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Short communication

Mapping species richness and human impact drivers to inform global pelagic conservation prioritisation

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ABSTRACT

Given the widely recognized need to better protect the oceans but limited resources to do so, methods for prioritizing potential protected area sites are important. This is particularly true for the open oceans, where few protected areas currently exist and data availability is limited. Here, we examine the relationship between the distributions of tuna and billfish species richness (an indicator of pelagic biodiversity), the human impact drivers of fishing pressure (quantified as cumulative removals) and sea surface temperature increase (quantified as the increase in large positive anomalies) in tropical to temperate oceans at the scale of a 5° × 5° grid. We investigate relationships using Generalised Additive Models and Regression Tree analysis, and identify the top 50 "hotspot" cells for species richness and each of the two impact drivers. We find that both impact drivers significantly overlap with high species richness, but relationships are complex, non-linear and ocean-basin specific. Higher fishing pressure is associated with higher species richness in the Indian and Pacific Oceans, and this overlap is particularly prominent in the central Pacific, and in the Indian Ocean around Sri Lanka. In the Pacific and Atlantic Oceans, species richness is generally higher in areas that have seen lower levels of change in sea surface temperature and only one cell, near Easter Island, is a hotspot for species richness and sea surface temperature increase. While species richness and impact drivers overlap in some areas, there are many areas with high species richness and limited apparent impact. This suggests that area-based conservation strategies that aim to protect areas of high pelagic biodiversity may be achievable with limited displacement of fishing effort.

1. Introduction

Many marine ecosystems have come under severe stress from increasing human impacts (Halpern et al., 2008; Myers and Worm, 2003; Nellman et al., 2008; Roberts, 2003; Sala and Knowlton, 2006; Worm et al., 2006) and the last decade has seen considerable progress in the development of conservation and restoration strategies to mitigate these impacts. Such strategies typically involve some system of restriction on fisheries (Worm et al., 2009), and improved spatial management with Marine Protected Areas (MPAs) as an important component (Hughes et al., 2007; Norse et al., 2003). Establishing the relative priority of areas for protection has been a key part of this process, particularly in coastal ecosystems such as coral reefs (Roberts et al., 2002). However, there has been less progress in developing conservation strategies for the open ocean, particularly those waters beyond national jurisdictions that make up 65% of global oceans by area. These open ocean waters are presently very poorly represented with respect to protected area coverage; depending on what is considered a protected area, between 0.08% and 0.65% of the open ocean currently falls within MPAs (Wood et al., 2008). The critical importance of improving management of the open oceans is increasingly recognized (Game et al., 2009; Wood et al., 2008) and although there has been some controversy around the issue, future efforts will likely involve the establishment of large-scale MPAs, among other measures (Alpine and Hobday, 2007; Game et al., 2009; Mills and Carlton, 1998; Norse et al., 2003; Sumaila et al., 2007).

Conservation resources are limited (Halpern et al., 2006), and in order to ensure that these limited resources are directed effectively it is important to identify clear conservation objectives and to

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pinpoint priority areas that can meet these objectives most effectively (Margules and Pressey, 2000). A common (but by no means the only) objective for conservation is to protect biodiversity. Like terrestrial and coastal ecosystems, the open ocean is not homogenous and distinct areas exist where many species aggregate (Sydeman et al., 2006; Trebilco et al., 2009; Worm et al., 2003, 2005). Similarly, the distribution of human activities likely to impact upon biodiversity is not uniform (Halpern et al., 2008). Relative conservation priorities will depend on area-specific combinations of these and other factors. Describing the spatial distribution of factors that contribute to conservation priorities in the open ocean will be necessary to inform management strategies aiming to protect biodiversity values.

Among open ocean species, there is particular concern for large predators including tunas, billfish, sharks and sea turtles, and a growing number of these have been listed as threatened or endangered by the International Union for Conservation of Nature (IUCN). In contrast to most taxa found on land, species richness of tunas and billfish consistently peaks at intermediate latitudes, around 20–30° N or S (Worm et al., 2003, 2005). This latitudinal pattern has been relatively stable over the last 50 years (Worm et al., 2005) and is also found in foraminiferan zooplankton (Rutherford et al., 1999), marine mammals (Schipper et al., 2008; Whitehead et al., 2008), oceanic sharks, squids, and Euphausiids (Tittensor et al., 2010). This illustrates that broad diversity patterns are consistent across taxonomically distant pelagic taxa at regional scales (Tittensor et al., 2010), and suggests that large predators may have the potential to act as umbrella species in developing spatial conservation strategies that aim to protect pelagic biodiversity values.

Consideration of pelagic diversity patterns will be useful in assessing global conservation priorities in the open ocean (Tittensor et al., 2010; Worm et al., 2005). However, experiences in terrestrial and coastal environments have shown that prioritisation is far more informative when planning is informed by additional information on the distribution of human impacts or other socio-economic drivers (Brooks et al., 2006; Myers, 2003; Myers et al., 2000; Possingham and Wilson, 2005; Sala et al., 2002; Wilson et al., 2006).

Available global datasets for human impact drivers in the oceans were recently mapped and overlaid for the first time (Halpern et al., 2008). In this paper, we examine the distribution of tuna and billfish species richness, an indicator of pelagic biodiversity, in relation to relevant impact drivers including fishing pressure and sea surface temperature (SST) increase. Both fishing and SST have well-known impacts on pelagic biodiversity, and are considered the two major drivers (Boyce et al., 2008; Lehodey et al., 2003; Sund et al., 1981). While there are other factors that will need to be considered in developing conservation priorities for pelagic ecosystems (such as the cost of protection) here we focus on biodiversity and human impact. We present the relationship between these factors as one of several sources of information that may be used in developing conservation priorities for pelagic waters. We anticipate that observed relationships will inform efforts to develop a conservation priority landscape for the open oceans.

If the primary goal of conservation is to protect biodiversity values, it is useful to group the relationship between biodiversity and these two major impact drivers into four categories:

(1) Areas with high levels of both human impact and biodiversity will be "hotspots" of threat to biodiversity, and are likely to experience large biodiversity losses. Therefore they typically rank as high conservation priorities. This hotspots approach has long been promoted for setting conservation priorities on land (Mittermeier et al., 2004; Myers, 2003; Myers et al., 2000).
(2) Areas with high biodiversity and low impact may also be considered conservation priorities, to be protected from future impacts, although the urgency for immediate protection may be lower (Game et al., 2008; Wilson et al., 2007). For impacts associated with fishing, these areas would involve minimal displacement of fishing effort, which limits negative impacts on other areas (Worm et al., 2003).
(3) Areas with low biodiversity and high impact may often be of lower conservation priority. However, it will be important to determine whether historical impacts have reduced biodiversity in such areas, and if so, whether recovery is possible. In addition, some low-biodiversity areas may be considered to be of high conservation value for other reasons (e.g. provision of ecosystem goods and services), and may also be less resilient to additional impacts (such as climate change) than higher diversity systems (Kareiva and Marvier, 2003).
(4) Finally, those areas of low biodiversity and low impact may be of lowest immediate conservation concern, although they may have other intrinsic values worthy of conservation.

Choosing which of these four categories to focus on depends on conservation objectives and available resources. This paper focuses on categories 1 and 2, but the richness and impact overlay it presents could inform open ocean research and area protection prioritisation more generally. We recognise that species richness may not be the most appropriate indicator of biodiversity in all contexts; for instance, 'representative' rather than absolute biodiversity may be more important in some situations. We also recognise that the hotspots approach may overemphasise areas that include environmental transition zones and wide-ranging species (Eken et al., 2004; Williams et al., 1997). This is likely to be disadvantageous in terrestrial environments, as such areas may not capture sites with maximum ecological significance. However, in the open ocean, a measure that emphasizes zones of transition and wide-ranging species may be advantageous, as transitional areas with steep environmental gradients such as persistent fronts, eddies and zones of upwelling are well recognized as being highly productive and ecologically significant. In addition, the majority of pelagic species are wide-ranging, so approaches that emphasise this characteristic may be expected to be less problematic than on land.

2. Methods

2.1. Data layers

Biodiversity data represent tuna and billfish species richness. Species richness was derived by rarefaction estimation of the expected number of species per 50 individuals from Japanese longline logbook data (1990–1999) as reported in Worm et al. (2005). Data were available at a $5° \times 5°$ grid scale. This dataset was selected because of the global coverage and because the congruence of tuna and billfish diversity patterns with those for other pelagic taxa across a range of trophic levels suggests that species richness of tuna and billfish is a useful indicator for overall pelagic species richness (Worm et al., 2005; Tittensor et al., 2010).

The impact driver layers selected for consideration in our study were: (i) Pelagic fishing (millions of tons caught per half degree cell per year divided into high and low bycatch categories by Halpern et al., 2008, originally from the Sea Around Us Project). This variable included all reported fish catch from 1999–2003, on the basis of FAO and other sources (Pauly, 2007; Watson et al., 2004). (ii) SST increase (the change in the frequency of positive temperature anomalies in $1km^2$ grid cells that exceed the standard deviation for that location and week of the year between 1985–1990 and