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Global and regional priorities for marine biodiversity protection

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ABSTRACT

The ocean holds much of the planet's biodiversity, yet <4% of the ocean is within protected areas. On land, the protecting of areas with low biodiversity and under little threat, rather than biodiversity hotspots, is a well-known problem. Prudence suggests that we not repeat this pattern in the ocean. Here we assessed patterns of global marine biodiversity by evaluating the protections of 4352 species for which geographic ranges are known, and mapping priority areas using an index that considers species vulnerability, coverage by marine protected areas (MPAs), and human impacts. Species have, on average, only 3.6% of their range protected. Moreover, species of conservation concern (threatened, small-ranged, and data deficient) have less protection than species on average. Only 5 nations currently protect 10% or more of their exclusive economic zone (EEZ) as strict Marine Reserves (IUCN category I–IV) in accord with the 2020 Aichi Biodiversity Targets. One nation by itself, Australia, accounts for 65% of the global area of Marine Reserves. The Coral Triangle is the clear and dominant global priority for biodiversity, but we identify additional global and regional priorities in each ocean basin. As an example, we show that for the United States, the Marianas and Samoan Islands are the top marine conservation priorities. Despite recent advances, the world has yet to protect most of the area and species that need it. Where to protect those species, however, is increasingly clear.

1. Introduction

The ocean covers two-thirds of the planet and holds a broader phylogenetic diversity of life than terrestrial ecosystems (Mora et al., 2011). Recent studies document severe declines in the ocean environment and threats to its biodiversity (Halpern et al., 2015a, 2015b; McCauley et al., 2015; Pauly and Zeller, 2016; Pauly et al., 1998; Sala and Knowlton, 2006; Tittensor et al., 2010). These threats are complex, persistent, and will likely increase in the future.

Protected areas are the front line action for conservation, with numerous documented benefits in marine environments (Caselle et al., 2015; Lester and Halpern, 2008; Lester et al., 2009; White and Costello, 2014). However, <4% of the ocean has formal protection (Lubchenco and Grorud-Colvert, 2015), far less than the 14% rate on land (Butchart et al., 2015; Jenkins and Joppa, 2009). Less than 1% of the ocean is in no-take reserves, the most effective type of marine protected area (MPA) (Costello and Ballantine, 2015). The high seas, or Areas Beyond National Jurisdiction (ABNJ), is largely unmanaged. While this situation presents a challenge, an optimistic view is that sensible and sustainable policy actions are still possible. The recent surge in the creation of new MPAs is an encouraging sign of growing political will in that direction (Lubchenco and Grorud-Colvert, 2015).

Unlike in terrestrial conservation, MPAs are still in their political infancy, with the policy process not yet as advanced as the science (Lubchenco and Grorud-Colvert, 2015). Clear and quantitative metrics for biodiversity priorities can help shape where and how future protections occur. A major concern is to avoid repeating the mistakes made on land, where much of the area protected has low biodiversity importance or is not under threat (i.e., the "rock and ice" problem). However, recent analyses suggest a similar pattern is emerging in the ocean (Devillers et al., 2015). Governments are implementing more and larger MPAs, but not necessarily in the best locations for biodiversity (Lubchenco and Grorud-Colvert, 2015). While protection of biodiversity is not the only objective of MPAs, and many sociopolitical factors affect where and how they are implemented, the future of much of biodiversity depends on protected areas.

Building upon extensive new datasets, we analyzed global marine species occurrence, protection, and risk; assessing the ocean using a new index of conservation priority. We advance upon earlier studies (Klein et al., 2015; Roberts et al., 2002; Selig et al., 2014; Wood et al., 2008) by incorporating a broad array of nine marine taxa, explicitly considering the existing MPAs and human impacts to the ocean, and by evaluating protection and risk at the level of species, taxon, and

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geographical regions. Our objective is to inform the ongoing development of marine conservation policies and provide data to advance further marine biodiversity science. This fills a need highlighted by Watson et al. (2014) in their review of the global protected area system, providing a global analysis of MPA coverage for species and identifying important marine conservation gaps.

2. Materials and methods

We compiled geographic ranges for 4352 marine species from data provided by the International Union for the Conservation of Nature (2014), BirdLife International and NatureServe (2014), and the State of the World's Sea Turtles (Halpin et al., 2009; Kot et al., 2015). These consisted of species from 9 broad taxa: plants (139 mangroves and seagrasses), fish (1721 marine fish), echinoderms (369 sea cucumbers), crustaceans (246 lobsters), cnidarians (842 corals), mollusks (632 cone snails), mammals (118 cetaceans, pinnipeds, and sirenians), reptiles (65 sea snakes and sea turtles), and birds (220 seabirds and penguins). These were the groups for which a substantial number of species have expert-drawn polygon range maps. We excluded predominantly freshwater species from our analysis, including 4 river dolphins (*Platanista gangetica*, *Inia geoffrensis*, *I. araguaiaensis*, and *I. boliviensis*), an Amazon manatee (*Trichechus inunguis*), and 2 sea snakes (*Hydrophis sibauensis*, *Laticauda crockeri*). We did not include the Jamaican Petrel (*Pterodroma caribbaea*) as its marine distribution is unknown and it is likely extinct. We merged subspecies distributions into a single parent species layer. We excluded extinct and non-native species and range portions considered transitory, migratory, and/or outside the native range. For birds, ranges included breeding and nonbreeding range. To avoid spatial errors from occurring in the projection to an equal-area system, we densified (added vertices to) species distributions that traversed the 180th meridian. Lists of species are in Supplementary materials (Appendix A).

Range maps have some limits for understanding biodiversity patterns. They represent broad distributions and can be prone to commission errors (Jetz et al., 2008; Loiselle et al., 2003). That is, species do not occur throughout their mapped range. Simple polygons do not capture variations in habitat quality within a range and important movements over time such as migrations. Nevertheless, conservation advances using the information available, and for most species, range maps are the standard for broad scale analyses.

Data for land and administrative boundaries are from Natural Earth (http://www.naturalearthdata.com) and Open Street Map (https://www.openstreetmap.org), Exclusive Economic Zones from Marine Regions (http://www.marineregions.org/downloads.php), and Major Fishing Areas from the United Nations Food and Agriculture Organization (volume 1990, http://www.fao.org/fishery/area/search/en). Protected areas data are from the World Database on Protected Areas (IUCN and UNEP-WCMC, 2015). When protected area polygons overlapped, we ranked the overlap area as the highest IUCN category of the overlapping protected areas. Cumulative anthropogenic impacts to marine biodiversity are from Halpern et al. (2015a), which calculates a global index of marine impacts from fishing, pollution, climate, shipping, and other factors. To assess marine impact per species, we calculated from Halpern et al. (2015a) the mean value that occurred within the species range.

For each species, we calculated the percent of its marine geographic distribution that is within an existing MPA. We calculated the median percent protection for all species, for each taxon, and within each taxon for categories of conservation concern (IUCN threatened, small-ranged, and data deficient). We include data deficient because such species are often found to be threatened once enough data are available for a determination (Bland et al., 2015; Costello, 2015; Dulvy et al., 2014; Trindade-Filho et al., 2012; Webb and Mindel, 2015). We ranked taxa using the ensemble average of the median MPA protection scores from the taxa total and the three conservation categories. This ranking assesses existing MPA protections for each taxon, emphasizing those species that need protection most.

For each species, we calculated a priority score equal to the proportion of the species' range that is unprotected divided by the natural log area of the species' range. This score increases as range size decreases, in accordance with the well-established relationship between range area and extinction risk (Manne and Pimm, 2001; Manne et al., 1999; Purvis et al., 2000). Conversely, if a large proportion of the species' range is within protected areas, the score accordingly decreases. We then summed scores across species in a specified group and multiplied by impact for the relevant priority maps.

To assess the political distribution of protection, for each sovereign nation we calculated the percent of their EEZ set aside in what we term strict Marine Reserves (IUCN category I–IV), and their relative contribution to the global area protected. We generated histograms from these data, representing the probability density of percent area in each metric. We looked at IUCN I–IV because category V and VI areas have few restrictions even though they cover large areas. We might examine true no-take areas, the strictest type of protection, but many MPAs in the WDPA are documented as partial no-take, sometimes listing an amount of area. Without details of the location of the no-take area, we cannot precisely calculate coverage of species ranges and EEZs. We used IUCN categories I–IV instead, recognizing that it is not optimal.

For the diversity maps, we overlaid a 50 × 50 km grid on the species ranges and counted how many species occurred in each cell and summed their priority scores. We performed spatial analyses in ArcGIS 10.3 and used an equal-area projection (Eckert IV) centered on the meridian 160° west. Results are available at http://BiodiversityMapping.org and Dryad (http://dx.doi.org/10.5061/dryad.3mn1t).

3. Results

Broadly, marine biodiversity has very little protection. Considering the 4352 species assessed, a median of 3.6% of a species' geographic range is within an MPA of any kind. Beyond this coarse statistic, 83.1% of species have <10% of their range within an MPA, and 23.5% fall below 1%. Considering the highest level MPAs (IUCN category I), <4.7% of the species evaluated had >1% of their range protected.

Fig. 1 shows the cumulative distributions of percent protection of species, grouped by taxa and by categories of conservation concern (IUCN threatened, small-ranged, and data deficient). Lines with a steep slope near the origin, or high *y*-intercept, indicate that more species in the group have low protection. Lines above the black line (within-taxon total) or grey line (all-taxa total) fare worse than broader categories. Most troubling, species of conservation concern have less coverage than species overall. Considering each taxon individually and the total set, 70% of small-ranged (7/10), 89% of threatened (8/9, no lobsters are listed as threatened), and 90% of data deficient (9/10) species have less MPA coverage than their taxonomic totals. This implies that the current array of MPAs - already too small and insufficiently protected - does not protect the species that need it most.

To summarize how individual taxa fare, we ranked overall taxon protection as the average of the median percent MPA coverage for each within-taxon category (all species, threatened, small-ranged, and data deficient). This weights taxa rankings toward species of conservation concern. Cone snails score the lowest with 0.8%, followed by fish (1.7%), lobsters (1.7%), and seabirds (2.3%). Reptiles had the highest coverage (5.2%), followed by plants (4.9%), corals (4.5%), mammals (3.7%), with sea cucumbers (3.2%) ranking in the middle.

Relatively little of the ocean overall is within MPAs (<4% area), and the vast majority of that is open to extractive use (fishing, etc.). Most of the protected area is IUCN categories V, VI, or undesignated (Fig. 2A), indicating few restrictions or little management whatsoever. MPAs are largely restricted to Exclusive Economic Zones (EEZs), and there is a strong skew toward a few countries (Fig. 2A–B). High concentrations of MPAs occur around Australia, New Zealand, the Pacific

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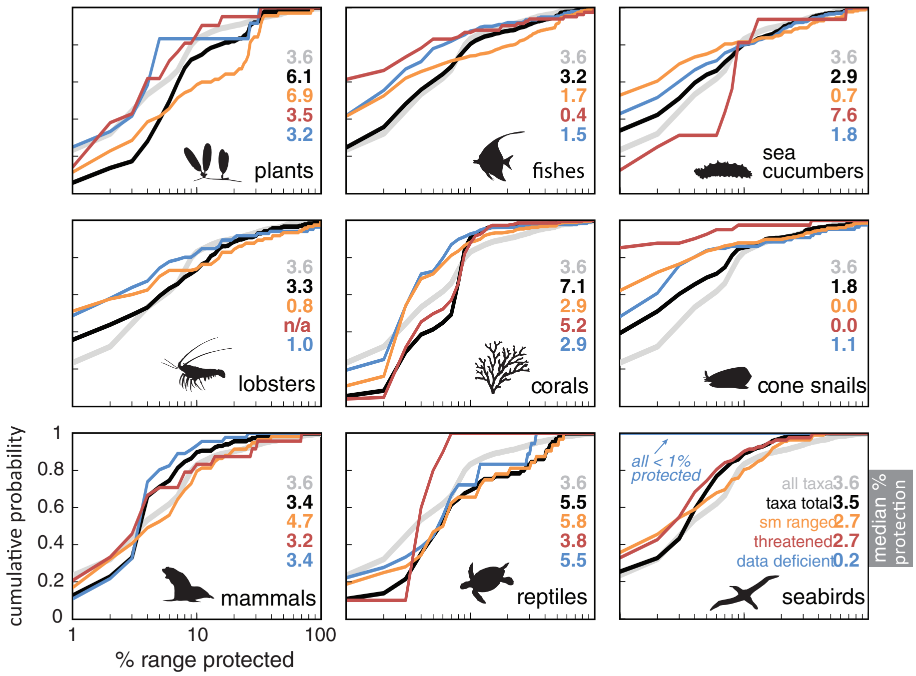

Fig. 1. Most marine species are poorly covered by marine protected areas of any kind (IUCN category I–VI). The plots accumulate species according to the percent of their entire geographic distribution that lies within marine protected areas. The resulting cumulative distributions accrue species in 1% bins until all species in that group (100%) are represented. Each taxon is represented as a whole, and subdivided into small-ranged, threatened, and data deficient species – the latter being categories that often deserve conservation attention. Species groups with fewer protections (i.e. data deficient seabirds, 0.2% median value, all species <1%) accrue species quickly, while those with better protections (i.e. threatened sea cucumbers, 7.6% median value) accrue species more slowly. The grey line is the empirical distribution for all 4352 species considered and is identical across panels, serving as a reference. The numbers in each panel are the median percent range protections for that group (labels in bottom-right panel). As protected areas currently cover small amounts of most species ranges, the x-axis is log-scaled to highlight the patterns below 10%.

Remote Island Areas (PRIAs) of the United States, Argentina, and a few other island nations. Looking at stricter Marine Reserves (MRs, IUCN category I–IV), nearly 83% (134/162) of sovereign nations have <1% of their EEZs set aside. Only 5 nations currently protect >10% of their EEZ (Fig. 2B), the benchmark goal set by the United Nations (Costello and Ballantine, 2015). Worldwide, just the top 6 nations account for 90% of

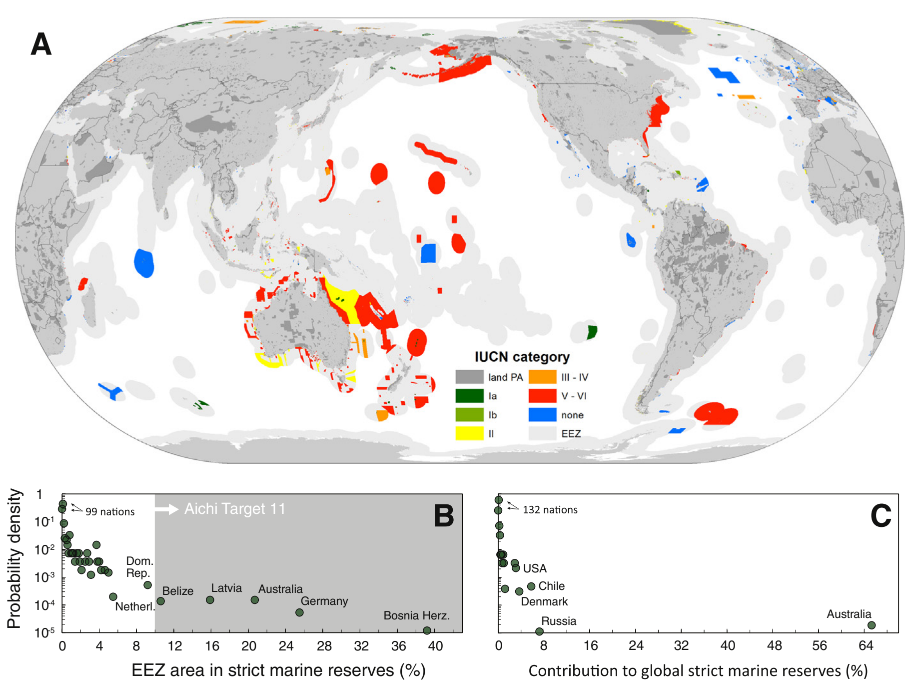

Fig. 2. (A) The global network of terrestrial and marine protected areas. Colors indicate IUCN category or lack thereof for marine protected areas. Dark grey indicates terrestrial protected areas. Light grey shows Exclusive Economic Zones (EEZ) and white is the Areas Beyond National Jurisdiction (ABNJ). (B) Percent of a country's EEZ that is protected as strict Marine Reserves (IUCN category I–IV). Only five nations currently meet the 2020 Aichi Biodiversity Targets (Strategic Goal C, Target 11) by setting aside 10% of their EEZ in strict marine reserves. Ninety-nine nations (61%) currently protect 0.1% or less of their EEZ in this way. (C) Relative contribution of each nation's area from (B) to the global total. Australia, by itself, accounts for >65% of the global area of Marine Reserves. Collectively, 132 nations contribute ≤0.1% to the global area. Of the 162 nations with administered tenure in the ocean, 39 have no protections.

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the global MR area (Fig. 2C), and 39 nations have established zero marine reserves within their EEZ.

To rank areas for conservation attention, we used a priority index that considers the local number of species, their range sizes, coverage by existing MPAs, and the human impact within each species' range (see Materials and methods). At the global scale, the Coral Triangle region is the dominant priority (Fig. 3). This is the case when looking at species overall, as well as individual categories of conservation concern (Fig. 3 left panels). The driving factors are the region's high number of species (Figs. A1–A4) with relatively small ranges (Fig. A5) and the low MPA coverage (Fig. 2A).

Factoring in human impacts (Halpern et al., 2015a) elevates some other areas to a relatively higher priority (Fig. 3 right panels, Fig. A6 for individual taxa). Prominent among them are the Ryuku Archipelago, Melanesia, the Red Sea, the area surrounding Madagascar, parts of east Africa, Sri Lanka and the Maldives, and the Caribbean. These regions are relatively diverse, although less so than the Coral Triangle, but importantly they have greater human impacts. The Ryuku Archipelago is also interesting as it is critical spawning habitat for the Pacific bluefin tuna (*Thunnus orientalis*) that are historically overexploited and on which overfishing is currently occurring (ISC, 2016; Shimose et al., 2016).

For a summary view of global priorities, we averaged the right column maps of Fig. 3. This ensemble prediction (Fig. 4A) thus incorporates the relatively higher importance of some categories of species (e.g., threatened, small-ranged), while also incorporating the known human impacts in the ocean (Halpern et al., 2015a). Fig. 4A is our recommendation for prioritizing marine biodiversity conservation efforts at a global scale. It highlights the Coral Triangle as the global priority, while also showing areas mentioned above that have relatively greater human impacts or concentrations of species of conservation concern.

Many conservation decisions take place at regional or national levels rather than globally. We also provide guidance at a regional level using the 19 FAO Major Fishing Areas. We first condensed these into 8 regional zones based on proximity within the same ocean basin. We then rescaled the ensemble biodiversity priority (Fig. 4A) within each zone to highlight places of regional priority (Fig. 4B). Unsurprisingly, some regional priorities appear that are less obvious at a global scale, being overshadowed by the species-rich Coral Triangle. Nevertheless, targeted conservation efforts in these regions is important to sustain unique regional and local ecosystems and to protect their species from extinction. Examples of such places occur in the mid to southern Atlantic, where the regional view highlights the Caribbean, the eastern Brazilian coast, Cape Verde Islands, and southern Africa. Other regions likewise have their own priority areas. Naturally, there are other ways to regionally divide the ocean for similar analyses.

As nations often focus conservation efforts to waters over which they have sovereign management, Fig. 5 rescales our priorities at the national level for the United States. The United States has both extensive and diverse areas within its EEZ, particularly in the Pacific Ocean. By evaluating priorities within the EEZ of a particular nation, our results can provide national level guidance by setting priorities considering political and spatial constraints. In the case of the United States, the

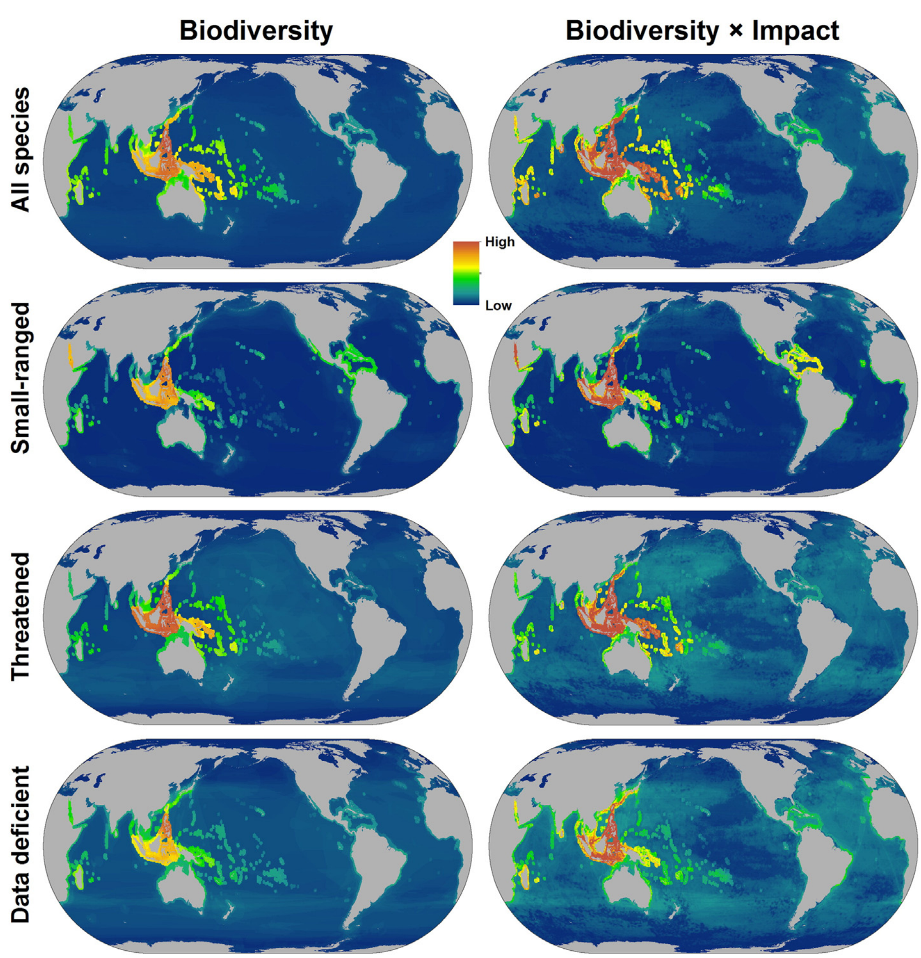

Fig. 3. Models of marine biodiversity conservation priorities considering species (total, small-ranged, threatened, and data deficient) and human threats. Left column panels develop priorities from species range size and the percent of the range within MPAs (see Fig. 1). From these priorities, right column panels add cumulative human impact (see Halpern et al., 2015a) to the previous priority scheme. In all plots, the Coral Triangle region is the constant global priority. Other significant priorities include eastern Melanesia, Micronesia, the Ryuku Archipelago, the Caribbean, Sri Lanka, the Red Sea, and the region surrounding Madagascar.

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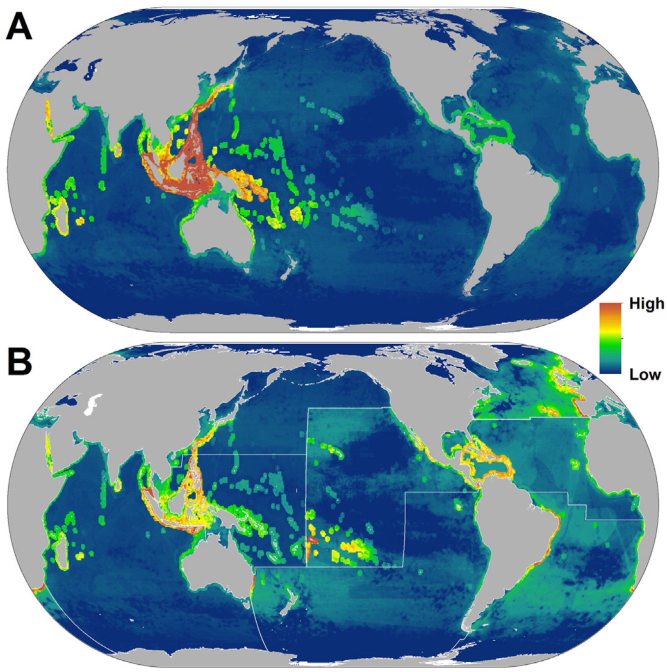

Fig. 4. Top global (A) and regional (B) marine biodiversity priorities. Regional priorities are global priorities, normalized within major ocean regions. The 8 regions are proximate aggregates from the 19 FAO Major Fishing Areas. Rescaling the results from (A), panel (B) highlights regional priorities that may be muted from high biodiversity areas in other regions.

northern Mariana Islands and Guam, American Samoa, Puerto Rico and the Virgin Islands, and southern Florida and the Florida Keys score high biodiversity priorities (Fig. 5).

4. Discussion

Most of the marine realm lacks protection and we are far from the Aichi Target 11 of protecting 10% of the ocean by 2020 (Woodley et al., 2012). Unlike on land where most areas are already managed, in the ocean we can learn from previous mistakes in the terrestrial realm and choose well nearer the outset. Currently, all marine taxa have insufficient protection (Fig. 1). This situation is worse for the species of most conservation concern, suggesting that marine protection is repeating the mistakes made on land. The Coral Triangle, known to be exceptional since the days of Wallace (1869), is clearly the highest conservation priority globally, yet it too has little protection (Fig. 2). Establishment and enforcement of MPAs in this region is a vital component of any conservation strategy for marine biodiversity, although consideration of local sociopolitical conditions will often dictate the specific actions.

There are also clear priorities in other parts across the world (Fig. 4). These collectively occupy a small fraction of the ocean, but harbor exceptional diversity. Conservation attention should focus on such areas, particularly with creation of no-take marine reserves. They can successfully protect species as well as potentially have beneficial spillover effects for proximate fisheries (Costello and Ballantine, 2015; Edgar et al., 2014; McClanahan and Mangi, 2000).

Priorities may differ depending on the individual taxon. This is particularly prominent for marine mammals and seabirds (Fig. A6), which is perhaps expected. They have different life history strategies and phylogeographic origins compared to other marine taxa. For seabirds, threats to their terrestrial breeding grounds have been a major driver of their historical declines (Croxall et al., 2012). These are often small islands, and research suggests such areas offer substantial conservation opportunities (Spatz et al., 2014).

Of special concern are the many data deficient species. Studies on terrestrial and marine taxa find that data deficient species are likely to be classified as threatened once better studied (Bland et al., 2015; Costello, 2015; Dulvy et al., 2014; Trindade-Filho et al., 2012; Webb and Mindel, 2015). This data gap may influence our estimates of where truly threatened species occur. Many taxa have more data deficient species than threatened ones. For example, lobsters have no threatened species but 86 species are data deficient. For sea cucumbers, more than half of the species are data deficient. Prudence suggests protecting areas with many of these likely threatened species, and this could encourage further study to resolve the problem of data deficiency. Beyond the problem of data deficient species, there are the many taxa for which we have no suitable data at all (Costello et al., 2010), and the deep seas are still largely a mystery.

The choice of data and analysis methods likely affect our findings. We benefited from a broader array of taxa and threat data than was available for previous studies, although still could not include many taxa. Whether these well-known taxa adequately represent the patterns of marine diversity overall is a question worthy of further exploration. Even for the taxa considered, specific priorities might differ depending on the chosen methodology. For instance, our results for marine mammal priorities differ somewhat from a recent study focused on those species (Davidson et al., 2012). Similarly, Peters et al. (2013) evaluated cone snails, using a different methodology, and found a somewhat different geographic pattern. Selig et al. (2014) and Klein et al. (2015) also identified somewhat different priorities than we present here. We suspect that those differences arise mainly because of the use of modelled species distributions, and different taxa, rather than the expert-drawn ranges that we used. However, a detailed study would be necessary to confirm this and to identify the potential pros and cons of each approach. Understanding precisely why different approaches produce different results, and which is better for guiding conservation, is an important area for future study.

Marine protected areas are an effective means to recover biodiversity (Caselle et al., 2015; Lester et al., 2009). If MPAs are to have a major role in marine conservation, we might expect their coverage of species to increase, and there has been a recent upsurge in creation of MPAs (Lubchenco and Grorud-Colvert, 2015). Estimates of the cost to operate a comprehensive global MPA system suggest it is entirely feasible and may even present net financial benefits due to increased fisheries yields (Balmford et al., 2004). However, protected areas only protect when well implemented and both the place and the species within are under threat (Edgar et al., 2014; Jenkins et al., 2015). If we are not careful, we risk repeating the same mistakes as happened on land, protecting lots of area, but failing to protect the most important places.

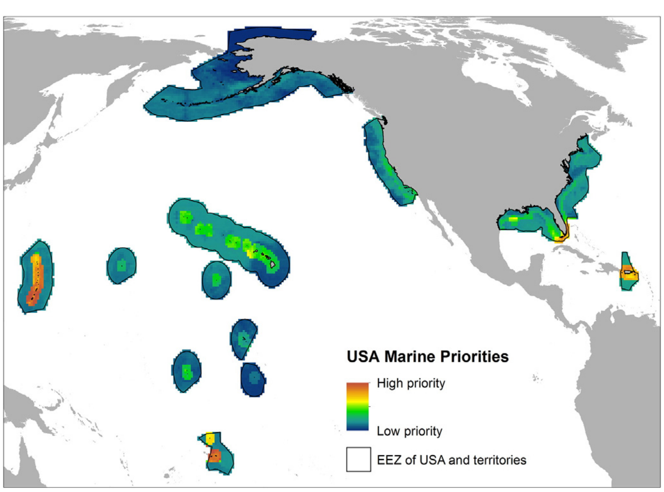

Fig. 5. Marine biodiversity priorities, rescaled for the EEZ of the United States. Our analysis indicates the Marianas and Samoan Islands are the top priority within the EEZ, while Puerto Rico and the Virgin Islands, southern Florida and the Florida Keys, and the Hawaiian Islands form additional priorities.

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