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Pelagic provinces of the world: A biogeographic classification of the world's surface pelagic waters

Mark D. Spalding[a], Vera N. Agostini[b], Jake Rice[c,*], Susie M. Grant[d]

[a] Global Marine Team, The Nature Conservancy and Conservation Science Group, Department of Zoology, University of Cambridge, 93 Centre Drive, Newmarket CB8 8AW, UK
[b] Global Marine Team, The Nature Conservancy, 255 Alhambra Circle, Miami FL 33139, USA
[c] Ecosystem Sciences Branch, Department of Fisheries and Ocean, 200 Kent Street, Ottawa, Ontario K1A 0E6, Canada
[d] British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

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ABSTRACT

Off-shelf waters cover 66% of the planet. Growing concerns about the state of natural resources in these waters, and of future threats have led to a growing movement to improve management and conservation of natural resources. However, efforts to assess progress and to further plan and prioritise management interventions have been held back in part by the lack of a comprehensive biogeographic classification for the high seas. In this work we review existing efforts at classifying the surface pelagic waters of the world's oceans and we present a synthesis classification which draws both on known taxonomic biogeography and on the oceanographic forces which are major drivers of ecological patterns. We describe a nested system of 37 pelagic provinces of the world, nested into a system of four broad realms. Ecologically we have also differentiated a system of 7 biomes which are spatially disjoint but united by common abiotic conditions creating physiognomically similar communities. This system builds on existing work and is further intended to align closely with the coastal biogeographic regionalisation provided by the Marine Ecoregions of the World classification. It is hoped that it will provide a valuable tool in supporting threat analysis, priority setting, policy development and active management of the world's pelagic oceans.

1. Introduction

Off-shelf waters cover some 66% of the surface of the planet, the vast majority lying in areas beyond national jurisdiction. The shallow photic layer of these waters, termed oceanic epipelagic, typically has lower biomass and species diversity than adjacent neritic (or continental shelf) pelagic waters (Jennings et al., 2008). However, as a result of the vast overall extent of the high seas, the global totals of biomass, productivity and indeed biodiversity in oceanic pelagic waters are very high. These waters play a critical role in climatic processes and in supporting commercial and some artisanal fisheries. They are also home to far ranging species, such as tunas and large sharks, dolphins and whales, squid, seabirds and turtles. Many of these creatures are poorly understood, but the pivotal role they play in trophic food webs is increasingly evident (Hinke et al., 2004; Kitchell et al., 2002). The fish communities inhabiting pelagic waters have undergone dramatic biological changes in recent decades, primarily as a result of growing high seas fishing impacts (FAO, 2007; Kura et al., 2004; Myers and Worm, 2003; Sibert et al., 2007; Worm et al., 2006). They also now face an increasing array of other impacts such as pollution and climate change (Ellison, 2007. Halpern et al., 2008; Lohmann et al., 2007).

Alongside these growing concerns, efforts to better manage these waters are growing in scope and strength, both through increasing management interventions within waters of national jurisdiction and through increasing international collaborative efforts in the high seas. These international collaborations include binding instruments of international law such as the UN General Assembly resolutions on sustainable fisheries (UNGA, 1995, 2006); "soft law" provisions such as the International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2008a), the International Plans of Action for Conservation of Sharks, Seabirds, the management of fishing capacity and the control of IUU (Illegal, Unreported and Unregulated) fishing (FAO, 1999, 2001); the Code of Conduct for Responsible Fisheries (FAO, 1995); the growing number and expanding coverage of Regional Fisheries Management Organisations (FAO, 2008b), and increased

* Corresponding author. Tel.: +1 613 990 0288; fax: +1 613 954 0807.
E-mail addresses: mspalding@tnc.org (M.D. Spalding), vagostini@tnc.org (V.N. Agostini), Jake.Rice@dfo-mpo.gc.ca (J. Rice), suan@bas.ac.uk (S.M. Grant).

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coordination of efforts between intergovernmental organisations such as IOC, UNEP, FAO, and CBD (e.g. the Assessment of Assessments jointly coordinated by IOC and UNEP (www.unga-regular-process.org)) and the FAO, IUCN, CBD collaboration on identifying and protecting ecologically significant and vulnerable marine habitats (http://www.cbd.int/decision/cop/?id=11663).

Existing geo-political classifications, including Exclusive Economic Zones and extended state jurisdictions, are in many cases a poor tool for the management of natural systems, which show little or no fidelity to such boundaries. Even management units which are intended to have some biological basis, such as areas covered by Regional Fisheries Management Organizations, and UNEP Regional Seas, are compromises between ecological and political requirements, and at best reflect the distributions of a few species of particular interest to the respective agencies. Effective management of natural resources must instead utilise the patterns of distributions of all the major interacting species, and the oceanographic drivers that underpin these. As the need for such management interventions are becoming increasingly acknowledged, so the need to devise a classification that supports such management becomes increasingly imperative.

This paper presents a new global classification for the oceanic epipelagic waters of the world's oceans and semi-enclosed seas, based on considerations of biodiversity and on the underlying oceanographic drivers of biodiversity patterns. The work builds on discussions held at workshops held in Mexico City in January, 2007, and in Ponta Delgada in the Azores in October, 2007 (CBD, 2008). In the Mexico workshop 30 scientists defined a set of basic principles and a framework for the recognition and classification of open ocean biogeographic regions, while a pelagic sub-group proposed a first draft classification which forms the basis for the present paper. The smaller Azores workshop was organised under the auspices of the Secretariat of the Subsidiary Body of Scientific, Technical and Technological Advice for the Convention on Biological Diversity and further developed framework guidelines for biogeographic classification.

The resulting classification is particularly relevant given the recent focus of both the CBD and FAO on issues related to the high seas, and the commitment of governments to address threats to the deep sea. The policy developments that require these classification systems, and the uses they will serve, are developed in Rice et al. (2011). This work parallels another ongoing effort to derive a similar classification for the deep ocean benthos as well as a similar global synthesis classification focused on coastal and shelf waters – the marine ecoregions of the world (MEOW) (Spalding et al., 2007).

2. A review of existing work

Many publications exist (see references below) describing patterns in the distribution of various taxa (mostly planktonic) at global or single ocean scales, dating back to the 1940s. Recent years have also seen the appearance of other ecological classifications of pelagic waters which have largely ignored taxonomic patterns and have derived maps based on simple or combined measures of climate, physical oceanography and biological productivity (Briggs, 1995; Bailey, 1998; Longhurst, 1998). Here we compare many of these classifications, looking for synergies and common ideas which might underpin the development of a new synthesis classification, and also explore some of the challenges that have been considered and explored in these earlier publications.

2.1. Taxonomic classifications

In considering taxonomically-derived classifications, which taken together represent a broad array of planktonic taxa, we found considerable congruence in terms of both terminology and the apparent number and distribution of biogeographic units, as laid out in Table 1. Although there is clearly cross-reference between these studies most were derived independently from direct observations of specific taxa, supporting the idea that common patterns exist across taxonomic groups (Ekman, 1953; Steuer, 1933; Hedgpeth, 1957; Brinton, 1962; McGowan, 1971; McGowan and Walker, 1994; Beklemishev, 1960, 1971, Beklemishev et al., 1977; Bé, 1971, 1977; Bé and Gilmer, 1977; Casey, 1977; Honjo, 1977; Backus, 1986; White, 1994; Semina, 1997).

Latitudinal subdivisions in these earlier works show two levels of a hierarchy. At the highest level (the "regions" of Bé (1971, 1977), Bé and Gilmer (1977) and Semina (1997)) there are three divisions, essentially colder northern, warm and colder southern waters. Many other authors converge on a finer classification, which Bé and to some degree Ekman (1953) and Semina (1997), also point to, and which was summarised in an earlier review by Boltovskoy (1998). This consists of nine latitudinal "belts": Arctic, Subarctic, Northern Transitional, Northern Subtropical, Tropical, Southern Subtropical, Southern Transitional, Subantarctic, and Antarctic (the Boltovskoy review; Boltovskoy, 1998) is not included in Table 1 as it is not a new or independent study, but rather a synthesis.

In producing these classifications, most authors focused on single ocean basins, but of those who considered larger areas, there is also strong agreement about latitudinal divisions. Almost all point to distinctive taxonomic units by ocean basin, and in some cases also separating out a distinctive biogeographic entity for the Eastern Tropical Pacific.

The primary importance of oceanic drivers emerges as a feature of almost all taxonomically-derived maps. Among these drivers, the distribution of currents and gyres are of greatest influence, although temperature and salinity fronts are also noted. Several authors have utilised early physical oceanographic classifications such as Sverdrup et al. (1942) to delineate or refine taxonomic regions, particularly where field observations are scarce. Beklemishev (1971) goes so far as to suggest that ocean gyres are the only stable basis for species distributions, and that the transition zones may have distinctive elements but that these are "terminal communities" with no stable base. This has been challenged by others, including McGowan (1971) who points out that there are endemic species in some transition zones.

2.2. Non-taxonomic classifications

A number of global studies have developed biogeographic maps without direct reference to species or taxonomically defined assemblages. One of the first of these was that proposed by Dietrich et al. (originally published in German in 1957) (1980). This work argues that patterns of ocean surface currents, modified by ice conditions in high latitudes are among the principle "causes leading to a natural classification". Using this information the authors proposed a system of seven major regions – trade wind currents, equatorial countercurrents, monsoon currents, horse latitudes, jet stream, west wind drift, and polar – with subdivisions for some of these. This work forms the background for very similar classifications developed by Hayden et al. (1984) and by Bailey (1998). In the polar regions, consideration has also been given to the role of ice dynamics in driving taxonomic patterns (e.g. Tréguer and Jacques, 1992).

In a very different approach, Longhurst (1998) proposed a system of biomes, with nested, finer-scale "biogeochemical provinces". These are based on environmental variables such as sea surface temperature, mixed layer depth, nutrient dynamics and circulation, but then strongly influenced by satellite-derived measures of algal ecology, notably surface productivity. This

Table 1
Comparison of the latitudinal classes utilized in twelve large-scale phylogenetic bio-regionalisations of pelagic species. Where authors offer a hierarchical system higher geographic classes are highlighted in bold, with arrows marking their latitudinal spread, and with finer resolution subdivisions to the right. Where authors recognized distinct longitudinal regionalization these are marked with short vertical separators (note that not all authors consider more than one ocean basin).

Author	**Ekman 1953**	**Steuer 1933**	**Hedgpeth 1957**	**Brinton 1962**	**McGowan 1971 McGowan & Walker 1994**	**Beklemishev 1960, 1971, Beklemishev et al. 1977**
Coverage	**Global**	**Global**	**Global**	**Pacific**	**Pacific**	**Global**
Focal Taxa	**Various**	**Copepods**	**General**	**Euphausids**	**Various**	**General**
90^0 North	Arctic	Circumpolar Arctic	Arctic	-	-	Arcto-Boreal
	Arcto-boreal	Subarctic Atl | Pac	Boreal Atl | Pac	Subarctic	Subarctic	-
Sub-tropical convergence	-	-	-	Transition	Transition	Mixing Zone
		Northern Subtropical Atl | Pac	Warm Temperate Atl | Pac	North Central	Central	-
Equatorial	(Warm Water)	Tropical Atl. | Pac.	Tropical Atl | IndoPac	Equatorial	Equatorial	Tropical
		Southern Subtropical Atl | Ind | Pac	Southern Warm Temperate	South Central	-	-
Sub-tropical convergence	-	-	-	-	-	-
	Anti-boreal	Circumpolar Subantarctic	Antiboreal	Sub-Antarctic	Sub-Antarctic	Low Antarctic
90^0 South	Ant-arctic	Circumpolar Antarctic	Antarctic	Antarctic	Antarctic	High Antarctic

Author	**Bé 1971 Bé 1977 Bé and Gilmer 1977**	**Casey 1977**	**Honjo 1971**	**Backus 1986**	**White 1994**	**Semina 1997**
Coverage	**Atlantic and Indian**	**Pacific**	**North & Central Pacific**	**Atlantic**	**Pacific**	**Pacific**
Focal Taxa	**Formen-ifera & pteropoda**	**Radiolaria**	**Coccolitho-phorids**	**Unknown, probably various**	**General**	**Phytoplankton**
90^0 North	Polar (Arctic)	-	-	Arctic	Arctic	Arcto-Boreal
	Sub Polar (Subarctic)	Subarctic	Subarctic	Subarctic	Subarctic	
Sub-tropical convergence	Transitional	Transitional	Transitional	Transitional (including. Mediter-ranean)	North Temperate	Transition
	Sub-Tropical	North Central	Central Zone; North or Central Gyre	Northern Subtropical	North Central	North Central
Equatorial	Tropical	Equatorial	Equatorial North	Tropical	Cen. Equatorial | Eastern Tropical	Transition Equatorial Transition
			Equatorial South			
Sub-tropical convergence	Sub-tropical	South Central	Central Zone South	Southern Subtropical	South Central	South Central
	Transitional	-	-	Transitional (Southern temperate)	South Temperate	Transition
	Sub-Polar	Sub Antarctic	-	Sub-Antarctic	Sub-Antarctic	
90^0 South	Polar (Antarctic)	Antarctic	-	Antarctic	Antarctic	Antarctic

approach leads to many partitions or boundaries that closely match those proposed by taxonomic biogeographers, but in excluding the spatial dynamics of taxonomic assemblages and their constituent species it also leads to some dramatic divergences. In a few areas this system does not strictly follow the surface circulation patterns, and even some of its broader-scale biomes subdivide major ocean gyres. It is not straightforward to determine whether it is the data on productivity, temperature, or nutrients which are driving this divergence, however the consequence is the splitting of a small number of regions which others have defined as being reliable units of taxonomic integrity.

Aside from anomalies in just a few of the Longhurst biomes, there are considerable overlaps among the broad array of taxonomic classifications, and between these and the non-taxonomic classifications. Such overlaps are undoubtedly derived from the common oceanographic drivers which underpin both approaches. One important addition from the non-taxonomic maps is the clear identification, either as major divisions or as sub-divisions, of boundary currents at continental margins and of semi-enclosed seas. That such spatial units were left out of the taxonomic classifications is a function of the scale of observation and the taxonomic groups under review. The global taxonomic studies were focussed on holopelagic species (species with no life-history dependence on continental shelf influences), intentionally not considering species which have life-history linkages to continental shelves (meropelagic species). These meropelagic species are the most distinctive taxonomic elements of pelagic biotas in these boundary regions.

Although not a taxonomic classification as such, the Large Marine Ecosystem (LME) concept has been influential in many policy and management contexts (c.f. http://www.lme.noaa.gov/). It is a spatially based concept, like the biogeographic classification systems being considered here, and also the result of expert processes. However it is not a nested approach to spatial classification and considers seafloor characteristics and ecosystem processes linked to benthic habitats and taxa. Hence it cannot be directly compared to the classifications considered here. Nonetheless many of the LMEs that have been identified correspond well with the realms and provinces we report, suggesting substantial compatibilities may be found between the uses of both this strictly epipelagic classification and the LMEs.

2.3. Challenges

An important conclusion emerging from these studies is that the dynamic nature of ocean currents, gyres, and fronts poses a considerable challenge to placing boundaries between biogeographic regions. Any true representation of such dynamic processes would require the positioning of boundaries in a temporally-variable, and only partially predictable, system. By contrast, boundaries defined on a static map will be schematic, each line representing either a fixed point in time or, more usefully, a zone of change that is both blurred and variable over time.

The caveat that fixed lines are in reality blurred and variable applies to all of the classifications so far described – such fixed lines are clearly useful for generic or descriptive work, and for policy and planning. Some further recognition of the large areas of shifting boundaries is given with the inclusion of the broader zones of transition as separate spatial units (Polovina et al., 2001). At the same time it is important to consider the possibility of delineating variable ocean boundaries that can then be applied in near-real time. Work is rapidly advancing in this field, using similar “rules” to those defined by Longhurst, which can be applied, using satellite data or other sources to define boundaries when required (Devred et al., 2007; Platt et al., 2005). In fact such approaches may be highly complementary: with fixed lines of the type developed and presented here being useful for longer-term planning and policy development, and with dynamic systems used for real-time delivery of management actions.

In addition, climate change in affecting the oceans, changing some oceanographic features at rates and magnitudes unmatched in our data records (IPCC, 2007; Hollowed et al., 2011). Species are undoubtedly responding to the changes in oceanographic conditions in a variety of ways, including likely some changes in distributions. However it has proven difficult to quantify these changes even for our most data-rich coastal systems, and it appears some taxa are much more sensitive to these climate-driven changes in oceanographic conditions than others (Tasker, 2009). For this reason as well the fixed lines should be considered blurred in management applications. However the possible impacts of climate change on biogeography provide another value to these comprehensive classification systems, where the integrity of large-scale patterns of co-occurrences of taxa are captures for comparison with future trends.

The apparent convergence of terminology and spatial units drawn up by different biogeographers is in fact more complex, with variable locations for many boundaries. Some of this variation reflects real differences in the distribution of the taxa used in the different studies. There is also likely to be considerable variance introduced by other factors, including: the low resolution “sketch map” nature of the illustrations; changing understanding of physical oceanographic processes which may have underpinned the drawing of boundaries; real decadal-scale changes in the positions of some features, and simple “noise”. Unfortunately the available information lacks sufficient detail to distinguish the role of true taxonomic variance from these other influences.

A further challenge relates to the drawing of summary boundaries from the combination of range maps from wide-ranging, dynamic and often poorly documented species. Ekman (1953) points out that oceanic waters have a relatively weak taxonomic characterization, further weakening the likelihood of finding most taxa sharing common range boundaries. Based on this, McGowan (1971) stated that “the zooplankton (and probably the phytoplankton) of the world’s oceans have no biogeography”, although he goes on to produce a classification based on patterns of endemism. A number of other authors point to the broad ranges of species; as well as to patterns of bipolarity in many non-equatorial species including euphasiids (Brinton, 1962), foraminiferans (Bé, 1971, 1977), and pterapods (Bé and Gilmer, 1977). Many species are restricted to particular ocean basins, however others, particularly those of the strictly oceanic/holopelagic plankton, are found in more than one ocean, even in the warmer water regions where land barriers (between Atlantic and Indo-Pacific waters) are substantial obstacles to dispersal (Hedgpeth, 1957; Semina, 1997).

Based on these observations, epipelagic classifications have to draw on patterns at lower taxonomic resolution, using species and subspecies to try and delineate regions (McGowan, 1971) rather than the higher taxa that were used in equivalent continental shelf or terrestrial classifications (Olson et al., 2001; Spalding et al., 2007). It remains important to note, however, that even subtle differences at the level of individual species may be additive, combining with other unique species and also characteristic oceanographic conditions to more clearly define distinctive assemblages (Semina, 1997; McGowan and Walker, 1994).

3. Developing a consistent global coverage

Existing studies provide a sound foundation for understanding biogeographic patterns in the high seas. However, the differences between schemes, the narrow taxonomic focus of many, the geographic limitations of some, and the lack of biogeographic considerations in the non-taxonomic classifications, provide a clear incentive for the development of a synthesis classification. Such a synthesis would reflect improvements due to the advances in oceanographic knowledge, cartographic technology, and better understanding of marine biodiversity patterns. Importantly, a new synthesis would also be of direct value to the rapidly advancing science of conservation planning, and provide support for the international conservation agreements which are setting targets for conservation action based on biogeographic measures.

A particular focus of the current work was to develop a phylogenetic or taxonomic system "based on taxonomic configurations, influenced by evolutionary history, patterns of dispersal, and isolation" (Spalding et al., 2007). At the same time it was recognised that large-scale communities with broadly similar structural and functional compositions, albeit made up of different species, were found in disparate locations around the world. These are equivalent to terrestrial biomes such as humid forests, grasslands or tundra (Udvardy, 1975): while the latter can be predicted by climate (primarily temperature and rainfall) so pelagic biomes are largely a function of water movements (currents, gyres, upwellings), nutrients and temperature. Biome-type classifications are also described as physiognomic, a term that relates to the structuring component of dominant vegetation which helps to define terrestrial biomes. Recognizing the important links between taxonomic and physiognomic systems, we decided to group our biogeographic units both in terms of taxonomic and physiognomic patterns.

Ideally we would apply quantitatively rigorous algorithms to finely resolved spatial data on the occurrence of taxa at the species level of resolution, so all biogeographic units would be delineated objectively on consistent standards of taxonomic resolution. In practice the available data do not support such scientifically idea approaches. As noted in the section on challenges, there are severe biases in the coverage of distributional data on occurrence of taxa both among regions of the oceans (more data from areas which are rich in science capacity) and among pelagic taxa. With such biases in the available data, application of quantitative algorithms would only provide pretence of scientific rigour, while actually having the biases in the data likely dominate many of the resultant patterns. Our desire for comprehensive consideration of pelagic biodiversity, rather than restrictive treatment of only the most data-rich subset of taxa, led us to apply a qualitative approach, with expert dialogue informed by global maps of such distributional data as existed for the pelagic zone.

Thus the remainder of this paper details a new biogeographic classification derived entirely from the synthesis of existing information, with three major sources of input: a) biogeographic assessments in the peer-reviewed literature, including the global studies already mentioned and outlined in Table 1 as well as a number of physical oceanographic sources; b) expert knowledge from the authors and several other experts who attended the workshop in Mexico City (see acknowledgments); c) expert knowledge and review from researchers very familiar with specific areas. We were guided by the following principles:

1. The new system would have a strong biogeographic basis, be of practical utility and be a parsimonious system – drawing from and minimising divergence from existing classifications (as in Spalding et al. (2007)
2. Recognising the tight linkages between taxonomic biogeography and a small number of oceanic drivers, and also recognising the incomplete state of knowledge of distributions of most marine taxa, maps should be underpinned by oceanographic drivers, selected and informed by taxonomic patterns as far as possible. Such an approach allows for effective integration of existing classification schemes, production of a more consistent map, integration of the latest information on oceanographic processes, and treatment of areas for which no or little information on the distribution of taxa exists.
3. In defining and developing such patterns our ecological interest would concentrate entirely on portraying taxonomic patterns, and would not be broadened to other biotic measures such as productivity.
4. Recognising that oceanographic drivers, and the taxonomic patterns they produce, vary dramatically with depth and further that available knowledge rapidly diminishes with increasing depth it was decided to focus on patterns in surface waters, the epipelagic, to approximately 200 m depth.
5. Oceanic pelagic biotas also include large numbers of species that depend, for at least part of their life history, on shelf or continental slope waters. Such species have been variously termed "meroplanktonic" (Ekman, 1953), "boundary species" (Brinton, 1962) or "distant neritic" (Briggs, 1995). Their ranges extend far out into the high seas and they make up an important part of the biomass and productivity of many epipelagic waters. Taking this influence into consideration it was decided to extend the classification provided by holoplanktonic biogeographers to include coastal boundary currents and semi-enclosed seas.

4. Pelagic provinces of the world

4.1. Definitions

The principal focus of the work was to prepare a single system of provinces that would encapsulate the patterns described by earlier authors. Mirroring the MEOW classification, and recognising earlier work (above and Table 1), these provinces were also nested into larger-scale realms. Finally, recognising that very similar oceanographic drivers are repeated in multiple locations, a parallel classification of provinces into spatially disjunct biomes was undertaken. Following the guidelines above, and through the subsequent review process, we developed the following definitions.

Provinces – large areas of epipelagic ocean that can be defined by large-scale, spatially and temporally stable (or seasonally recurrent) oceanographic drivers. Provinces host distinct species assemblages that share a common history of co-evolution. Oceanographic drivers may include major ocean gyres, equatorial upwellings, upwelling zones at basin edges, semi-enclosed pelagic basins and large-scale transitional elements. Taxonomic refinement will typically be driven by isolation at the scale of ocean basin and hemisphere.

Biomes – groupings of provinces with common oceanographic processes (boundary current systems, mid-oceanic gyres etc.). These may be separated by large physical distances and have very different evolutionary histories. They would therefore be expected to host ecosystems with comparable structural and functional properties, but would not host the same species.

Realms – the largest scale units of phylogenetic organisation in the oceans, paralleling the "regions" described by some authors (above). These are very large regions across which biotas are internally coherent at higher taxonomic levels, as a result of a shared and unique evolutionary history. Realms have high levels of endemism, including unique taxa at generic and family levels in some groups. The distribution of individual species often does not encompass all of a realm, but coherence is often present at generic or family levels.

4.2. Pelagic provinces of the world

The resulting map is presented in Fig. 1. We describe 37 pelagic provinces which are broadly grouped into 4 realms (Northern Coldwater, Indo-Pacific Warmwater, Atlantic Warmwater and Southern Coldwater). These are listed with brief descriptions in Table 2. This is a global classification system covering all off-shelf pelagic waters, including, but not restricted to, all waters beyond national jurisdiction. As already noted we focus on the upper 200 m of the water column, but recognize important exchanges with other depth layers of the pelagic ocean, as well as coastal and shelf waters (see section below on linking to other existing classification systems). The close links between this new synthesis and existing classifications can be seen from comparison with Table 1.

We have grouped these provinces into 7 major biomes: polar, gyre, eastern boundary currents, western boundary currents, equatorial, transitional and semi-enclosed seas.

Gyres emerge as dominant systems and form the central feature of this and most other classifications. As such they may contain more distinctive features and unique species than transitional and convergence systems. The eastern and western boundaries of gyral systems often merge into somewhat distinctive “boundary current” systems. These have received less consistent attention from taxonomic studies, which focus on holopelagic species and which typically place them as part of associated gyres. We have separated them as unique systems in terms of oceanographic processes, with typically more rapid current systems, but also with dramatic associated processes such as temperature gradients, upwelling and nutrient enrichment. Such systems are consequently rich in distinctive meropelagic species, which have dominated more localised studies of individual boundary current provinces.

Similar distinctive systems are found in the enclosed pelagic seas. Clearly each has distinctive oceanographic conditions as a consequence of their physical separation. They are also home to distinctive biotas, dominated by meropelagic species. Many also show patterns even in the holopelagic species.

It is important to note that the pelagic realm is characterised by fluid boundaries. All boundaries are dynamic, their positions changing often daily, seasonally, interannually, and decadally. Within this general variability, certain boundaries may be particularly dynamic, such as the widths and northern and southern limits of boundary currents. Moreover, at any given time the transitions between provinces are not abrupt, but are gradients of change over distances from a few tens of kilometres to several hundred, depending on the nature of the oceanographic processes underlying the biotic transitions. Boundaries between the several central basin gyres and the adjacent provinces tend to be particularly gradual. The boundaries in Fig. 1 are best considered as approximate mid-points in regions of transition, but should be viewed as being drawn with broad brush-strokes.

4.3. Linking to other systems

As already stated this classification has focused on the epipelagic zone and species that are strictly pelagic. More complex patterns would emerge if we were to include deeper waters, however the paucity of knowledge of distribution patterns among deeper-dwelling organisms precludes any such study at the present time. We cannot assume that surface patterns are maintained in deeper waters, as dominant oceanographic patterns vary with depth. Although there is certainly overlap in biotic characteristics for many species whose vertical distribution extends into deeper waters, there are changes in range with depth (see, for example, Casey (1977)), suggesting that a biogeographic classification for deeper pelagic waters might look somewhat different to an epipelagic classification. The dominant characteristics of deeper pelagic waters (mesopelagic, bathy-pelagic) need to be described when sufficient data become available; we note that important links exist amongst the physical and ecological structure of these habitats and should be treated in future studies.

As discussed above, the pelagic realm is characterised by fluid boundaries. The lack of sharp edges also holds where this

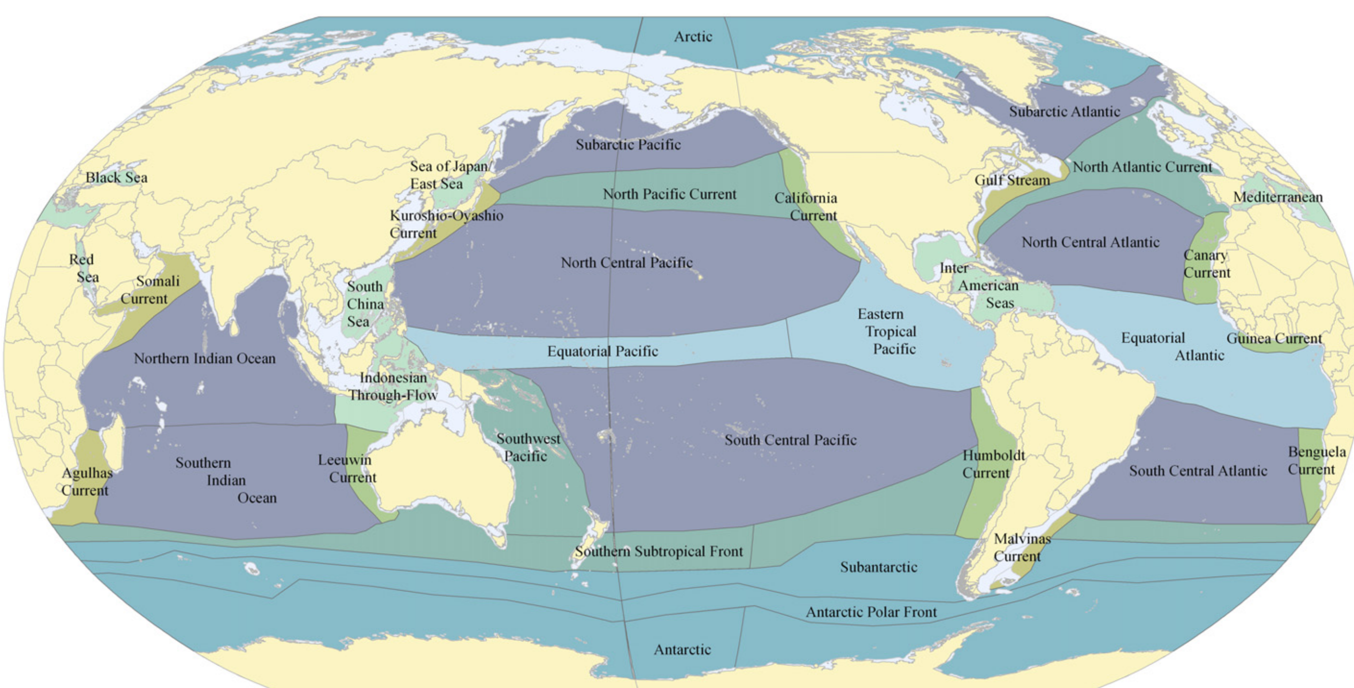

Fig. 1. Pelagic provinces of the world. Continental shelf areas (to 200 m) are marked in pale blue. Individual provinces are labeled, while the colors represent the different biomes, matching those used in Table 2.

Table 2
Pelagic provinces (as displayed in Fig. 1). Brief descriptions characterize each province in terms of water masses, currents, productivity and other processes influencing patterns of biodiversity. Each province is assigned to one of seven biomes, and shading matches colors in the map in Fig. 1 (Polar, Transitional, Gyre, Equatorial, Western Boundary, Eastern Boundary, and Enclosed Seas). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Realm and Province	Biome	Description
Northern Coldwater Realm		
Arctic	Polar	Cold, low salinity water formed by seasonal ice-melt and input from rivers. Productivity is high in summer, with circulation restricted by land masses surrounding the Arctic Ocean.
Subarctic Atlantic	Gyre	The Subarctic Atlantic province is a broadly gyral system that is bounded by the North Atlantic Drift, and the Irminger, Greenland and Labrador Currents. A counter-clockwise circulation system forms around the persistent Icelandic low-pressure system at around 60°N, and drives the upwelling of nutrient rich waters from lower depths to the photic zone, increasing productivity.
Subarctic Pacific	Gyre	A counter-clockwise circulation system forms around the persistent Aleutian low-pressure system at around 60°N. This drives the upwelling of nutrient rich waters from lower depths to the photic zone, increasing productivity.
Indo-Pacific Warmwater Realm		
Agulhas Current	Western Boundary	The western boundary current of the South Indian Ocean and one of the major currents of the Southern Hemisphere. The two major source regions for the Agulhas current are the Mozambique channel to the north and along the coast; and a major contribution from the Madagascar current to the east. The Agulhas current brings warm water poleward. It retroflects and returns eastward with part of the flow recirculating in the counter-clockwise flowing Southern Indian Ocean Gyre and part of the flow feeding the Antarctic Circumpolar Current. Another component of the Agulhas current feeds the Benguela current, advecting warm water into the South Atlantic in the form of pinched off anticyclonic rings. This warm-water link -between the Atlantic and Indian oceans is likely to have a strong influence on global climate patterns.
California Current	Eastern Boundary	The eastern limb of the North Pacific gyre, a nutrient rich and highly productive coastal upwelling system, characterized by high inter-annual variability and strong horizontal gradients of temperature, salinity and biomass. It is a transition ecosystem between subtropical and subarctic water masses. High species diversity is maintained by immigration from adjacent systems, which may also explain the remarkable resilience to varied conditions.
Sea of Japan /East Sea	Semi-enclosed sea	A marginal sea of the Western Pacific Ocean, connected to other seas by five shallow straits. The East Sea has three major basins: the Yamato Basin in the southeast; the Japan Basin in the north; and the Tsushima Basin (Ulleung Basin) in the southwest. The Tsushima Warm Current, a branch of Kuroshio Current, flows northward through the Korea Strait along the Japanese shore, and the Liman Cold Current flows southward through the Strait of Tartary along the Russian shore.
Eastern Tropical Pacific	Equatorial	Several major oceanic current systems meet in this region, resulting in a unique variety of tropical and temperate life. Its complex biogeography , including isolated islands, the convergence of numerous currents and highly productive upwelling have given rise to high diversity, endemism and concentrations of species that support both fisheries and tourism. In particular, the cyclonic eddy of the Costa Rica dome located in this area creates a nutrient rich upwelling with cool, relatively low-oxygen waters, maintaining a high biomass of fish.
Equatorial Atlantic	Equatorial	Although non-gyral, the opposing flows of the Equatorial Countercurrent and the North and South Equatorial Currents allow for some continuity of biotas, while equatorial upwelling creates quite different conditions from adjacent gyres. This upwelling is seasonal (July-September), and centered at 2°30'S.
Equatorial Pacific	Equatorial	Like its Atlantic counterpart this is a non-gyral province, but with some some continuity of biotas provided by the opposing flows of the Equatorial countercurrent and the Equatorial Currents to north and south. The upwelling in this region creates quite different conditions from adjacent gyres. This upwelling is quasi–permanent, and centered around the equator.
Humboldt Current	Eastern Boundary	The eastern limb of the south Pacific gyre, a relatively slow, shallow, cold-water current. It is the largest upwelling system in the world, with very high productivity driven by cold, nutrient-rich water being brought to the surface. Its high rates of primary and secondary productivity support some of the world's largest fisheries as well as large numbers of marine mammals.
Indonesian Flow-through	Semi-enclosed sea	Dominated by the Indonesian Throughflow, an ocean current that transports water between the Pacific Ocean (relatively warm fresh water) and the Indian Ocean (cooler, saltier waters) through the Indonesian Archipelago. The direction of transport is strongly dependent on seasonal and annual climate, although the total net annual transport is mostly southward from the Pacific Ocean into the Indian Ocean.
Kuroshio-Oyashio Current	Western Boundary	A strong surface oceanic current of the Pacific Ocean, the westernmost limb of the North Pacific Gyre. It is the northeasterly flowing continuation of the Pacific North Equatorial Current between Luzon of the Philippines and the east coast of Japan. The temperature and salinity of Kuroshio water are relatively high for the region This warm tropical water traveling poleward supports the coral reefs of Japan, the most northerly coral reefs in the world.
Leeuwin Current System	Eastern Boundary	The confluence of several different currents in this province creates a unique oceanic current system. A warm ocean current flows southward near the western coast of Australia, and around Cape Leeuwin to enter waters south of Australia where its influence extends as far as Tasmania. The West Australian Current and Southern Australian Countercurrent, which are produced by the West Wind Drift on southern Indian Ocean and at Tasmania, respectively, flow in the opposite direction. In contrast to northward flowing coastal currents at similar latitudes, the Leeuwin Current results in the continental shelf waters of Western Australia being warmer in winter and cooler in summer than corresponding regions off other continents. The Leeuwin Current is also responsible for the presence of the most southerly true corals at the Abrolhos Islands and the transport of tropical marine species down the west coast and across into the Great Australian Bight.
North Pacific Current	Transitional	This transitional system forms the northern part of the North Pacific Subtropical Gyre. The North Pacific Current is a slow, warm water current that flows west-to-east between 40° and 50° N in the Pacific Ocean. It is formed by the collision of the Kuroshio Current, running northward off the coast of Japan, and the cold, subarctic Oyashio Current, which flows south and circulates counterclockwise along the western North Pacific Ocean. In the eastern North Pacific, it splits into the southward California Current and the northward Alaska Current.
North Central Pacific	Gyre	This gyre is located between the equator and 50° N latitude, comprising most of the North Pacific Ocean. It has a clockwise circulation pattern and is bounded by four major ocean currents: the North Pacific Current to the north, the California Current to the east, the North Equatorial Current to the south, and the Kuroshio Current to the west.

(continued on next page)

Table 2 *(continued)*

Realm and Province	Biome	Description
Northern Indian Ocean	Gyre	Currents in the Northern Indian Ocean are mainly controlled by the monsoon, and are dominated by a large circular clockwise current. During the winter monsoon, however, this current reverses. Large numbers of submarine plateau and ridges emerge as small isolated islands. Deep water circulation is controlled primarily by inflows from the Atlantic Ocean, the Red Sea, and Antarctic currents.
Red Sea	Semi-enclosed sea	A salt water inlet of the Indian Ocean between Africa and Asia. It is the world's northernmost tropical sea, with a rich and diverse ecosystem including 2,000 km of coral reef extending along its coastline. The Red Sea water mass exchanges its water with the Arabian Sea, Indian Ocean via the Gulf of Aden. The climate of the Red Sea is the result of two distinct monsoon seasons; a northeasterly monsoon and a southwesterly monsoon. Very high surface temperatures coupled with high salinity makes this one of the hottest and saltiest bodies of seawater in the world.
Somali Current	Western Boundary	A surface current of the western Indian Ocean, caused during the northern summer months by the blowing of the southwest monsoon along the coast of East Africa. At 6°to 10° N (off Somalia), the northeastward Somali flow turns eastward as the Monsoon Current. With the monsoon's reversal to the northeast in September, the current begins to weaken until, in the winter, it disappears entirely, to be replaced by a slow southwestward drift.
South China Sea	Semi-enclosed sea	A marginal sea south of China, part of the Pacific Ocean. There are over 200 identified islands and reefs within the South China Sea, most of them within the Spratly Islands.
South Central Pacific	Gyre	This very large oligotrophic area is the least productive system in the South Pacific. Its anticlockwise circulation is driven by the Humboldt Current, the South Pacific Current and the South Equatorial Current. The latter feeds into the Eastern Australian Current System.
Southern Indian Ocean	Gyre	The Indian Ocean covers about 20% of the water on the earth's surface, and its currents are mainly controlled by the monsoon. An unusual feature is the large number of submarine plateau and ridges, which locally emerge as tiny isolated islands. The southern Indian Ocean is dominated by a large circular anticlockwise current. The average northern limit of icebergs is 45° south latitude.
Southwest Pacific	Transitional	This transitional province contains the East Australian Current System, which moves warm water southwards down the east coast of Australia, transporting tropical fauna to sub-tropical regions further south. The primary inflow to the Tasman and Coral seas is supplied by the South Equatorial Current. Anticyclonic circulation drives the exchange of water between the Tasman Sea and the Southern Ocean.
Atlantic Warmwater Realm		
Benguela Current	Eastern Boundary	The eastern boundary current of the South Central Atlantic gyre the strongest wind driven coastal upwelling system, playing a significant role in global ocean and climate processes. The Benguela Current has a well-defined, generally weak, mean flow that is mostly confined near the continent and a more variable transient flow on its western side, where it is dominated by large eddies. It is 200-300 km wide, widening rapidly as it flows north to become as wide as 750 km. It is one of the most productive ecosystems in the world, supporting a large biomass of fish (especially small pelagics), crustaceans, sea birds and marine mammals.
Black Sea	Semi-enclosed sea	The world's largest meromictic basin where the deep waters do not mix with the upper layers of water that receive oxygen from the atmosphere. As a result, over 90% of the deeper Black Sea volume is anoxic water. Basin topography and fluvial inputs result in a strongly stratified vertical structure and a positive water balance. The upper layers are generally cooler, less dense and less salty than the deeper waters, as they are fed by large fluvial systems, whereas the deep waters originate from the warm, salty waters of the Mediterranean. The Black Sea supports a complex ecology in its upper waters, characterised by quasi-endemic species which thrive in the fresher surface waters, as well as cosmopolitan stenohaline and euryhaline species.
Canary Current	Eastern Boundary	Part of a clockwise ocean current system in the North Atlantic Ocean. The Canary Current branches south from the North Atlantic Current and flows southwestward along the northwest coast of Africa before turning westward to eventually join the Atlantic North Equatorial Current. The cool temperature of the water is produced by upwelling caused by offshore winds from the continent. The Canary Current is strongest near the coast, accelerating as it passes between the Canary Islands and the coast, and becoming progressively weaker offshore. As the current flows around the Canary Islands, it lessens the heating effect of the Sahara, and this thermal mixing creates productive fishing grounds
Inter American Seas	Semi-enclosed sea	This province is almost completely enclosed by insular and continental landmasses. Water enters the Caribbean sea from both north and south Atlantic sources, notably from the Guiana Current which transports low salinity, and more oxygenated waters, influenced by upstream riverine inputs from the Amazon and Orinoco Rivers. The Caribbean Current moves slowly westwards, but is accelerated through the Yucatan Channel and then forms the Loop Current which flows in a broad clockwise loop around the Gulf of Mexico before feeding out via Florida to begin the Gulf Stream.
Guinea Current	Eastern Boundary	Characterized by areas of upwelling and increased biological productivity. Summer intensification of the Guinea Current is related to strong coastal upwelling. However, the Guinea Current is unusual among upwelling regions in that there seems to be no correlation between sea surface temperature and wind patterns on a seasonal time scale.
Gulf Stream	Western Boundary	The western limb of the North Atlantic Gyre plays an important role in the poleward transfer of heat and salt and serves to warm the European subcontinent. Its transport varies in space and time, intensifying north of Cape Hatteras, where meandering also intensifies. Meanders often pinch off from the current to form Gulf Stream rings. Once it reaches the Grand Banks, the structure of the Gulf Stream changes from a single, meandering front to multiple, branching fronts eventually splitting off into the North Atlantic Current and the Azores current.

classification meets adjacent marine systems, notably at continental margins and into the deeper pelagic. We would expect our patterns to "bleed over" into the adjacent systems. At shelf edges and in adjacent pelagic waters communities are characterised by a blending of species from both the shelf and pelagic systems. Perhaps not surprisingly then, there appears to be relatively good convergence between the semi-enclosed sea and boundary provinces defined here (which are influenced by shelf-related oceanography and by meroplanktonic species) and the MEOW ecoregional and provincial boundaries.

The delineation of pelagic provinces and biomes was conducted independently of the ongoing biogeographic classification of high

Table 2 *(continued)*

Realm and Province	Biome	Description
Malvinas Current	Western Boundary	A branch of the Antarctic Circumpolar Current. It flows northward along the continental shelf of Argentina until it reaches the Brazil Current offshore from the Rio de la Plata estuary
Mediterranean	Semi-enclosed sea	This province is an almost landlocked system, where evaporation greatly exceeds precipitation and river runoff. Evaporation is especially high in its eastern half, causing the water level to decrease and salinity to increase eastward. This pressure gradient pushes relatively cool, low-salinity water from the Atlantic across the basin; it warms and becomes saltier as it travels east, then sinks in the region of the Levant and circulates westward, to spill over the Strait of Gibraltar. Thus, seawater flow is eastward in the Strait's surface waters, and westward below; once in the Atlantic, this chemically-distinct "Mediterranean Intermediate Water" can persist thousands of kilometers away from its source.
North Atlantic Current	Transitional	A warm ocean current part of the North Central Atlantic Gyre, which continues the Gulf Stream to the northeast, and splits in two west of Ireland. One branch (the Canary Current) goes south while the other continues north along the coast of northwestern Europe where it has a considerable warming influence on the climate. Other branches include the Irminger Current and the Norwegian Current. The North Atlantic Current is generally thought of as the end of the Gulf Stream, however it goes on to feed some of the major subarctic currents completing the poleward transport of tropical waters.
North Central Atlantic	Gyre	In the central part of the North Atlantic Ocean a large gyral system is formed, bounded by the Gulf Stream to the north, the Canary Current to the east, and the North Atlantic Equatorial Current to the south. The centre of the Gyre which is offset to the west is termed the Sargasso Sea. It has relatively stable high salinity waters famous for its large accumulations of *Sargassum* seaweed, and is important for migratory species such as eels and loggerhead turtles.
South Central Atlantic	Gyre	Waters of the South Atlantic Subtropical Gyre are characterized by clockwise flow. This is driven by the warm Brazil Current System, which flows south along the coast of Brazil, after its diversion from the Atlantic South Equatorial Current.
Southern Coldwater Realm		
Antarctic	Polar	Seasonal sea-ice dynamics drive the formation of cold, fresh, bottom water. Productivity is high, especially around the marginal ice zone. The Polar Front forms a major taxonomic boundary, across which only the most mobile birds and mammals migrate. Close to the Antarctic Continent is the westward flowing Antarctic Coastal Current, and clockwise gyres are present in the Ross Sea and Weddell Sea regions.
Antarctic Polar Front	Polar	This province lies between the Polar Front and the Subantarctic Front, within the eastward flowing Antarctic Circumpolar Current. This frontal region separates colder, fresher Antarctic waters from the warmer waters to the north, and is characterized by a sharp drop in temperature of up to 3 °C from north to south. Mixing and upwelling creates areas of very high productivity and enhanced biological activity.
Southern Subtropical Front	Transitional	This province marks the northern boundary of the Antarctic Circumpolar Current, extending across all three major ocean basins. It is characterized by enhanced meridional gradients of sea surface temperature and salinity, and its location has high seasonal and interannual variability.
Sub-Antarctic	Transitional	This transitional province is located between the Subantarctic and Subtropical fronts, and extends across all three major ocean basins. Characterized by low salinity, cold temperatures and high concentrations of nutrients. Seasonal productivity results from seasonal differences in the depth of the mixed layer.

seas benthic communities. While there are consistencies in approach between these initiatives, the biological and physical conditions in epipelagic and deep benthic communities are vastly different and are, for the most part, separated by poorly described deep pelagic systems which likely greatly modify any direct connections between these systems. In the pelagic system the dominant processes were major oceanographic features; in the benthic system the dominant features were bathymetry, substrate, bottom temperature, and bottom oxygen concentration (UNESCO, 2009). Some of the dominant patterns in bathymetry occur on scales far smaller than the major oceanographic features (seamounts, seeps and thermal vents), whereas the patterns in deep-sea temperature and oxygen occur on much larger scales. Consequently, although benthic-pelagic coupling of energy transfer is an important process in the high seas (Buesseler et al., 2007; Rex et al., 2006; Smith et al., 2001, 2008), taxonomic patterns between these systems will not necessarily be similarly coupled.

5. Conclusions and implications for policy and management

We believe that this system of 37 pelagic provinces of the world provides a unique and important contribution not only to the science of biogeography, but also to the growing interest in planning and managing our oceans in a systematic manner in the face of unprecedented human impacts and in light of growing opportunities. New policy developments by international conservation agencies (CBD, 2008, 2009) and other international agencies coordinating the management of industry sectors (FAO, 2008a,b) emphasise the ecosystem approach and spatial management on scales including trans-boundary integrated planning and management. These policy frameworks provide new opportunities for States, Regional Fisheries Management Organisations and Regional Oceans Management Organisations to design and implement conservation measures in the high seas on scales that correspond to the dynamics of the ecosystems being conserved.

Identifying these pelagic biogeographic provinces is a crucial first step in delineating those scales, and the boundaries which should guide the placement of spatial management measures. Interest in the establishment of high seas marine protected areas (MPAs) as a cornerstone of marine conservation is high, notwithstanding the governance challenges (Corrigan and Kershaw, 2008; Gjerde and Breide, 2003; Kelleher and Gjerde, 2005). The provinces offer a clearer basis for understanding the scales at which population-based conservation measures can be expected to derive benefits, and over which such measures must be coordinated. If MPAs or other spatial measures are to produce the desired benefits, they must be implemented at appropriate scales and with due regard for ecological processes. In particular they must consider expected variation in boundaries over time; the very large-scale required for temporally stable ecological processes to function; and the greater stability of populations and communities in the central or core areas of some, notably gyral, provinces compared to those at their boundaries.

The expert approach to developing our pelagic system means that many boundaries are not positioned precisely. In the types of policy applications discussed above, our system will be valuable in informing strategic dialogic among jurisdictions, as called for in, for example, the regional approach of the CBD for identifying ecologically and biologically significant areas (CBD, 2009), and the regional approach of the UN Regular Process for Global Marine Assessments (UNGA, 2009). When policy dialogue moves to the tactical scales of specific management interventions, such as detailed location of MPAs or EBSAs. The best site specific data should be consulted as part of the planning process, and greater analytical rigour (taking into account the substantial biases in data availability) can be applied at that stage.

Our system captures major oceanographic elements, but it is worth noting that considerable further "texture" is to be found in epipelagic waters, including hotspots, aggregations, and fronts which may be spatially variable or seasonal in nature. These have not been included but their location and the biota they support are obviously of considerable relevance for the management and conservation of the high seas and such areas have been recognised in finer resolution regional biogeographic classification systems, such as in the Northeast Atlantic (Ardron, 2008; Dinter, 2001) and Southern Ocean (Grant et al., 2006). Additionally, migratory species such as tuna and cetaceans are often a focus of high seas conservation and management efforts. While specific provinces may be of particular importance to these species, many travel across provinces and realms and are again associated with features such as fronts and hotspots (e.g. Polovina et al., 2001; Block et al., 2001). These species are ecologically and often commercially important in each of these ecosystems and provinces they temporarily occupy, and appropriate conservation and management needs to be considered within this context.

As in all natural systems, climate change will likely have considerable impacts on oceanographic conditions and on the distribution and dynamics of species and communities (Cheung et al., 2009; Rijnsdorp et al., 2009), with a high likelihood of more dramatic changes in dominant species and entire community structuring (Hollowed et al., 2011; Tasker, 2009). From the perspective of a biogeographic classification it is to be expected that such changes will initially be contained within the broad and blurred boundaries already described, but within a few years or perhaps decades it is likely that such changes will require the redrafting of biogeographic boundaries. Such change needs to be seriously considered by policy and management agencies, particularly those working at international levels where planning and response times are invariably slow. Efforts must be encouraged to better track biotic and oceanographic changes, to understand processes and improve our predictive ability with respect to climate change impacts on ocean ecosystems.

The open ocean presents considerable challenges for ecological observation and biogeographic description, due to the challenges of access, the highly mobile nature of the biota, and the temporal variation in abiotic conditions. This lack of basic, descriptive information can then impede progress on ocean management and conservation. The development of a global classification of pelagic provinces provides a basic framework for understanding and describing spatial variance in the ecological characteristics of the ocean. This is valuable for ecosystem based conservation planning and management interventions (Spalding et al., 2007; Rice et al., 2011) and provides a powerful alternative to single taxa approaches to ecological management, or to using abiotic or political classifications which can omit ecological considerations completely. Biogeographic provinces are particularly important for spatial tools in planning and management, such as the development of ecologically representative systems of protected areas in the high seas (CBD, 2004). These biogeographic provinces provide the starting framework for what should be "represented" in the representative networks.

The fluid nature of ocean boundaries, and the 'noise' invariably associated with demarcated areas on maps of this nature, mean that precise boundaries remain both uncertain and mobile on several time scales. The maps are of value in policy, planning and management at global and/or basin scales, but expert consultation is recommended for individual applications. Where policy or management applications need delineation of patterns at finer spatial resolutions, these maps will clearly require augmentation of information specific to each application.

A further challenge is that large tracts of the global oceans considered in this classification lie in international waters, beyond national jurisdictions, presenting a host of challenges for resource management and conservation efforts (Gjerde, 2006; High Seas Task Force, 2006; Kimball, 2005). Even where sections of particular provinces lie within waters under national jurisdiction, it is unlikely that individual states will be able to achieve effective management without broader collaboration, due to the broad scale and dynamic nature of pelagic ecosystems. The only exceptions to this may be some of the coastal boundary current and semi-enclosed seas where it may be possible, through international agreements, to conserve and manage large-scale pelagic ecosystems under existing or evolving jurisdictional frameworks (Colmenares and Escobar, 2002; Ilueca, 2001).

As a final note, any biogeographic classification system is just a benchmark in a constantly evolving process of data collection, analysis, and interpretation. The past decade has been marked by a major initiative to expand our sampling of marine biodiversity under the Census of Marine Life (CoML) (O'Dor et al., 2010). Not only did CoML augment marine biodiversity sets greatly (Snelgrove, 2010), it also contributed to major consolidations of data bases on marine biodiversity and their integration with contemporary data management tools (Vanden Berghe et al., 2010; Vandepitte et al., 2010). Synthetic analyses are emerging of the CoML data for specific taxonomic groups (Gallo et al., 2010; Wietz et al., 2010), habitat types (Schlacher et al., 2010; McAllister et al., 2011), and marine areas (Griffiths et al., 2011; Miloslavich et al., 2011). So far the majority of publications from this new data source have focused on coastal or benthic areas (Howell, 2010), but increasingly new results on distributions of high seas pelagic taxa will be appearing. Several years into the future the amount of new formation that will have been analyzed should allow substantial refinement of the delineation of the provinces and realms proposed here, supported by more systematic quantitative analyses.

Ethical statement

This paper and the processes which led to it are fully consistent with the ethical standards and practices required by **Ocean and Coastal Management**. The nature of the paper ensures that there are no ethical issues associated with the research leading to the paper.

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