic environment, with a multiplicity of finer scale features, finding consistency among classification options may require more time.

The pelagic and benthic sections will apply these principles and address the considerations, including the spatial scale(s) at which the approach will be applied, and the number of levels in each hierarchy.

# 4. Data available for developing a global biogeographic classification of open and deep oceans

The data used to inform and assist the biogeographic classification process should correspond to ecological patterns and processes in open and deep ocean regions. Because the biogeographic classification covers large oceanic areas around the world, the data needed to have consistent global coverage. The geographical coverage of biological data is often insufficient, and physical data such as bathymetry, temperature and substratum have commonly been used as surrogates of the ecological and biological characteristics of habitats and their associated species and communities.

The data were sourced from a number of publicly available databases and from researchers working in deep and open ocean environments. In addition to physical data, such as bathymetry, temperature, salinity and dissolved oxygen, the scientists also considered modelled detrital sinking fluxes and primary productivity. Geomorphological data included plate boundaries, seamounts, sediment thickness and hydrothermal vent locations. Purely biological data were, at this stage, limited to predicted and actual cold water coral reef locations and data on hydrothermal vent organisms. It is hoped that additional biological data can be used in the future to further refine the biogeographic classification. It should be noted that not all the available data were, at the present time, directly used in delineating biogeographic regions. Some data, such as the sediment thickness data, were found not to have the necessary resolution for this purpose. Other data, such as the cold water coral data, will likely be of importance in future refinements of finer-scale regions. Data are listed in

Table 2, below.

**Table 2: Global datasets considered during the biogeographic classification process.**

| Features | Data | Sources | Extent |
|---|---|---|---|
| Temperature | Annualized Temperature (Surface, 800 m, 2000 m, 3500 m, and 5500 m) | World Ocean Atlas (http://www.nodc.noaa.gov/OC5/WOA05/woa05data.html) | Global |
| Salinity | Annualized Salinity (Surface, 800 m, 2000 m, 3500 m, and 5500 m) | World Ocean Atlas (http://www.nodc.noaa.gov/OC5/WOA05/woa05data.html) | Global |
| Dissolved Oxygen | Annualized Dissolved Oxygen (Surface, 800 m, 2000 m, 3500 m, and 5500 m) | World Ocean Atlas (http://www.nodc.noaa.gov/OC5/WOA05/woa05data.html) | Global |
| Detrital sinking flux | Detrital sinking flux (100 m, 200 m, 500 m)calculated from Yool Model | Yool, Andrew et al., 2007, The significance of nitrification for ocean production, Nature, v. 447, p.999 – 1002, plus supplemental material from the author | Global |
| Primary productivity | Model estimates of ocean net primary productivity | Oregon State University (http://web.science.oregonstate.edu/ocean.productivity/standard.php) | Global |
| Sea Surface Temperature | 1 Jan 2000 - 31 Dec 2007 mean derived from MODIS-Terra data | NASA (http://oceancolor.gsfc.nasa.gov/cgi/climatologies.pl?TYP=mtsst) | Global |
| Bathymetry | Global gridded (1 min) data | GEBCO (2003) | Global |
| Plate boundaries | Plate boundaries, including ridges, transforms, and trenches | University of Texas PLATES Project: (http://www.ig.utexas.edu/research/projects/plates/) | Global |
| Bathymetry, topography and depth masks | | ETOPO2 | Global |
| Seafloor sediment thickness | | NGDC (National Geophysical Data Center) | Global |
| Seamounts | Predicted Seamount locations and depths | Kitchingman & Lai (2004). (http://www.seaaroundus.org/ecosystemsmaps/default.aspx) | Global |
| Cold water coral reefs | Distribution of known cold-water coral areas based on species distributions (includes *Lophelia pertusa*, *Madrepora oculata* and *Solenosmilia varialilis*). In addition, predicted distributions of cold water coral reefs. | UNEP-WCMC, provided by Andre Freiwald and Alex Rogers | Global |
| Hydrothermal vents | Hydrothermal Vent Locations and similarity/dissimilarity of benthic communities | InterRidge and Cindy VanDover | Global |

# 5. Pelagic systems

## 5.1 Review of pelagic biogeography

The scientists working on the pelagic biogeographic classification reviewed the overall conceptual approaches to biogeographic classification systems (see section 3). They noted the two main approaches to biogeographic classification schemes:

- taxonomic - A system based on organisms or communities of organisms (that is, a phylogenetic system), referred to as realms, provinces etc; for example the "Eastern boundary current community"
- physiognomic – A system based on structural features of habitat, or ecological functions and processes, referred to as biomes, habitats, etc; for example the "warm temperate Atlantic ecosystem"

Although conceptually different, such systems are clearly highly inter-dependent, and the distinction becomes blurred at finer scales. Moreover, the scientists agreed that for pelagic biological diversity, the patterns of species distribution and dispersal are such that taxonomic and physiognomic classes will often converge at sub ocean-basin scales. These scales would be featured as cornerstones of the pelagic biogeographic classification system.

One of the key purposes of networks of marine protected areas on the high seas is a universally acknowledged need to ensure the conservation of the characteristic composition, structure and functioning of ecosystems. Composition would be best reflected in biogeographic classification systems based on taxonomic similarity, whereas structure and function would also require consideration of systems based on physiognomic classifications. One of the desired features of the network of MPAs was the inclusion of *representative* areas within the network. This objective would require considering a taxonomically based system, as marine biomes with the same physiognomic features in different parts of the sea could have different species compositions. Hence even a well-positioned MPA in one zone would not be representative of the species in a similar biome elsewhere, even if the main physical features and processes were very similar.

The scientists then reviewed the major data and information sources available for high seas pelagic communities, habitats and biogeographic classification. Many sources are available, with the sources of information used in the subsequent delineation of zones including, chronologically (Steuer 1933, Beklemishev 1960, Bé 1971, Beklemishev 1971, McGowan 1971, Bé 1977, Bé and Gilmer 1977, Beklemishev et al. 1977, Casey 1977, Honjo 1977, Backus 1986, Angel 1993, McGowan and Walker 1994, Olson and Hood 1994, Sournia 1994, Van der Spoel 1994, Van der Spoel 1994, White 1994, Briggs 1995, Semina 1997, Shushkina et al. 1997, Boltovskoy 1998, Pierrot-Bults and van der Spoel 1998, Angel 2003, Boltovskoy et al. 2003, MacPherson 2003, Irigoien et al. 2004, Morin and Fox 2004, Boltovskoy et al. 2005, Sibert et al. 2007).

## 5.2 Characteristics of pelagic habitats and their importance to biogeographic classification

After reviewing a variety of proposed systems, including those developed for marine pelagic systems within national jurisdictions, the scientists concluded that the main large-scale physical features that an appropriate system should capture included:

- core areas of gyres
- equatorial upwelling
- upwelling zones at basin edges
- important transitional areas – including convergence and divergence areas

**Ocean gyres** are circular, almost closed patterns of current flow, which form when large ocean currents are constrained by the continental land masses found bordering the three oceanic basins. Each ocean basin has a large gyre located at approximately 30° North and South latitude in the subtropical regions. The currents in these gyres are driven by the atmospheric flow produced by the subtropical high pressure systems. Smaller gyres occur in the North Atlantic and Pacific Oceans centered at 50° North. Currents in these systems are propelled by the circulation produced by polar low pressure centres. In the Southern Hemisphere, these gyre systems do not develop because of the lack of constraining land masses.

**Upwelling areas** are areas of upward movement of cold, nutrient-rich water from ocean depths, produced by wind or diverging currents. Upwelling regions tend to have very high levels of primary production compared to the rest of the ocean. Equatorial upwelling occurs in the Atlantic and Pacific Oceans where the Southern Hemisphere trade winds reach into the Northern Hemisphere, giving uniform wind direction on either side of the equator. Surface water is drawn away from the equator, causing the colder water from deeper layers to upwell. The equatorial region, as a result, has high productivity and high phytoplankton concentrations.

**Areas of convergence and divergence** are areas where currents either meet (convergence) or move in different directions (divergence). For example, the Antarctic Convergence, an ocean zone which fluctuates seasonally, is considered by some to separate the Southern Ocean from other oceans. This ocean zone is formed by the convergence of two circumpolar currents, one easterly flowing and one westerly flowing.

These oceanographic features are readily differentiated, and generally have distinct assemblages of species, and some distinct species. The boundary/transitional areas are also critical in pelagic-benthic coupling. Where there is sufficient information to explore patterns thoroughly, spatial patterns of change found in the oceanographic features are generally compatible with spatial patterns of change in ecosystem function and/or productivity, as reported in, for example, the Longhurst (1998) productivity-based system. In addition some taxonomic systems separate out along these features, particularly for transitional areas, and discontinuities in the ranges of at least some taxonomic groups may be tracked along their boundaries.

The delineation of pelagic ecoregions was itself hierarchical. Starting with those main physiognomic features, fine-scaled biographic units nested within the large-scale features were then considered, such as specific boundary current upwelling centres, and core areas of gyres. Such nested areas were functionally defined but were considered to generally reflect distinctive taxonomic biogeography. At least physical oceanographic information is available for this level of nested partitioning of most of the major features. Information on species ranges is available for validation of the taxonomic meaningfulness of the candidate boundaries in enough of those nested cases to allow a tentative acceptance of the patterns more generally, although focused follow-up work is warranted.

A further level of nesting is often ecologically reasonable, to reflect habitat functional systems at finer scales. These have been defined for the coast and shelf areas (Spalding et al, 2007). In the coastal seas these are not primarily taxonomically distinct, but represent identifiable "habitats" and reflect scales at which ecological processes seem to function. It was recognized that there are insufficient data to apply this nested scale of disaggregation globally. However it should be possible to explore the process using particularly well-studied examples, such as the Antarctic and California Current. From these comparatively information-rich cases the usefulness and feasibility of this further nested partitioning of biogeographic units could be evaluated, informing a decision about the value of investing the effort needed for delineating such finer-scaled habitat-based units. Likewise, classifying the largest scaled units into a set of types or ecological biomes can produce ecological insights. These would recognize the commonalities between, for example eastern boundary currents, equatorial upwellings etc. that may be repeated in different oceans. However, this further step was not a priority in the development of the current biogeographic classification system.

The scientists at the Mexico workshop highlighted the need for consistent use of terms, many of which may have broad or variable interpretations in the wider scientific and technical community. For this report the concept of "**core**" versus "**edge**" is particularly important. The term "Core areas" represents areas of stability in the critical ecosystem processes and functions, whereas at "edges" important ecosystem processes are often in transition and display sharp gradients. This central role for ecological processes, notably productivity, shows that the resultant system acknowledges that these processes are of considerable importance, even though they are not the basis for delineating the biogeographic units.

The pelagic system also contains some features which present specific challenges for biogeographic classification:

**Deep Pelagic** - Little information was available at the Mexico meeting that could be used to explore the power of the proposed system to reflect biogeographic patterns of the deeper pelagic biota. The expert view of the scientists was that no contradictory patterns were known to occur in the deeper pelagic biota, but this was a weak basis for any decision about how well the system actually worked for the deep pelagic biodiversity. Further follow-up by experts is warranted.

**Hotspots** – Time did not allow the scientists to determine if all known hotspots were captured in ecologically appropriate ways by the proposed system. The group agreed that centres of species richness probably are well captured, sometimes by transition/convergence areas which are rich through the mix of different communities, and sometimes by core areas of features that capture major productivity processes.

**Migratory species**: 3 types of migratory pattern were identified:

1. Those shifting consistently between two locations or general areas e.g. humpback whales. A good classification system should ensure that each general area was within a clearly defined unit, but the classification would not have to show any particular relationship between the two locations.
2. Those aggregated at one location and then moving widely; e.g. species with fixed breeding grounds and wide feeding ranges. A good classification system should ensure that the consistent location was within a clearly defined unit, but on a case-by-case basis the distribution of the species otherwise might or might not be informative about boundaries of other units, depending on what affected the migration

3. Those showing more constant movements. The species of this class most appropriate for delineating biogeographic regions were species of limited motility, species whose pelagic life history stages are captives of oceanography. Their distributions can be informative about the effects of water-mass, gyres and boundary/transitional zones on ranges and distributions of other species in the assemblages.

**"Fuzzy" boundaries**: Pelagic biogeographic units were noted to be different from benthic, shelf and terrestrial units in showing far greater temporal and spatial variability in the location of their boundaries, with these boundaries sometimes extending, due to their dynamics or the composition of the units, into national EEZs. Although some boundaries are clean and fairly abrupt (spanning only a few tens of km) others are a gradient with mixing of species from different zones across an area sometimes hundreds of km in width. Some of these transitions zones are relatively permanent features of biodiversity and were considered to represent biodiversity zones in themselves. Moreover, even when biodiversity boundaries are abrupt between zones, the location of these boundaries is often moving through time. In addition, in some cases boundaries on current biogeographic maps only appear fuzzy because data are available on the biodiversity in the core of two zones, but information is simply absent on the pattern of how species composition changes between the two cores.

The three different types of fuzzy boundaries are all important considerations in establishing a pelagic biogeographic classification system. In addition to permanent transition zones representing biogeographic zones in themselves, it is important that the presentation of a pelagic classification system communicate clearly whether a "fuzzy boundary" reflects the range over which a moving but relatively abrupt boundary can be expected to be found, or if it represents a broad area where the location of a boundary is simply poorly known.

## 5.3 Using habitat features to predict biological patterns

Notwithstanding the extensive list of information sources (see section 7.1), it was agreed that in practice there were many inconsistent data and major gaps in high seas distributional data on many taxonomic groups, particularly plankton and invertebrates, and major geographic gaps in data even for fish and marine tetrapods. Hence, however important a taxonomic classification system might be for supporting the identification of representative areas, information gaps would preclude use of a purely taxonomic system and a blended system would be necessary. This was considered reasonable, given the close linkages between the two approaches at finer scales. Consequently, it was agreed that information from both biological and environmental (physical/chemical) datasets should be used to derive a logical and consistent biogeographic classification, with taxonomic data being used to calibrate the system when available, such that it would be reasonable to expect that the classification would have good predictive strength for taxonomic patterns where data are currently absent.

## 5.4 Developing the pelagic classification system

### Methods

Applying the principles and reasoning presented above, the scientists used a Delphic (expert-driven) approach to prepare a first map of biogeographic zones for open ocean pelagic systems globally. Participants at the Mexico workshop consulted directly the many systems already published (Annex B), and reviewed summaries of the data sources listed in

Table 2. The Atlantic map was influenced particularly strongly by White (1994), the Pacific map by Olson and Hood (1994), and the map of the Southern Ocean by Grant et al. (2006). The major addition for the Atlantic and Pacific was the addition of boundary currents along continental edges and greater consideration of the permanent transition zones. The map of the Indian Ocean was advised by a number of publications.

Boundaries proposed by the main authors listed above were checked against the summaries of data sources and expert knowledge of participants, and generally accepted as a starting point for further work unless major inconsistencies were identified. Next, where potential boundaries between biogeographic regions were emerging from the initial steps, the experts searched for oceanographic and bathymetric features and processes that could provide a physiognomic basis for the biogeographic patterns. In the large majority of cases, coincidence of key references, data summaries, and major oceanographic features was good enough for at least fuzzy boundaries among provinces to be identified. Where experts or data summaries could provide data on biogeographic patterns not captured by, or inconsistent with, the literature sources, the new information was used to delineate provinces. This occurred primarily in the Indian and Southwest Pacific Oceans. In the regions of the world's oceans with the better inventories of pelagic biodiversity, some major oceanographic features like central gyres and boundary currents consistently coincided with provinces delineated on taxonomic grounds. Hence, when these types of features occurred in parts of the oceans that were particularly information poor regarding biodiversity, the experts assumed that the features would correspond to provinces as well. For all provinces, experts were assigned to conduct follow-up investigations following the workshop. Some boundaries were adjusted based on the follow-up investigations, but no new provinces were proposed, nor were any suggested to be dropped.

## Results

The experts produced a map of pelagic biogeographic classes, which is presented in Figure 1. The biogeographic classification included 29 provinces as follows:

1. Agulhas Current
2. Antarctic Regional Zone
3. Antarctic Polar Front
4. Arctic Regional Zone
5. Benguela Current
6. California Current
7. Canary Current
8. Eastern Tropical Pacific Zone
9. Equatorial Atlantic Zone
10. Equatorial Pacific Zone
11. Gulf Stream
12. Humboldt Current
13. Indian Ocean Gyre
14. Indian Ocean Monsoon Gyre
15. Kuroshio Current
16. Leuwin Current
17. Malvinas Current
18. Non-gyral Southwest Pacific Zone
19. North Atlantic Transitional Zone
20. North Central Atlantic Gyre
21. North Central Pacific Gyre
22. North Pacific Transitional Zone
23. Somali Current
24. South Central Atlantic Gyre
25. South Central Pacific Gyre
26. Subantarctic Regional Zone
27. Subarctic Atlantic Regional Zone
28. Subarctic Pacific Reginal Zone
29. Subtropical Convergence

These provinces have unique environmental characteristics in regards to variables such as temperature, depth and primary productivity, as documented in the statistic related to each bioregion available in Annex A.

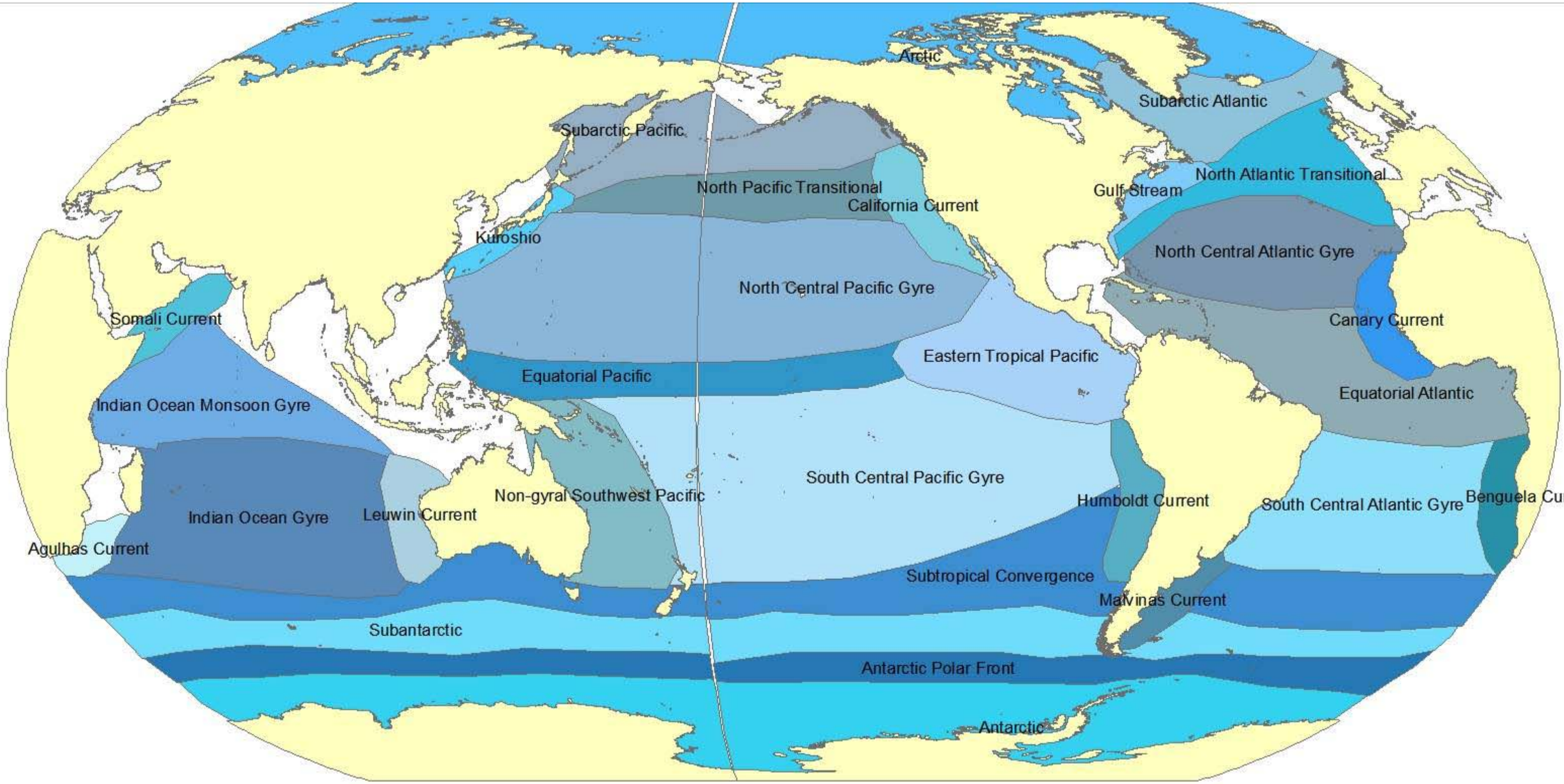


**Figure 1: Map of pelagic bioregions.**

## A pelagic data-driven classification

A cluster analysis was undertaken to provide further information for the pelagic classification. The cluster analysis utilised three global data layers: bathymetry, sea surface temperature and primary productivity. These data were determined to be of importance for the distribution of habitats, species and communities in the world's oceans.

The methods used were the same ones already implemented for the biogeographic classification of the Southern Ocean (Grant et al., 2006; Anon., 2007). Environmental data from the full 0.5° grid were clustered using a non-hierarchical clustering algorithm (the CLARA routine in the R package) to reduce the full range of environmental heterogeneity down to 200 distinct groups. Hierarchical clustering (UPGMA) was then used to obtain final 20-group and 40-group clusterings. The choice of 20 and 40 groups for the final output yielded regionalisations with a sufficient level of spatial detail to be interesting and useful, but without being overwhelmingly complex. A Gower metric was used in the clustering (equivalent to a Manhattan distance with equal weights on each of the input data layers). All computations were performed using Matlab (Mathworks, Natick, 2007) and R (http://www.r-project.org/).

The results of the cluster analysis can be seen in Figure 2. An overlay of the pelagic bioregions on the cluster analysis show generally good correspondence between the clusters and selected bioregions in most areas. The similarities support the hypothesis of the pelagic group that there is an environmental basis for large-scale biogeography patterns. The cluster analysis also helps point out areas where considering only physiognomic factors may miss important biogeographic boundaries. Further work with all the information sources can further refine the placement of boundaries among the pelagic biogeographic regions.

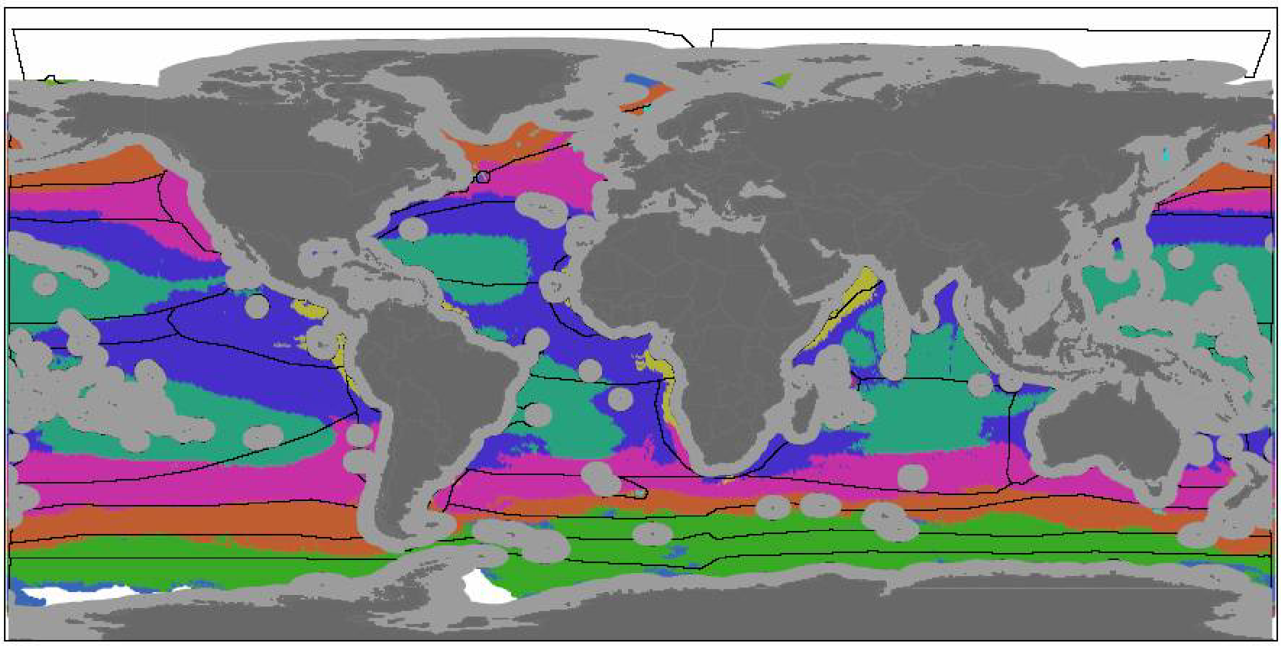


**Figure 2: Proposed pelagic provinces (black lines) overlaid on top of a cluster analysis.** The analysis was created using bathymetry, sea surface temperature and primary productivity (different clusters in different colours).

## Robustness of the classification system and its further uses

The exact boundaries on the pelagic biogeographic map will remain a work in progress. The priority areas for more detailed follow-up include:

- Low latitude Atlantic features. - At present this region is treated as a single unit, but the group was particularly information poor with regard to this region, so the "region" may be more heterogeneous than some of the other regions. .
- Position of boundaries and subzones in the Indian Ocean
- Boundaries for the South America eastern boundary current
- Major divisions, zones of convergence and divergence, and/or nested zones at the next finer scale for the Arctic and Antarctic.
- The faunal distinctiveness of the Labrador (northwest Atlantic) and Oyashio (northwest Pacific southward flowing currents
- Position of the eastern boundary between non-gyral and gyral south central Pacific zone.
- The relative affinity of the Bering Sea species composition with the Arctic or the sub-Arctic.

Notwithstanding the need for additional refinements, the major zones are considered reasonable for use in planning and management for conservation and sustainable use of pelagic marine biodiversity. It is important that the currently "undifferentiated" provinces not be used as an excuse to delay action using the units that have already been identified.

There are some important differences in the proper use of these biogeographic zones compared to similar approaches for terrestrial zones. A major difference is that pelagic conservation approaches must deal with shifting ocean boundaries and large generalised provinces. Thus, spatial planning should target core areas such as the centres of gyres, or the most stable areas within zones with shifting boundaries. For some zones MPAs may not be the most appropriate conservation tool for the dynamic pelagic system. Focused research is needed on the robustness of different management tools (including, but not exclusively, MPAs) for conservation and sustainable use of pelagic biodiversity within biogeographic zones.

# 6. Benthic systems

## 6.1 Review of deep sea benthic biogeography

An extensive review of deep sea benthic biogeography has been undertaken and is available in Annex D of this document.

## 6.2 Deep sea Benthic Biogeographic Units

At the Mexico meeting, a expert group on the distribution of organisms in the deep sea produced a preliminary map containing the locations of what were termed "the centers of distribution" of deep sea provinces at bathyal and abyssal depths. In addition, because hydrothermal vent communities were felt to be governed by processes separate from those determining the locations of broad bathyal provinces, a separate hydrothermal vent geography was produced.

The experts at the Mexico City meeting recognized that for much of the deep sea there is very little information that can be used to delineate biogeographic units, at the level of either province or region. The lack of information is partly due to lack of sampling in many deep sea regions, but also due to a lack of mapping or synthesis of data from expeditionary reports or other sampling programs where species have been identified, other than what has been summarized in textual form for deep sea explorations conducted by Russian scientists (e.g., Vinogradova 1997, Zezina 1997, Sokolova 2000).

On the other hand, physical and chemical data taken during routine hydrocasts over the past century or so have all been compiled by the U.S. National Oceanographic Data Center (NODC) and are readily available for download. Much of the discussion in Mexico City revolved around whether a biologically-based dataset could be used (as for the pelagic scheme) or whether a proxy-based approach was needed for the benthos to achieve a more consistent global understanding of likely biogeographic subdivisions. At the time it was felt a biological approach should be adopted wherever possible, but that has proved difficult given the paucity and inconsistency of available data by area and by taxon. Hence for this benthic classification the tasks involved compiling available biological information, and as much of the hydrographic data as possible and plot the distribution of variables that might correlate with the distribution of benthic animals. To a certain extent, this effort is predicated on the idea that benthic species, at least those that are not highly mobile, are influenced in their distribution by the major water masses of the ocean. And, while the surface water mass distributions are well known, and to a certain extent well delineated, at depths below 800 m, water masses have not been comprehensively mapped.

The objective of the present effort, then, is to produce maps of the bathymetry, T, S, O, and organic matter flux for discrete depth layers that could then be used to assess the relationship between known organism distributions and water mass characteristics. It is acknowledged that this is a very restricted subset of factors that can potentially influence species composition and distribution, and often a combination of factors will be important. However, these factors are widely recognized as being key determinants, even if they alias other parameters. In addition, we have reviewed the pertinent literature on deep sea zoogeography produced since the 1970s, and have drawn biogeographic maps using that literature and some of the hydrographic data as guides.

## Methods and Resources

All hydrographic and benthic data have been entered into ArcGIS 9.2 and converted to shape files. The bathymetric data are ETOPO2 data downloaded from the National Geophysical Data Center (NGDC). These data are estimates of bathymetry derived from satellite radar altimetry measurements. Temperature, salinity, and oxygen (ml/l) data were obtained by download from the NODC (see Hydrography, below). Only annualized means were used. Organic flux from the bottom of the surface mixed layer or 500 m in areas where a mixed layer is missing were obtained from a model developed by Andrew Yool and colleagues at the Southampton (U.K.) Institute of Oceanography (Yool et al. 2007).

All data were binned into 0-300, 300-800, 800-2000, 2000-3500, 3500-6500, and > 6500 m layers. The 0-300 and 300-800 m layers were discarded as they are almost exclusively within the EEZs of various nations. Less than 1 percent of the 300-800 m bottom is present in high seas areas. The depth bins were chosen based on results of analysis of bottom samples taken over much of the world ocean by Russian investigators. Subdivision or replacement of these depth bins may occur during subsequent analyses in order to not lose important data from each ocean basin. For example, in some areas there are important changes in water mass characteristics at about 2000 m depth, and these will be noted because they may determine changes in bottom community composition, even though the Russian investigators considered the lower bathyal to extend more or less unbroken between 800 and 3500 m (see Annex D).

## Bathymetry

The following figures illustrate the global distribution of benthic substrate within the depth zones 300-800 m (upper bathyal), 800-2000 and 2000-3500 m (upper and lower portions of the lower bathyal), 3500-6500 m (abyssal), and >6500 m (ultra-abyssal and hadal).

For the most part, the upper bathyal (300-800 m) (Figure 3) follows the continental margins, the major exception being the large plateau areas off New Zealand and the Kerguelan Islands. However, virtually all of the upper bathyal is within the EEZ of one nation or another.

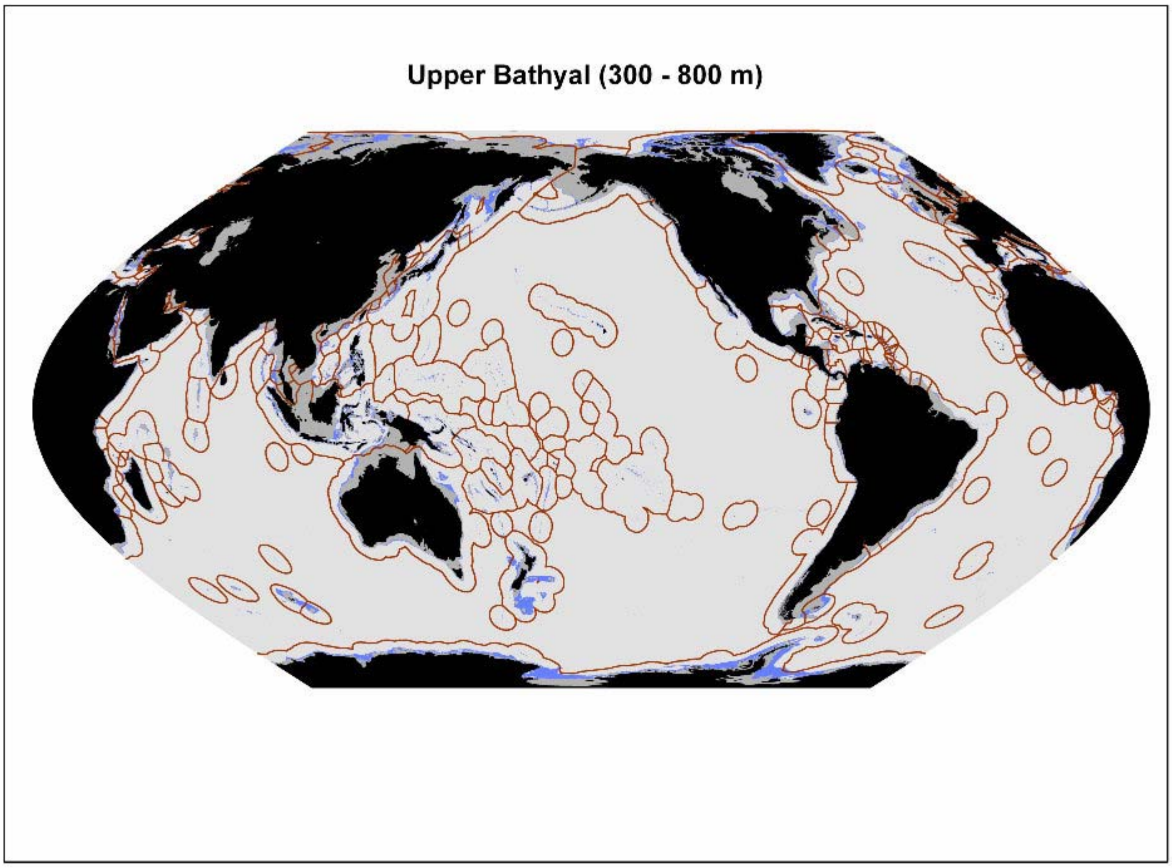


**Figure 3: Map of seafloor areas at upper bathyal (300 – 800 m) depths.**
Depths are indicated in blue, and EEZ boundaries, outlined in brown. Note there are only a few areas of upper bathyal outside areas of national jurisdiction.

The lower bathyal (800-3500 m) (Figure 4 and Figure 5) consists almost entirely of three physiographic categories: lower continental margins, isolated seamounts and oceanic island slopes, and mid-ocean ridges. The lower bathyal of the continental margins are for the most part sedimentary, having accumulated large deposits from continental run-off. These areas may be part of the extended continental shelves of coastal nations. In contrast seamount and island flanks (and often the summits) and mid-ocean ridges can be free of sediment, offering large expanses of hard substrate for settlement of invertebrates, and habitat for bathyal fishes. Seamounts and ridges provide areas of lower bathyal depth in offshore areas dominated by abyssal plains. These topographic features will have a different fauna from the surrounding seafloor because they are “islands” of shallower habitat providing a wide range of depths for different communities. Bare rock surfaces can be common because of accelerated current flow scouring the often steep flanks. The physical structure of the seamount interrupts currents and creates hydrographic eddies and flows that can restrict the dispersal of larvae and plankton and keep species and production processes concentrated over the seamount. Even though the area covered by ridges and seamounts may be small in relation to the surrounding seafloor, their geographical location may be very important in determining distribution of bathyal species across the wider ocean basins. The importance of seamount depth can be seen in Figure 5, where the predicted summit depths of seamounts based on satellite altimetry (Kitchingman & Lai

2004) are plotted for depth ranges 300-800 m, 800-2000 m, and 2000-3500 m. These show the extent of seamount habitat offshore throughout the world ocean.

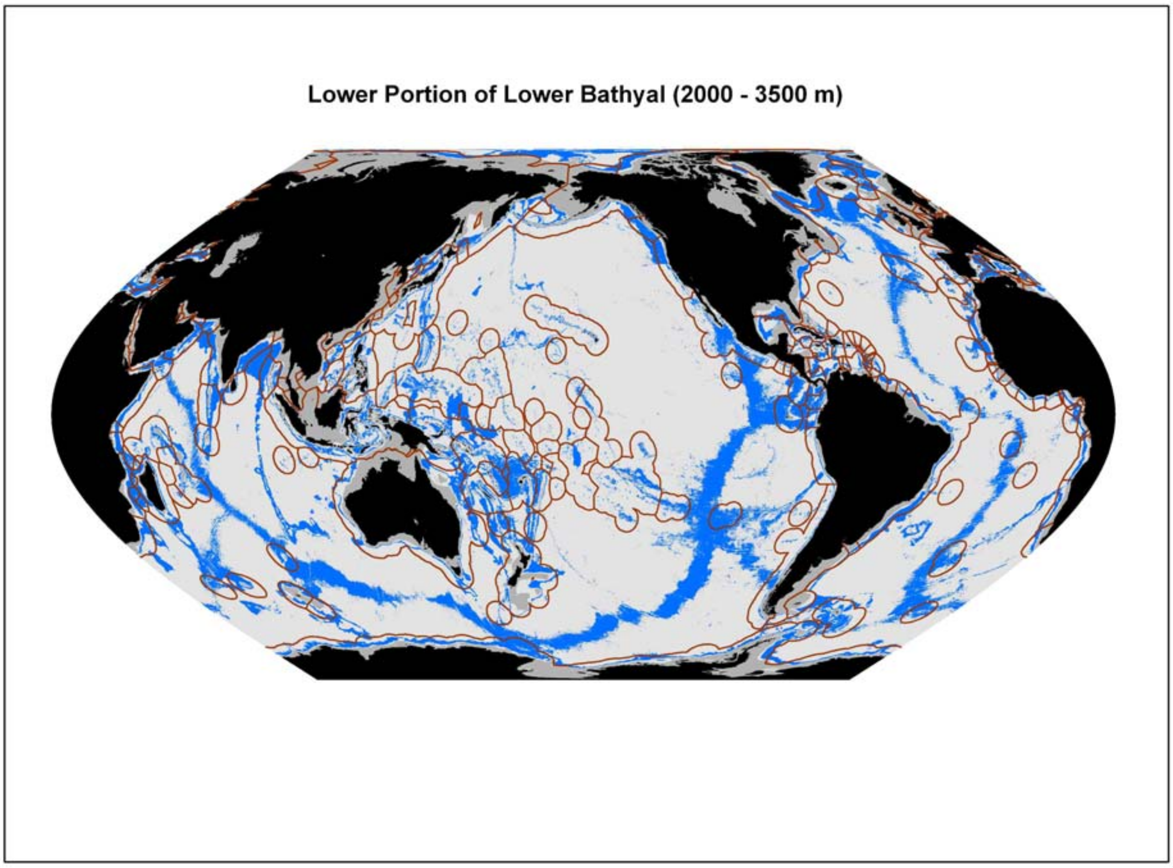


**Figure 4: Seafloor areas in the lower part of lower bathyal zone (800 – 2000 m).**
Colours as in slide 1. Several ridges and seamount systems, particularly in the Indian, Pacific, and South Atlantic Oceans are at this depth.

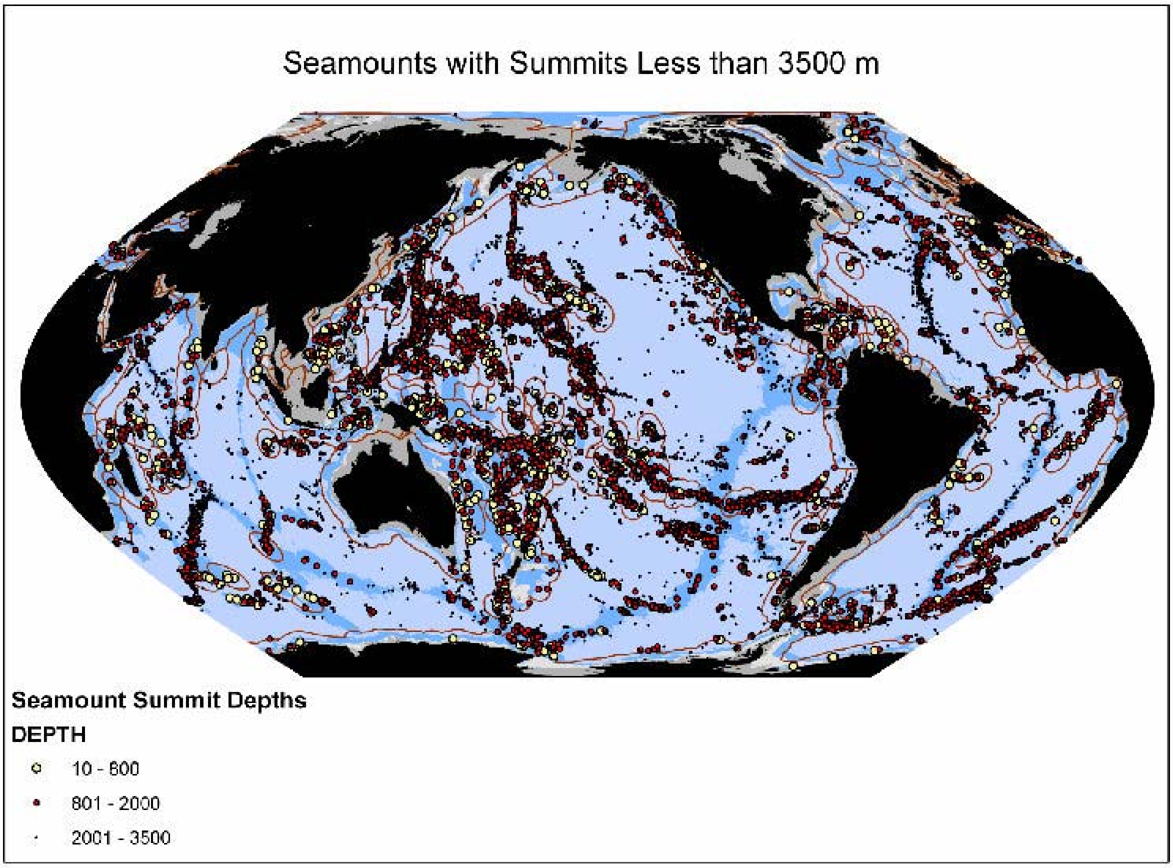


**Figure 5: Seamounts with summits shallower than 3500 m, with 2000 – 3500 m.**
Bathymetry is indicated in darker blue. Most of the seamounts with summits shallower than 800 m are within areas of national jurisdiction; however, there are many seamounts with summits at fishable depths (<2000 m) in high seas areas.

In most of the literature on the bathyal, it is the continental margins that have been sampled most frequently, with some mid-ocean ridges sampled occasionally. Because of their hard substrates and often distant location offshore, seamounts and mid-ocean ridges have only recently been investigated using modern oceanographic tools such as submersibles and remotely operated vehicles (ROVs).

The abyssal (3500-6500 m) (Figure 6) covers the bulk of the deep ocean floor. With the exception of the central Pacific, the ocean basins are separated by parts of the mid-ocean ridge system. There are, however, gaps in nearly all the ridges, allowing some water flow from one basin to another. In the Indo-West Pacific Region there are a few small basins that are completely isolated from the rest of the abyssal ocean, but these are mostly within the EEZ of various nations. The Guatemala Basin is one of the most isolated abyssal basins with most of its areas outside of any country's EEZ.

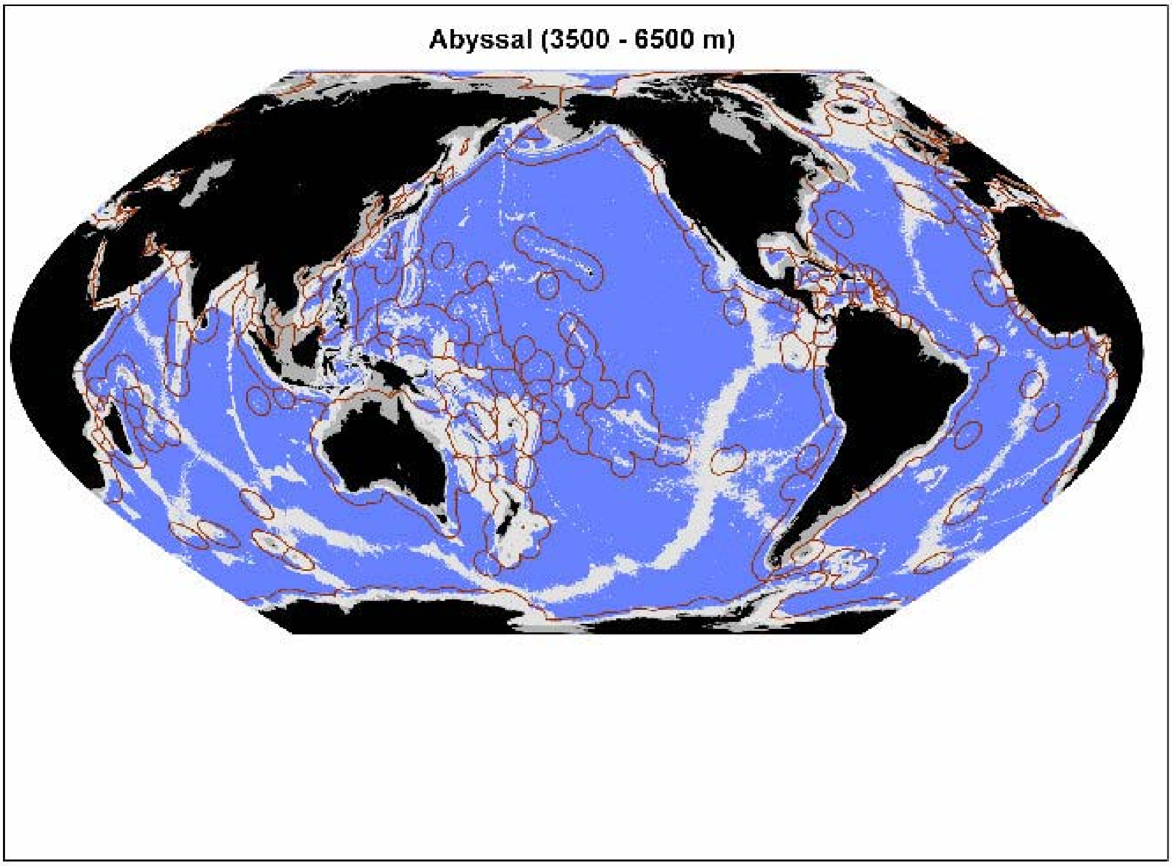


**Figure 6: Abyssal zone (3500 - 6500 m –blue).**

The ultra-abyssal and hadal areas (>6500 m) (Figure 7) are, for the most, part restricted to plate boundaries where subduction of lithospheric plates occurs. Most of the trenches, then, are in the western Pacific, stretching from the Aleutians to Japan, the Philippines, Indonesia, the Marianas, and finally to the Kermadec trench around New Zealand. The eastern Pacific has only the Peru-Chile trench and the Atlantic the Puerto Rico and Romanche trenches. All but the Romanche and Scotia Trench are within the EEZs of various countries, with the latter being within the Antarctic management area.

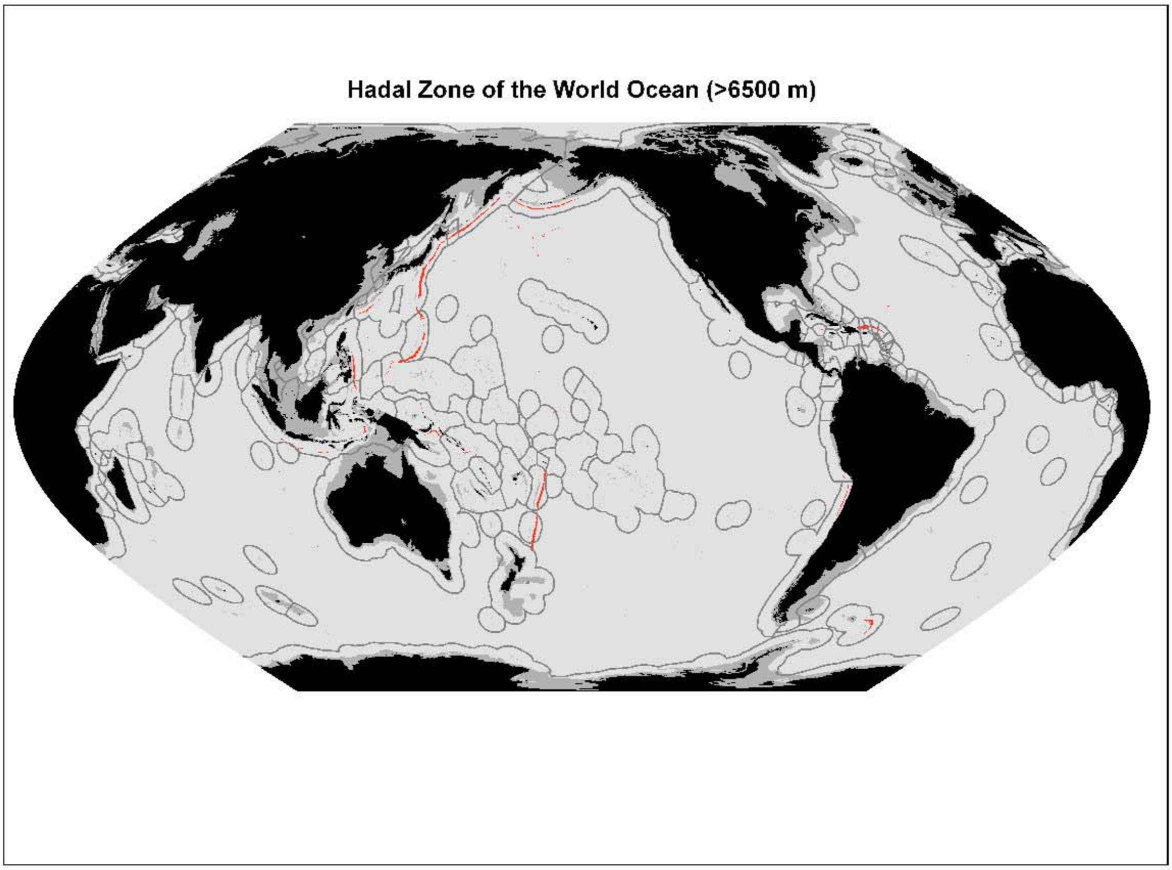


**Figure 7: Hadal zone (>6500 m) of the world ocean.**
Most of the hadal zone is within national jurisdictions, the major exception being the Romanche Trench in the Atlantic (too small to show on this map).

## Hydrography of the World Ocean

There have been many summaries of water mass characteristics of the World Ocean, one of the latest and most comprehensive being that of Tomczak and Godfrey (1994). However, as with many of the earlier presentations, variables important to our understanding of biogeography such as temperature and dissolved oxygen, are given broadly only for the surface and abyssal waters with one meridional profile deemed sufficient to characterize the ocean basin interior. Over the last decades, however, most of the hydrographic data taken during research cruises has been compiled by NOAAs National Oceanographic Data Center and is available online (**www.nodc.noaa.gov**). One can generate maps online or download data for later processing. We have used both approaches: the online maps are useful for quick visualization of patterns and the downloaded data were used to make GIS layers for temperature, salinity, and dissolved oxygen.

From the perspective of using hydrographic data in the pursuit of biogeographic units within the World Ocean, only the major features associated with the large ocean basins will be discussed. Because species distributions are limited vertically as well as horizontally, hydrographic patterns will be summarized at depth intervals of 800, 2000, 3500, and 5500 m. The hydrographic data are plotted on the bathymetric maps in a manner that emphasizes the contact of the water with the benthos at the probable biogeographic change depths of 800, 2000, 3500, and 5500 m.

Temperature

At 800 m (Figure 8) water temperatures differ significantly among the major ocean basins. The Arctic is very cold, below 0 C, as is the Southern Ocean. A steep front exists along the northern border of the Southern Ocean with temperatures rising from 3 to 6 C over a distance as short as 5 degrees of latitude. Particularly steep gradients occur north and west of the Kerguelen Plateau south of the Indian Ocean. The gradient becomes less steep entering the Pacific and is very weak in the South Atlantic. As a consequence, at 40 S the Atlantic is the coldest ocean with water about 4 C, the Pacific slightly warmer at 4 C in the east and 7 C in the west. North of the convergence the Indian warms quickly to around 9 C at this depth. The Indian overall is warmer (6-10 C) than the Pacific (3.5 – 6 C). The Atlantic, however, is cold in the south, but due to the effects of the Gulf Stream and Mediterranean outflow warms to more than 10 C between 20 to 40 N.

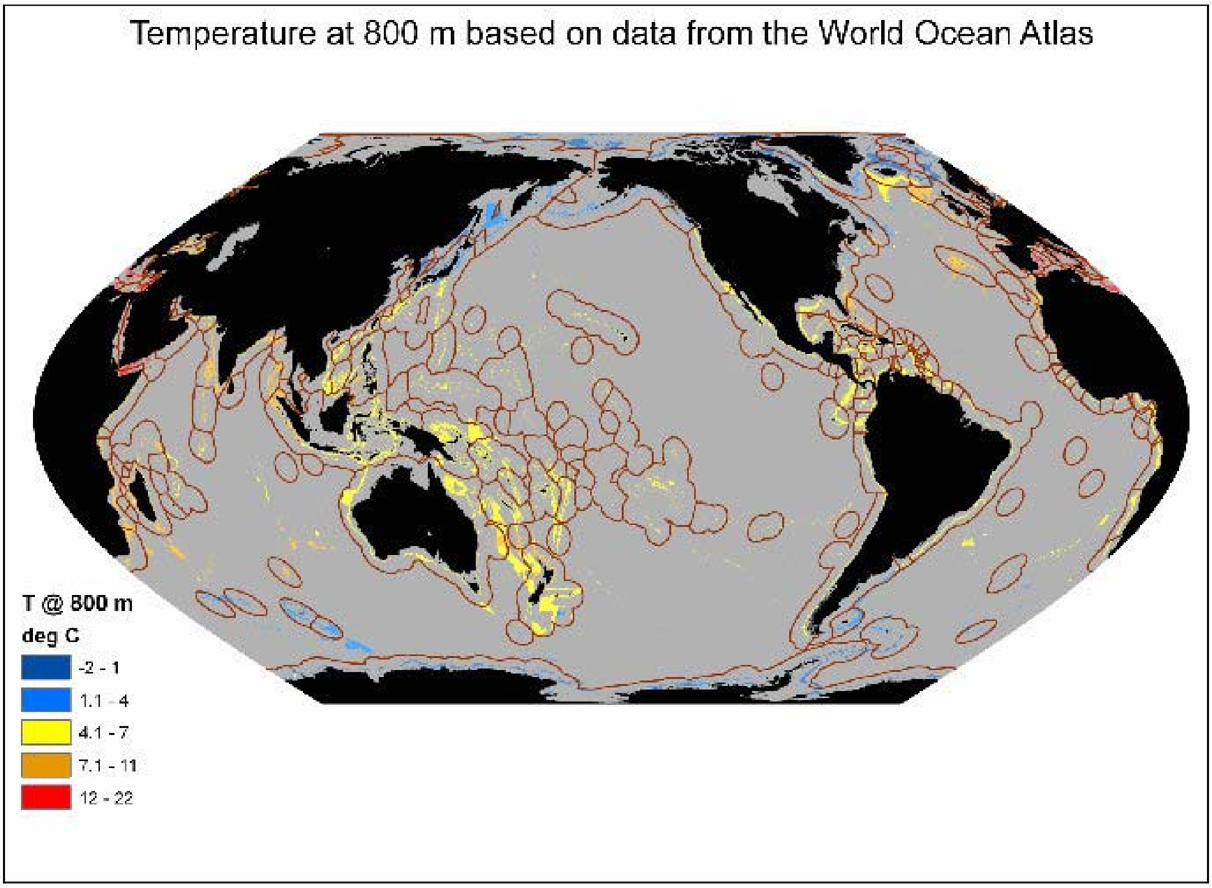


**Figure 8: Bottom water temperature at 800 m.**

At 2000 m (Figure 9) the water has cooled considerably in the Indian Ocean, being about 2.5 to 3 C everywhere north of 40-45 S. The Pacific over most of its area at this depth is about 0.5 degrees cooler, but the Atlantic shows a more complicated and warmer temperature pattern. At this depth the water is for the most part between 3 and 4 C, flowing southward and incorporating some features of Labrador Sea Water and lower Mediterranean Outflow Water. The latter is particularly evident west of the Straits of Gibraltar. The Southern Ocean is coldest to the east of the Weddell Sea, the latter being the locus of formation of Antarctic Bottom water, and warmest south of the eastern Pacific.

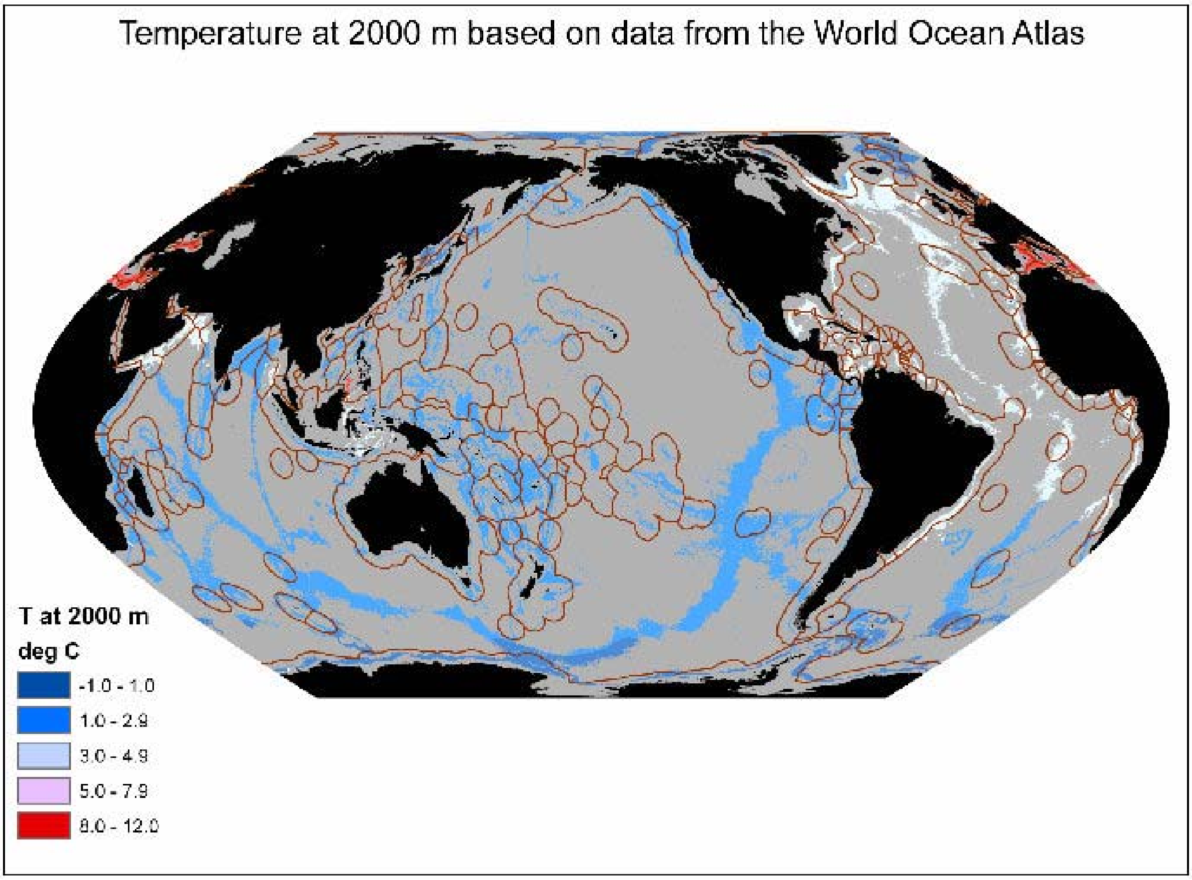


**Figure 9: Water temperature at 2000 m, with 2000 – 3500 m depth interval visible.**

The ocean basins become more subdivided by topography at 3500 m. While there is no noticeable change in the temperature regime in the Southern Ocean, the effects of

Antarctic Bottom Water is clearly seen in both the Indian and Pacific Oceans, where temperatures are between 1.25 and 1.5 C over most of the area (Figure 10). Exceptions are the NW Indian Ocean and the southeastern Pacific where waters can reach 2 C. The Atlantic remains the warmest of the major basins, being about 2.5 C over most of the eastern basins. The coldest parts of the Atlantic are in the Cape Basin on the east side and the Argentine and Brazil basins on the west side. They are more subject to Antarctic Bottom Water whereas all the basins northward are more influenced by the slightly warmer North Atlantic Deep Water.

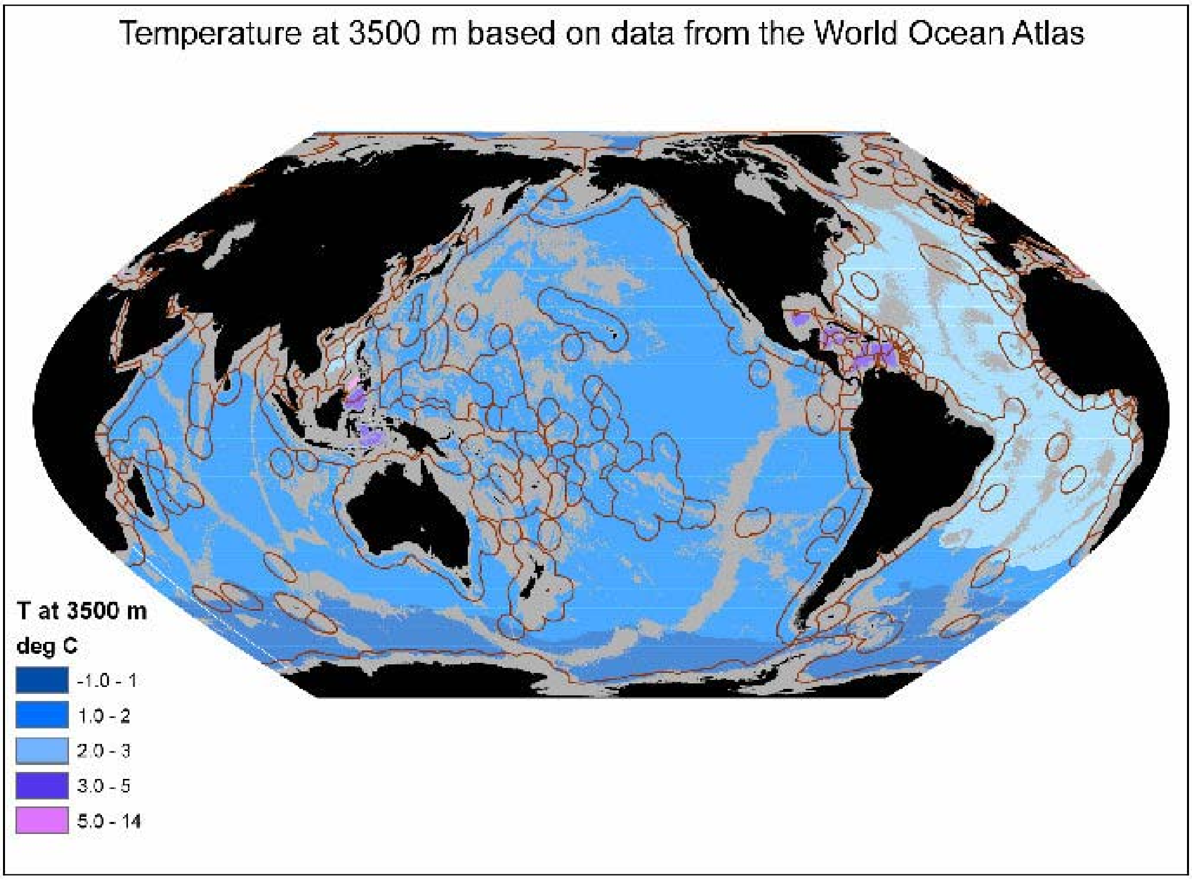


**Figure 10: Water temperature at 3500 m, with depths 3500 – 5500 m visible.**

The deepest parts of the ocean basins, at 5500 m (Figure 11) reflect the temperature pattern seen at 3500 m, the major exception being the NW Atlantic, where the deep waters have cooled slightly to 2.25 C, and the deep water in the Weddell Sea and eastward, where bottom temperatures are below 0 C.

Temperature gradients can also indicate the location of frontal zones, where water masses meet and mix. The major surface water convergence areas (e.g. Subtropical Convergence, Antarctic Convergence) signify large changes in water characteristics, such as between Antarctic, Temperate, and Tropical waters. Many species do not cross such boundaries, because of physiological limitations to either adults or their early life stages. These convergence zones may not extend below upper bathyal depths, but the "downstream" effects of increased productivity, etc., may well influence benthic composition or abundance.

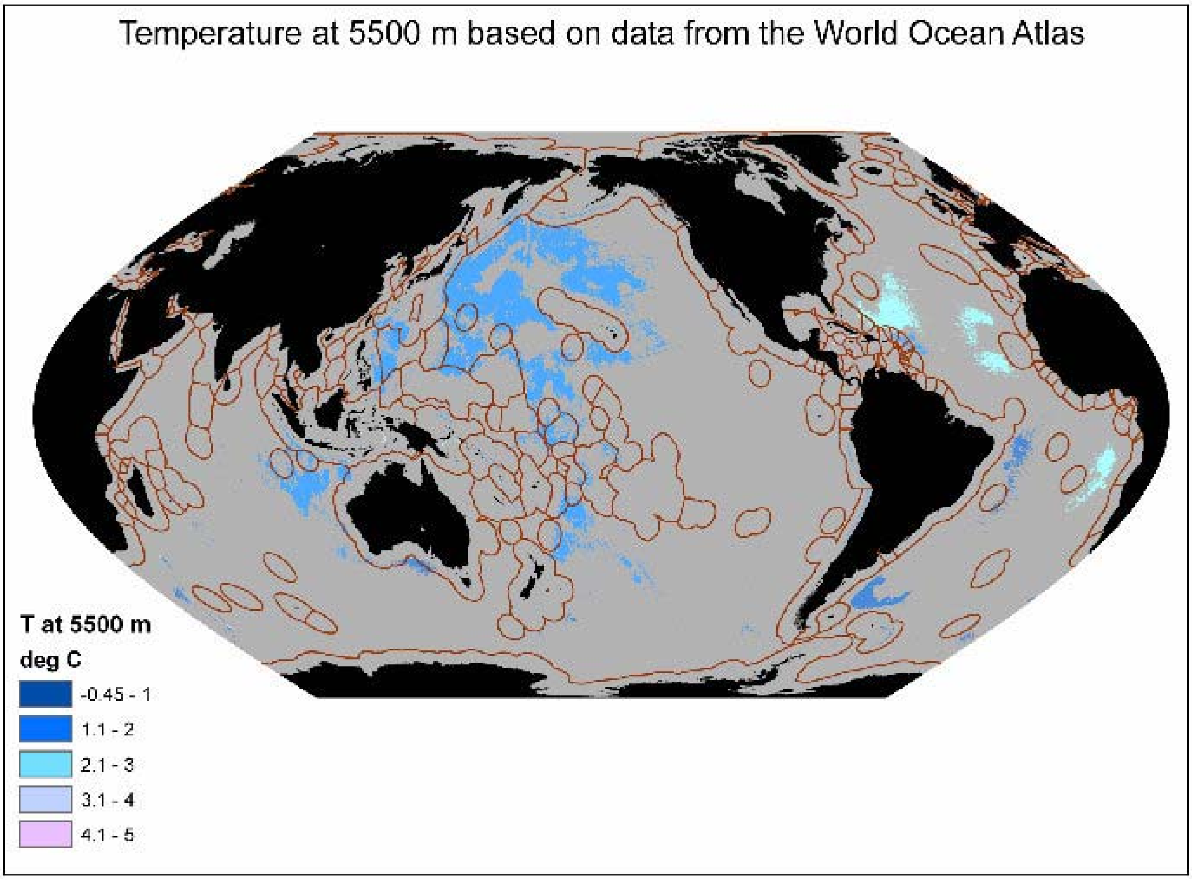


**Figure 11: Water temperature at 5500 m with 5500 – 6500 m depth interval visible.**

## Salinity

The salinity structure of the World Ocean does not vary by much more than 1 psu (practical salinity unit) over most of the area and at all depths. However, salinity levels, and salinity gradients, can indicate different water masses which can determine species distributions. One of these water masses, Antarctic Intermediate Water, is characterized by a salinity minimum at around 1000 m in the South Pacific. The profile at 800 m (Figure 12) shows clearly that this water mass does not extend northwards into the North Pacific, and many deepwater fish species associated with such water do not occur in the northern Pacific (e.g. orange roughy, oreos). Other areas where salinity is very different are at 800 m in the NW Indian Ocean where the salinity may be over 36, and in the North Atlantic where the salinity is influenced by the Gulf Stream and Mediterranean outflow. Because of the Gulf Stream the high salinity water extends as far north as the Iceland-Faeroes Ridge on the eastern side of the Atlantic. In deeper water, the salinity becomes more uniform, but at 2000 m (Figure 13) one can still see the influence of the waters above. This trend continues to 3500 and 5500 m (Figure 14 and Figure 15), but at these depths only the Atlantic and Arctic Oceans have salinities at or above 34.9.

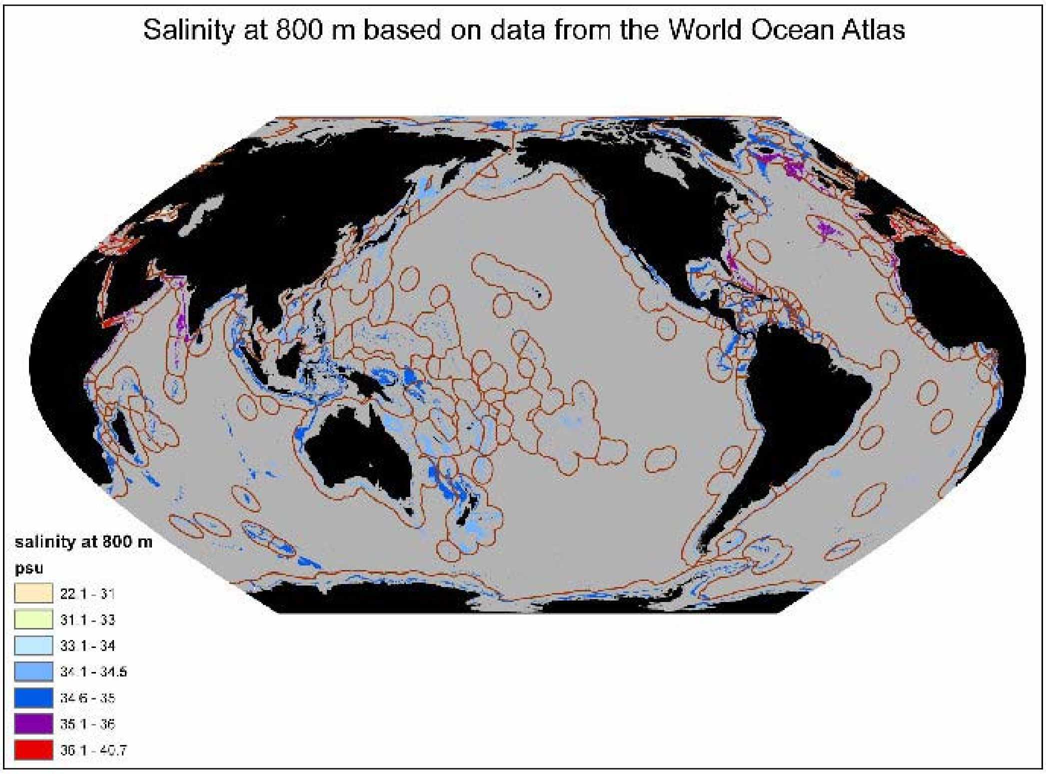


**Figure 12: Bottom water salinity at 800 m.**

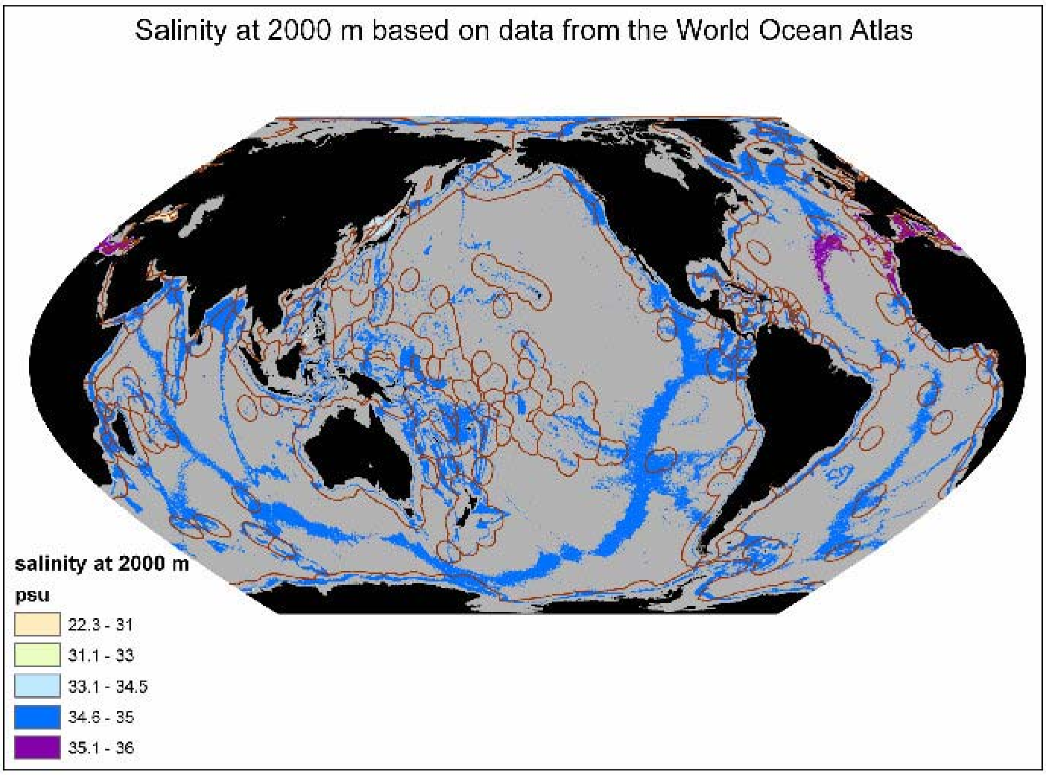


**Figure 13: Salinity at 2000 m, with 2000 – 3500 m depth interval visible.**

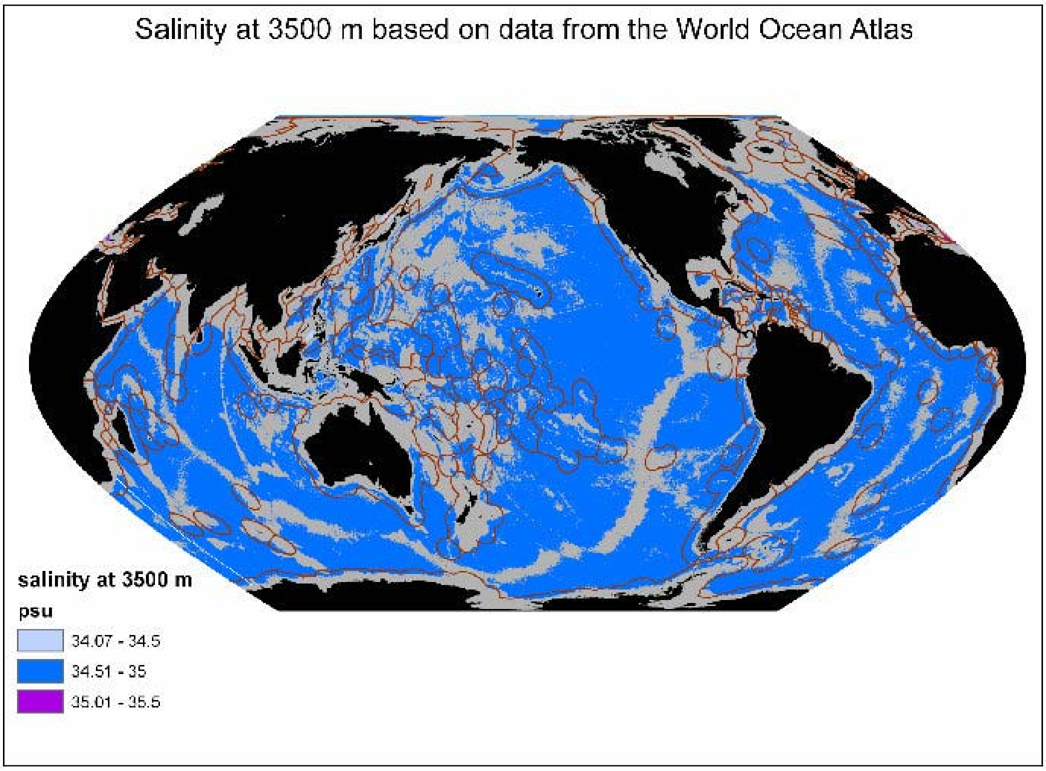


**Figure 14: Salinity at 3500 m, with 3500 – 5500 m depth interval visible.**

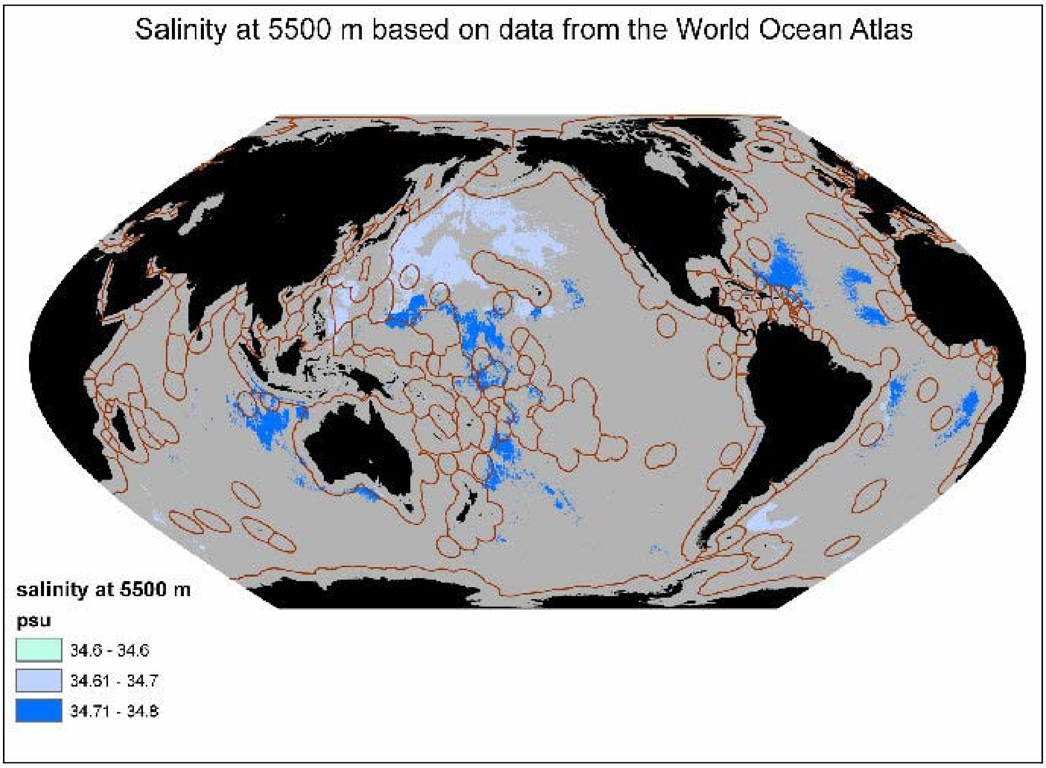


**Figure 15: Salinity at 5500 m, with 5500 – 6500 m depth interval visible.**

## Oxygen

As with temperature, oxygen is important to determining the presence of species in various parts of the ocean. Oxygen values vary over a wide range, highest values generally associated with the colder, deeper, and younger waters. At 800 m (Figure 16) those waters are in the Arctic, which has dissolved oxygen concentrations at about 7 ml/l, and the Antarctic Intermediate Water in all three major basins where values are between 5 and 5.5 ml/l. Very strong oxygen minima (<1 ml/l) occur at this depth in the northern Indian and eastern and northern Pacific Oceans. The Atlantic oxygen minimum is much higher, about 2.5 ml/l off the coast of NW Africa.

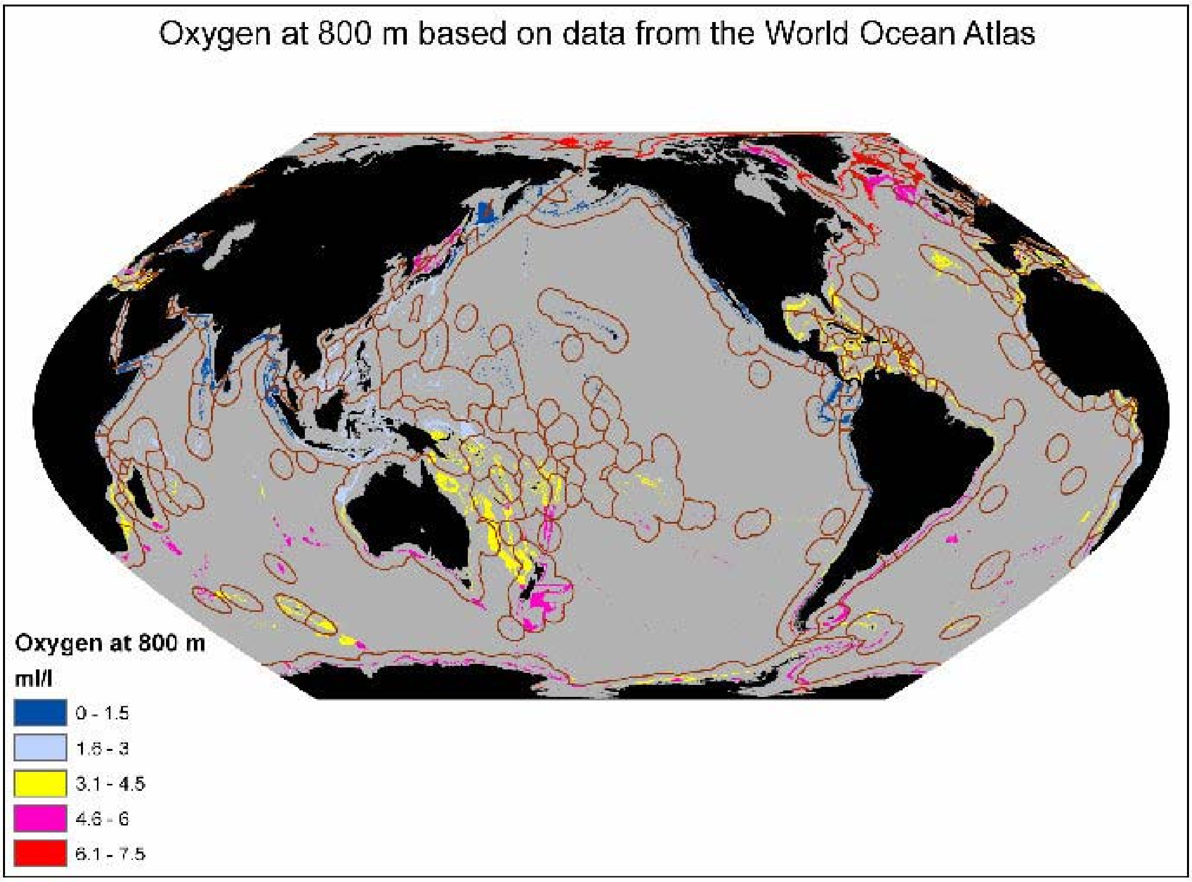


**Figure 16: Dissolved oxygen concentration at 800 m.**

At 2000 m the influence of the upper Antarctic Bottom Water can be seen in both the Indian and Pacific Oceans where dissolved oxygen values are between 3 and 4 ml/l over most of the southern portions of both basins (Figure 17). In the Pacific, oxygen is consumed by decomposition processes as the water moves slowly northward, resulting in values below 2 ml/l at 45 N. In contrast, Atlantic waters at this depth are very highly oxygenated (6.5 to 5.5 ml/l, north to south) due to the southward flowing North Atlantic Deep Water.

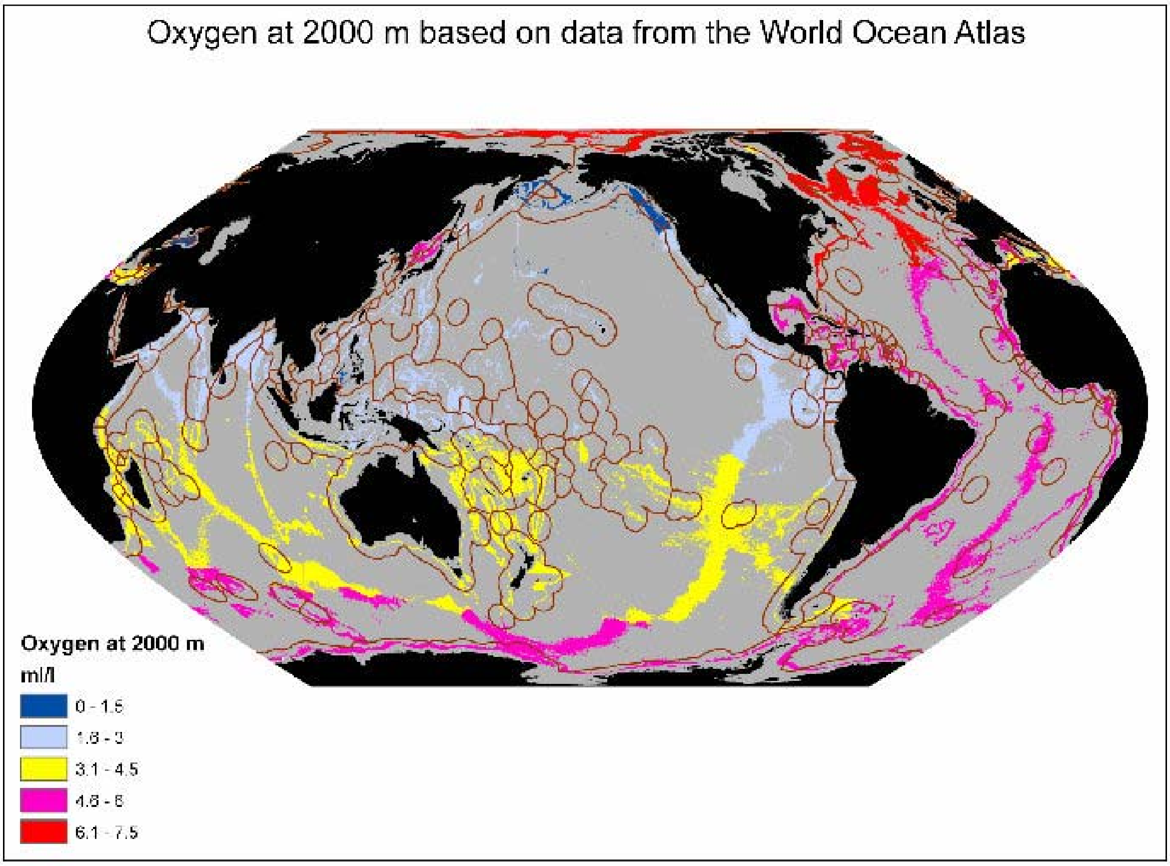


**Figure 17: Dissolved oxygen at 2000 m, with 2000 – 3500 m depth interval visible.**

From 3500 m to the deepest parts of all the basins the pattern of dissolved oxygen follows that seen at 2000 m (Figure 18 and Figure 19). However, in the Indian and Pacific basins, the better oxygenated Antarctic Bottom Water has spread all the way to the northern reaches, so that dissolved oxygen values are always more than 3 ml/l. The pattern established in the Atlantic at 2000 m carries all the way to the bottom, where except for the Argentine and Cape Basins, dissolved oxygen concentrations are at least 5.2 ml/l and are about 6 ml/l in the NW Atlantic basin.

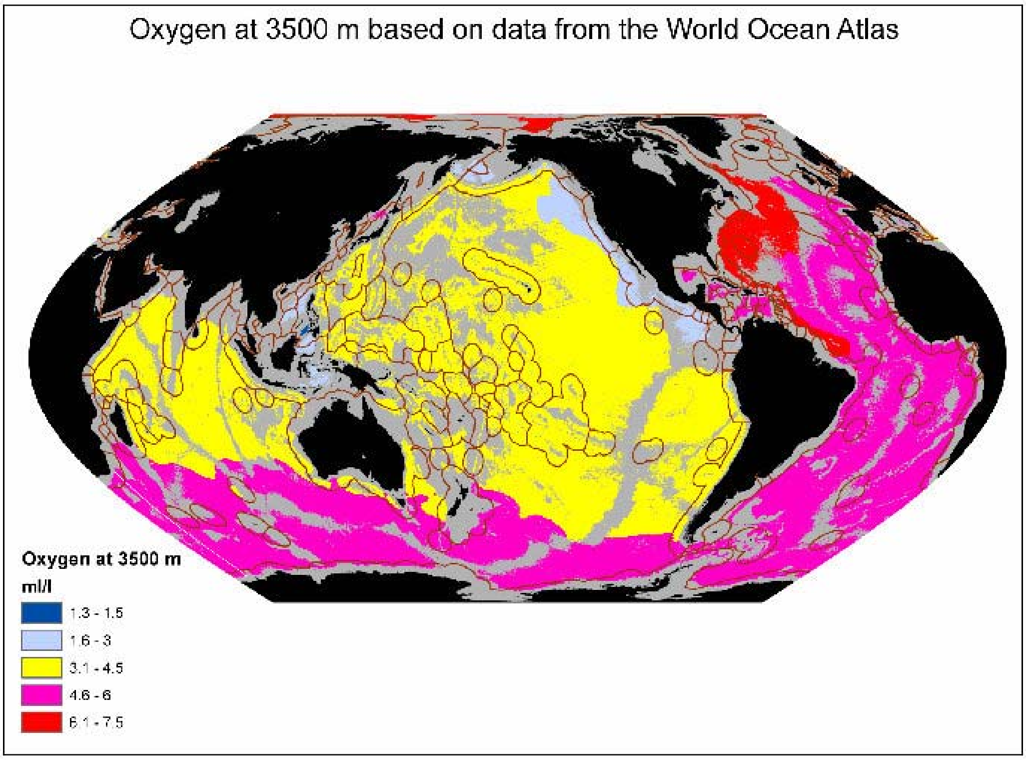


**Figure 18: Dissolved oxygen at 3500 m, with 3500 – 5500 m depth interval visible.**

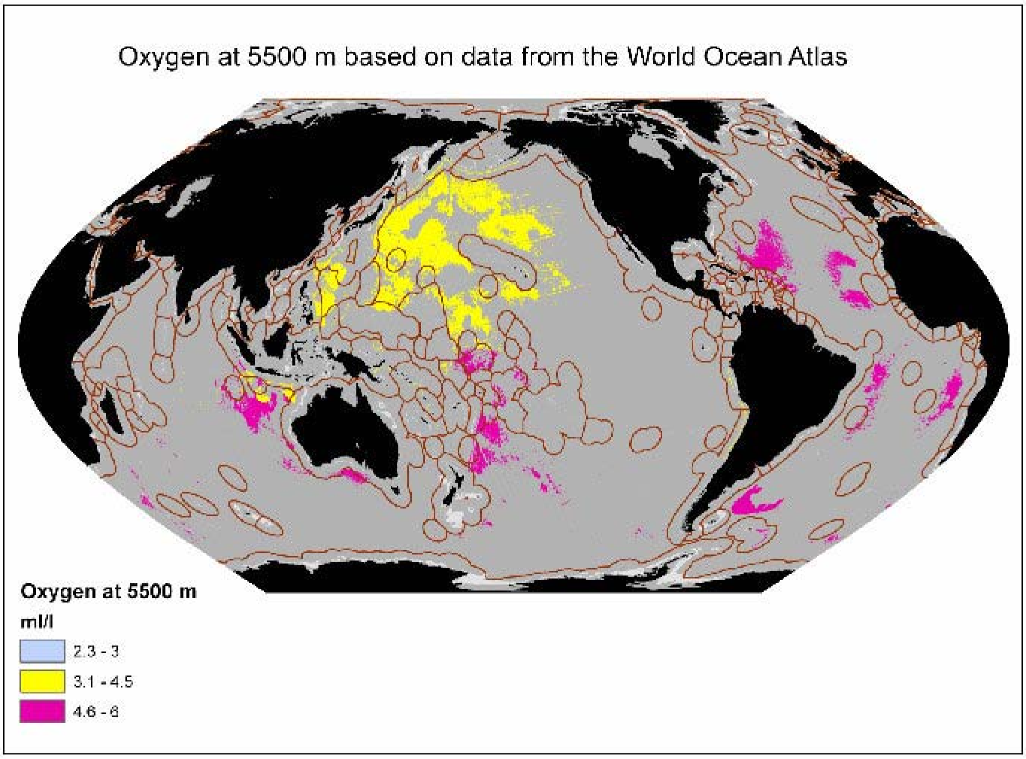


**Figure 19: Dissolved oxygen at 5500 m, with 5500 – 6500 m depth interval visible.**

Organic matter flux

With the exception of communities in the vicinity of hydrothermal vents, the benthos at depths below about 200 m relies on deposition of organic matter produced in the upper, photic zone, of the water column for their food input. Modelling this input has long been a problem, with most information coming from widely scattered sediment traps. The advent of space-based remote sensors promised the possibility that phytoplankton production over the whole ocean could be measured. However, the link between phytoplankton biomass and production is not easily modelled and deposition of phytoplankton cells to the seafloor is influenced by a multitude of factors, not the least of which is the degree of turbulent mixing in the upper 500 m. If mixing is strong and production slight, most of the production is consumed in the upper part of the water column and very little makes it to the deep sea floor. On the other hand, if production is strong (for example during seasonal blooms or due to constant influence of upwelled, nutrient-rich, deep waters), then a larger proportion of the new production would settle to the bottom. From the Yool (2007) model (Figure 20) it can be seen that areas downstream of upwelled water (eastern Pacific especially 20-30 N and S of the equator, southeastern Atlantic) and under strong currents (NW Pacific and NW Atlantic), as well as in areas of strong fronts (Sub-Antarctic Convergence) all show high levels of export of organic matter out of the 500 m depth layer. One might expect the benthos in these areas to have higher biomass and diversity compared to areas in the same biogeographic unit where organic matter input is less.

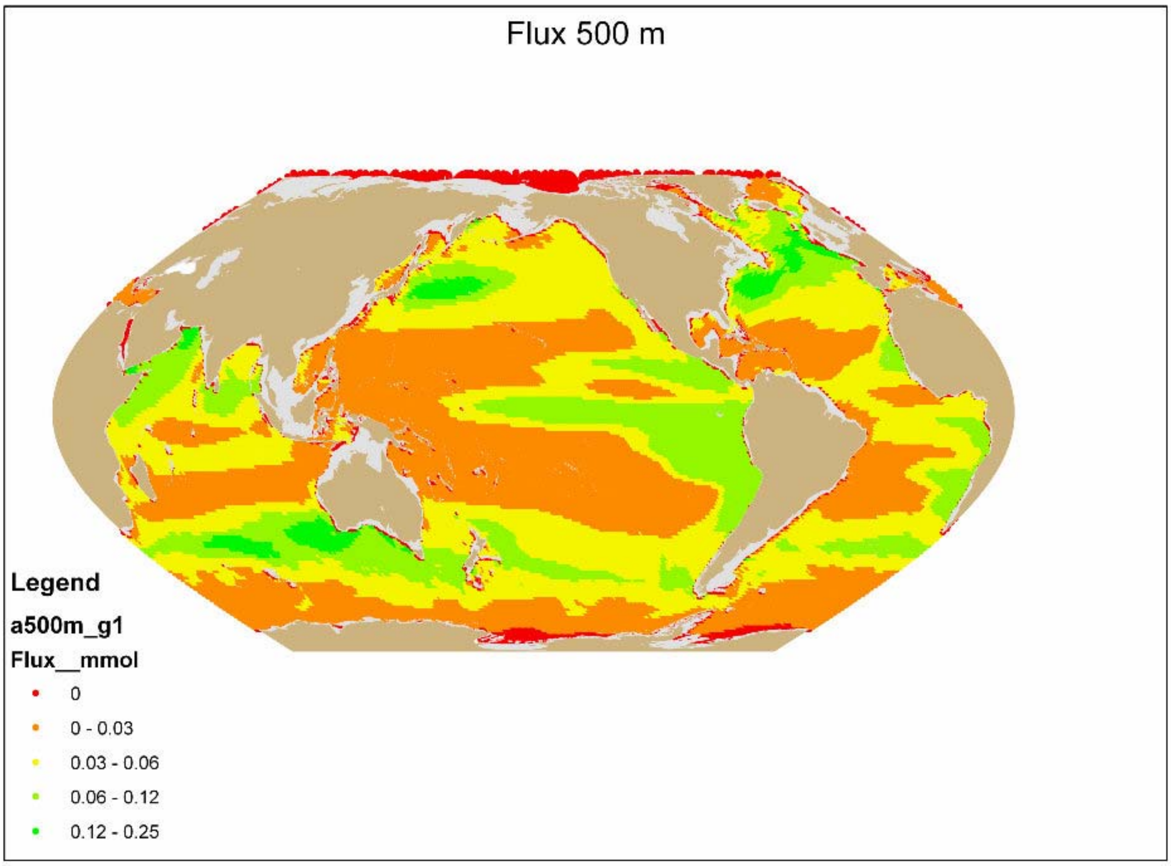


**Figure 20: Map of estimated flux of organic matter.**
Measured in mmol N m-2 d-1 passing through the 500 m depth layer as modelled by Yool et al. (2007). This model is less accurate at high latitudes where the mixed layer depth may be greater than 500 m.

### Hydrography Summary

From a benthic biogeographical perspective it seems clear that the hydrographic variables of importance are temperature and dissolved oxygen, although salinity can be used to characterize certain water masses such as Antarctic Intermediate Water. These three factors differ considerably in various parts of all ocean basins. The greatest differences are at 800 m, but only a small proportion of high seas benthic habitat exists at that depth. On the other hand, the lower bathyal, consisting of large mid-ocean ridges as well as seamounts, are found at depths in the ocean where temperatures and dissolved oxygen values differ from ocean to ocean, especially between the Indian, Pacific, and Atlantic, as well as among the smaller basins of the Atlantic. Hydrographic factors then may provide clues to potential province distribution, which can be tested as more species distributional data, especially at bathyal depths, becomes available.

## 6.3 Proposed benthic biogeographic units

The benthic biogeographic units adopted here start with the concepts regarding regions and provinces promoted by Menzies et al. (1973) and Vinogradova (1979) for the abyssal areas, Belyaev (1989) for the hadal (ultra-abyssal) areas, and Zezina (1973, 1997) for the bathyal. In this proposal, boundaries are altered on the basis of more recent data, some of them published and cited in the review (see Annex), and others being unpublished observations or re-analyses of existing data. In particular, the lower bathyal zone is being explored by means of ROV or submersible dives occurring primarily along the Aleutian and Hawaiian Ridges in the Pacific, on the Corner Rise and New England Seamounts in the North Atlantic, and through trawl studies around New Zealand and from the Reykjanes Ridge to the Mid-Atlantic Ridge region off the Azores.

Our proposed deep sea benthic biogeographic classification encompasses at present three large depth zones: the lower bathyal, 800-3500 m, the abyssal, 3500-6500 m, and the hadal, which is found only at depths greater than 6500 m, primarily in the trenches. We have not given much consideration to the upper bathyal, depth range 300-800 m, because almost the entire bottom at that depth is within the EEZ of one country or another. We also readily acknowledge that the lower bathyal covers too broad a depth range, and may warrant further splitting at around 2000 m where there are marked changes in species composition or diversity for a number of taxa (e.g., demersal fish). The hadal is also for the most part encompassed by the EEZs of various countries; however, the biogeographic provinces for that realm are well-established through the work of Belyaev (1989).

All of the provinces proposed below are to be considered as hypotheses that need to be tested with species distribution data as the latter can be compiled into digital (GIS) form, especially for the lower bathyal where data are sparser. One would expect that the deeper provinces are more likely to withstand additional species distribution information than are the shallower provinces. In fact, the least robust of all the classification hypotheses are those for the bathyal. On the other hand, the abyssal classification most likely won't change much for the Atlantic Basins, the pattern for which has been tested using the distributions of deep sea protobranch bivalves (Allen & Sanders 1996). The Indian and Pacific Ocean basins are much less well studied and the patterns have been deduced using the Russian literature and proxies such as temperature and organic matter input.

Lower Bathyal Provinces (Figure 21)

As has been noted, the bathyal is not that well known even today. Proposed biogeographic provinces and their approximate coverage include:

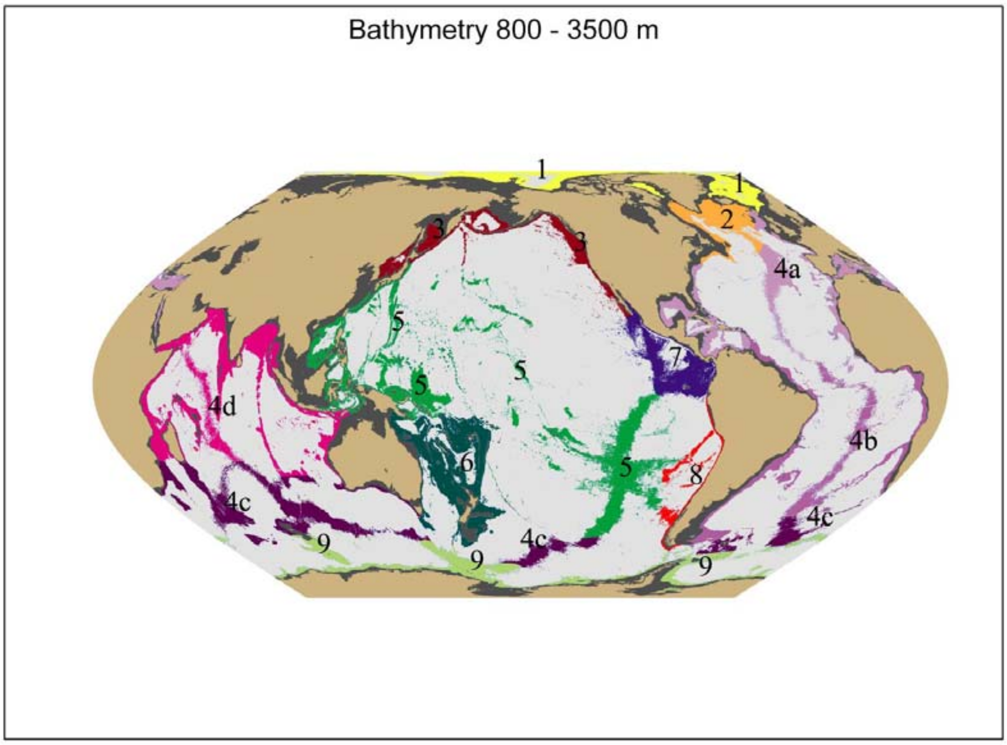


**Figure 21: Map of lower bathyal provinces. Depth range 800 to 3000m.**

**1. Arctic**, including entire Arctic Ocean Basin and Norwegian-Greenland Sea in the east and to the Bering Strait in the west;
**2. North Atlantic Boreal**, from the Iceland-Faroe Ridge in the north south along the Reykjanes Ridge, over the Newfoundland Seamounts and following the Western Boundary Undercurrent southward along the eastern slope of North America to off Cape Hatteras;
**3. North Pacific Boreal**, along the Aleutian Ridge in the North through the Gulf of Alaska to approximately the Mathematicians Seamounts in the eastern Pacific and including the Emperor Seamounts and the area off Hokkaido in the west;
**4. Central Atlantic-Indian-South Australian**, perhaps divided into
**4a, North Atlantic**,
**4b, South and Central Atlantic**,
**4c, Southern Indian**, and
**4d, Central and Northern Indian** sub-units; includes all of the Mid-Atlantic Ridge from the southern extension of the Reykjanes Ridge to the junction with the Walvis Ridge in the south, all of the Indian Ocean from about 40 S northwards and easterly to encompass the Antarctic Intermediate Water south of Australia, including seamounts off Tasmania;
**5. Pacific**, from Hokkaido southward to seamounts along the Mariana Ridge to the Solomon Islands and Fiji, probably extending eastward beyond the East Pacific Ridge to about 83 W off Chile and Peru; it may be that this province will need subdivision to separate the western part from the central and eastern areas.
**6. New Zealand-Kermadec**, plateaus around New Zealand and extending northward along the Kermadec and Lau Ridges almost to Tonga;
**7. Cocoplatensis**, encompassing all the ridges and seamounts of the Cocos Plate;

**8. Nazcaplatensis**, suggested by Parin et al. (1997) to encompass the ridges of the Nazca Plate;
**9. Antarctic**, both east and west, with subdivisions centered on the Weddell Sea eastward to the Macquarie Ridge and from Ross Sea to the Antarctic Peninsula.

Abyssal Provinces (Figure 22)

The abyssal provinces have been designated based on the deep basin(s) in which they occur. The scheme heavily modifies that of Menzies et al. (1973) and Vinogradova (1997) based on newer data.

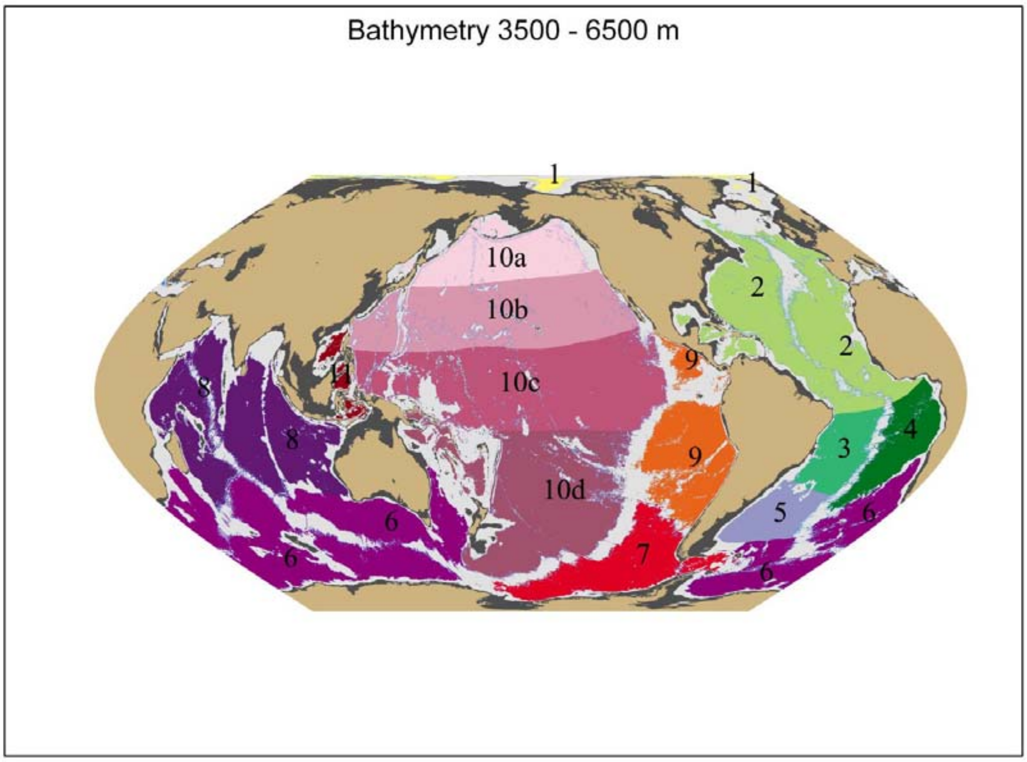


**Figure 22: Map of the abyssal provinces. Depth range 3500 to 6500 m.**

**1. Arctic basin**;
**2. North Atlantic**, including all areas north of the equator under the influence of North Atlantic Deep water;
**3. Brazil Basin**;
**4. Angola and Sierra Leone Basins**;
**5. Argentine Basin;**
**6. Antarctic East**, which includes the areas where very cold bottom water flows into Cape, Agulhas, Natal, and Crozet and South Indian Basins and perhaps the Tasman Sea to about 170 E;
**7. Antarctic West**, includes the Amundsen Plain in the region from the Ross Sea to the Antarctic Peninsula and north to the Antarctic-Pacific Ridge and the Southeast Pacific Basin;
**8. Indian Ocean**, including all the basins north of approximately 30 S (this region is not well studied and some parts of this province may have species following the Antarctic Bottom Water northward);

**9. Chile-Peru-Guatemala Basins**, also includes the smaller Panama Basin and other minor deep areas east of the East Pacific Rise and north of the Chile Rise;
**10. Pacific Ocean**, encompassing the entire Pacific from the Antarctic and East Pacific Ridges in the south-east to the Aleutian ridge in the north and all of the abyssal depths in the western Pacific (divided into sub-units from north to south based on projections of food delivery from the photic zone as well as general decline in dissolved oxygen from south to north).

Hadal Provinces (Figure 23)

No changes are made to the scheme presented by Belyaev (1989), which includes:

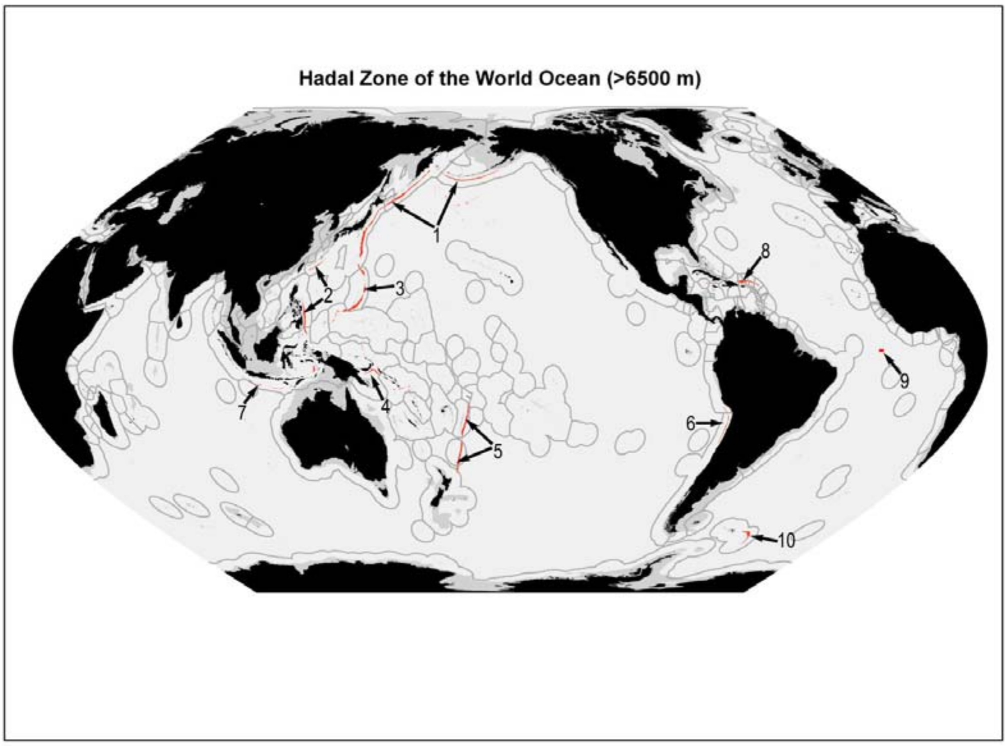


**Figure 23: Map of the hadal provinces based on the scheme presented by Belyaev (1989). Depth > 6500 m.**

## Pacific Ocean Subregion:

**1. Aleutian-Japan Province** (Aleutian, Kuril-Kamchatka, Japan, Izu-Bonin Trenches),
**2. Philippine Province** (Philippine and Ryuku Trenches),
**3. Mariana Province** (Volcano, Mariana, Yap and Palau Trenches),
**4. Bougainville-New Hebrides Province** (New Britain, Bougainville, Santa Cruz, and New Hebrides Trenches),
**5. Tonga-Kermadec Province**,
**6. Peru-Chile Province**.
Indian Subregion:
**7. Java Province**.

### Atlantic Subregion:

**8. Puerto Rico Province** (Puerto Rico and Cayman Trenches)
**9. Romanche Province**.
Antarctic-Atlantic Subregion:
**10. Southern Antilles Province**

Hydrothermal Vent Provinces (Figure 24)

The scheme below follows that of Van Dover et al. (2002), updated by Van Dover (unpublished). The hypothesized provinces and their relationships are indicated by dashed lines in the figure according to the ridge system on which they occur.

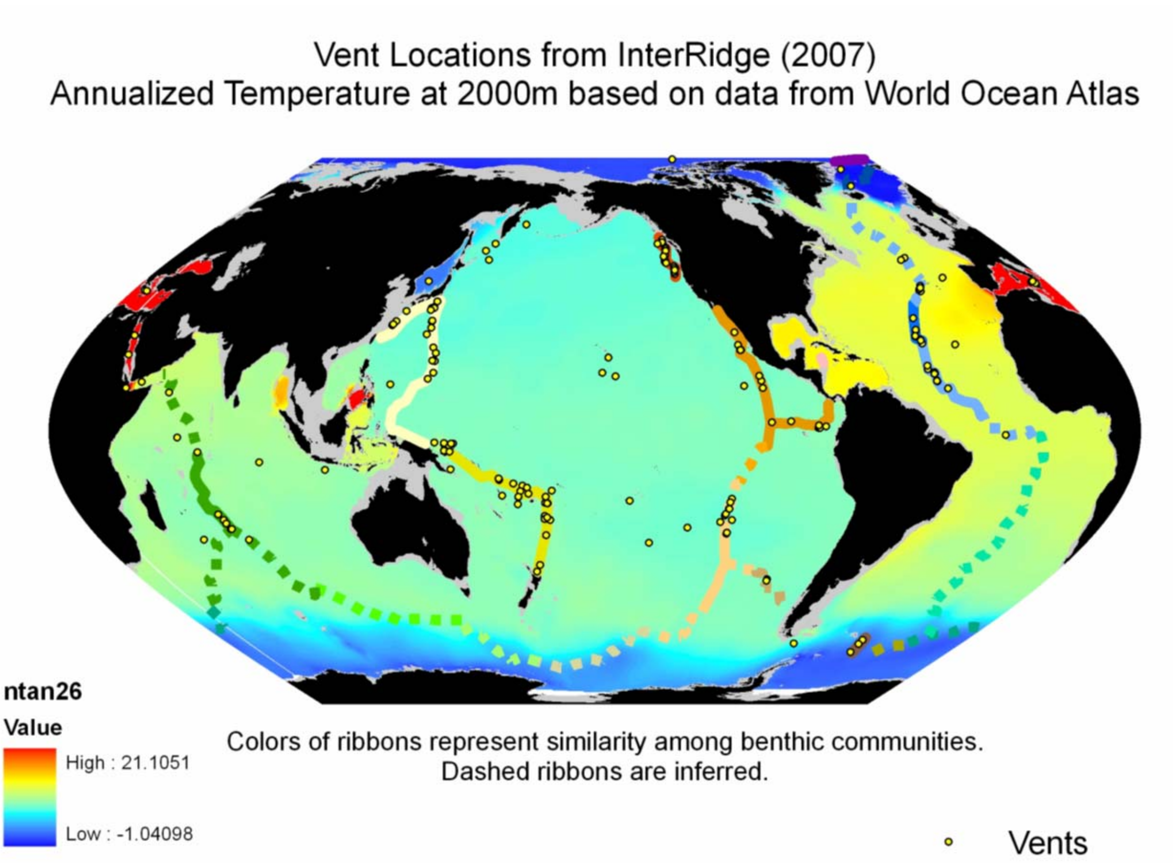


**Figure 24: Map of the hydrothermal vent provinces. Scheme follows that of Van Dover et al. (2002).**

## Pacific Ocean

**1. East Pacific Rise**, encompassing all of the East Pacific Ridge from about the challenger Fracture Zone to the ridges surrounding the Cocos Plate.
**2. Southern East Pacific**, including southern section of the East Pacific Rise, the Chile Rise and the Pacific-Antarctic Ridge.
**3. Western Pacific Back-Arc Spreading Centers**, including all of the ridges on the western edge of the Pacific Plate as well as around the small plates in the region.
**4. Northeast Pacific Ridges**, encompassing the ridges of the Juan de Fuca Plate.

### Atlantic Ocean

**5. Mid-Atlantic Ridge North**, in the region from 15 to 30 N, could be extrapolated to include the MAR south to the equator.
**6. Azores**, includes the part of the MAR in the region of the Azores; not know whether this province extends north to Iceland because of the deepening of the ridge or whether the Mid-Atlantic Ridge Province exists in this deeper area north of the shallower Azores Province.
**7. Mid-Atlantic Ridge South**, hypothesized province, but no data currently exist.

### Arctic Ocean

**8. Arctic**, including the Mohns Ridge north of Iceland and the various vent sites in the Arctic Basin.

### Southern Ocean

**9. East Scotia Ridge**, hypothesized province, data not yet available.

### Indian Ocean

**10. Central Indian Ridge**, encompasses the region where the Mid-Indian, Southwest Indian, and Southeast Indian Ridges meet. It is likely the fauna of this province extends to varying degrees along each of the two southward trending ridges, and that some part of each ridge may belong to its own province.

#### Robustness of classification system and further work

All of the proposed provinces are to be considered as hypotheses that will be tested with species distribution data as they can be compiled, especially for the lower bathyal where data are more sparse. Among the different analytical approaches available, the use of Multivariate Regression Tree (MRT) analysis has been used to delineate biogeographic provinces based on the community composition data (Bachraty et al., 2007). Non metric, multidimensional scaling techniques combined with hierarchical clustering have been used to compare similarities at the generic level among regions with hydrothermal vent activity. Redundancy analyses (RDA) performed on abundance as well as on presence/absence data with Hellinger transformation have been used at the regional level (Vaillette et al., 2007) in areas without hydrothermal vent activity. Since all of the base maps used here are in GIS format, species distribution data will also be assembled in a GIS database and the existence of provinces tested using spatial analysis techniques.

## 7. Strategy for nesting with other existing classification systems

It is important that the Global Open Oceans and Deep Seabed (GOODS) biogeographic classification be compatible with existing global and regional biogeographic classification systems, which are described in section 3.1 of this report. Particular attention was paid to the compatibility between GOODS biogeographic classification and the Marine Ecoregions of the World (MEOW) (Spalding et al 2006). MEOW is the newest classification system covering coastal areas and continental shelves, and it is based on an extensive review and synthesis of existing regional and national classification systems, as well as expert consultation (see Figure ). Because the MEOW classification has already provided for congruence between key biogeographic boundaries on the national and regional level in coastal and shelf waters, compatibility between MEOW and GOODS will allow for a nested classification system that incorporates the finer-scale classifications in coastal waters on national and regional scales with the larger spatial units in the open ocean and deep sea area. The MEOW classification is displayed in section B of the Annex.

The GOODS and MEOW systems are compatible in terms of approaches and definitions, and this compatibility was enhanced through the participation of one of the principal authors of MEOW in the GOODS process. It should be noted, though, that because of the biogeographic realities of oceanic systems, classifications developed for shelf areas and deep and open ocean areas will always have some overlapping or fuzzy boundaries. Purely pelagic species often visit continental shelf areas, and many partly pelagic species are linked to the continental shelf for some stages of their life history. There may also be some apparent mismatches of boundaries, but these could generally represent true biological changes caused by the influence of the continental shelf.

It is important that the GOODS biogeographic classification be considered in conjunction with finer scale biogeographic classifications that have been adopted or developed e.g. for the Southern Ocean and for the OSPAR maritime area, and which provide a finer scale delineation of biogeographic classes. On the higher levels of a nested hierarchy, the GOODS classification is compatible with these regional systems. Any regional efforts towards identifying and/or developing representative networks of marine protected areas are most appropriately undertaken using these regional systems.

Compatibility is also affected by the mandate of the GOODS biogeographic classification to concentrate on marine areas beyond EEZs, which are political, not biological features. The MEOW classification system was developed for areas from coastlines to the 200 m depth contour. The expert group agreed that the complementarity between the two systems could be enhanced if:

1. The high seas pelagic classification system should continue across EEZ boundaries into adjacent waters, whenever the distribution of the underlying oceanographic features and species groups continued into the EEZ. This would ensure the capture of important units such as many boundary currents and their biological assemblages.
2. The small slivers of high seas above 200 m would not be to be treated as special for the purpose of delineating biogeographic zones.
3. The gap between GOODS and MEOW in the 200-300 m depth contour be addressed.

Even with these two practices employed, some marine areas do not fall into either system; particularly marginal seas and semi-enclosed ocean basins of the Caribbean, Gulf of Mexico, Mediterranean, Black Sea, Red Sea, Southeast Asian Seas. These basins were not addressed in the GOODS biogeographic classification, but they do warrant attention in future.

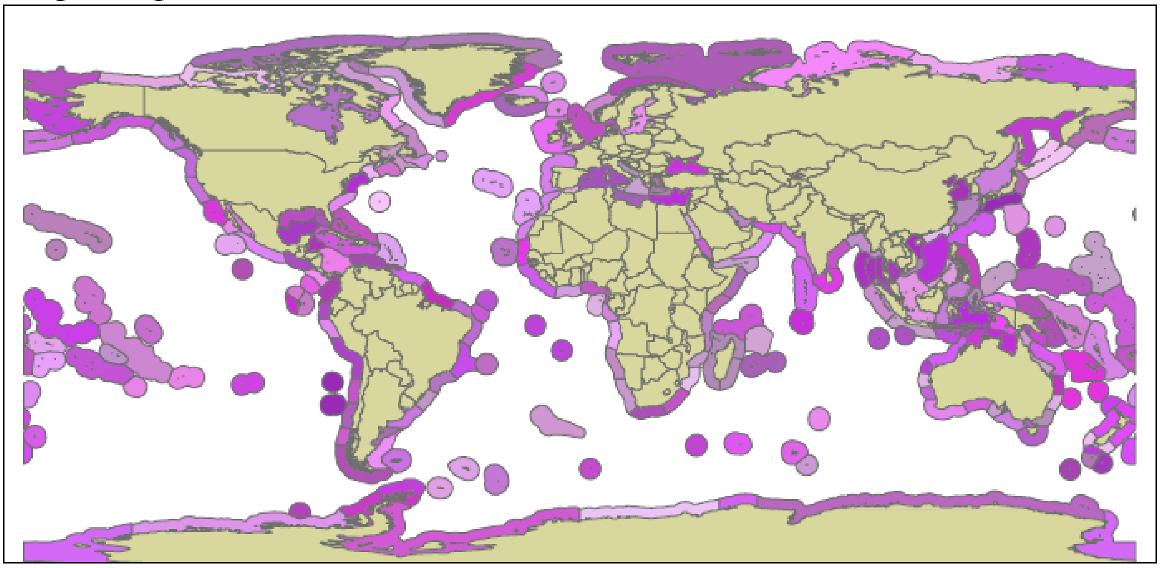


**Figure 25: The MEOW classification system.**

# 8. Gaps in scientific knowledge and further research needed

## 8.1 Limits of current biogeographic theory

Current biogeographic theory suffers from limited understanding of open ocean and deep sea ecosystems, as well as from a lack of knowledge about the vulnerability, resilience and functioning of marine biodiversity in these areas. Most marine scientific research activities have been conducted in shallow coastal waters where biodiversity is far more accessible than in remote deep sea environments, which require specialized technology and equipment to access. This is a direct result of the comparative lack of research funding for deep seas and open oceans, which cover vast areas of the planet. Furthermore, the multidisciplinary nature of the scientific questions of relevance to the deep sea, together with the great costs of research in areas which previously had been thought of as 'untouched', has meant that deep and open ocean research has been given a far lower priority than issues closer to home, which were seen as being of more direct relevance to day-to-day uses of the ocean.

Our knowledge about deep and open ocean areas beyond the limits of national jurisdiction is limited to a few thousand biological samples, and an uneven spread of both biological and geological samples across the globe that were collected in recent years, as documented by the Census of Marine Life (CoML) project on the diversity of abyssal marine life (CeDaMar). A map of published benthic species records deeper than 2000 m gathered thus far can be found on the CeDaMar website (http://www.cedamar.org/index.php?option=com_content&task=view&id=164&Itemid=117). These samples have provided for the description of patterns of species distribution in areas beyond national jurisdiction, and will, in the future, help our understanding of the composition and richness of species through ongoing programs such as CoML, and the associated Ocean Biogeographic Information System (OBIS).

It is with the help of OBIS programmes and other databases worldwide that this study provides the first/preliminary attempt at classifying the seafloor into distinct biogeographic classes. The work was driven by the hypothesis that environmental parameters define species distribution, and thus bioregions. The limited existing information available to us is severely skewed in its geographic and taxonomic spread, and is therefore inherently biased. This bias can be explained by the differences in research efforts in different ocean basins, the diverse technologies and methods used to explore and characterize the open ocean and benthic realms, and the priorities for study and action in each region.

Recent scientific advances based on research carried out in the context of CoML and other ongoing programmes have provided clear evidence of the links between marine biodiversity and the functioning and provision of goods and services by the marine environment in deep sea areas (Danovaro et al, 2008). However, further basic research on 'what lives where' and what affects the patchy nature of deep sea biotic distributions is needed to advance our understanding of this vast reservoir of unexplored marine diversity and its associated biogeographic classifications. This information will also provide for an assessment of human activities in these remote areas.

## 8.2 Towards improved global biogeographic knowledge and precautionary action

The following activities will improve coherent global biogeographic research efforts:

a. Improve the consistency and validation of data.
b. Improve the scientific basis for biogeographic classification by:
- Encouraging research into hydrography and species distribution in order to provide for improved delineation of provinces, especially at bathyal depths
- Integrating the vulnerability and resilience of open ocean and deep seabed biodiversity to classification analysis
- Developing analytical strategies to delineate fuzzy boundaries
- Developing strategies to analyse nested systems (from finer-scale classifications to regional scales)

c. Ensure continued knowledge-gathering and scientific understanding of the ecology, processes and dynamics associated with open ocean and deep sea ecosystems in areas beyond national jurisdiction in order to
- assist the management and conservation of biodiversity beyond national jurisdiction; and
- create an understanding of the services provided by this biodiversity for the benefit to humankind and in the regulation of the planet's biogeochemical processes.

d. Develop major networking projects that help collate and update geo-referenced datasets, promote the growth of taxonomic expertise, and facilitate the integration of biodiversity data and independent datasets.
d. Provide for cooperation among the various organizations involved in open ocean and deep sea ecosystem research in areas beyond national jurisdiction.
f. Share and disseminate the results of research and provide, as a priority, for scientific information-sharing related to open ocean deep sea biodiversity and resources (actual and potential), as well as the services provided by biodiversity.
g. Promote the provision of government-funded research of open ocean and deep sea environments in developing countries, noting that it would promote more flexibility in the sharing of research data and results.

## 8.3 Dealing with uncertainty

The ocean continuum can display clear patterns of distribution and composition of faunal assemblages that change in time and space. These changes are the result of complex interactions nested in different scales (evolutionary to local). They pose challenges to modellers and managers regarding what constitutes sustainable use of resources (what resources can be exploited at what amount and what frequency?). Our limited knowledge, as documented in previous paragraphs, leads to the need to deal with uncertainty in management of ocean resources. This uncertainty is evident when forecasting changes that in a simplistic way can be attributed to only the interaction of species, the variability of the environment, or a combination of both, and that can help conservation of biodiversity, services and resources in open ocean and deep sea areas beyond national jurisdiction.

Dealing with uncertainty can be differentiated into (i) how the number of areas will change as you move to different levels in a hierarchical classification and (ii) how the boundaries within a level may be uncertain because of data quality and quantity. These are two very different issues. The higher level classification presented in this document does not imply a homogeneous distribution of species throughout those regions. Existing work shows that each region will have a large degree of smaller scale heterogeneity in the physical environment as well as discontinuous distributions of species throughout. An elaboration of a hierarchy is needed to show what is most likely to happen with more data and analyses.

The management and protection of a wide, representative range of biodiversity and ecosystem processes is one way to deal with this uncertainty. This approach will ensure that important but poorly understood ecological processes, or poorly studied areas, are protected. Biogeographic classification forms a basis for the application of the representative areas approach. Thus, the improvement of the information basis for biogeographic classification, in particular in relation to the availability of biological data on a global scale, will also improve our ability to deal with uncertainty.

Understanding connectivity is critical for the design of representative networks of open ocean and deep sea marine protected areas, and for the development of conservation strategies to protect species associated with degraded and fragmented seascapes. Without knowledge about connectivity patterns, it may be impossible to interpret the cause of changes observed through time and space in open ocean and deep sea ecosystems beyond national jurisdiction. As a result, the dynamics of many ecological systems that are widely separated across an ocean basin are coupled in complex ways through the activities of individuals who move between them, including in areas within national jurisdiction. Improved mapping of bioregions, and associated ecosystems and habitats, will also improve our understanding of connectivity.

Research methods such as taxonomic identification of taxa and the use of model organisms are increasingly combined with new ones such as metagenomics and biodiversity informatics; these methods are based on the identification of genes present in a given environmental sample and thus allow the conduct of biodiversity studies at the community/ecosystem level (Venter et al, 2004). It is thought that new approaches such as genomics, proteomics and biodiversity will contribute enormously to our further understanding of deep and ocean areas, including from a biogeographic standpoint.

As part of efforts aimed at reducing uncertainty in the future, it will be important to compile a comprehensive and dynamic list of potential programmes and activities contributing to further biogeographic work in deep and open ocean areas. The list of programmes and activities related to marine areas beyond national jurisdiction that were compiled by the United Nations Division for Ocean Affairs and the Law of the Sea for the first meeting of the United Nations Open-ended Informal Working Group to study issues related to the conservation and sustainable use of biodiversity in marine areas beyond national jurisdiction and the eight meeting of the United Nations Informal Consultative Process represent an excellent basis to this end.

# 9. Applications in policy

## 9.1 Policy processes concerned with classification of deep sea and open ocean areas

Recent policy discussions on the conservation and sustainable use of biodiversity, including genetic resources, in marine areas beyond national jurisdiction have pointed out – inter alia – the need for more information on the biodiversity to be found in those areas, and for a classification of those areas to be developed according to scientific criteria. These processes have all recognized, directly and/or in the context of informal discussions associated with those negotiations, that biogeographic classification can contribute to policy-setting and implementation.

Biogeographic classification enhances the knowledge and global understanding of marine life by integrating and centralizing information on its taxonomy, distribution and the biophysical characteristics that influence it. Marine biogeographic classification can thus assist in implementing ecosystem-based management measures and spatial management tools such as representative networks of marine protected areas. By identifying the range and distribution of marine species, habitats and ecosystem processes, it provides visual information that can be viewed in conjunction with information on human impacts to set boundaries for management actions. It can also: i) serve as a basis to identify areas representative of major marine ecosystems and habitat types to include in networks of representative marine protected areas; ii) help to assess gaps in existing marine protected area programs where representative examples of specific habitats or ecosystems are not included or may be inadequate; iii) help to set priorities for management action in areas of high human use; and iv) guide further marine scientific research into areas where significant information gaps exist.

Given these applications, biogeographic information, especially when combined with ecological information, can assist the implementation of the provisions of a number of international and regional conventions, such as the Convention on Biological Diversity (CBD), which relate to the conservation and sustainable use of biodiversity and the use of area-based measures. In addition, the CBD also addresses deep seabed genetic resources beyond the limits of national jurisdiction.[4] Collecting further biogeographic information is crucial to consolidating current knowledge about the status and trends of, and possible threats to, deep seabed genetic resources beyond national jurisdiction, and for providing information relevant to the identification and implementation of technical options for their conservation and sustainable use.[5]

[4] See paragraph 7 of CBD COP Decision VIII/21.
[5] (as called for in paragraph 54 of CBD COP Decision VII/5).

However, the value and contribution of biogeographic knowledge to the policy-making process is still not widely understood. At the regional level, some activities of the Convention for the Protection of the Marine Environment of the North-East Atlantic (the OSPAR Convention) and the Antarctic Treaty System regime provide good illustrations of how biogeographic classification can contribute to more effective policies and management practices. These illustrations should be documented fully and disseminated widely.

The overarching international legal framework governing human activities in marine areas beyond national jurisdiction is set forth in the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and other sector-based and environmental agreements.[6] In recent years, the Convention on Biological Diversity (CBD), the United Nations Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS) and the UN Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biodiversity beyond areas of national jurisdiction (hereby referred to as the UN Working Group) have devoted significant attention to the need to enhance international cooperation and action in areas beyond national jurisdiction. They are considering the potential need for more detailed rules and/or mechanisms to enhance the protection and preservation of the marine environment and the conservation, sustainable and equitable use of marine biodiversity in these areas, and there is a clear demand for biogeographic information by their constituencies.

## 9.2 Pertinent decisions and recommendations

A number of international policy processes have expressed a clear need for biogeographic information, and have undertaken work towards this end. Most pertinent to the work at hand, the CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) considered a draft version of the present document, which was presented to the thirteenth meeting of SBSTTA as information document UNEP/CBD/SBSTTA/13/1NF/19. In its recommendation XIII/3, SBSTTA took note of the draft report; encouraged Parties to contribute to its peer-review; and requested the Executive Secretary to make available the final report for the information of participants in the ninth meeting of the Conference of the Parties.

[6] These are described in detail in the Report of the Secretary General on Oceans and Law of the Sea, Addendum, A/62/66/Add.2 of 16 September 2007 and will not be repeated here.

Additional related work has also taken place in the context of the CBD. The document "Options for preventing and mitigating the impacts of some activities to selected seabed habitats, and ecological criteria and biogeographic classification systems for marine areas in need of protection" for consideration by the SBSTTA[7], presents the results of an expert workshop charged with reviewing biogeographic and ecological criteria for the classification of ocean regions and ecosystems (the 'Azores Workshop'). The information gathered and reviewed at the Azores Workshop represents a combination of ecological with biogeographic classification criteria. This information is intended to assist in the implementation of CBD's provisions and further work on the establishment of marine protected areas in areas beyond the limits of national jurisdiction; it will also assist in determining area-based management of uses and fisheries management measures, as well as broader ecosystem-based and integrated management approaches.[8]

The CBD Secretariat, in cooperation with UNEP-WCMC, has developed an interactive map and reviewed relevant databases of marine areas beyond national jurisdiction; yet again, biogeographic information and data are crucial to the development of such decision-support tools.[9]

Recent meetings of UNICPOLOS have noted the usefulness of geographically linked data in the context of marine genetic resources, ecosystems approaches to management and capacity-building:

- At the eighth meeting of the United Nations Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS) in June 2007, some delegations suggested that the study of marine genetic resources has contributed to the global understanding of the biogeography and taxonomy of deep sea marine biodiversity.[10]

- At the seventh meeting of UNICPOLOS in June 2006, it was proposed that the General Assembly invite States to consider that an ecosystem approach should, *inter alia*, be applied within geographically specific areas based on ecological criteria.[11] UNICPOLOS 7 also noted that the implementation of integrated ecosystem approaches call for geographically specific management approaches.[12]

- At the fourth meeting of UNICPOLOS in June 2003, it was suggested that the Global Marine Assessment could benefit from a 'super-portal' that would build on existing resources, including the Census of Marine Life Ocean Biogeographic Information System (OBIS).[13] At the same meeting, it was suggested that issues that could benefit from attention in future work of the General Assembly on oceans and the law of the sea should include capacity-building for the collection of marine geographic data;[14] this suggestion had already been put forward at the third meeting of UNICPOLOS.[15]

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[7] See UNEP/CBD/SBSTTA/13/4.
[8] Paragraphs 44 (b) and 46 of Decision VIII/24 of the Conference of the Parties (COP) to the CBD refer.
[9] The development of such tool and review were called for in paragraph 44 (c) of CBD COP Decision VIII/24.
[10] Report of UNICPOLOS 8, paragraph 32.
[11] Report of UNICPOLOS 7, paragraph 6.
[12] Report of UNICPOLOS 7, paragraph 62.
[13] Report of UNICPOLOS 4, paragraph 128.
[14] Report of UNICPOLOS 4, Part C.
[15] Report of UNICPOLOS 3, Part C.

- At the first meeting of the UN ad hoc Working Group in 2006, in the context of discussions on area-based management measures (including representative networks of marine protected areas), it was noted that further cooperation was necessary to further develop criteria for the identification of ecologically and biologically significant areas, the development of systems of marine protected areas and biogeographic classification systems.[16] The UN ad hoc Working Group also suggested that future studies should include what has been done and where further work needs to be done, in particular in relation to the criteria for the identification of potential marine protected areas in areas beyond national jurisdiction and for the development of systems of marine protected areas, and on biogeographic classification systems.[17]

- The second meeting of the UN ad hoc Working Group (28 April to 2 May 2008) considered, among other items, the environmental impacts of human activities on marine biological diversity beyond areas of national jurisdiction and the role of area-based management tools. Support was expressed for the work on biogeographic classification, following a scientific presentation of the GOODs report in the opening session.

## 9.3 Possible applications of biogeographic theory to the conservation and sustainable and equitable use of deep sea and open ocean areas and biodiversity

Sound biogeographic information has many possible applications. Below, two examples of practical applications of biogeographic classification, which refer to marine protected areas and spatial planning, are presented.

### Applying biogeographic classification in the context of marine protected areas

So far it has been difficult to undertake strategic action towards the development of "*comprehensive, effectively managed and ecologically representative systems of protected areas"* in deep and open ocean areas due to our incomplete knowledge about how and where species and their habitats are distributed geographically. As noted in section 2.2 of the report, these areas should incorporate the full range of biodiversity in protected sites, including all habitat types. The amount of each habitat type should be sufficient to cover the variability within it, and to provide duplicates (as a minimum) so as to maximize potential connectivity and minimize the risk of impact from large-scale effects (CBD, 2004).

By informing governments about the large-scale distribution of the elements of marine biodiversity within a science-based framework for biogeographic classification, the results of this report and the recommendations of the Azores Workshop, provide tools that can assist governments in making significant progress towards the 2012 target for establishing representative networks of marine protected areas.

Preliminary steps towards a representative network can build on "Scientific criteria and guidance for selecting areas to establish a representative network of marine protected areas, including in open ocean waters and deep sea habitats", as identified by the Azores workshop. The Azores Workshop also identified examples of the variety of features and habitat types that would meet the scientific criteria for identifying ecologically or

[16] Paragraph 60 of the report of the meeting.
[17] Annex II of the report of the meeting.

biologically significant marine areas or species (recommendation XIII/3 of the CBD SBSTTA). Thus it would be possible to select sites incorporating these features in each of the biogeographic units identified herein, pending the developing of finer resolution maps.

The following four initial steps recommended by the Azores expert meeting can now be taken:

- **Scientific identification of an initial set of ecologically or biologically significant areas.** The criteria [as proposed by the workshop] (should be used, considering the best scientific information available, and applying the precautionary approach. This identification should focus on developing an initial set of sites already recognized for their ecological values, with the understanding that other sites could be added as new and/or better information comes available.

- **Develop/choose a biogeographic habitat and/or community classification system.** This system should reflect the scale of the application, and address the key ecological features within the area. Usually, this will entail a separation of at least two realms – pelagic and benthic. **This report provides such a classification system.**

- **Drawing upon steps 1 & 2 above, iteratively use qualitative and/or quantitative techniques to identify sites to include in a network.** Their selection for consideration of enhanced management should reflect their recognized ecological importance, vulnerability, and address the requirements of ecological coherence through:
  - representativity;
  - connectivity; and
  - replication.

- **Assess the adequacy and viability of the selected sites.** Consideration should be given to their size, shape, boundaries, buffering, and appropriateness of the site management regime.

### Applying biogeographic classification in the context of marine spatial planning

In the context of marine spatial planning, biogeographic scientific information is combined with information on uses, impacts and opportunities for synergy among stakeholders to identify specific areas for protection or for specific uses over different time scales. This approach has been successfully used in the marine coastal areas of many countries around the world (Ehler and Douvere, 2007).

In a policy setting, normally, stakeholders' aspirations, expectations and interests are analyzed against biogeographic and other similar scientific information such as knowledge of ecological processes, biodiversity impact assessments, etc. so as to agree on possible common agendas. In this way, the resulting policies represent the combination of scientific knowledge, stakeholders' interests and political decisions for actions such as the identification of areas to be subjected to restricted management measures or areas where to conduct further investigations. An example in this regard is given by the regional units identified in the context of the Regular Process for the Global Reporting and Assessment of the State of the Marine Environment including Socio-economic Aspects, as these regions represent a combination of ecological, legal, policy and political criteria that serve well the purpose of assessing the state of the marine environment from a combined ecological and human use perspective.[18]

### 9.4 Future efforts linking biogeographic classification with policy-making

There is an increasingly clear recognition of the importance of the contribution of biogeographic classification to priority-setting in the policy context, and also an increasing policy demand for biogeographic information on open ocean and deep sea areas beyond national jurisdiction. As a result, there is a need to bridge the gap between such policy demand and scientific research aimed at generating biogeographic knowledge.

One factor impeding the filling of this gap is funding. Biogeographic investigations, especially in the open and deep ocean realms, are expensive and time-consuming, and the analysis of the data collected presents complex challenges. Such programmes will benefit from the political support needed to build international scientific cooperation at a global scale, as well as adequate funding. An example is provided by the Census of Marine Life and its Ocean Biogeographic Information System (OBIS). The Census and OBIS have existed for almost ten years and have provided a body of scientific knowledge that is unique and comprehensive, with equally unique implications for policy and applications for both conservation and development. Yet, the future of these and of similar programmes is unclear.

Another factor that needs to be considered is the transfer of biogeographic information to the policy-making level in a manner that is accurate, timely and relevant. This is a challenge facing the scientific community, and it is a pressing one. This report demonstrates that the scientific community involved in the biogeography of the oceans is increasingly aware of this responsibility and is willing to address policy needs, so that the conservation and sustainable use of biodiversity in marine areas beyond national jurisdiction at all levels – genetic, species, ecosystems and seascapes – can be achieved in the years to come.

## 10. Conclusions

The pelagic and benthic biogeographic classifications presented in this report represent the first global attempt at comprehensively classifying the open ocean and deep seafloor into distinct biogeographic regions. This bioregional classification was based on a physiognomic approach, which uses geophysical and environmental characteristics of the benthic and pelagic environments to identify homogeneous regions of similar habitat and associated biological community characteristics. This work is hypothesis-driven and still preliminary, and will thus could require further refinement and peer review in the future. However, in its present format it provides a basis for discussions that can assist policy development and implementation in the context of the CBD and other fora.

Biogeographic classification will help us understand the distribution of species and habitats for the purposes of scientific research, conservation and management. The process initiated at the Mexico Workshop, and reported upon here, has mobilized an international

[18] See UNGA/60/30 as well as relevant documents hosted by www.unesco.org/ioc and http://www.un.org/Depts/los/global_reporting/global_reporting.htm.

multidisciplinary scientific expert group with the aim to deliver the biogeographic information required by policy-makers.

Future refinements of the biogeographical classification of ocean regions will rely, to some extent, on improved scientific information, especially biological information, which could eventually provide a basis for describing global patterns of representative marine fauna and flora. However, at the present time, and in the context of the precautionary approach, the major open ocean pelagic and deep sea benthic zones presented in this report are considered a reasonable basis for the conservation and sustainable use of biodiversity in marine areas beyond the limits of national jurisdiction. It is important that the need for further refinement to biogeographical provinces not delay action to be undertaken towards this end, and that such actions continue to be supported by the best available scientific information.

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## Annex A

### Further information related to biogeographic classification

The tables below provide statistics on the location, sea surface temperature (SST), primary productivity and depth for each of the pelagic bioregions.

| PROVINCE | Min. longitude | Max. longitude | Min. latitude | Max. latitude | Min. SST | Max. SST |
|---|---|---|---|---|---|---|
| Agulhas Current | 21.5 | 41.5 | -38.5 | -20.5 | 18.099128 | 26.777761 |
| Antarctic | -179.5 | 179.5 | -78 | -59.5 | -1.655391 | 3.544897 |
| Antarctic Polar Front | -179.5 | 179.5 | -64 | -53.5 | -0.777912 | 8.218083 |
| Arctic | -178.5 | 179 | 65.5 | 89 | -0.834574 | 8.686408 |
| Benguela Current | 4.5 | 18 | -38 | -10 | 18.415394 | 26.070262 |
| California Current | -137 | -117 | 25 | 49 | 10.52992 | 20.692091 |
| Canary Current | -25.5 | -12 | 2 | 25 | 22.240133 | 28.311105 |
| Eastern Tropical Pacific | -134.5 | -84 | -7 | 17 | 22.908915 | 29.235557 |
| Equatorial Atlantic | -58 | 9.5 | -11.5 | 18 | 24.731996 | 28.23903 |
| Equatorial Pacific | -179.5 | 179.5 | -1.5 | 10 | 26.263902 | 30.122715 |
| Gulf Stream | -72 | -53 | 36.5 | 43.5 | 14.209465 | 25.332274 |
| Humboldt Current | -83.5 | -73.5 | -39.5 | -9 | 14.185082 | 24.659914 |
| Indian Ocean Gyre | 29.5 | 106.5 | -43 | -10 | 10.631061 | 28.159073 |
| Indian Ocean Monsoon Gyre | 43.5 | 102 | -12 | 18 | 27.343619 | 30.044181 |
| Kuroshio | 134 | 147.5 | 28.5 | 39.5 | 16.665439 | 25.364168 |
| Leuwin Current | 104.5 | 120.5 | -40 | -11.5 | 12.591852 | 28.569654 |
| Malvinas Current | -60.5 | -49 | -48 | -36 | 7.636815 | 20.153859 |
| Non-gyral Southwest Pacific | 146.5 | 173 | -41 | -12.5 | 15.029561 | 28.214292 |
| North Atlantic Transitional | -77 | -9 | 30 | 58 | 7.494788 | 25.521978 |
| North Central Atlantic Gyre | -75 | -12.5 | 16.5 | 40 | 20.222337 | 27.292707 |
| North Central Pacific Gyre | -179.5 | 179.5 | 6 | 36.5 | 17.875715 | 29.263524 |
| North Pacific Transitional | -179.5 | 179.5 | 34.5 | 48 | 8.148159 | 21.7399 |
| Somali Current | 53.5 | 68.5 | 7 | 21.5 | 26.773463 | 27.957892 |
| South Central Atlantic Gyre | -50 | 17.5 | -38 | -9 | 14.015105 | 27.370159 |
| South Central Pacific Gyre | -179.5 | 179 | -40 | 2.5 | 14.830539 | 30.288748 |
| Subarctic Atlantic | -60.5 | 9.5 | 47 | 69.5 | 2.064646 | 13.996807 |
| Subarctic Pacific | -179.5 | 179.5 | 39.5 | 59.5 | 3.692216 | 17.083236 |
| Subtropical Convergence | -179.5 | 179.5 | -49.5 | -20 | 2.378059 | 22.295362 |
| Subantarctic | -179 | 179.5 | -56.5 | -43.5 | -0.209903 | 12.729183 |

| PROVINCE | Min_primar | Max_primar | Min_DEPTH | Max_DEPTH |
|---|---|---|---|---|
| Agulhas Current | 307.718928 | 865.769437 | 500 | 5000 |
| Antarctic | 33.608603 | 924.919546 | 200 | 6300 |
| Antarctic Polar Front | 63.679736 | 271.730894 | 400 | 6500 |
| Arctic | 97.657209 | 936.738161 | 100 | 5500 |
| Benguela Current | 404.470026 | 1184.218602 | 200 | 5000 |
| California Current | 267.517587 | 610.55545 | 200 | 5500 |
| Canary Current | 311.685843 | 1427.258151 | 400 | 5400 |
| Eastern Tropical Pacific | 271.543765 | 841.335378 | 1000 | 5000 |
| Equatorial Atlantic | 172.031947 | 2326.097666 | 200 | 7800 |
| Equatorial Pacific | 180.628157 | 453.339809 | 1000 | 8000 |
| Gulf Stream | 424.999081 | 734.962992 | 1500 | 5000 |
| Humboldt Current | 355.471031 | 827.371387 | 1000 | 5500 |
| Indian Ocean Gyre | 171.39184 | 681.237696 | 100 | 6500 |
| Indian Ocean Monsoon Gyre | 244.272224 | 801.097928 | 200 | 6000 |

| | | | | |
|---|---|---|---|---|
| Kuroshio | 347.967696 | 685.367755 | 1000 | 5500 |
| Leuwin Current | 238.385854 | 474.106272 | 1500 | 6500 |
| Malvinas Current | 406.395006 | 1086.473362 | 200 | 5700 |
| Non-gyral Southwest Pacific | 202.279111 | 715.750456 | 100 | 5000 |
| North Atlantic Transitional | 285.055795 | 836.136166 | 100 | 5800 |
| North Central Atlantic Gyre | 146.893148 | 551.327049 | 200 | 6500 |
| North Central Pacific Gyre | 104.324699 | 738.136336 | 500 | 10500 |
| North Pacific Transitional | 302.720266 | 702.99124 | 1000 | 7000 |
| Somali Current | 461.557302 | 1221.372511 | 1500 | 5500 |
| South Central Atlantic Gyre | 135.196632 | 749.996063 | 200 | 6500 |
| South Central Pacific Gyre | 82.306994 | 764.847155 | 500 | 8750 |
| Subarctic Atlantic | 246.503739 | 799.588425 | 200 | 4500 |
| Subarctic Pacific | 294.629762 | 607.770132 | 200 | 7000 |
| Subtropical Convergence | 123.602418 | 1002.803625 | 200 | 6000 |
| Subantarctic | 76.024561 | 812.665048 | 200 | 7000 |

## Annex B

# Table of regional biogeographic classifications

**Regional marine biogeographic classifications**
*(Adapted from Spalding et al, 2007)*

| PUBLICATION | REGION |
|---|---|
| Powles H, Vendette V, Siron R, O'Boyle B. 2004. Proceedings of the Canadian Marine Ecoregions Workshop. Ottawa: Fisheries and Oceans Canada. | The Arctic, Northwest Atlantic, Northeast Pacific |
| Dinter W. 2001. Biogeography of the OSPAR Maritime Area. A synopsis of biogeographical distribution patterns described for the North-East Atlantic. Bonn, Germany: Federal Agency for Nature Conservation. | The Arctic, Northeast Atlantic |
| Banks D, Williams M, Pearce J, Springer A, Hagenstein R, Olson D, eds. 2000. Ecoregion-Based Conservation in the Bering Sea. Identifying important areas for biodiversity conservation Washington DC: World Wildlife Fund and The Nature Conservancy of Alaska. | The Arctic |
| Van den Hoek C. 1975. Phytogeographic provinces along the coasts of the northern Atlantic Ocean. Phycologia 14: 317-330. | Northeast Atlantic |
| ICES. 2004. Information and advice about appropriate eco-regions for the implementation of an ecosystem approach in European waters. Pages 115-131 in ICES, ed. Report of the ICES Advisory Committee on Fishery Management and Advisory Committee on Ecosystems, 2004, vol. Volume 1, No. 2, Book 1. Copenhagen: International Council for the Exploration of the Sea (ICES). | Northeast Atlantic, Mediterranean |
| Bianchi CN, Morri C. 2000. Marine Biodiversity of the Mediterranean Sea: Situation, Problems and Prospects for Future Research. Marine Pollution Bulletin 40: 367-376. | Mediterranean |
| WWF MedPO. 2001. Defining the Mediterranean SubER: an overview.: WWF Mediterranean Programme Office, Conservation Unit. | Mediterranean |
| Wilkinson T, Bezaury-Creel J, Hourigan T, Wiken E, Madden C, Padilla M, Agardy T, Herrmann H, Janishevski L, Morgan L. 2006. Spaces: Marine Ecoregions of North America. Montreal, Canada: Report developed by the North American Marine Ecoregions project team, Commission for Environmental Cooperation. | Northwest Atlantic, Northwest Pacific, Northeast Pacific, Tropical Atlantic |
| Hayden BP, Ray GC, Dolan R. 1984. Classification of coastal and marine environments. Environmental Conservation 11: 199-207. | Northwest Atlantic |
| DeBlieu J, Beck M, Dorfman D, Ertel P. 2005. Conservation in the Carolinian Ecoregion: An Ecoregional Assessment. Arlington, VA, USA: The Nature Conservancy. | Northwest Atlantic |
| Schumacher JD, Stabeno PJ. 1998. The continental shelf of the Bering Sea. Pages 789-822 in Robinson A, Brink K, eds. The Sea. The Global Coastal Ocean - regional studies and syntheses. New York: John Wiley and Sons, Inc. | Northwest Pacific |
| Floberg J, et al. 2004. Willamette Valley-Puget Trough-Georgia Basin Ecoregional Assessment, Volume One: Report. The Nature Conservancy with support from the Nature Conservancy of Canada, Washington Department of Fish and Wildlife, Washington Department of Natural Resources (Natural Heritage and Nearshore Habitat programs), Oregon State Natural Heritage Information Center and the British Columbia Conservation Data Centre. | Northeast Pacific |
| TNC. 2004. Southern California Marine Ecoregional Assessment. San Francisco: The Nature Conservancy. | Northeast Pacific |
| TNC 2006. Northern California Marine Ecoregional Assessment. San Francisco: The Nature Conservancy. | Northeast Pacific |
| Hayden BP, Ray GC, Dolan R. 1984. Classification of coastal and marine environments. Environmental Conservation 11: 199-207. | Northeast Pacific |
| Sullivan Sealey K, Bustamante G. 1999. Setting Geographic Priorities for Marine Conservation in Latin America and the | Northeast Pacific, Tropical Atlantic, Tropical Eastern Pacific |

| | |
|---|---|
| Caribbean. Arlington, Virginia, USA: The Nature Conservancy. | |
| Huggins AE, et al. 2007. Biodiversity Conservation Assessment of the Insular Caribbean Using the Caribbean Decision Support System, Technical Report.: The Nature Conservancy. Also online at: http://conserveonline.org/workspaces/Caribbean.conservation/ CDSS_summary_report_final.pdf. | Tropical Atlantic |
| Smith ML, Carpenter KE, Waller RW. 2002. An introduction to the oceanography, geology, biogeography, and fisheries of the tropical and subtropical western central Atlantic. Pages 1-23 in Carpenter KE, ed. The Living Resources of the Western Central Atlantic. Volume 1. Introduction, molluscs, crustaceans, hagfishes, sharks, batoid fishes and chimaeras. Rome: Food and Agriculture Organization of the United Nations. | Tropical Atlantic |
| Geselbracht L, Torres R, Cumming G, Dorfman D, Beck. M. 2005. Marine/Estuarine Site Assessment for Florida: A Framework for Site Prioritization. Final Report for Florida's Wildlife Legacy Initiative, a program of the Florida Fish and Wildlife Conservation Commission. Gainesville, Florida: The Nature Conservancy. | Tropical Atlantic |
| Almada VC, Oliveira RF, Goncalves EJ, Almeida AJ, Santos RS, Wirtz P. 2001. Patterns of Diversity of the North-Eastern Atlantic Blenniid Fish Fauna (Pisces: Blenniidae). Global Ecology and Biogeography 10: 411-422. | Tropical Atlantic |
| WWF. 1999. WWF Africa Ecoregion Assessment Workshop participants notes: WWF-US. | Tropical Atlantic, Western Indo-Pacific |
| WWF 2004. The Eastern African Marine Ecoregion Vision: A large scale conservation approach to the management of biodiversity. Dar es Salaam, Tanzania.: World Wide Fund for Nature. | Tropical Atlantic, Western Indo-Pacific |
| Allen GR. 2002. Indo-Pacific coral-reef fishes as indicators of conservation hotspots. Proceedings of the Ninth International Coral Reef Symposium, Bali 2: 921-926. | Western Indo-Pacific, Central and Eastern Indo-Pacific |
| Bakus G, Arthur R, Ekaratne S, Jinendradasa S. 2000. India and Sri Lanka. Pages 295-324 in McClanahan T, Sheppard CRC, Obura D, eds. Coral Reefs of the Indian Ocean. Their ecology and conservation. Oxford, UK. | Western Indo-Pacific |
| Sheppard CRC. 1999. Corals of Chagos, and the biogeographical role of Chagos in the Indian Ocean. Pages 53-66 in Sheppard CRC, Seaward MRD, eds. Ecology of the Chagos Archipelago. London: Published for the Linnean Society of London, by Westbury Publishing. | Western Indo-Pacific |
| Ch'ng KL. 1993. South East Asian Marine Region. Report from an IUCN/CNPPA working group of representatives from South East Asian nations. Pages 18. Malaysia: Ministry of Science, Technology and the Environment, Malaysia. | Central and Eastern Indo-Pacific |
| Pauly D, Christensen V. 1993. Stratified models of Large Marine Ecosystems: a general approach and an application to the South China Sea. Pages 148-174 in Sherman K, Alexander LM, Gold BD, eds. Large Marine Ecosystems: Stress, Mitigation, and Sustainability. Washington, DC: AAAS Press. | Central and Eastern Indo-Pacific |
| Lourie SA. 2006. Report on challenges in biogeographic classification of Sumatra/Java and the Eastern Indian Ocean. Pages 6. | Central and Eastern Indo-Pacific |
| Green A, Mous P. 2006. Delineating the Coral Triangle, its ecoregions and functional seascapes. Report based on an expert workshop held at the TNC Coral Triangle Center, Bali Indonesia (April - May 2003), and on expert consultations held in June and August 2005. Version 3.1 (February 2006). Pages 50: The Nature Conservancy, Coral Triangle Center (Bali, Indonesia) and the Global Marine Initiative, Indo-Pacific Resource Centre (Brisbane, Australia). | Central and Eastern Indo-Pacific |
| Commonwealth of Australia (2005) National Marine Bioregionalisation of Australia. Department of Environment and Heritage, Canberra, Australia | Temperate Australasia, Central and Eastern Indo-Pacific |
| Thackway R, Cresswell ID. 1998. Interim Marine and Coastal Regionalisation for Australia: an ecosystem-based classification for marine and coastal environments. Version 3.3. Canberra: Environment Australia, Commonwealth Department of | Temperate Australasia, Central and Eastern Indo-Pacific |

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|---|---|
| the Environment. | |
| Lyne V, Last P, Scott R, Dunn J, Peters D, Ward T. 1998. Large Marine Domains of Australia's EEZ. CSIRO Marine Research and Department of Environment and Land Management, Tasmania. Report commissioned by Environment Australia. | Temperate Australasia, Central and Eastern Indo-Pacific |
| Boschi E. 2000. Species of Decapod Crustaceans and their distribution in the American marine zoogeographic provinces. Revista de Investigación y Desarrollo Pesquero 13: 7-136. | Central and Eastern Indo-Pacific |
| Emanuel BP, Bustamante RH, Branch GM, Eekhout S, Odendaal FJ. 1992. A zoogeographic and functional approach to the selection of marine reserves on the west coast of South Africa. South African Journal of Marine Science 12: 341-354. | Temperate Southern Africa |
| Engledow HR, Bolton JJ. 2003. Factors affecting seaweed biogeographical and ecological trends along the Namibian coast. Pages 285-291 in Chapman ARO, Anderson RJ, Vreeland VJ, Davison IR, eds. Proceedings of the 17th International Seaweed Symposium. Oxford, UK. | Temperate Southern Africa |
| Turpie JK, Beckley LE, Katua SM. 2000. Biogeography and the selection of priority areas for conservation of South African coastal fishes. Biological Conservation 92: 59-72. | Temperate Southern Africa |
| Bolton JJ, Leliaert F, Clerck OD, Anderson RJ, Stegenga H, Engledow HE, Coppejans E. 2004. Where is the western limit of the tropical Indian Ocean seaweed flora? An analysis of intertidal seaweed biogeography on the east coast of South Africa. Marine Biology 144: 51-59 | Temperate Southern Africa |
| Knox GA. 1960. Littoral ecology and biogeography of the southern oceans. Proceedings of the Royal Society of London, B 152: 577-624. | Temperate Australasia, Southern Ocean |
| Snelder, T.; Leathwick, J.; Image, K.; Weatherhead, M.; Wild, M. (2004). The New Zealand Marine Environment Classification. *NIWA Client Report CHC2004–071*. 86 p. | Temperate Australasia |
| Walls K. 1994. The New Zealand Experience in Developing a Marine Biogeographic Regionalisation: Great Barrier Reef Marine Park Authority. | Temperate Australasia |
| Linse K, Griffiths HJ, Barnes DKA, Clarke A. 2006. Biodiversity and biogeography of Antarctic and Sub-Antarctic Mollusca. Deep Sea Research II 53: 985-1008. LME. 2006. Large Marine Ecosystems: information portal. (1 December 2006; http://www.lme.noaa.gov/Portal/) | Temperate Australasia, Southern Ocean |
| Grant, S., Constable, A., Raymond, B. and Doust, S. (2006) Bioregionalisation of the Southern Ocean: Report of Experts Workshop, Hobart, September 2006. WWF-Australia and ACE CRC. | Southern Ocean |

# Annex C

## Case study: Biogeographic Classification of the OSPAR Maritime Area (Northeast Atlantic)

Wolfgang Dinter and Jeff Ardron, German Federal Agency for Nature Conservation

In 1998, a workshop was hosted by the German Federal Agency for Nature Conservation (BfN), whereby draft criteria for the identification, selection, and management of OSPAR MPAs were agreed upon, which were later finalised and adopted by OSPAR (2003). During the workshop it was agreed that MPAs may, in addition to protecting species and habitats under immediate threat, also conserve additional features taking into account factors such as ecological significance, biodiversity, naturalness, sensitivity, and representativity. It was recognised that some of these ideas needed further elaboration, particularly representativity. This led to the development of a biogeographic classification system.

Dinter collated existing classification systems within the Northeast Atlantic and consulted scientists regarding their latest research, from which he developed a biogeographic classification for the OSPAR Maritime Area (Dinter, 2001). The classification is delineated into three large *biomes*. A benthic biome considers the seafloor (benthos) less than 1000 m depth, of which there are 17 zones (Figure 6). A deep sea biome treats the seafloor and waters deeper than 1000 m, into two broad zones (Figure 6). A third pelagic biome considers the water column less than 1000 m in depth, of which there were three zones (Figure 217). Thus altogether, there are 22 biogeographic zones. The Dinter classification system has been used by Contracting Parties when submitting MPA nominations to OSPAR, as well as in the status reports reporting on the progress of the MPA network (OSPAR 2006, 2007).

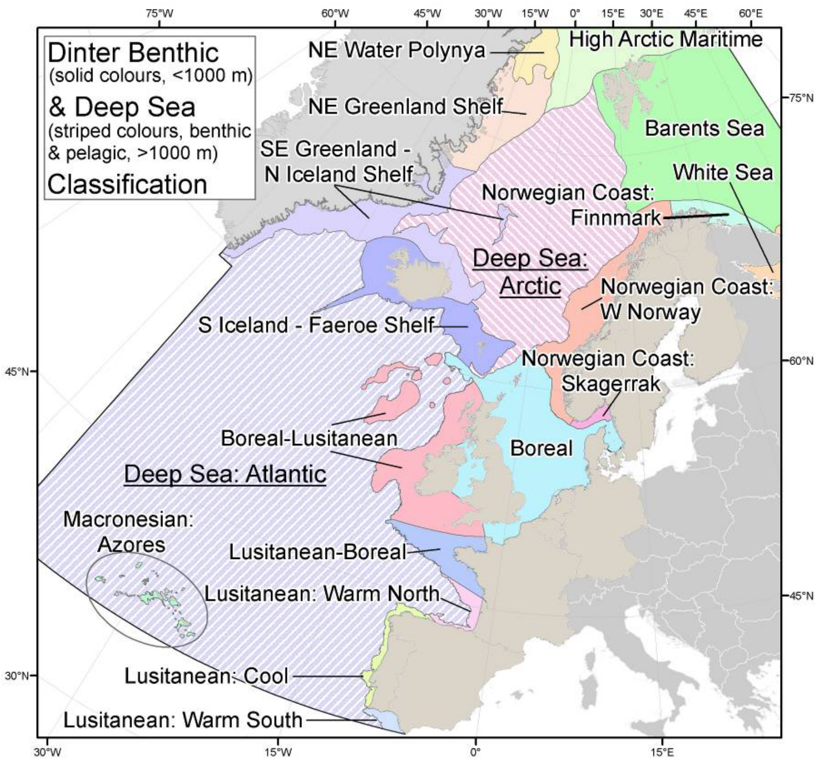


**Figure 26: Dinter benthic biome (< 1000 m) and Deep Sea biome (> 1000 m, including benthos and deep waters).**

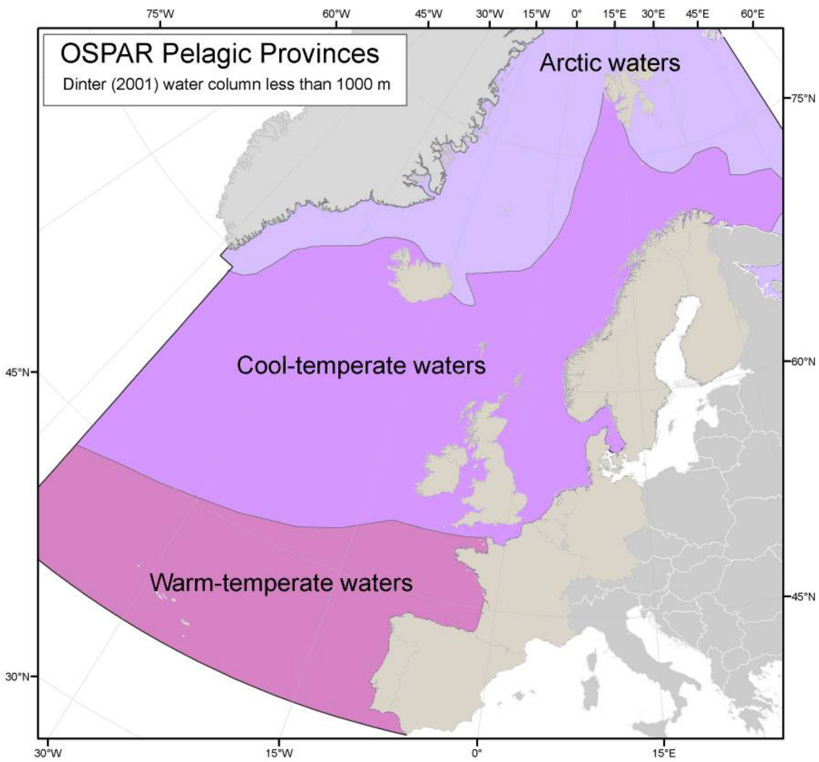


**Figure 217: Dinter pelagic biome.**

## Annex D

**Review of deep sea benthic biogeography**

The first explorations of the deep sea benthos occurred off Norway and Britain and the fauna from the two regions proved to be remarkably similar. However, following the analysis of samples from the Challenger Expedition, Murray and Hjort (1912) suggested that there was, in fact, some heterogeneity in the distribution of animals over the deep sea floor. Later expeditions ("Valdivia" from Germany and "Albatross" from the United States) showed that many families and genera were widespread but species were not. Ekman (1935) suggested that even though the deep sea seems to be homogeneous in its physical features, the fauna of the abyss could be divided into four major groups, Atlantic, Pacific, Arctic, and Antarctic. Ekman also suggested that species ranges increased with depth, those at bathyal depths having more limited ranges than those in the abyss.

In the 1950s the idea of a cosmopolitan fauna existed among some investigators. Following more detailed sampling by the "Galathea" expedition, some groups, such as the isopods, were found to have no cosmopolitan species (Wolff 1962), whereas others, such as the polychaetes were thought to be widespread (Kirkegaard 1954, 1995) (Vinogradova (1997) notes the data showed this not to be true). Knudsen (1970) also considered the Bivalvia to be widely distributed, but only three of 193 species appeared to be cosmopolitan (Vinogradova 1997).

Vinogradova (1997) summarized the literature on deep sea fauna studies up to the time of the writing of her 1997 paper. Many of the papers deal with individual animal groups and primarily concern species found in the muddy bottoms of the abyss. From this analysis she categorized the studies of deep sea benthic fauna into three major schools of thought regarding deep sea zoogeographic patterns:

- Those who think that the bottom fauna should be very widespread because of the lack of ecological barriers and relative homogeneity of conditions on the deep sea floor.
- Those who think that the deep sea fauna is fractionated by the presence of topographic features that divides the sea floor into about 50 separate ocean basins.
- Those who subscribe to the idea that species generally have much larger ranges at greater depth.

In this account we review some of the important deep sea benthos literature that covers samples taken over large areas or in habitats not previously well sampled to determine whether there are patterns in the deep sea fauna that suggest the presence of bottom faunal regions or provinces.

Menzies & al. (1973) summarized the distributions of much of the larger deep sea fauna as well as the smaller and direct developing peracarid group, the isopods. They recognized five large zones in depths over 4000 m, one for each ocean. These zones were divided into 13 provinces and 17 regions and subregions. The scheme uses temperature and topography as determinants for province definitions and, though similar to that of Ekman (1953), is more finely subdivided. The regions and provinces outlined by Menzies et al. (1973) are listed below in the box:

**Regions and provinces by Menzies et al (1973)**

Pacific Deep-Water Region
- A-1. Northwest Pacific province
- A-2. Central Pacific province
  - A-2a. Northern Mid-America trench area
  - A-2b. Southern Mid-America trench area
  - A-2c. Peruvian area
  - A-2d. Easter Island area
  - A-2e. Tuamoto-Marquesas area
  - A-2f. Northern New Zealand area
  - A-2g. New Guinea-Borneo-Philippine area
  - A-2h. China Sea region

Arctic Deep-Water Region
- B-1. Norweigian province
- B-2. Greenland-Fram province
- B-3. Eurasian province
- B-4. Siberian province
- B-5. Canadian province

Atlantic Deep-Water Region
- C-1. Northwestern Atlantic province
- C-2. North-South Eastern Atlantic province
- C-3. Caribbean-Gulf province
- C-4. Mediterranean province

Indian Deep-Water Region
- D-1. Andaman province
  - D-1a. Southern India area
  - D-1b. Arabian area
  - D-1c. Afro-Indian area

Antarctic Deep-Water Region
- E-1. Antarctic Circumpolar province
  - E-1a. Atlanto-Indian Antarctic area
    - E-1a (1). Eastern South Atlantic subarea
    - E-1a (2). Western South Atlantic area
    - E-1a (3). Southeastern Indian subarea
  - E-1b. Austro-Indian Antarctic area
    - E-1b (1). Southwestern Indian subarea
    - E-1b (2). Eastern Australian subarea
  - E-1c. Southeastern Pacific Antarctic area
- E-1c (1). South Central Pacific subarea

Kussakin (1973) discussed the antiquity of the deep sea fauna and the peculiarities of the geographical and vertical distribution of isopods. Isopod data from shallow cold and cold temperate regions and from the entire World Ocean at depths of more than 2000 m were used. A total of 6700 samples representing 525 species were analyzed. He found that the most ancient isopod families lived on tropical shelves whereas the more recently evolved species inhabited the shelves of cold regions. The deep sea fauna was considered to be the youngest. Kussakin hypothesized that deep sea species evolved from shallow Antarctic species as glaciation around the southernmost continent increased and waters, both shallow and deep, cooled. The sinking of the Antarctic shelf with increasing ice thickness adapted the new cold water species to increasing pressure and allowed the colonization of the entire deep sea.

Kussakin suggested that his delimitation of roughly the same three regions previously taken by Vinogradova is more precise, with the Antarctic (termed Austral) dividing-line in some places shifted slightly southwards as far as the subtropical convergence. Species endemism among isopods is very high, which prompted Kussakin to restrict composition comparisons to the genus level. He also noted that the composition of the Indo-Pacific deep sea region resembles the Atlantic deep sea region as well as the Austral deep sea region and the Arctic-boreal region of the shelf zones.

Kussakin's deep sea classification is presented in the box below.

**Deep sea classification by Kussakin (1973)**

- Austral deep sea region
    - Andean austral province
    - Gondwanian austral province
- Indo-Pacific deep sea region
    - Indian province
    - West-Pacific province
    - East-Pacific province
    - North-Pacific province
- Atlantic deep sea region
    - West-Atlantic province
    - East-Atlantic province
    - North-Atlantic province
    - Arctic province

Vinogradova (1979), summarizing her earlier work written in Russian, compared the species compositions of the bottom fauna in different deep sea regions of the Pacific Ocean. She admitted having made deductions based on common and easily identifiable parts of the deep sea fauna. Based on earlier work, she noted that the ranges of species tended to contract, rather than expand with depth. She came to believe that species ranges were constricted due to the presence of deep sea ridges, causing a delimitation of basins with their own faunas. The Pacific contained 53% of the endemic species overall, but the lower abyssal had 93% of the endemics. For the entire World Ocean, she found that 85% of the species occurred in one ocean only, and 4% were common to the Atlantic, Indian, and Pacific Oceans. Overall, Vinogradova characterized the fauna of the deep sea regions as highly endemic with a large number of endemic genera and families.

The Vinogradova (1979) zoogeographical classification of the abyssal and hadal zones was based on an analysis of the fauna at the species level. This includes, for the abyssal, three regions, six subregions, and eight provinces, as listed in the box below.

Vinogradova (1979) zoogeographical classification of the abyssal and hadal zones

I. Pacific-North-Indian deep sea region
1. Pacific subregion
    a. North-Pacific province
    b. West-Pacific province
    c. East-Pacific province
2. North-Indian subregion

II. Atlantic deep sea region
3. Arctic subregion
4. Atlantic subregion
    d. North-Atlantic province
    e. West-Atlantic province
    f. East-Atlantic province

III. Antarctic deep sea region
5. Antarctic-Atlantic subregion
6. Antarctic-Indian-Pacific subregion
    g. Indian province
    h. Pacific province

The distribution of tunicates taken in the Atlantic Ocean at depths greater than 2000 m by various expeditions over a 15-year period is the subject of a short paper by Monniot (1979). Sampling devices and sample numbers varied from basin to basin but sorting was uniform, all samples being washed over a 0.25 mm sieve.

Monniot (1979) used the Kulczensky-2 index to compute the similarity of the tunicate faunas amongst the basins in the Atlantic. The northern and eastern Atlantic Basins have the strongest affinities, with similarity coefficients above 40 % for the Labrador, European, Angola-Guinea, and Cape Basins. The Surinam, Brazil, and Argentine Basins on the western side of the Atlantic have low affinities with each other and with the basins to the north and east. These weak affinities could be the result of insufficient collecting. Monniot also suggests that the Cape Basin could have strong affinities with the Antarctic basin.

Sibuet (1979) summarized the available data on deep sea Asteroids, primarily from the eastern Atlantic basins. Asteroids were sampled during 12 cruises organized by the Centre Océanologique de Bretagne, beginning in 1969. More than 100 trawl samples were taken from 1800 to 4500 m in seven Atlantic basins: European, Mediterranean, Labrador, Cape, Angola, Greenland, and Norwegian. The fauna was divided into those species occurring above or below 3000 m. While her data were admittedly limited she used Kulczinski-2 index to look at faunal similarity among the seven basins at these two depth intervals.

From 1800 to 3000 m, the highest faunal similarity was between the Norwegian and Greenland basins, and the European-Mediterranean-Angolan basins. A similar pattern was seen at the level of genera, except that the Greenland and European basins were also quite similar. From 3000 to 5000 m the Norwegian and Greenland basins had similar species and generic compositions, as did the European-Angola-Cape basins at the species level, with the addition of the Labrador basin at the generic level. The results are affected somewhat by the different levels of sampling in the various basins, with the European Basin sampled the most frequently and the Cape and Labrador Basins the least.

The fauna of the ultra-abyssal and hadal parts of the seafloor was admirably summarized by Belyaev (1989). He noted there were 37 such deep areas, 28 of which were in the Pacific. Most are part of recognizable trenches, but others are broad deep areas of the abyssal sea floor. In general, Belyaev found that about 56% of the species were endemic to the ultra-abyssal, but about 95% of those were found only in one trench. Of the non-endemic species, 22% were found in the abyssal area where the trench was located, suggesting that the trench fauna originated from the abyssal province in which the trench was located.

Several areas had either not been sampled or the data not analysed at the time of his monograph, nevertheless, Belyaev suggested that the abyssal classification scheme of Vinogradova (1979) be supplemented with ultra-abyssal provinces as follows:

Pacific Ocean Subregion has the ultra-abyssal provinces *Aleutian-Japan* (Aleutian, Kuril-Kamchatka, Japan, Izu-Bonin trenches), *Philippine* (Philippine and Ryuku Trenches), *Mariana* (Volcano, Mariana, Yap and Palau Trenches), *Bougainville-New Hebrides* (New Britain, Bougainville, Santa Cruz, and New Hebrides Trenches), *Tonga-Kermadec*, and *Peru-Chile*.

North Indian Subregion has only the *Yavan* ultra-abyssal province. The Atlantic Subregion has the *Puerto Rico* and *Romanche* trench provinces. The Antarctic-Atlantic Subregion has the *Southern Antilles* ultra-abyssal province.

Vinogradova (1997) produced a long review of the state of deep sea zoogeography of the abyssal and hadal zones, with emphasis on work done by Russian scientists and generally previously only available in Russian. After a thorough review of these and other studies, she does not modify the deep sea regionalization scheme she presented for the first time in English in 1979, including the additions made later by Belyaev (1989).

In her review, Vinogradova also considers the idea of distributions that are based on trophic considerations and on the possibility of bipolarity due to cold shallow waters at the poles connected by deep cold waters. On the first point, it is clear that there is greater food delivery to the deep sea at high latitudes and off the margins of continents and that the centers of the basins are impoverished due to food limitation. In particular, Mironov proposed what he called "circular" distributions, following the margins of the ocean basins and divided the basins into western, eastern, northern, Antarctic, and central regions.

Reviewing species distributions in the Pacific, Vinogradova concluded that there was an apparent bipolarity of bottom fauna distribution in certain groups. Most seem to be eurybathic species following deep abyssal cold waters, from the Antarctic to the northern Pacific. She noted that several endemic species in deep sea trenches were related to abyssal species and possibly colonized these areas through pathways of penetration of deep Antarctic waters.

Zezina (1997) reviewed the distributional studies on the bathyal fauna, but for the most part classified bathyal regions according to what she knew of the distributions of brachiopods. She considered the bathyal fauna to be divisible into four main latitudinal climatic belts: I, those corresponding to the distributional limits of tropical (low latitude) species; II, the limits of northern and southern subtropical species; III, the limits of low boreal and antiboreal species; and IV, the limits of most cold-water species.

Zezina created the following scheme (see box below) for classifying the geographical distribution of the bathyal fauna, suggesting that they approximate latitudinal zones.

**Zezina (1997) classification of bathyal zones**

**For depths less than 700 m:**

BOREAL-ARCTIC AREA contains North Pacific Subarea in which there are the *Asian-Aleutic Province, North-American Province,* and *Californian Province (subtropical)*, the North Atlantic Subarea, and the Arctic Subarea.

AMPHIATLANTIC TROPICAL AREA contains the Atlantic-Central American Subarea in which there are the *Caribbean Province (subtropical)* and *Brazilian Province*, the Lusitano-Mauritanian Subarea (subtropical), and the Mediterranean Subarea (subtropical).

WEST INDO-OCEANIC TROPICAL AREA

INDO-WEST PACIFIC TROPICAL AREA contains the Indo-Malayan Subarea and the Japanese Subarea (subtropical)

SOUTH BRAZILIAN-URUGUAYAN SUBTROPICAL AREA.

SOUTH AFRICAN SUBTROPICAL AREA.

SOUTH AUSTRALIAN SUBTROPICAL AREA in which there are the *Australian Province* and the *Tasmanian Province.*

NEW AMSTERDAMIAN ANTIBOREAL AREA.

NEW ZEALANDIAN-KERGUELENIAN ANTIBOREAL AREA which contains the New Zealandian subarea in which there are the *North New Zealandian Province* and *South New Zealandian Province*, the Kerguelenian Subarea, and the Macquarian Subarea.

ANTARCTIC-SOUTH AMERICAN AREA which contains the South American Subarea and the Antarctic subarea.

And for depths 700-2000 m:

BOREAL BATHYAL AREA which contains the North Atlantic subarea and North Pacific subarea.

AMPHI-ATLANTIC BATHYAL AREA in which there are the *Central Atlantic Province and the Lusitano-Mauritano-Mediterranean Province (transitional).*

WEST-INDO-OCEANIC BATHYAL AREA.

WEST INDO-OCEANIC BATHYAL AREA

WEST PACIFIC BATHYAL AREA in which there are the *Malayan Province* and the *Japanese Province.*

ANTARCTIC BATHYAL AREA.

Zezina (1997) noted that these faunistic units became less distinguishable with depth. Following others she suspected that the deeper parts of the sea were impoverished because of the lack of food and in the brachiopod distributions there were fewer latitudinal zones with depth. In the Pacific there are seven latitudinal belts at depths less than 700 m (these belts correspond more or less to the those of the continental shelves and slopes) whereas at depths greater than 700 m there are only three latitudinal belts and those correspond more or less to the zonation seen in the abyss by Vinogradova (1979).

Zezina also notes in her chapter that the bathyal zone is a place where relict species, “living fossils,” have often been found. Such organisms are prevalent among crustaceans and fish, but also includes crinoids and gastropods among others. She offers several explanations as to why such ancient species may have survived on the slopes and not on the shelves or in the abyss. Chief among these are the lack of long term temperature changes, fluctuating sea levels at shallow depths, and the downward displacement of “older” taxa by the evolution of newer, more specialized species in shallow water.

Parin et al. (1997) review studies conducted on the aseismic block-volcanic Nazca and Sala y Gomez Ridges located on the Nazca Plate. The Nazca Ridge is a deep, narrow plateau on which seamounts with summits from 200 to 850 arise. In contrast the Sala y Gomez Ridge consists largely of a chain of guyots with summits depths of 200-500 m. Samples in the area were taken by trawl and baited traps at stations with depths of 200 to 550 m, with one station at almost 800 m. Parin et al. divided the area into five geomorphologically distinct sub-areas reflected in the groupings of seamounts. Faunal similarity (using the Hacker-Dice index) among 22 seamounts based on 155 genera shows a clear separation of north-eastern seamounts located eastward of 83° W and northward of 23° S from all others. Faunistic differences between vertical zones were found to be less important than those between areas westward and eastward of 83° W.

Endemicity and species relationships were investigated for echinoids, shrimp, tanaids, and fish species from the Nazca and Sala y Gomez Ridges. Among the echinoids, 15 of the 17 genera were found in the Pacific and the Atlantic, however, eight of the 19 species were endemic to the ridge. Only one species was cosmopolitan. The 29 shrimp species had very broad distributions, many being found across the Pacific (10) and in other oceans (7). Among the tanaids, two (of nine) were endemic, and six were also common to the North Atlantic. Fish were also widespread, with 74% of the fish genera being found also in Hawaii, and 85% in Japan. However, 51% of the fish species were endemic to the seamounts of the two ridges.

The biogeographic position of these two ridges could not be agreed to by the three authors of the paper. Mironov adheres to the view that the fauna f the ridges divides along the area of 83° W, with the portion to the west of this line belonging to the Indo-West Pacific Region and the portion to the east being part of the Peru-Chile Province of the Eastern Pacific Tropical Region. Parin and Nesis, on the other hand, consider the whole of the two ridges to belong to a separate unit, which they name the Nazcaplatensis Province, after the lithospheric Nazca Plate on which the ridges sit. They consider the Nazca Ridge, the portion to the east of 83° W, to be merely an impoverished section of the province as a whole. In general, the composition of the fauna in this region can be explained by eastward dispersal of the western Pacific fauna across a biogeographic barrier (the relatively mountain-less abyssal area) and active speciation *in situ*.

The Southern Ocean has generally been considered to be a zoogeographic unit of its own and the source of species for the deep sea wherever Antarctic Bottom Water has spread. Linse et al.(2006) investigated the two largest classes of molluscs (gastropods and bivalves) at both the local and regional scales throughout the Southern Ocean. Patterns of endemism were very different between bivalves and gastropods. On the basis of distributional ranges and radiation centers of evolutionarily successful families and genera three biogeographic provinces in the Southern Ocean were defined: 1. The continental high Antarctic province excluding the Antarctic Peninsula; 2. The Scotia Sea province which includes the Antarctic Peninsula; and 3. The Sub Antarctic province comprising the islands bathed by the Antarctic Circumpolar Current. A multivariate analysis of the combined gastropod and bivalve data showed that at all levels, from family to species, the areas within the Antarctic Convergence form one biogeographic unit with closest affinities to the islands of the Sub-Antarctic, with the exception of the shelf and islands around New Zealand. The southern part of South America is very closely related to the Southern Ocean fauna at the level of family, but less so at the level of genus and species.

Some current efforts are devoted to analysing the biogeographic relationships among deep sea hydrothermal vent faunas at a global scale (Bachraty et al., 2007), recognizing 6 biogeographic provinces based on the benthic community composition data; and at a regional scale the distribution patterns of fauna associated with ferromanganese nodules in the tropical north Pacific (Veillette et al., 2007) and the biogeography of the western Pacific back arc basins (Desbruyeres et al., 2006).

## Annex E

**Scientific Experts' Workshop on Biogeographic Classification Systems in Open Ocean and Deep Seabed Areas Beyond National Jurisdiction; Universidad Nacional Autónoma de México (UNAM) in Mexico City; 22-24 January 2007.**

## Participants

1. Vera N. Agostini - *fisheries oceanography/pelagic ecology*, Pew Institute for Ocean Science, Rosenstiel School of Marine and Atmospheric Science, University of Miami,
2. Eddy Carmack - *Climate oceanography; water mass formation; high-latitude circulation and processes*. Department of Fisheries and Oceans; Institute of Ocean Sciences, Canada
3. Wolfgang Dinter - *Biogeographic systems as applied in Northeast Atlantic and Antarctica*. German Federal Agency for Nature Conservation Marine and Coastal Nature Conservation Unit
4. Robert Y. George - *Isopods, Biodiversity, Conservation, deep Sea Biology,* UNCW, USA
5. Susie Grant - *Biogeography and Southern Ocean systems.* British Antarctic Survey, UK
6. Tony Koslow - *Seamounts, zooplankton.* CalCOFI, SCRIPPS Institution of Oceanography, University of California, USA
7. Vladimir E. Kostylev - *Benthic ecology, habitat mapping and modeling.* Natural Resources Canada, Bedford Institute of Oceanography, Canada
8. Leanne C. Mason - *ocean meta-analysis (both high-seas and regional seas), Marine protected areas, MARXAN, GIS.* Environment Department University of York, UK
9. Luis Medrano - *Evolutionary biology of marine mammals with emphasis on ecology and genetics.* Instituto de Ciencias del Mar y Limnología UNAM, Mexico
10. Tina N. Molodtsova - *deep sea corals.* P.P. Shirshov Institute of Oceanology, Russia
11. Carlos Mortera-Gutiérrez - *Geophysics.* Instituto de Geofisica, UNAM, Mexico
12. Elliott Norse - *Conservation biology*. Marine Conservation Biology Institute, USA
13. John Roff - *Geophysical approaches to marine biodiversity and conservation.* Acadia University, Canada
14. David Salas de León - *Physical oceanography*. Instituto de Ciencias del Mar y Limnología UNAM, Mexico
15. Kathryn M. Scanlon - *Geology of marine habitats.* U.S. Geological Survey, USA
16. Ricardo Serrão Santos - *Ecology and biology of seamounts and vents*. Department of Oceanography and Fisheries, University of the Azores, Portugal
17. George Shillinger - *Use of satellite tracking of multiple pelagic species to determine open ocean migration corridors, important feeding areas, and other areas of concern with tracks stretching from the shores of Costa Rica to the High Seas off of Chile*. The Tagging of Pacific Pelagics program out of Stanford University's Hopkins Marine Lab, USA
18. Craig R. Smith - *Deep Sea Biology*. CeDAMAR; Department of Oceanography; University of Hawaii at Manoa; USA
19. Mark Spalding - *Global marine habitat mapping and leader of recent Marine Ecoregions of the World coast and shelf biogeographic classification*; The Nature Conservancy, United Kingdom
20. Elizabeth Tyler - Protected Areas Programme, United Nations Environment Programme, World Conservation Monitoring Centre, UK
21. Cindy Lee Van Dover - *Vents*, ChEss, Duke University Marine Laboratory, USA

22. Les Watling - *Crustacea, deep corals*. Department of Zoology, University of Hawaii at Manoa, USA

## Steering Committee

23. Salvatore Arico - *Benthic Ecology*; UNESCO's Division of Ecological and Earth Sciences; France
24. Julian Barbiere - *Coastal and ocean management*; Integrated Coastal Area Management and Regional Programmes; Intergovernmental Oceanographic Commission (IOC); UNESCO; France
25. Malcolm Clark - *Deepwater fisheries, seamounts*; NIWA; New Zealand
26. Ian Cresswell - *Australian terrestrial & marine and coastal biogeographic regionalisations, MPAs.* Australian Department of the Environment and Heritage; Australia
27. Elva Escobar - *Deep Sea Benthic Ecology*. Instituto de Ciencias del Mar y Limnología Universidad Nacional Autonoma de Mexico; Mexico
28. Kristina Gjerde - *Marine Policy*; IUCN Global Marine Program, Poland
29. Jake Rice – *Fisheries biology*; Canadian Science Advisory Secretariat, Fisheries and Oceans Canada

## Local Committee / Observers

30. Veronica Aguilar; Observer
31. Porfirio Alvarez, National Ocean Programs; Observer
32. Mariana Bellot; Observer; CONABIO
33. Adolfo Gracia - *Fisheries biology*; ICML UNAM
34. Conn Nugent, JM Kaplan Fund
35. Margarita Caso; Observer; Instituto Nacional de Ecología, SEMARNAT
36. Sergio Cerdera; Observer; CONABIO

## Support and Translation

37. Daniela Popoca Nuñez; CONABIO
38. Daniella Sánchez Mercado; Interpreter for UNAM