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Approaches to biogeographic classification of the world's oceans

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Abstract

This paper reviews existing global approaches to biogeographic classification of the world's oceans, giving particular emphasis to recent developments in this regard. The paper examines the methods, scale, types of data and classification systems (hierarchical or non-hierarchical) that have been used, and provides some specific national and global examples. The paper concludes that there is no one correct way to undertake a biogeographic classification, and that the type of approach selected depends on user needs and the type of management application that the classification will be used for, as well as data limitations.

1. Introduction

The international policy background

At the present time, the world's oceans are seriously under-protected, with only approximately 0.6% of the oceans and 6% of territorial seas within protected area systems (CBD, 2006a). With the continuing decline in the status of marine resources and the biodiversity, international policy has increasingly focused on calls to effectively protect a full spectrum of life on Earth, including in the oceans. This has resulted in the adoption of a number of targets relating to representative networks of marine protected areas. Most notably, the Johannesburg Plan of Implementation, 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"*

Similarly, 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, in 2007, the Conference of the Parties to the CBD adopted the following targets as part of a larger framework of targets for the year 2010 relating to specific biomes:

- *At least 10% of each of the world's marine and coastal ecological regions effectively conserved.*
- *Particularly vulnerable marine and coastal habitats and ecosystems, such as tropical and cold water coral reefs, seamounts, hydrothermal vents mangroves, seagrasses, spawning grounds and other vulnerable areas in marine habitats effectively protected.*

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. They also identified networks of marine protected areas as the primary tool to achieve this protection, but acknowledged that MPAs alone are not enough, and that achieving these targets will also require sustainable management actions over the wider marine and coastal environment in an ecosystem approach context.

As a result, a number of expert group activities are underway to develop biogeographic classification systems for ocean areas, and to review criteria for the potential selection of MPA sites in areas beyond national jurisdiction. These include two new global biogeographic classification systems, one for coastal and shelf areas (The Marine Ecoregions of the World – MEOW. Spalding, 2007) and another, currently under development by an expert group, for deep and open ocean areas (UNICPOLOS, 2007). Additionally, the Convention on Biological Diversity is organizing in October 2007 an expert workshop on ecological criteria and biogeographic classification systems for marine areas in need of protection. These international developments will be of interest and relevance to similar work currently undertaken for the Southern Ocean.

Why the focus on representative areas?

The recent international emphasis on representative networks of MPAs as part of integrated oceans management has its origins in the growing acceptance of the ecosystem approach as a primary framework for biodiversity conservation and management. An ecologically representative network of MPAs should incorporate the full range of 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 effects (CBD, 2004). By ensuring a good representation of biogeographic units within a system of protected areas globally, we can come close to ensuring that the full spectrum of life on Earth will also be protected (UNEP-WCMC, 2007)

Bio- or ecoregionalisation is essentially a classification process that aims to partition a large area into distinct regions that contain groups of plants and animals and physical features that are sufficiently distinct from their surroundings at a chosen scale (UNEP-WCMC, 2007). This requires an understanding of how and where species and their habitats are distributed over geographic space (Spalding, 2007), and an identification of types of marine habitats and delineation of their boundaries in a consistent classification. Without a classification system, the extent and significance of representative or distinctive habitats cannot be recognized. Such recognition is a fundamental prerequisite to determining the location and size of marine areas to be protected (Roff and Taylor, 2000). Biogeographic maps are therefore central to MPA network planning and to biodiversity management in general (UNEP-WCMC, 2007).

2. Approaches to biogeographic classification of the world's oceans

Global biogeographic classification systems

Although marine areas still lag behind terrestrial systems in using biogeographic tools, (CBD 2006c) there have been substantial efforts at biogeographic classification at the local, national and regional scales. There have been fewer such attempts globally, due mainly to the difficulties in acquiring data on this scale. The only purely data-driven global biogeographic classification, the Longhurst classification, uses oceanographic rather than species data. Of the existing biogeographic classifications, the Large Marine Ecosystems (LMEs) are perhaps the most widely used for management purposes. The coverage of the 63 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 new Marine Ecoregions of the World (MEOW) classification provides more comprehensive and finer scale coverage, 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. This latter gap is being filled by a current initiative to develop biogeographic criteria for the classification of open and deep ocean areas co-sponsored by UNESCO, IOC, IUCN, Australia, Canada, Mexico and the J.M. Kaplan Fund.

A number of widely used key global bioregional studies and systems, some of which are still in active use, are summarized in box 1.

Box 1

Selected global marine biogeographic classifications
(Adapted from CBD 2006c)

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. The MEOW system uses many of the boundaries developed by Briggs to inform its own subdivisions, however it was felt by the creators of MEOW that the strict definition is both difficult to apply and leads to bias in favour of subdividing species-poor areas and in ignoring major differences in community composition.

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. At the present time the system is restricted to shelf areas and, in some cases, to adjacent major current systems and does not include 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. The MEOW system uses many of the same boundaries as LMEs either for its Provinces or Ecoregions, but in a few areas the fit is poor. 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)
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 appealled 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 as well as expert consultation. It covers coastal areas and continental shelves, but not the high seas. The classification system includes 12 realms, 58 provinces and 229 ecoregions.

Biogeographic Criteria for the Classification of Open and Deep Ocean Areas (A joint expert effort under the co-sponsorship of UNESCO, IOC, IUCN, Australia, Canada, Mexico and the J.M. Kaplan Fund – 2007) (UNICPOLOS, 2007)
This expert process seeks to work towards developing a global biogeographic classification for open ocean and deep sea areas primarily in marine areas beyond national jurisdiction. The expert group is in the process of developing preliminary maps depicting potential boundaries for biogeographic realms, provinces and 'ecological regions' in the open ocean, and, to the extent possible, for the deep seabed, through the use of GIS and other mapping tools. The work is still in progress, though preliminary results, including maps, are available.

Commonly used methods for undertaking biogeographic classification

There is no universally agreed method for biogeographic classification, but rather, as stated by Dinter (2001), there are as many methods as there are biogeographers. The type of classification undertaken depends on user needs and the type of management application that the classification will be used for. The availability of data and the unique characteristics of the marine environment may also place some limitations to what can be achieved.

Much of the ambiguity in classifying marine areas comes from the fluid nature of the ocean environment, where there are rarely any sharp or absolute boundaries. Rather, boundaries tend to be "fuzzy", allowing for continual movement of organisms and abiotic conditions. Transitions between boundaries are typically 10s or hundreds of kilometers wide (CBD 2006c). Given the dynamic nature of the ocean, biogeographic classification relies greatly on the judgment of experts with thorough knowledge of the areas to be classified (ICES, 2004).

Further complexity is added by the fact that conditions change over a variety of temporal scales, some of which are unpredictable. These changing conditions may result in a considerable shift in biogeographic boundaries through time and space, and such boundaries are often average and simplified locations of transition zones rather than fixed lines in space (CBD, 2006c).

Keeping in mind these complications, the process of biogeographic classification has commonly combined qualitative information (expert opinion, descriptive data) and quantitative statistical analyses. Depending on the purpose of the classification, the availability of data, and other practical considerations, some biogeographic classification efforts have put more emphasis on the expert review process than on the data analysis. For example, Large Marine Ecosystems were delineated to a great degree based on expert opinion. Others, such as the Longhurst classification, have been primarily data driven.

The data analysis component will generally identify the ecological patterns and processes relevant to the purpose of the classification, as well as the underlying drivers controlling those patterns and processes. Available relevant data are compiled and processed using Geographic Information Systems (GIS) software. A data matrix is then compiled for individual sites, and a clustering algorithm is applied to group sites with similar characteristics. The clusters are processed to meet the specific requirements of the application. Finally an expert review process is conducted to validate the bioregion. (Grant et al, 2007 and UNEP-WCMC, 2007). Box 2 below gives an overview of the bioregional classification of the Great Barrier Reef Marine Park.

Box 2

Ecoregional classification of the Great Barrier Reef Marine Park
(Adapted from http://www.gbrmpa.gov.au/)

The primary objective of the Great Barrier Reef Marine Park is biodiversity protection, and the rezoning of the Park designated a number of no-take areas towards this end. Achieving this objective required information about the composition and spatial distribution of biodiversity. Interviews of over 60 scientists were conducted to collect information about:

- Major patterns in distribution of organisms and communities and their habitat requirements
- Major environmental patterns and processes in geomorphology and oceanography which influence productivity, biogeography, community composition and life histories or the region's biodiversity
- Special and unique reefs, islands and other areas for consideration when selecting the no-

take areas. These areas contain unique and outstanding communities, habitats and processes that are critical to species at various stages of their life cycles or to ecosystem functions.

Following data collection and processing, classification and regression tree analysis were undertaken to spatially cluster areas of similar species composition. Finally, the results of the classification, as well as individual data sets were analysed by workshops of expert scientists.

The types of data used in biogeographic classification

The type and the scale of data used are dependent on the objectives of the bioregeographic classification. For example, biogeographic classifications designed to inform biodiversity objectives, fisheries management and marine mammal conservation might each have different data requirements, and be undertaken on different scales. If the sole objective of the classification is to support the selection of a network of representative MPAs, information relating to unique or threatened areas, hotspots or natural areas might not be required at this stage (though it may be considered later in the site selection process). For example, the recent workshop to develop biogeographic criteria to classify open and deep ocean areas held in Mexico consciously excluded any information that did not relate to representative areas (UNICPOLOS, 2007).

Most biogeographic classifications use either biological (species taxonomic, community, habitat) data or data relating to physical features and processes (oceanographic processes, bathymetry, etc.). Mixed systems using both biological and physical features are also common. (Roff and Taylor, 2000). The recent workshop on biogeographic criteria to classify open and deep ocean areas (UNICPOLOS, 2007) summarized the existing approaches as follows:

1. **Taxonomic** – A system based on similarities and differences in organisms or communities of organisms (aka phylogenetic). E.g. realms, provinces;
2. **Physiognomic** – A system based on similarities and differences in habitats/functions/ecological processes. E.g. biomes, habitats, ecosystems (where "habitats" can include abiotic information such as depth and currents).
3. **Mixed –** A system incorporating taxonomic, ecological and physiognomic data.

Although purely biological classifications eliminate the need to look for correlations between organisms and physical parameters, they are difficult to undertake at larger scales due to the lack of reliable information. Most marine organisms cannot be mapped via remote sensing, and direct sampling is labour intensive and tends to result in uneven point data, which is sparse when compared to the vastness of the oceans. The advantage of using physical features is that at large scales they control the distribution of organisms, and there is considerable research which suggests that populations and communities are strongly correlated with habitat types at a number of spatial scales (Roff and Taylor, 2000).

This strong relationships between physical parameters, biological parameters and species is also demonstrated by the fact that many biogeographic approaches produce similar boundaries. The biogeochemical provinces in Longhurst's (Longhurst, 1998) coastal biome overlap to a good extent with Large Marine Ecoystems (UNEP-WCMC, 2007). Some of Longhurst's boundaries are also fairly close to those suggested by taxonomic biogeographers (CBD, 2006c and UNEP-WCMC, 2007).

Examples of the types of data used in biogeographic classification of the marine environment include physical oceanography (e.g. water masses, fronts, gyres and wave energy), geomorphology (depth, substratum, sediment), biological oceanography (primary and secondary production), and biological data (fish stock, marine mammal distribution and abundance) (Grant et al. 2006 and UNEP-WCMC, 2007). In the deep sea, depth zones, topographic highs (such as seamounts) and chemosynthetic ecosystems are likely of importance to biogeography. (UNICPOLOS, 2007)

Box 3

Developing a bioregional classification of Canada's maritime areas
(Adapted from Powles et al, 2004)

A recent workshop to develop a bioregional classification for Canada's seas used the following data:

- geological properties (includes the degree of enclosure, bathymetry and surficial geology)
- physical oceanographic properties (includes ice cover, freshwater influence, water temperature, water masses, currents, and mixing/stratification)
- biological properties (divided into primary productivity, species distributions, population structure and assemblages/communities)

Considerations of scale

The scale of the biogeographic units should be appropriate to reflect gradients of change (Lewis et al, 2003), and the scale of mapping might take into account the following considerations (CBD, 2006b):

(i) What is the realistic scale at which habitats can change markedly?
(ii) What is the scale at which the relevant information is available?
(iii) What is a meaningful scale at which zoning can be best delineated and management best applied?

For example, the Great Barrier Reef Marine Park bioregionalisation was undertaken on a scale of 10s to 100s of kilometers because this was a scale over which habitats change markedly. It was a scale at which much relevant information was available and it was also meaningful for subsequent planning and management (Lewis et al, 2003). In general, it would be expected that biogeographic units in heterogeneous coastal areas with their multitude of habitats would be smaller than biogeographic units further offshore, where the environment is more homogeneous.

Classification systems

The definition of biogeographic units in marine ecosystems is further complicated by their three-dimensional nature. Different taxa can be found at differing depths in the water column or on the seafloor, and under different abiotic conditions. Many biogeographic classifications, particularly in deeper ocean areas, have solved the problem of three-dimensionality by developing parallel biogeographic systems for the pelagic and benthic environments (CBD, 2006c).

By developing parallel classifications, the three-dimensional pelagic and (almost) two-dimensional benthic system can be considered separately. The pelagic environment is more fluid and often less predictable, while the benthos is made up of its own unique features defined by variables such as depth and sediment type, and hosts different communities of organisms. The two are not completely disconnected, though, but exchange energy and organisms takes place. The life cycle of a single organism may have both benthic and pelagic phases (UNICPOLOS, 2007).

A considerable number of the existing classification systems are hierarchical and nested. For example, the Marine Ecoregions of the World (MEOW) uses a system of 12 realms, 58 provinces and 229 ecoregions. The Longhurst classification has divided the oceans into 4 biomes and 57 biogeochemical provinces. The Large Marine Ecosystems on the other hand, use a non-hierarchical classification. The advantage of a good hierarchical and nested system is that it will allow for multiscale analyses, with each level of the hierarchy relevant for conservation planning or management interventions, from the global to the local (Roff and Taylor, 2000). A nested hierarchy will also provide for compatability with other systems, for example between global and regional systems (Spalding, 2007). Above all, a good classification system will have practical utility.

Roff and Taylor (2000) suggest that the scale at which a feature has its dominant effect is where it should be used in a hierarchical classification system. At large scales, physiographic and oceanographic features would dominate. At smaller scales, identification of biotopes should provide verification of such physical classifications of habitat types.

Box 4 provides a summary of how the two recent global biogeographic classifications have dealth with the Southern Ocean.

Box 4

The Southern Ocean in global bioregional classification systems

Although the Large Marine Ecosystem (LME) classification only identified a single Antarctic LME, the two recent global classification systems have provided more detail for the Southern Ocean.

Marine Ecoregions of the World (MEOW) *(Note: This classification only covers coastal and shelf areas to the 200m isobath):*

Southern Ocean
59 .Subantarctic Islands
- 2 1 2 .Macquarie Island
- 2 1 3 .Heard and Macdonald Islands
- 2 1 4 .Kerguelen Islands
- 2 1 5 .Crozet Islands
- 2 1 6 .Prince Edward Islands
- 2 1 7 .Bouvet Island
- 2 1 8 .Peter the First Island

60 .Scotia Sea

2 1 9 .South Sandwich Islands
2 2 0 .South Georgia
2 2 1 .South Orkney Islands
2 2 2 .South Shetland Islands
2 2 3 Antarctic Peninsula

61 .Continental High Antarctic
2 2 4 .East Antarctic Wilkes Land
2 2 5 .East Antarctic Enderby Land
2 2 6 .East Antarctic Dronning Maud Land
2 2 7 .Weddell Sea
2 2 8 .Amundsen/Bellingshausen Sea
2 2 9 .Ross Sea

62 .Subantarctic New Zealand
2 3 0 .Bounty and Antipodes Islands
2 3 1 .Campbell Island
2 3 2 .Auckland Island

Biogeographic Criteria for the Classification of Open and Deep Ocean Areas *(Note: this classification only covers areas beyond the 200m isobath. The classification is also still work in progress).*

Pelagic areas:
Antarctic
Antarctic Polar Front
Subantarctic

Benthic areas (*This classification is still in progress, but will consider the following factors*):

1) Depth zones:
   - Upper bathyal
   - Lower bathyal
   - Abyssal
   - Hadal
2) Hydrographic settings:
   - Water mass
   - Transport pathways
3) Geomorphology:
   - Trenches and troughs
   - Abyssal basins
   - Topographic highs (seamounts, ridges, plateaus, islands)
   - Slopes
   - Shelves
4) Chemosynthetic ecosystems:
   - Vents
   - Seeps
   - Whale falls

The need for periodic review of boundaries

Even if the best possible information is used to define bioregions, their boundaries may need to be reviewed over time as new information becomes available. Because of the general paucity of data for the marine environment, there will always be some uncertainty associated with bioregion boundaries. Improving technology and increased sampling efforts may change our understanding of where these boundaries lie, and may even result in the addition of new classes into the classification system, particularly at lower levels of the hierarchy. In addition, the impacts of climate change may also have an effect on bioregion boundaries.

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