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Measuring progress in marine protection: A new set of metrics to evaluate the strength of marine protected area networks

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A B S T R A C T

Marine protected areas (MPAs) have proven to be a valuable tool for both promoting the sustainable use of marine resources and long-term biodiversity conservation outcomes. Targets for marine protection under the Convention on Biological Diversity have seen rapid growth in MPAs globally, with progress judged using targets for total area protected rather than evaluating growth based on the capacity to protect biodiversity. The value of a MPA network to biodiversity conservation depends on a range of attributes of both individual MPAs and portfolios of MPAs, which are not captured by simple area-based targets. Therefore, a clear and efficient set of metrics are needed to effectively evaluate progress towards building MPA networks, considering the representation and adequacy of protection for biodiversity. We developed a universally applicable set of metrics that can evaluate network structure in relation to its capacity to conserve marine biodiversity. These metrics combine properties of effective individual MPAs with metrics for their capacity to function collectively as a network. To demonstrate the value of these metrics, we apply them to the Australian MPA network, the largest in the world. Collectively, the indicators suggest that while Australia has made significant progress in building a representative and well-structured MPA network, the level of protection offered to marine biodiversity is generally low, with insufficient coverage of no-take MPAs across many bioregions. The metrics reveal how the current value of the MPA network could be greatly increased by reducing the prevalence of multi-use zones that allow extractive activities known to negatively impact biodiversity.

1. Introduction

Marine protected areas (MPAs) are increasingly being established around the world in an effort to halt the decline of biodiversity and conserve ecosystem function (Klein et al., 2015; O'Leary et al., 2016). These legally protected ocean sanctuaries are widely accepted as the most effective way to regulate human pressures on the marine environment, such as commercial and recreational fishing, shipping, and mining (Metcalfe et al., 2015). With both the frequency and magnitude of impacts on marine ecosystems increasing globally (Halpern et al., 2015), and the area of marine protection lagging well behind terrestrial protection (UNEP-WCMC and IUCN, 2016), the strategic expansion of effective marine conservation is increasingly urgent.

MPAs often have multiple objectives, including socioeconomic objectives, such as maintaining public support, and preventing loss of income for local communities (Rossiter and Levine, 2014; Watson et al., 2014). However, the primary objective of MPAs is protecting biodiversity, such that a MPA cannot be deemed successful unless it first achieves these biological objectives (Agardy et al., 2011; Fox et al., 2012). The performance of protected areas is dependent on many elements, including their design and management, and the broader context within which they exist (Barnes et al., 2016). Similarly, many factors contribute to MPA effectiveness, with impact evaluation studies around the world identifying several design and management features that correlate with better biological outcomes, such as increased biomass of exploited species. Important design features include larger MPAs, and those more isolated from human activities, being more effective for protecting reef fishes (Edgar et al., 2014). Management features include excluding extractive uses (i.e., no-take reserves) (Halpern, 2003; Edgar et al., 2014), actively enforcing restrictions (Edgar et al., 2014) and sufficient resources for management (e.g., staff, equipment) (Gill et al., 2017).

There is growing evidence that to benefit biodiversity, MPAs must also function collectively to protect the full range of marine ecosystems. The broader-scale goals of MPAs, such as protecting ecosystem function, rely on functional connectivity among MPAs to support the ecological and evolutionary processes necessary to enable species to persist over time (Horigue et al., 2015). While often difficult to quantify, a detailed understanding of the range of anthropogenic pressures on marine

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ecosystems is critical to effective management and conservation (Ban et al., 2010). Likewise, for MPAs to be effective at mitigating threats to biodiversity, they must be situated in areas of high pressure and biodiversity value, rather than in areas with minimal opportunity costs (Devillers et al., 2015). Therefore, the structure of MPA networks must consider the distribution of key pressures to marine biodiversity in order to design MPAs that offer appropriate levels of protection from threats.

To accommodate MPAs with a broad range of objectives, the International Union for Conservation of Nature (IUCN) recognises different types of MPA, ranging from those primarily for biodiversity conservation (i.e., no-take) to those that promote a range of extractive, recreational and commercial activities (i.e., multi-use) (Day et al., 2012). While jurisdictions apply the IUCN categories to their MPAs, the IUCN provides guidelines for how to assign different categories of protection based on MPA management objectives, with the goal of presenting a globally standardised way for MPAs to be compared across jurisdictions (Day et al., 2012). Given that destructive fishing is considered the most significant threat to marine environments after increasing sea temperature (Halpern et al., 2007), many argue that no-take MPAs are the only legitimate MPAs (e.g., Miller and Russ, 2014; Costello and Ballantine, 2015). This argument is supported by the empirical evidence for increased species richness, biomass and density of fishes (e.g., Micheli et al., 2004; Lester et al., 2009; Edgar et al., 2014; Starr et al., 2015), as well as increased spill-over effects into surrounding fishing areas (e.g., Gell and Roberts, 2003; Halpern et al., 2009) of no-take relative to multi-use areas.

In recognition of the important role MPAs play in the conservation of marine ecosystems, targets for protection have been set under the Convention on Biological Diversity (CBD) to expand marine protection to 10% of all coastal and marine waters by 2020 (CBD, 2011). However, recent reviews have concluded that the 10% target, while ambitious, is unlikely to meet all of the objectives for MPAs (O'Leary et al., 2016). While these targets recognise the need for ecologically representative, connected and well-managed MPAs, the primary metric used to measure progress, total area protected (Tittensor et al., 2014), assumes all MPAs make an equal contribution to marine protection. This focus on the total area protected disregards the attributes of individual areas, such as their size and level of protection from human activities, which have been demonstrated to be important to the effectiveness of MPAs (Halpern, 2003; Edgar et al., 2014; Gill et al., 2017).

With increasing recognition of the need to design functioning MPA networks (Krueck et al., 2017), it is critical to develop metrics that can provide more meaningful measures of progress in marine conservation. These metrics must capture factors we know to be important for the effectiveness of individual MPAs, but also the structure of portfolios of MPAs that reveal their collective contribution to protecting vulnerable marine habitats and species. To better understand how growth in MPAs over time has influenced their capacity to protect biodiversity, we propose a set of metrics that can measure progress towards building robust MPA networks for biodiversity conservation. We then demonstrate these metrics using a case study of the Australian MPA network, the largest in the world (Devillers et al., 2015), using long-term, spatially explicit data. We illustrate how shifting the emphasis from total area protected to evaluating features associated with successful MPAs can provide deeper insights into whether growth in marine protection has improved the strength of the MPA network. These metrics provide a template for improving global efforts to evaluate progress in marine protection, and identifying how to strengthen the value of existing MPA networks for biodiversity conservation.

2. Methods

2.1. Proposed indicators of the capacity of MPAs to protect biodiversity

To understand how a MPA network has changed over time, and how these changes have influenced the protection for biodiversity, we propose a series of indicators of change:

1. Trend in the number of MPAs;
2. Trend in the total area protected;
3. Trend in size class distribution of MPAs;
4. Trend in the level of protection for marine species;
5. Trend in biodiversity representation;
6. Trend in management effectiveness;
7. Trend in level of connectivity; and.
8. Trends in pressures on the marine environment.

Within the context of biological objectives for MPAs, these indicators capture both existing (e.g., 1, 2, 5) measures of progress towards Aichi Target 11 (CBD, 2011) and those without agreed indicators (e.g., 6, 7, 8; Tittensor et al., 2014). Additionally, they include measures that track features of effective MPAs, as revealed by the impact evaluation literature (e.g., 3, 4, 8; Halpern et al., 2010; Edgar et al., 2014; Klein et al., 2015). Current progress in building MPAs is evaluated based on the 1st and 2nd indicators, which disregards important attributes of successful MPAs.

Given larger MPAs have been shown to offer greater benefits for biodiversity (Edgar et al., 2014), the 3rd indicator, size class distribution, provides a measure of how the area protected is distributed among MPAs. Likewise, the benefits of no-take MPAs for biodiversity are well-documented and extensive relative to multi-use areas (Edgar et al., 2014; Costello and Ballantine, 2015; O'Leary et al., 2016). Tracking the distribution of the level of protection for biodiversity offered by MPAs (4th indicator) can help reveal the equality of protection across biodiversity, and the degree to which other objectives for MPA establishment can be accommodated within the network. To avoid residual reserves (i.e., Devillers et al., 2015), it is essential to know which habitats and species are protected within MPAs (5th indicator). When combined with information about the size (3rd indicator) and level of protection offered to biodiversity (4th indicator), this indicator provides a powerful picture of whether MPA expansion is leading to a more robust network than change in representation alone.

In addition to elements of the design of MPAs, effective management (6th indicator) is a critical variable in MPA success or failure (Barnes et al., 2016; Gill et al., 2017). Protected area management effectiveness evaluations offer an opportunity to calculate a numerical indicator of effective management, as proposed by Leverington et al. (2010). Repeat evaluations of MPAs can therefore provide a measure of trends in management effectiveness. Beyond the effectiveness of individual MPAs, species persistence also relies on functional connections (i.e., ability to disperse between areas; Santini et al., 2016) between MPAs (7th indicator). Functional connectivity can be estimated using the protected connected (PC) metric (e.g., Santini et al., 2016), which measures the percentage of species with a specified proportion of their distribution included in connected PAs, using species specific information about dispersal capability and matrix permeability (e.g., ocean currents; Krueck et al., 2017). This metric can therefore estimate trends in functional connectivity of MPAs over time. Finally, understanding the distribution of threats across the marine environment (8th indicator) provides critical information about whether MPAs have levels of protection and management effort well matched to the threats they experience. Multiple pressures on marine biodiversity can be combined into a threat index (Ban et al., 2010). When represented spatially, change in the threat index can be used to assess trends in the pressures surrounding MPAs, revealing whether MPAs are located in areas of pressure on biodiversity with protection matched to threats.

Analysing all indicators as trends allows for change to be assessed, potentially revealing negative trends, such as Protected Area Downgrading, Downsizing, and Degazettement (PADDD; Mascia and Pailler, 2011), using indicators 1, 2, 3, and 4. While each indicator alone provides valuable information, collectively they provide a meaningful assessment of MPA progress, identifying strengths and