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

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Abstract

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.

Key words: marine protected areas, marine reserves, Australia, biodiversity conservation, bioregions, spatial analysis

Highlights:

- Not all MPAs are equal, therefore total area is an inadequate indicator of progress.
- Indicators of progress can draw on attributes of effective MPAs and MPA networks.
- We developed a suite of metrics to evaluate MPA network structure and performance.
- Strengths of the Australian MPA network: well-structured and representative.
- Weaknesses: No-take areas are heavily underrepresented.

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 (Metcalf 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 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 toward 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 Pallier 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 weaknesses in how area targets are being met. While MPAs can be evaluated based on an endless list of factors (e.g., social, governance), the indicators presented here provide a balance between essential information, as set out by the Aichi Targets, and feasibility.

2.2 Case study of change in the Australian Marine Protected Area Network

Australia has the largest MPA network in the world (3.1 million km²), which has more than quadrupled in size over the past two decades to exceed 30% of Australian waters (Devillers et al. 2015). This growth makes it an excellent case study to evaluate how expansion of marine protection has influenced the capacity of the MPA network to protect biodiversity. While the large area protected has been touted as a victory for marine conservation through improved representation of

biodiversity (Barr and Possingham 2013), there has been little consideration of whether growth has been well targeted to strengthen marine protection.

To understand the changes in marine protection within the Australian MPA network we used the Collaborative Australian Protected Area Database (CAPAD), which has compiled spatially explicit records of all MPAs, and marine components of terrestrial PAs (Appendix 1), on a biennial basis since 2002 (CAPAD 2014).

2.2.1 Trend in the number of MPAs and area protected

We examined every area that came in or was excised from the Australian National Representative System of Marine Protected Areas (NRSMPA) over time to determine the change in the number and size of MPAs throughout the study period.

To report changes in area, we adopt the terminology of PADDD with losses in area occurring through *downsizing* (a decrease in the area of an existing MPA) or *degazettement* (total loss of protection status). In keeping with these definitions, we describe increases in area protected as *upsizing* (area added to an existing MPA), or *new* MPAs (whole areas that have newly acquired protection).

2.2.2 Trend in size class distribution of MPAs

To examine trends in the size of MPAs across the network, for each time step we categorized every MPA in the Australian network into size classes using a log scale (e.g. <1, 1-10, 10-100 km² etc.) and calculated the proportion of MPAs in each size class. As large MPAs (greater than 100km²) are more effective in conserving fish biomass (Edgar et al. 2014), we identified the number of MPAs in Australia that have reached or exceeded that size.

2.2.3 Changes to the level of protection for marine biodiversity

Australian MPAs are divided into zones that permit different activities (Agardy et al. 2011), making it necessary to evaluate the level of protection at the scale of zone. Changes to the level of protection for an MPA can occur in two ways: 1) an amendment in the legislation that alters the activities permitted within all MPAs or protection zones of a particular type (termed a policy change); and 2) a change to how a MPA is zoned that moves areas within the MPA into a zone with higher or lower protection (termed a zone change).

To examine changes in the level of protection, we evaluated both policy and zone changes across the network. A decrease in legal restrictions on the number, magnitude, or extent of human activities within a PA is termed a *downgrade* in protection (Mascia and Pallier 2011). In accordance with this

definition, we define an *upgrade* in protection as a legal change to the human activities permitted within a PA to reduce harmful impacts. Policy changes were extracted from MPA management plans, government reports and legislation, peer-reviewed literature, media reports and discussions with experts. We verified any changes identified with the relevant agencies across Australia. Zone changes were identified using the CAPAD data (see Appendix 1).

2.2.4 Standardising level of protection across jurisdictions

Each jurisdiction in Australia has its own zoning scheme and preliminary analyses revealed that the IUCN categories are not applied consistently, making it difficult to compare the level of protection across jurisdictions. Therefore, to achieve consistent categorisation across the Australian NRSMPA, we conducted a comparative analysis that organized the zones for each jurisdiction according to the activities they permit based on MPA management plans. We then applied the IUCN Best Practice Guidelines (Day et al. 2012) to determine the appropriate IUCN category based on the highest impact activity permitted within a zone (see Table A1 for a detailed breakdown of how these criteria were applied to each jurisdiction). We used this standardised classification of the level of marine protection across Australia to assess trends in area of the MPA network within each IUCN category.

2.2.5 Change in representation and level of protection for biodiversity

While ideally this indicator would be assessed using information on the distribution of marine species and ecosystems, the lack of network-wide habitat mapping and biodiversity monitoring data prevented a detailed assessment of the trend in representation for the NRSMPA. Therefore, we assessed trends in representation of broad marine ecotypes, which provides a coarse measure of the representation of marine biodiversity (Barr and Possingham 2013). To determine how changes to the NRSMPA influenced the representation of Australia's marine ecosystems, we used the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) classification system. IMCRA classifies the marine environment of Australia's EEZ into broad bioregions according to a range of ecosystem attributes (e.g., geomorphic features, climate characteristics) and distributions of selected species (e.g., demersal fishes; IMCRA Technical Group 1998). We calculated the proportion of each IMCRA bioregion with any form of marine protection, presenting the area protected on a categorical scale (e.g. <1%, 1-10%, 10-25%, etc.). We use the 10% target for protection set by the CBD (CBD 2011) as a reference point to estimate "adequate" protection and quantify change in the level of representation over time.

We were also interested in the equality of protection offered to the different bioregions. Using our standardised IUCN classification, we grouped protection categories into no-take (IUCN Category IA-

III) and multi-use zones (IUCN Categories IV-VI) based on whether extractive uses were permitted. We then calculated the proportion of each bioregion within each of these protection categories. This enabled us to evaluate the change in the equality of protection offered to biodiversity over time.

2.2.6 Trend in management effectiveness, connectivity and pressures on the marine environment

Unfortunately, we were not able to identify the necessary data to populate the proposed indicators for management effectiveness, connectivity and pressures for the Australian MPA network. While some data were available on management effectiveness and selected pressures, these data were generally patchy and not available at the national scale. Therefore, these indicators were omitted from further analysis.

3. Results

3.1 Changes to the number of MPAs and total area protected

Between 2002 and 2014, 107 new MPAs were established in Australia's waters, bringing the total number to 324 (262 MPAs and 62 marine components of terrestrial PAs). No new marine components of terrestrial PAs were added during the study period. More than 2.6 million km² were added, bringing the total area protected to 3.26 million km² (Figure 1). Forty-seven of the additions were small MPAs in coastal waters, accounting for approximately 2% of the area added since 2002. The vast majority of new area (98%) was the result of 60 large, offshore (3-200 NM from coastline; Vince et al. 2015) MPAs within Commonwealth waters, totalling 2.37 million km². These offshore MPAs now account for 71% (by area) of the total MPA network (Appendix 1, Figure A1).

We identified very few changes to the size of existing MPAs, with only one MPA, Ningaloo Marine Park in Western Australia, being upsized (350 km² added in 2004) during the study period. No MPAs were degazetted or downsized in Australia between 2002 and 2014.

3.2 Size distribution of MPAs

We found that over time, the size class distribution of MPAs shifted toward larger MPAs, with the greatest increases in the two largest size classes (Figure 2). The shift in size class distribution was driven by the 60 large, offshore MPAs. The overall median MPA size increased from 12.5 km² in 2002 to 46 km² in 2014, while the median size of offshore MPAs jumped from 665 km² to 3,725 km² between 2002 and 2014. By 2014, approximately 45% of the NSRMPA exceeded the definition of a large MPA (>100km²) associated with better biodiversity outcomes by Edgar et al. (2014).

3.3 Changes to the level of protection for marine biodiversity

The protection for Australian MPAs ranges from strict protection (Category IA and II) to multi-use areas (Category IV and VI) (Table 1). No Australian MPAs are classified as Category IB (wilderness areas) or Category III (natural monuments). The majority of the Australian NRSMPA is multi-use (65%), with the strongest growth in these categories occurring in 2012 (Figure 3) when the offshore MPAs were established. There has been a modest increase in the proportion of the MPA network made up of no-take areas (Categories IA and II); however, these areas comprise only about one third of the MPA network (Figure 3A), with the majority of this increase in Category II protected areas (Figure 3). There has been almost no growth in area within Category IA (strict nature reserve) (Figure 3A), such that this category has decreased as a proportion of the total network (Figure 3B). Using the strict interpretation of MPAs (as excluding all extractive uses), the Australian MPA network covers a total of 1.23 million km² out of the total 3.3 million km² network (15% of the EEZ) (Appendix 1, Figures A2 & A3).

In total, 8 MPAs (affecting 110,388 km²) had their protection upgraded as a result of rezoning or small reserves being encompassed within the boundaries of new MPAs (Appendix 1, Table A2). We found no evidence of policy changes that increased the protection of MPAs. A total of 33 MPAs (affecting 2,839 km²) had their protection downgraded during the study period, although 20 of these downgrades were subsequently reversed (Appendix 1; Table A2). Downgrades occurred both as a result of formal rezoning and policy downgrades (Category IA sanctuary zones changed to permit recreational shore fishing).

3.4 Change in the representation and level of protection of marine biodiversity

Growth in the Australian MPA network over time has resulted in a consistent trend of increasing the coverage of poorly represented bioregions (Figure 4A). Some progress was made in increasing the protection for poorly represented bioregions between 2002 and 2010, with the number of bioregions below the 10% threshold for adequate coverage reduced from 31 to 24 (Figure 4A). However, a major leap forward in achieving the CBD minimum 10% coverage target was achieved through the addition of the offshore MPAs in 2012, reducing the number of poorly represented bioregions to five (Figure 4A). These new MPAs also increased the protection for already well protected bioregions, moving eight bioregions to 50% or more of their area protected (Figure 4A). There is a distinct geographic bias in protection, with the most well-represented bioregions located around the Great Barrier Reef, off the north Queensland coast, and the poorest protected occurring in south-eastern Australia (Figure A4).

While most bioregions have reached the target of at least 10% of their area protected, the level of protection for these environments is not evenly distributed (Figure 4B & C). Much of the increase in

representation occurred within multi-use zones, where extractive uses are permitted (Figure 4C). We found that there has been less progress achieving strict protection for bioregions, with the majority of bioregions (61%) having less than 10% of their area within no-take zones (Figure 4B). Therefore, while there has been significant improvement in the overall representation of bioregions (Figure 4A), only a fraction of this growth offered ecosystems protection from extractive uses.

4. Discussion

The total area under protection is frequently used to track conservation progress (Tittensor et al. 2014), despite being criticised as treating all PAs as equal (Collen and Nicholson 2014). Yet, as our data demonstrate, using the total area protected as the sole indicator can obscure trends in other important metrics of the strength of MPA networks, which provide a more detailed picture of how growth contributes to marine conservation. In particular, our data reveal that considering trends across indicators can be important to understand the structure of an MPA network, where major progress in increasing the area protected (Figure 1) and broad representation of biodiversity (Figure 4A) may be compromised if not accompanied with protection from key threats to biodiversity (Figure 3B).

4.1 Properties of effective MPAs

Effective MPAs are those where the size, placement and level of protection (Edgar et al. 2014; Gill et al. 2017) are well matched to the distribution of biodiversity and key threats to biodiversity (Halpern et al. 2007; Devillers et al. 2015). Given the interaction between these factors (e.g., high levels of protection in areas of low biodiversity and/or low threat offer little conservation value) it is essential that measures of progress in marine protection can evaluate these trends. The lack of data on pressures and the distribution of species and habitats, along with the effectiveness of MPA management, limited our ability to provide such a detailed evaluation of progress for the Australian NRSMPA, highlighting the difficulty obtaining sufficient data to genuinely measure progress in marine protection.

While the distribution and intensity of threats could not be quantified, fishing pressure has been identified as one of the greatest pressures on marine environments (Halpern et al. 2015) and is often concentrated in coastal waters, where vulnerable and commercially valuable biodiversity are disproportionately located (Klein et al. 2015). This would suggest that the trend in large, often strictly protected offshore MPAs and smaller, more disjointed coastal MPAs with very few no-take zones within Australian waters is not well-matched to the distribution of vulnerable biodiversity or key threats (i.e., residual reserves; Devillers et al. 2015). While large offshore MPAs can target

important ecological assets (e.g. whale migratory route) or other habitats at high risk, our result highlights the importance of interrogating trends in the placement of MPAs to ensure large MPAs located in areas that minimise opportunity costs are not used as a convenient way to reach protection targets with little benefit to biodiversity (Wilhelm et al. 2014). The indicators reveal that in order to strengthen protection for vulnerable biodiversity, future MPA coverage in Australia should be targeted towards large, no-take areas in coastal environments (Edgar et al. 2014; Costello and Ballantine 2015).

The vast majority of the Australian MPA network is designated as multi-use, permitting various forms of fishing. While some multi-use zones can protect against the most destructive forms of fishing, such as demersal trawling, they have specific objectives focused on recreational and commercial usage of marine biodiversity (Day et al. 2012). The variability in activities permitted in multi-use zones across Australian MPAs (Table 1) makes it difficult to estimate their value for biodiversity. Given the clear indications that multi-use MPAs have fewer ecological benefits (e.g., for reef fishes; Edgar et al. 2014), the significant proportion of MPAs within these lower protection categories raise questions about the long-term capacity of the Australian NRSMPA to conserve marine biodiversity. Nevertheless, given other indicators suggest progress has been made in representation and size class distribution, rezoning exercises could be used to improve the equity of protection for biodiversity to significantly strengthen the Australian MPA network. However, it should be acknowledged that rezoning exercises can lead to downgrades in protection, such as those currently proposed for many of Australia's large, offshore MPAs (reducing existing no-take zones by 40-50%; Director of National Parks 2017). These findings demonstrate the value of a more nuanced set of indicators for identifying opportunities to strengthen the value of MPAs without necessarily increasing the area protected.

Our spatially explicit approach to quantifying change in the level of protection for MPAs revealed the vulnerability of these areas to changes in political ideology, as seen elsewhere in the world (e.g., Bernard et al. 2014). The examples we documented of downgrades in protection, some reversed after a change in government, reflect the global tension between protection for the intrinsic value of biodiversity versus a more utilitarian perspective on the value of the natural environment (Eagles 2002). Changes in protection for MPAs can make enforcement difficult (Halpern et al. 2010) and contribute to decreased public support of MPAs in general (Voyer et al. 2012). Despite some observed changes in protection level, Australian MPAs have been more stable than terrestrial PAs in Australia, where over 1,500 PADDD events have been documented impacting one third of the network (Cook et al. 2017). This relative stability may reflect the challenge of negotiating the establishment of MPAs, given conflicts with many stakeholder groups (Ruiz-Frau et al. 2015), but

emphasises the need to ensure that systematic conservation planning principles, and evidence for the attributes of effective MPAs, are taken into account at the time of establishment, as there may be little political will or scope for change in the future.

4.2 Properties of MPA networks

Ultimately, MPAs should be designed to function as an integrated network to protect biodiversity. While ideally MPA networks provide adequate representation of species and ecosystems (Sutcliffe et al. 2015), the lack of habitat mapping data for marine environments, means representation must often be judged on the basis of coarse ecoregion classifications (e.g., IMCRA). While habitat mapping data in Australia may be better than that of many other countries, data are still patchy and not available network-wide. Our longitudinal perspective of change clearly demonstrates the success of systematic conservation planning to achieve extensive progress toward minimum protection targets (10%) for bioregions (Figure 4). Nevertheless, there are inherent risks associated with planning MPAs based on coarse ecoregions rather than finer scale data on the distribution of species and ecosystems, as can be achieved for terrestrial PAs (e.g., representation of threatened species, ecosystems and key biodiversity areas; Venter et al. 2014; Butchart et al. 2015). Likewise, the focus of impact evaluation studies on exploited fishes (e.g., Edgar et al. 2014) leaves gaps in our understanding of how well these species represent the response of a broader range of biodiversity. There is clearly a need to capture biodiversity data across a wide range of habitats and taxonomic groups to ensure measures of progress provide the most comprehensive estimates possible.

Given studies have found that enforcement of protections is critical to positive biodiversity outcomes from MPAs (Edgar et al. 2014), the lack of management effectiveness data leaves a significant gap in our ability to determine whether legislative protection translates to genuine protection for biodiversity. Importantly, small, well-enforced MPAs may ultimately be more effective at conserving important biodiversity if resources are not provided to enforce larger areas (Gill et al. 2017), making management effectiveness data a critical element of interpreting trends in the structure of MPA networks.

In addition to gaps in biodiversity, pressure and management data, it was not feasible to assess the level of connectivity of MPAs, which is necessary to determine whether they function as a network to support the ecological and evolutionary processes required for persistence (Krueck et al. 2017). Therefore, while our study reveals the value of evaluating a more nuanced set of progress indicators, it also reveals the need to fill critical gaps in our ability to assess the strength of marine protection. Future research should also consider the social and political factors that may influence the capacity to strengthen existing MPA networks, particularly given evidence that governments are not

prioritising management of MPAs (Addison et al. 2015). Nevertheless, our findings reveal that assessing both individual and network-wide metrics of effective MPAs can reveal simple changes (e.g., increasing the level and equity of protection) to existing MPAs and strategic expansion of MPAs (e.g., within heavily exploited environments; Halpern et al. 2015; Klein et al. 2015) that could significantly strength of the network.

4.3 Conclusion

Our systematic assessment of change in an MPA network demonstrates the value of a broader set of metrics to evaluate progress in marine protection, going beyond total area protected. Collectively, these metrics can track progress in the development of a MPA network and help guide efforts towards strengthening conservation of marine biodiversity. Encouragingly, the application of these metrics to the Australian NRSMPA revealed opportunities to build on the strong progress towards a robust system of MPAs by extending no-take areas. However, it is critical that governments invest in improving data on the distribution of biodiversity, threats, connectivity and management effectiveness to provide the most meaningful assessment of progress in marine conservation.

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560 Table 1. Designated zones across Australian MPA network with corresponding IUCN category labels and activities permitted within each IUCN category. ✓
561 Indicates activities permitted within the zone. ✓♦ indicates discrepancies between jurisdictions regarding whether the activity is permitted within the zone.
562 See Tale A1 for full breakdown by jurisdiction of activities permitted in each zone.

ACTIVITY	Sanctuary Zone	Restricted Access Zone	Sanctuary Zone	Marine National Park Zone	Recreational Use Zone	Marine Park Zone	Habitat Protection Zone	Special Purpose Zone	General Use Zone
Assigned IUCN	IA	IA	II	II	IV	IV	IV	VI	VI
Scientific collecting/research*	✓	✓	✓	✓	✓	✓	✓	✓	✓
Anchoring a boat			✓	✓	✓	✓	✓	✓	✓
Boating			✓	✓	✓	✓	✓	✓	✓
Scuba/snorkel			✓	✓	✓	✓	✓	✓	✓
Commercial line fishing						✓	✓	✓	✓
Trapping						✓	✓	✓	✓
Longline fishing							✓♦		✓♦
Dropline fishing									✓♦
Spearfishing					✓♦	✓	✓	✓♦	✓
Recreational fishing					✓♦	✓	✓	✓	✓
Recreational collecting						✓	✓	✓♦	✓
Aquaculture and pearling							✓♦	✓♦	✓♦
Netting							✓♦	✓♦	✓♦
Trawling									✓♦
Mining operations*								✓♦	✓♦

563 *Permitted under permit

Figure 1. The area (black line) and number (grey bars) of MPAs in Australia from 2002-2014. No data were reported to CAPAD in 2006.

Figure 2. Size class distributions of MPAs in Australia over time. No data were reported to CAPAD in 2006.

A)

B)

Figure 3. Change in the level of protection across the Australian MPA network between 2002-2014 presented as A) total area (millions of km²) of the network in each IUCN category over time; B) the proportion of the network within each IUCN category. No data were reported to CAPAD in 2006.

Figure 4. Change in the number of IMCRA Provincial Bioregions represented within the MPA network over time according to the proportion of their area protected for: A) all MPAs; B) no-take zones (IUCN Category IA & II); C) multi-use zones (IUCN Categories IV & VI). Purple bars indicate bioregions below the 10% threshold for adequate protection and green bars are above this threshold. No data were reported to CAPAD in 2006.