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# *Reinventing residual reserves in the sea: are we favouring ease of establishment over need for protection?*

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ABSTRACT

1. As systems of marine protected areas (MPAs) expand globally, there is a risk that new MPAs will be biased toward places that are remote or unpromising for extractive activities, and hence follow the trend of terrestrial protected areas in being 'residual' to commercial uses. Such locations typically provide little protection to the species and ecosystems that are most exposed to threatening processes.

2. There are strong political motivations to establish residual reserves that minimize costs and conflicts with users of natural resources. These motivations will likely remain in place as long as success continues to be measured in terms of area ($km^2$) protected.

3. The global pattern of MPAs was reviewed and appears to be residual, supported by a rapid growth of large, remote MPAs. The extent to which MPAs in Australia are residual nationally and also regionally within the Great Barrier Reef (GBR) Marine Park was also examined.

4. Nationally, the recently announced Australian Commonwealth marine reserves were found to be strongly residual, making almost no difference to 'business as usual' for most ocean uses. Underlying this result was the imperative to minimize costs, but without the spatial constraints of explicit quantitative objectives for representing bioregions or the range of ecological features in highly protected zones.

5. In contrast, the 2004 rezoning of the GBR was exemplary, and the potential for residual protection was limited by applying a systematic set of planning principles, such as representing a minimum percentage of finely subdivided bioregions. Nonetheless, even at this scale, protection was uneven between bioregions. Within-bioregion heterogeneity might have led to no-take zones being established in areas unsuitable for trawling with a risk that species assemblages differ between areas protected and areas left available for trawling.

6. A simple four-step framework of questions for planners and policy makers is proposed to help reverse the emerging residual tendency of MPAs and maximize their effectiveness for conservation. This involves checks on the least-cost approach to establishing MPAs in order to avoid perverse outcomes. © 2014 The Authors. *Aquatic Conservation: Marine and Freshwater Ecosystems* published by John Wiley & Sons, Ltd.

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## INTRODUCTION

Anthropogenic activities increasingly threaten marine ecosystems, with major impacts from resource exploitation, land-based pollution, invasive species, climate change, and other sources (Halpern *et al*., 2008; Swartz *et al*., 2010). For instance, fishing activities are known to damage important habitats and adversely affect benthic biodiversity (Cook *et al*., 2013) and to modify ecosystem structures and functioning (Olsgard *et al*., 2008; Garcia *et al*., 2012). To mitigate the impacts of threats to global marine biodiversity, international treaties, such as the 1982 Rio Summit, encourage countries to adopt holistic conservation targets and more sustainable practices. Recent assessments of the global environment show, however, that little progress has been made 20 years after Rio (Rio + 20), with progress demonstrated toward only four out of the 90 most pressing environmental goals (UNEP, 2012). A similar concern has been expressed for the marine environment (Veitch *et al*., 2012), leading to calls for increased protection of marine ecosystems and species.

While several approaches can be used to protect marine biodiversity from anthropogenic threats, marine protected areas (MPAs) are recognized as a key management tool (Gaines *et al*., 2010; Veitch *et al*., 2012). MPAs are defined by the International Union for Conservation of Nature (IUCN) as 'a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values' (Dudley, 2008). Levels of restriction range from partial (e.g. focus only on benthic species, or only limiting one type of fishing gear or activity) to high (e.g. 'no-take' zones, also often named 'marine reserves') and almost total ('no-entry' zones). However, MPA effectiveness can be variable, depending on the objectives of management, appropriateness of zoning, and levels of compliance (Agardy *et al*., 2011; Mora and Sale, 2011), and marine ecosystem types are very unevenly represented within MPAs (Spalding *et al*., 2008). Even with these limitations, MPAs can contribute to social and ecological goals for sustainable use of marine natural resources (Fox *et al*., 2011; Ban *et al*., 2012; Rice *et al*., 2012).

Although MPAs are widely recognized tools for biodiversity protection, they currently cover less than 2.5% of the marine realm, compared with more than 12% of the world's land surface covered by protected areas (Mora and Sale, 2011; UNEP, 2012; Spalding *et al*., 2013). Furthermore, only a small proportion of MPAs comprise no-take zones (Wood *et al*., 2008), while most terrestrial reserves do not allow extractive uses. This context has led to the establishment of international targets for expansion of MPAs. The World Parks Congress (WPC) recommended in 2003 that at least 20–30% of marine and coastal areas be strictly protected by 2012. In 2002, the Convention on Biological Diversity (CBD) called for at least 10% of each of the world's terrestrial and marine ecoregions to be effectively conserved by 2010. In 2010, the CBD adopted a new strategic plan for biodiversity for 2011–2020, including 20 Aichi Biodiversity Targets.[1] Among these, Target 11 calls for formal protection of 10% of marine and coastal areas, including protected areas but also more generally 'other effective area-based conservation measures'.

Progress towards these targets for MPAs has, however, been much slower than expected and very variable among countries. Furthermore, MPAs have been largely restricted to national waters, now covering about 8% of continental shelves and equivalent areas (Spalding *et al*., 2013), a bias partly reflecting the challenges of implementing MPAs in the 64% of the world's oceans beyond national jurisdictions (Ardron *et al*., 2008; Game *et al*., 2009). A recent trend towards establishing very large MPAs ($>$100 000 km$^2$) such as Chagos, Cook Islands, and the Coral Sea (Table 1), is nonetheless accelerating the expansion of the global MPA coverage within national jurisdictions, while also raising debate about the effectiveness of extensive, remote MPAs for protecting global marine biodiversity (De Santo, 2013; Kaplan *et al*., 2013; Pala, 2013; Spalding *et al*., 2013; Toonen *et al*., 2013).

An important, unresolved question about MPAs is whether the many gaps in representation of species and ecosystems are random or systematic.

[1] http://www.cbd.int/sp/targets/

Table 1. (A) The world's 10 largest contiguous marine protected areas (MPAs), and their year of creation, size, percentage of countries' EEZs covered, cumulative contribution to the total world's MPA coverage, estimated average fish catch over 50 years (1950–2000) before their creation (in tonnes $year^{-1}$ $km^{-2}$, all species and all gear types combined - cf. global average 0.278), and approximate population within the MPAs and a 100 km buffer outside their boundaries. Fish catches were averaged across areas within each MPA. (B) The world's five largest proposed MPAs

**A**

| Rank | Name | Country | Year | ~ Size ($10^6$ $km^2$) | % EEZ | Cumul. % world MPA | Average fish catch# | Approximate population |
|---|---|---|---|---|---|---|---|---|
| 1 | New Caledonia | France | Announced | ~1.40 | ~12.69 | 11.1 | N/A# | 252,000 |
| 2 | Cook Islands | Cook Islands | Announced | ~1.00 | ~50.00 | 19.1 | N/A# | 10,900 |
| 3 | South Georgia and South Sandwich Islands Marine Protected Area | UK/Argentina | 2012 | 1.07 | - | 27.6 | N/A# | 30* |
| 4 | Coral Sea Commonwealth Marine Reserve | Australia | 2012 | 0.99 | 9.75 | 35.5 | 0.008 | 0* |
| 5 | Chagos Archipelago, British Indian Ocean Territory Marine Protected Area | United Kingdom | 2010 | 0.64 | 9.40 | 40.6 | 0.014 | 3000** |
| 6 | Phoenix Islands Protected Area and World Heritage Site | Republic of Kiribati | 2006/08 | 0.41 | 11.86 | 43.8 | 0.018 | <25 |
| 7 | Papahānaumokuākea Marine National Monument | USA | 2000/06 | 0.36 | 3.19 | 46.7 | 0.020 | ~45* |
| 8 | Great Barrier Reef Marine Park | Australia | 1975 | 0.34 | 3.39 | 49.4 | N/A# | ~920,000*** |
| 9 | Marianas Trench Marine National Monument | USA | 2009 | 0.25 | 2.17 | 51.4 | 0.171 | 0 |
| 10 | Pacific Remote Islands Marine National Monument | USA | 2009 | 0.23 | 1.98 | 53.3 | 0.019 | 0 |

**B**

| Rank | Name | Country | Year | ~ Size ($10^6$ $km^2$) | % EEZ | Cumul. % world MPA† | Average fish catch# | Approximate population |
|---|---|---|---|---|---|---|---|---|
| P1 | Sargasso Sea Marine Protected Area | International^ | Proposed | ~5.00 | N/A# | 52.1 | N/A# | 0 |
| P2 | Antarctic Ross Sea | International | Proposed | 3.60 | N/A# | 68.1 | N/A# | 0 |
| P3 | Pitcairn Island | UK | Proposed | 0.80 | 11.76 | 71.6 | N/A# | 55 |
| P4 | Bermuda's Exclusive Economic Zone | UK | Proposed | 0.30 | 4.41 | 73.0 | N/A# | 64,700 |
| P5 | Motu Motiro Hiva Marine Park (Easter Island) | Chile | Proposed | 0.20 | 5.43 | 73.9 | N/A# | 5,000 |

^The proposed Sargasso Sea MPA would be located in high seas, although Bermuda/UK's government is among the countries leading this proposal.
#Some values, identified by 'N/A' could not be estimated, either because the boundaries of the MPAs have not been finalized or because establishment predates the period encompassed by the global fisheries dataset.
†Cumulative percentage in Table B is calculated separately from Table A based on a global MPA coverage that considers a scenario in which all five proposed MPAs would be implemented.
*Inhabitants of the islands adjacent to these MPAs are primarily scientists, park managers, meteorologists and/or government officers.
**The indigenous population of the Chagos archipelago (UK) was evicted in the early 1970s to create a US military base on the atoll of Diego Garcia. The current resident population is composed of military and contracted civilian personnel.
***In addition to having a large population within 100 km from the marine park, the Great Barrier Reef Marine Park includes many islands, a few of which have resident populations; Palm and Magnetic islands have long-term residences; other islands have resorts with resident staff, and there are several research stations with resident staff.

While random gaps could be expected in any system, systematic gaps could result from the ease with which MPAs can be established and be inversely related to the level of extractive uses of the ocean. Such systematic bias, if present, would mirror the widely observed bias in terrestrial reservation towards over-representation of ecosystems with the least value for extractive uses (Scott *et al*., 2001; Joppa and Pfaff, 2009). One of the major disadvantages of this bias is that the species and ecosystems most associated with extractive uses and often most in need of protection continue to decline without effective intervention (Pressey *et al*., 2000). The phenomenon of protected areas being 'residual' to extractive uses (Margules and Pressey, 2000), although familiar in terrestrial regions, has been mentioned in the marine environment only briefly (Edgar *et al*., 2008; Guarderas *et al*., 2008; Edgar, 2011) and has not yet been formally explored.

In this paper, the tendency for MPAs to be residual and therefore ineffective in separating marine species and ecosystems from processes that threaten their persistence is assessed. Residual reservation arises from an implicit or explicit policy of locating MPAs to minimize the opportunity costs to those people engaged in extractive uses of the land and sea, even though many of the important threats to terrestrial and marine biodiversity arise from those extractive uses (Halpern *et al*., 2008; Rands *et al*., 2010). In the ocean, extractive uses with important present-day impacts on biodiversity include fishing, oil and gas extraction and deep-sea mining. Consequently, minimizing opportunity costs to resource exploitation in the ocean also minimizes the extent to which species and ecosystems are protected from these activities. Here, a series of questions related to the opportunity costs of MPAs that should be addressed by decision-makers, agency officials, and non-government organizations is proposed. Three case studies demonstrating residual tendencies of MPAs at three scales are then described: globally, within Australian waters, and within the Great Barrier Reef Marine Park. Finally, the questions related to the opportunity costs of MPAs are discussed again in light of each case study to assess the confidence with which managers, planners and policy makers can assert that marine biodiversity has been effectively protected by minimizing opportunity costs. Details about data sources and analyses are included in Supporting Information S1.

## QUESTIONS ABOUT MINIMIZING OPPORTUNITY COSTS IN DESIGNING MPAS

From its inception as a field of research (Pressey, 2002), systematic conservation planning has emphasized the fundamental importance of explicit conservation objectives for individual conservation 'features', defined here as species, ecosystems, natural processes, or other entities that contribute to a depiction of biodiversity (Pressey, 2004). A key principle of systematic conservation planning has always been efficiency (Pressey *et al*., 1993), or minimizing the costs of achieving explicit conservation objectives. Different kinds of costs are relevant to conservation planning (Naidoo *et al*., 2006) but the most important in marine conservation planning are typically opportunity costs, or the costs borne by those whose extractive uses are curtailed by the establishment of MPAs (Ban and Klein, 2009), and management costs (e.g. enforcement costs once MPAs are established) (Bergseth *et al*., in press). Even ad hoc establishment of MPAs considers opportunity costs, although often implicitly (McNeill, 1994; Jones, 1999; Stewart *et al*., 2003).

It is intuitively sensible that costs resulting from marine conservation planning should be minimized by reducing the extent to which MPAs impinge on extractive activities. However, this approach has weaknesses related to spatial scale. Given that extractive activities in the ocean present serious threats to marine biodiversity (Sala and Knowlton, 2006; Halpern *et al*., 2008; Harris, 2012), it is important to recognize that, particularly at broad spatial scales, marine biodiversity in more heavily used and threatened areas differs from that in less used and less threatened areas. These differences in composition of biodiversity arise from both physical and geographic variation between areas used for extraction and those not used, so that exploited and unexploited marine areas tend to be different ecosystems (Gray, 1997; Morato *et al.*, 2006; Halpern *et al.*, 2008; SoE, 2011). Therefore, minimizing the costs of MPAs at broad scales has the potential for perverse outcomes: protection avoids the more heavily used and costly areas (in financial and/or political terms) and is not afforded to biodiversity most in need of protection. The risk of perverse outcomes is reduced when explicit objectives are set for features defined at finer resolutions that are less physically and biologically heterogeneous (Bedward *et al.*, 1992). Nonetheless, even MPA planning based on relatively finely resolved subdivisions of the marine environment, such as the 70 marine bioregions within the Great Barrier Reef Marine Park (Fernandes *et al.*, 2005), might benefit from scrutiny to avoid issues related to residual reservation.

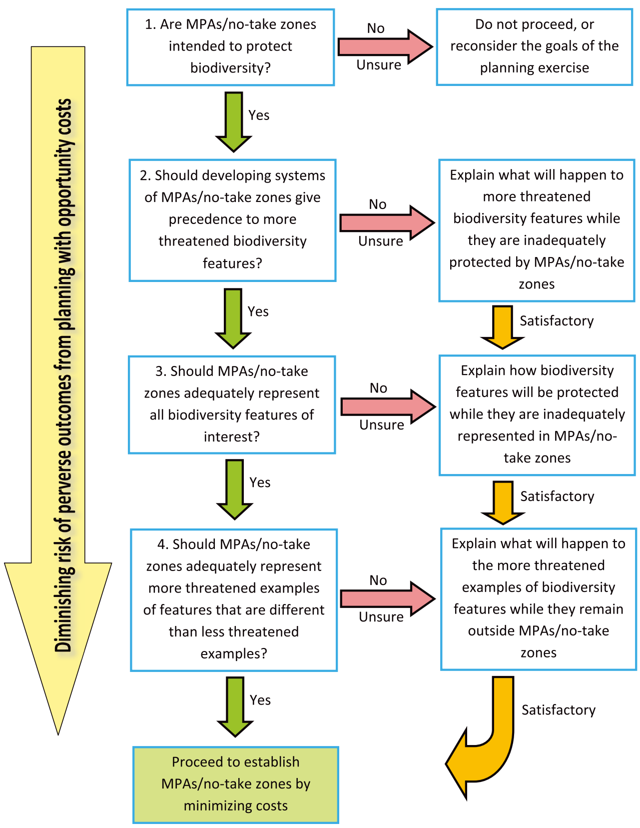


Figure 1. Four key questions related to opportunity costs. People involved in MPA planning should be able to answer these questions in the interests of accountability.

Considering the potential for perverse outcomes for marine biodiversity, four questions (Figure 1) related to minimizing opportunity costs when planning MPAs are proposed. It is suggested that policy makers, agency officers and representatives of non-government organizations should be able to answer these questions in the interests of accountability. Given that the primary objective of an MPA should always be conservation (Day *et al.*, 2012), and that MPAs are always intended to protect the natural structure and function of biodiversity, the questions are:

1. Are MPAs/no-take zones intended to protect biodiversity?
2. Should developing systems of MPAs/no-take zones give precedence to more threatened biodiversity features?
3. Should MPAs/no-take zones adequately represent all biodiversity features of interest?
4. Should MPAs/no-take zones adequately represent more threatened examples of features that are different from less threatened examples?

We suggest that negative or uncertain answers to any of the four questions require careful explanations to public or private funders of MPAs and to others concerned with marine biodiversity. Explanations (Figure 1) should focus on the likely fate of biodiversity features, or within-feature variation, left without adequate protection as a consequence of decisions about the locations of MPAs and no-take zones. A positive answer to each question leads immediately to the subsequent question. From question 1 to question 4, positive answers progressively reduce the risk of perverse outcomes arising from planning MPAs, and especially no-take zones, with the aim of minimizing opportunity costs. Positive answers to all four questions leave the way clear to minimizing opportunity costs without risks to biodiversity. Another route to this endpoint is to provide a series of satisfactory explanations, subject to scientific scrutiny, on the right-hand side of the figure, although successful navigation of this route is thought to be highly unlikely.

The use of the term 'biodiversity' in this paper recognizes that, especially in the ocean, much biodiversity remains unknown (Butler *et al.*, 2010).

Because of large gaps in knowledge in areas known to already experience threats to marine biodiversity, MPA planning must include not only well-studied features considered to be in need of protection (e.g. selected species, Mills *et al.*, 2011) but also a range of poorly known places with 'unknown' biodiversity represented through the use of surrogates (e.g. the marine bioregions targeted by Fernandes *et al.*, 2005).

Underlying question 1 (Figure 1) is the basic purpose of establishing MPAs and especially no-take zones. Minimizing opportunity costs entails the risk that biodiversity features will not be the primary focus when selecting potential locations of MPAs and no-take zones. Although the protection of biodiversity is often stated prominently in policies related to MPAs, reservation is also a political process concerned with public perceptions and achievement of aspirational targets, such as percentages of jurisdictions or global marine waters in MPAs, in politically expedient ways. In agreeing that biodiversity conservation underpins establishment of MPAs and no-take zones, people involved in policy and planning commit themselves to addressing the subsequent questions.

In question 2, the term 'precedence' relates to urgency of protection. Precedence concerns the sequence with which features should be protected, in the common situation where not all features can be adequately represented within a single planning process. With only 2–3% of global marine waters in MPAs, gaps in representation are to be expected, and it will take many years to expand MPAs, and especially no-take zones, to fully represent all marine ecoregions and habitat types (Spalding *et al.*, 2008). The same applies to most national jurisdictions. The rationale for question 2 is that marine biodiversity features vary in their co-occurrence with and exposure to threats imposed by extractive uses (Halpern *et al.*, 2008; Harris, 2012). Minimizing opportunity costs therefore entails the risk that MPAs and no-take zones will represent initially (and perhaps eventually) only those biodiversity features occurring in areas with little potential for extractive uses, thereby leaving unprotected the features most in need of protection. This is more than a remote possibility, given the well established tendency for political pragmatism to bias protection on land towards features least needing intervention (Scott *et al.*, 2001; Joppa and Pfaff, 2009). Clearly, those features more exposed to threats require more urgent protection because they will probably decline more rapidly without active intervention (Edgar *et al.*, 2008).

Question 3 relates to a fundamental purpose of conservation planning: representing the range of biodiversity (Margules and Pressey, 2000). 'Adequately represent' refers to both the variety and extent of representation. First, all known biodiversity features of conservation interest should have some level of representation in MPA systems or no-take areas, including those not already considered above as most threatened. Second, objectives for representation of individual features should reflect their relative need for protection, with proportionately more extensive representation of features that are rarer, more heterogeneous physically and biologically, and more exposed to threats (Pressey and Taffs, 2001a; Pressey *et al.*, 2003; Desmet and Cowling, 2004; Metcalfe *et al.*, 2013). Objectives should also consider, where possible, the historical extent and abundance of ecosystems and species (Jackson, 2001; Knowlton and Jackson, 2008). Without explicit objectives for all features of conservation interest, minimizing opportunity costs entails the risk that many features will be missed or protected at inadequate levels.

Question 4 addresses the potential for threats to biodiversity from extractive uses to be unevenly distributed within the ranges of individual features. In the tropics, harvesting of marine turtles, for example, might be more heavily focused on some genetic stocks than others (Wallace *et al.*, 2011). Similarly, marine bioregions and other mapped spatial units defined by physical or biological characteristics can be heterogeneous both in species composition and potential for extractive uses (Lindsay *et al.*, 2008; Williams *et al.*, 2010). Minimizing opportunity costs therefore entails the dual risk that more threatened examples of features will be given less protection and that these more threatened examples are genetically or compositionally different from the less threatened ones. Both these conditions apply to

MPAs, and especially to no-take zones, established in Australia's South-east Marine Region (Williams *et al*., 2009a).

Later in this paper we will review the evidence that MPAs and no-take zones address the requirements posed by each of these questions. In doing so, the discussion draws largely on the information presented in the following three case studies of MPAs and no-take zones globally, across the Australian marine jurisdiction, and in the Great Barrier Reef Marine Park.

## GLOBAL ANALYSIS

Globally, it is estimated that about 10 000 marine protected areas cover about 2.3% of the world's oceans (Figure 2; Spalding *et al*., 2013). The large majority of MPAs are located within countries' Exclusive Economic Zones (EEZs), only 0.17% being in the high seas (Spalding *et al*., 2013). MPAs provide various levels of protection, ranging from no-take zones to areas allowing different types and levels of activities (e.g. fishing, tourism). All areas that are called MPAs do not necessarily match international requirements for MPA designation, because many allow, for instance, higher levels of extractive activities than normally expected (Robb *et al*., 2010; Fitzsimons, 2011; Al-Abdulrazzak and Trombulak, 2012). Wood *et al*. (2008) have estimated no-take zones to cover less than 0.1% of the world's oceans, a coverage that has increased since 2008 with the recent creation of a number of large, remote MPAs. While most MPAs have a single level of protection, some, like the Great Barrier Reef Marine Park in Australia, are multi-use areas subdivided into zones of various levels of protection (Day, 2002; Fernandes *et al*., 2005). Many MPAs allow extractive activities such as commercial trawling and oil and gas exploration and extraction. For example, in Australia, trawling is permitted in specific areas of the Great Barrier Reef Marine Park and also in the Shark Bay Marine Park (a Western Australian state MPA), although both are World Heritage Areas and highly valuable MPAs. Several very large MPAs recently created or planned in the Pacific Ocean (e.g. Phoenix Islands Protected Area) allow fishing across most of their extents (Pala, 2013).

Out of the thousands of MPAs that exist, 10 of them, either existing or under creation, account for more than 53% of the world's total MPA area coverage (Table 1A), a percentage that increases to nearly 74% when considering five additional MPAs being proposed (Table 1B). These very large MPAs, most of them created after 2005, represent large percentages of some countries' EEZs (Table 1; Spalding *et al*., 2013). The Chagos (United Kingdom), the Coral Sea (Australia), and

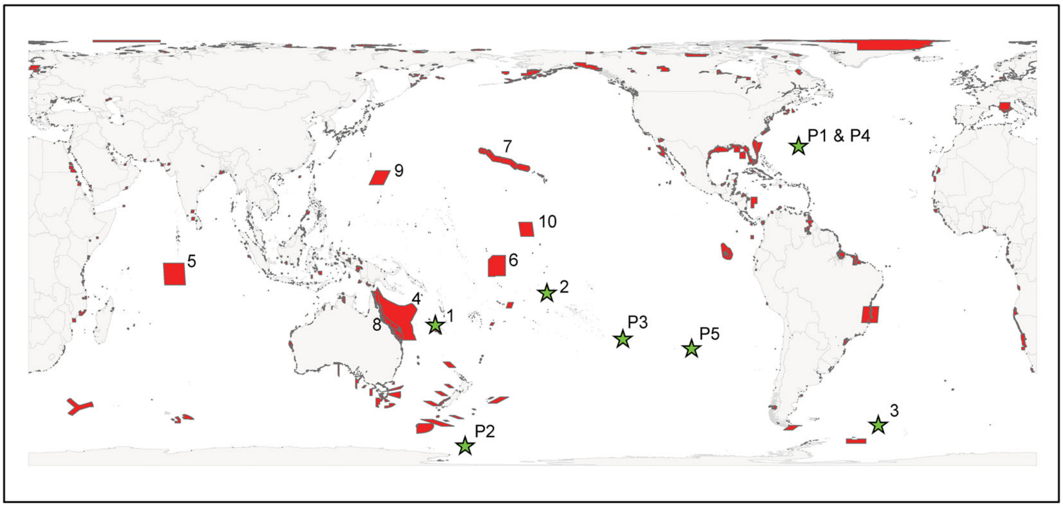


Figure 2. The world's largest established and proposed MPAs. World protected areas identified in the 2012 World Database of Protected Areas (WDPA) as being partly or fully marine (red polygons). Numbers indicate the 10 largest existing and announced MPAs, ranked by size. Numbers starting with P (Proposed) indicate the five largest proposed MPAs, ranked by size. Details on each large MPA are provided in Table 1(A) and 1(B). Green stars show the approximate locations of large MPAs when the MPAs boundaries were not finalized or available. The map uses a Behrmann equal-area projection.

the recently announced New Caledonia (France) MPAs each cover about 10% of the EEZ of their respective country. The largest proposed MPA, the Sargasso Sea[2] (numbered P1 in Figure 2) would alone, if created, represent about 22% of the world's total MPA coverage. Apart from the Great Barrier Reef Marine Park, which covers the continental shelf of north Queensland, Australia, these large MPAs were largely established in remote and uninhabited places, in parts of the ocean with little extractive activity (see Table 1 for details). Using reconstructions of average fish catches from 1950 to 2000 (Watson *et al.*, 2004), analysis indicates that fishing activities in these large MPAs before their implementation were limited, with average catches ranging from 0.008 to 0.171 tonne year$^{-1}$ km$^{-2}$ (all species and all gear types), compared with a global average of 0.278 and global maximum of 711.47.

While large, remote MPAs may benefit marine biodiversity in the long term, their relative contribution to averting imminent and direct anthropogenic threats is arguably small in the short term. Studies have pointed to advantages of extensive marine wilderness compared with small MPAs embedded in fished seascapes (Friedlander and DeMartini, 2002; Graham and McClanahan, 2013; Graham *et al.*, 2013). While remote MPAs might protect wilderness from future extension of human footprint, current anthropogenic threats to marine biodiversity are primarily concentrated in national waters closer to large population centres, especially on continental shelves (Halpern *et al.*, 2008). The biodiversity of marine waters around mainland UK and USA, for example, is under much more intense pressure from extractive activities (Halpern *et al.*, 2008) than the UK's Chagos MPA or the USA's Pacific Remote Islands MPA (Figure 2). As a consequence, the biodiversity of coastal waters is arguably in more immediate need of protection, particularly in the context of continuously declining marine biodiversity in these inshore regions (CBD, 2010; SoE, 2011; Vincent, 2011).

[2]http://www.sargassoalliance.org/

The 10 largest MPAs in the world (Figure 2 and Table 1) substantially increase the protective coverage of some marine jurisdictions (Table 1). Large-scale MPAs can contribute significantly to international targets such as the 10% Aichi target, possibly allowing the 10% global target to be reached by 2025 instead of 2054 (see projections made by Toonen *et al.*, 2013). A number of those large-scale MPAs have been created in EEZs around the overseas territories of developed countries (e.g. France, UK, USA), allowing those countries to reach international conservation targets before 2020.

## NATIONAL PICTURE: AUSTRALIA

The residual nature of MPAs can also be explored at the scale of a country. In late 2012, Australia completed a major planning process to establish a National Representative System of Marine Protected Areas (NRSMPA) in Commonwealth waters (i.e. under national, not state, jurisdiction). These new Commonwealth MPAs, covering more than 2.3 million km$^2$, were added to existing national and state MPAs, such as the Great Barrier Reef Marine Park and Commonwealth MPAs established in 2007 in the South-east marine planning region (Figure 3). Marine bioregional planning in Australia was implemented in six marine regions that encompass most of Australia's EEZ: North, North-west, South-west, South-east, Temperate East, and Coral Sea (Figure 3). Together with previously established MPAs, they cover about 3.1 million km$^2$, comprising more than a third of Australia's marine waters and constituting the world's largest national coverage of MPAs.

The NRSMPA planning process has been guided by a set of goals and principles,[3] taking into account information about the biology, environment, and human activities in Australia's waters (ANZECC, 1998, 1999). Goals were to have MPAs representing: (1) each of the 41 bioregions defined by the Integrated Marine and Coastal Regionalization of Australia (IMCRA), version 4.0; (2) all ocean depths; (3) examples of benthic and demersal

[3]http://www.environment.gov.au/coasts/mbp/publications/general/goals-nrsmpa.html

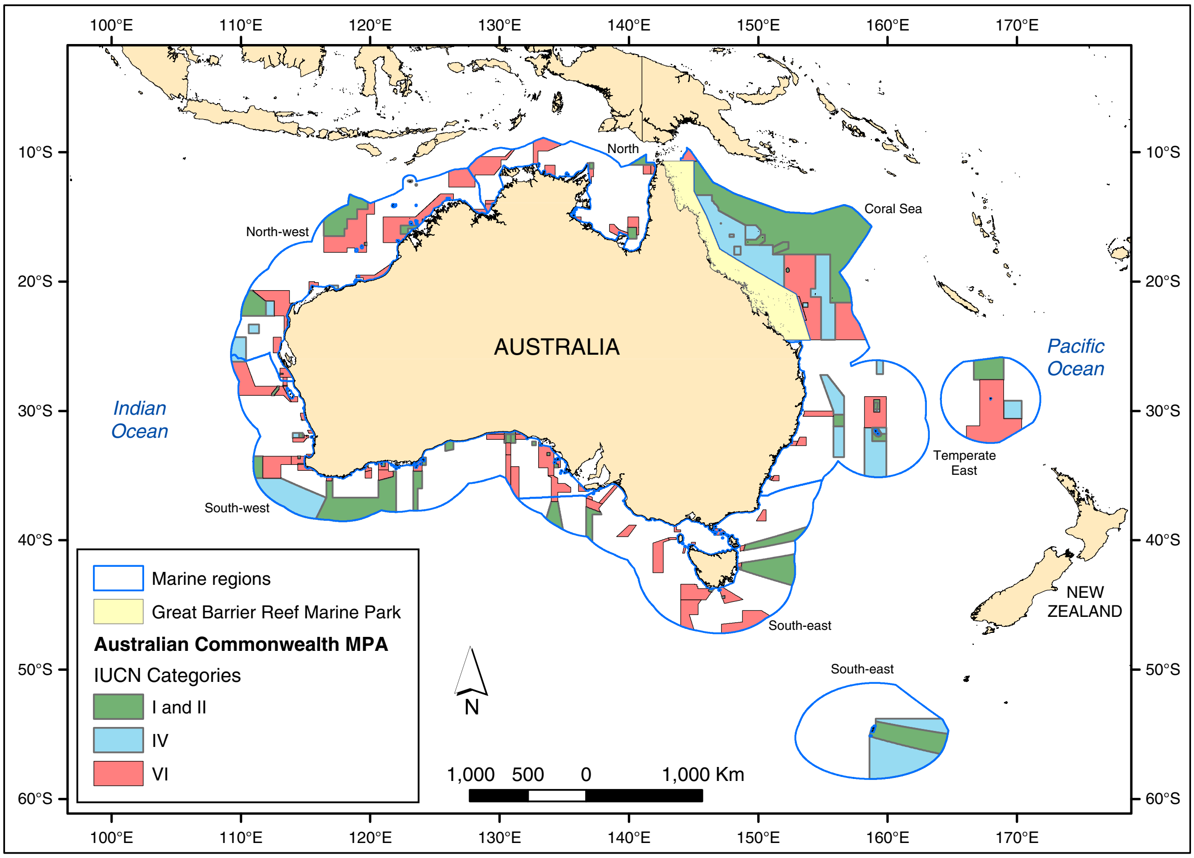


Figure 3. MPAs in Australian Commonwealth waters in late 2012. Australian MPAs announced in November 2012, in addition to some MPAs established previously in Commonwealth waters (e.g. South-east marine reserves created in 2007). Blue lines delimit the six Australian marine regions defined for bioregional planning. MPAs are classified by the Australian government using the International Union for Conservation of Nature (IUCN) categories. Category Ia areas ('Strict Nature Reserve') are strictly protected, set aside to protect biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure persistence of conservation values. Management of category II areas ('National Park') aims to protect natural biodiversity along with its underlying ecological structure and supporting environmental processes, and to promote education and recreation. Collectively, categories I and II are intended to indicate no-take MPAs. Category IV ('Habitat/Species Management Area') aims to maintain, conserve and restore species and habitats. Category VI ('Protected area with sustainable use of natural resources') aims to protect natural ecosystems where conservation and sustainable use can be mutually beneficial.

biological features; and, (4) all types of seafloor features (e.g. seamounts, canyons). Notably, however, no quantitative objectives appear to have been set for any of these features, in contrast to the process used to rezone the Great Barrier Reef Marine Park in 2004 (Fernandes *et al.*, 2009). Lack of explicit quantitative objectives is also inconsistent with Australia's long-established leadership in systematic conservation planning (Margules and Pressey, 2000) for which explicit, numerical objectives are a foundation. The lack of quantitative objectives enhanced the spatial flexibility to establish MPAs in low-cost marine waters, but to the potential detriment of marine biodiversity (and see criticisms of the 2007 MPA planning process outcomes for the South-east region by Nevill and Ward (2009) and Williams *et al.* (2009a)).

Despite the impressive extent of Australia's expanded MPAs, analyses of the distribution of those MPAs in relation to the IUCN categories cast doubt on the network's ability to effectively protect marine biodiversity from major threatening processes. In the analyses that follow, MPAs IUCN categories I–II (no-take or high-protection areas), category IV (habitat/species management areas), and category VI (sustainable use areas) are distinguished. This distinction is important because category IV, and especially category VI, zones permit extractive uses that can have negative impacts on marine biodiversity. Some Australian category VI zones, for example, permit trawling, long-lining, purse-seining and development for oil and gas extraction, all known to negatively affect marine biodiversity (SoE, 2011). Notably, a recent study (Fitzsimons, 2011) concluded that the Australian Government has mislabelled some of its MPAs by allowing extractive uses that the IUCN categories do not permit, a problem that also occurs in state-managed MPAs such as Shark Bay Marine Park, Western Australia.

The first goal of the NRSMPA planning process was to represent each of the 41 bioregions. Parts of all of the 41 provincial bioregions, other than the Cocos and Christmas Islands provinces (outside the scope of the recent planning process) and the North-east Shelf province (already protected by the Great Barrier Reef Marine Park), are represented to some extent by new MPAs. Bioregions differ strongly, however, in extent and nature of protection (Figure 4; and see Barr and Possingham, 2013). Out of 38 bioregions covered by the new MPAs, seven have less than 10% of their areas included within MPAs (e.g. in the North marine region), while others, such as the North-east and Kenn provinces, are almost fully protected in the new Coral Sea MPA. The extent of bioregions protected by IUCN category I or II MPAs is even smaller, with six bioregions without any such protection, 19 others with less than 10%, and only seven bioregions having more than 20% of their areas included. Importantly, the 33 bioregions on the continental shelf subject to most extractive activities in the Australian marine jurisdiction (Dambacher *et al.*, 2012) tend to have much lower levels of protection than the remainder. For all IUCN categories, the median percentage of shelf bioregion area in MPAs is 16.9%, compared with 36.2% for non-shelf bioregions. For no-take MPAs, the median percentage coverage of shelf bioregions is 2.3%, compared with 16.4% for non-shelf bioregions.

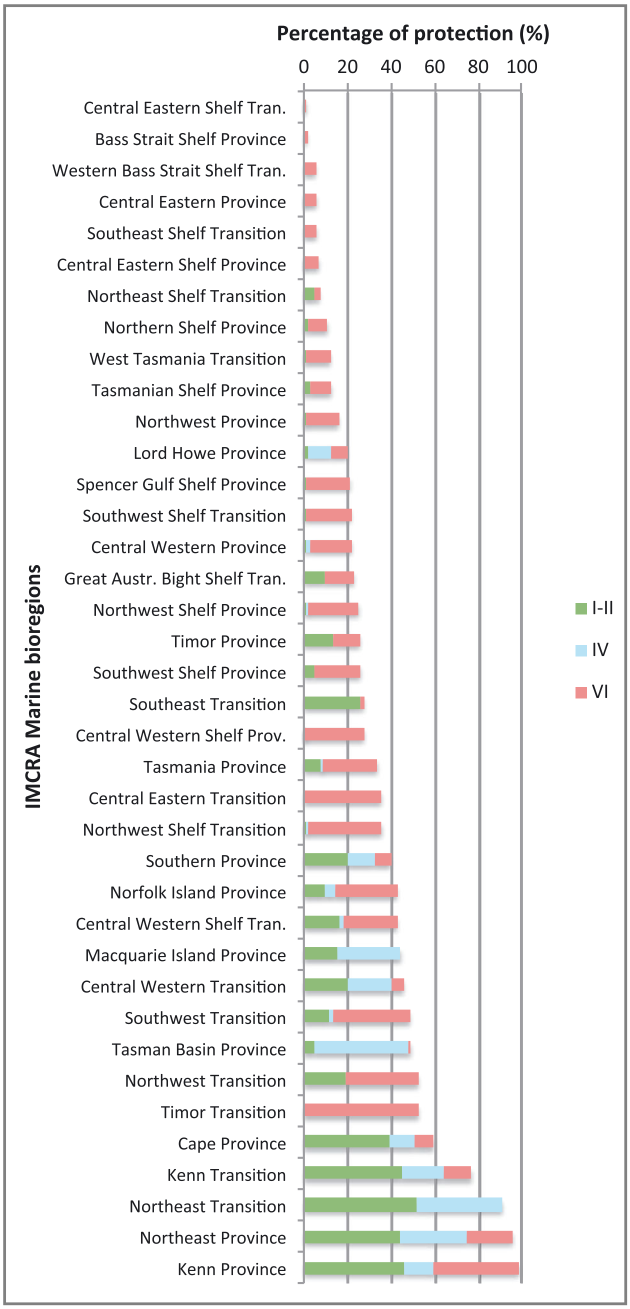


Figure 4. Percentages of each of the 38 Australian IMCRA v 4.0 bioregions used in the bioregional planning process covered by the expanded Commonwealth MPAs, by IUCN categories. Coverage is summed for all Commonwealth MPAs, including those established in 2007 in the South-east region and those announced in 2012. Three bioregions have been excluded from the figure: Cocos (Keeling) Island Province and Christmas Island Province, which were not covered by the recent bioregional planning exercise; and North-east Shelf Province which is entirely covered by the Great Barrier Reef Marine Park and not included in bioregional planning in 2007 and 2012.

Within planning regions, major biases in representation of habitat features are evident, strongly indicative of residual reservation. An extreme example occurs in the Temperate East region, covering 12° of latitude, where biodiversity features in the most threatened environments – the continental shelf and upper slope – lack any new no-take protection. Only two very small (1 $km^2$ and 4 $km^2$) marine reserves are present on the shelf, at Pimpernel Rock and the Cod Grounds, both preceding establishment of the new MPAs. Within the same region, the single offshore no-take MPA that includes some shallow water habitat, Middleton Reef, also preceded the new network (by 25 years). Thus, the most threatened habitats within the Temperate East region will receive no additional protection under the proposed zoning scheme in the form of no-take MPAs. In the South-east region, MPAs generally, and no-take areas in particular, disproportionately avoided the 'zone of importance' of Williams *et al.* (2009a), where highest biodiversity values and greatest threats to biodiversity overlap

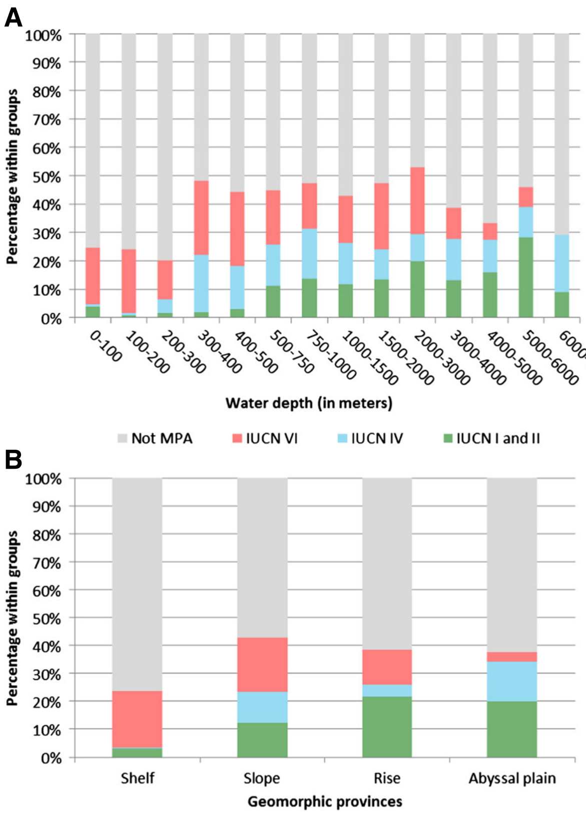


Figure 5. Coverage of depth classes and geomorphic provinces by Australian Commonwealth MPAs. (A) Water depth classes (Geoscience Australia, 2009) and (B) geomorphic provinces of Heap and Harris (2008). For each depth and geomorphic class, coverage was summed for all Commonwealth MPAs, including those established in 2007 in the South-east region and those announced in 2012. For each class on the x-axes, each percentage refers to (total extent in MPA category)/(total extent of class)*100. In part B, category VI MPAs exist on the shelf but occupy only 0.2% of its total extent.

(for further discussion, see Harris *et al.*, 2009; Williams *et al.*, 2009b). In the Coral Sea region, the very extensive MPA coincides with commercial fishery values that are marginal nationally (Hunt, 2013). Furthermore, the category II and IV zones that prohibit pelagic longlining, the most profitable of the Coral Sea fisheries, have been located to avoid all but the most marginal areas for this fishing method (Hunt, 2013).

With regards to water depth, all depth ranges are represented at some level in MPAs (Figure 5(A)), reflecting one of the stated goals of the planning process. However, there is a clear bias in MPA representation among depth classes, in addition to an uneven representation of IUCN categories among depths. Shallower waters have generally a lower MPA coverage and are dominated by category VI MPAs, allowing some level of extractive use (Figure 5(A)). Deeper waters have generally a higher MPA coverage, with larger percentages of no-take (Category I or II) MPAs. This pattern accords with the tendency for no-take MPAs to be concentrated near the outer limits of the marine jurisdiction (Figure 3) where extractive activities such as fishing tend to be at their lowest. The bias toward protection of deeper waters is evident in the representation of broad geomorphic provinces, defined by Heap and Harris (2008). While about 24% of the continental shelf is in any kind of MPA, only 3.1% is in no-take MPAs (Figure 5(B)), reflecting the relatively poor protection of shelf bioregions (Figure 4). The more remote and deeper geomorphic provinces are better protected, with 42.6% total MPA and 12.3% no-take on the continental slope, 38.4% MPA and 21.6% no-take on the continental rise, and 37.6% MPA and 20.0% no-take on the abyssal plain.

The NRSMPA planning process was guided by different biological datasets, including 45 Key Ecological Features (KEFs). These are areas identified by scientists as being valuable for their exceptional productivity, biological diversity, or both (Dambacher *et al.*, 2012). KEFs were selectively identified in all marine planning regions, except for the South-east region where MPAs were established before KEFs were defined. Dambacher *et al.* (2012) analysed the relationship between 31 Australian KEFs and anthropogenic pressures. They identified 15 different types of pressures, the most common being fishing, followed by ocean temperature and oil spills. KEFs cover about 22.3% of the marine planning regions in which they were mapped. The percentage of total KEF area represented in MPAs is 40.2%, although only 9.1% is within no-take MPAs. Inclusion of individual KEFs in MPAs is very uneven, ranging from none to 100%, with a median 60.7%. The median drops to 0.96%, however, when considering coverage by no-take MPAs, questioning the capacity of the MPAs to effectively protect KEFs.

While depth and seafloor types serve as approximate surrogates for the potential for extractive uses, it is also possible to review the Commonwealth MPAs directly in relation to two specific major uses: commercial fishing and exploration/extraction of oil and gas.

Analyses of average fish catches during the 11 years preceding the implementation of the new MPAs indicate that catches were 5.6 to 13.9 times lower in locations where the new MPAs are located, compared with areas left open to fisheries

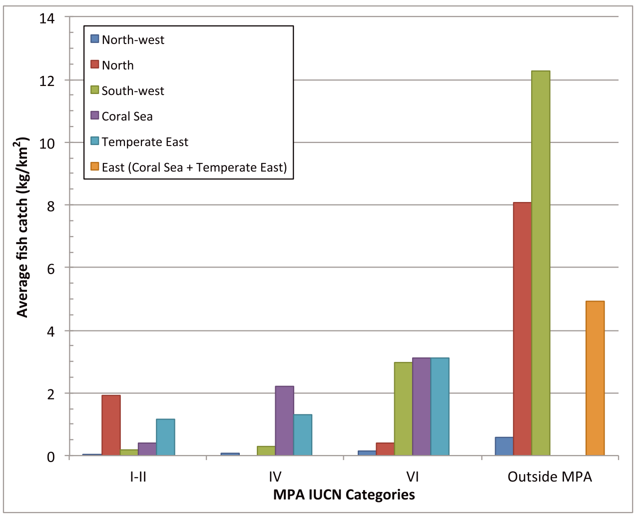


Figure 6. Australian Commonwealth MPAs in relation to previous fish catch. Average annual fish catch per km$^2$ between 2001 and 2011 at locations within and outside recent MPAs, by IUCN classification and for each Australian marine planning region (Coral Sea and Temperate East were combined into a single 'East' region for areas outside MPAs due to lack of data availability for the separate regions). The analysis focused on the 2012 MPAs, excluding the South-east MPA network created in 2007, and was done by CSIRO using detailed fishing data for all Commonwealth fisheries and some state fisheries, in the absence of a consistent fisheries dataset for all Australian state fisheries.

(Figure 6). Furthermore, average fish catches were 2.7 to 15 times higher in locations where category VI zones were established, compared with locations where no-take zones were established, with the exception of the North planning region where the reverse applied. The residual nature of Australia's MPA system in relation to fishing is reflected more accurately in Figure 6 by no-take MPAs than by the other MPA categories. Category IV and VI MPAs allow fishing to continue in various ways, and the impacts of fishing on biodiversity in these areas, and outside MPAs, have been underestimated. The risks to biodiversity posed by fishing have been assessed through a series of species- and fishery-specific assessments (Lack, 2010). Although these assessments identified major impacts of gear types on habitats and species considered to be vulnerable, they did not consider cumulative or trophic effects. The assessments have been interpreted to mean that impacts of gear not reaching an effect threshold for an individual species or habitat have no significant region-wide cumulative impacts on biodiversity. Consequently, extensive MPAs that include fishing (categories IV and VI) are widely, but incorrectly, believed to present little risk to biodiversity. Modelling indicates otherwise: indirect and cumulative impacts of fishing, at levels and with procedures that meet the sustainable harvest standards used in Australia, can be both far-reaching and substantial (Smith *et al.*, 2011; Garcia *et al.*, 2012).

MPAs have also been designed to minimize interference with oil and gas activities, which are most extensive in the North-west and South-east planning regions. Figure 7(A) illustrates, for the North-west region, the spatial relationship between MPAs and petroleum titles (e.g. permits allowing oil and gas exploration or exploitation), exploration acreage release (i.e. areas under consideration by the industry in 2011 and 2012), and all existing offshore wells. Some oil and gas exploration and production are intended to be allowed within category VI MPAs. No-take and category IV MPAs have been designed to avoid titles, release areas and active wells and, as a consequence, poorly represent some of the Key Ecological Features in this region. Across

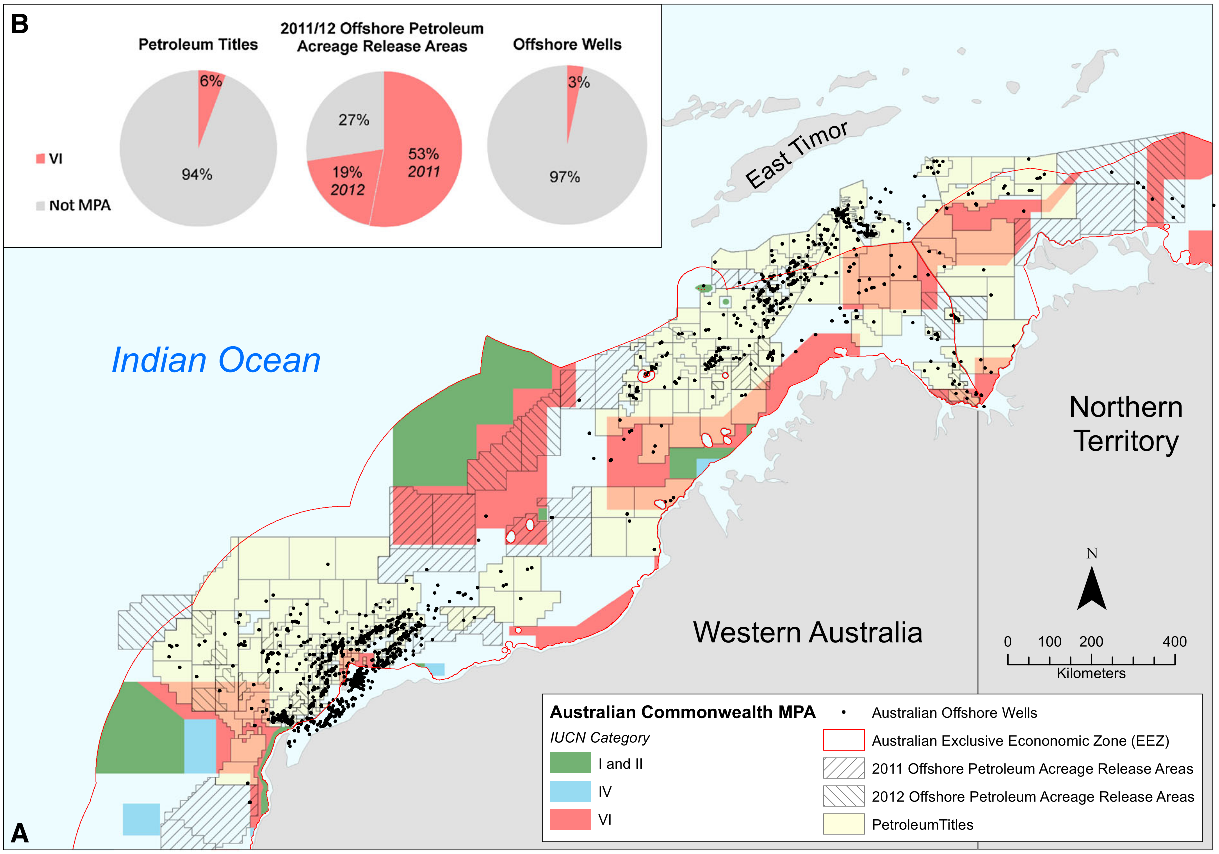


Figure 7. Australian Commonwealth MPAs in relation to oil and gas exploration and development. (A) New MPAs in the North-west planning region in relation to petroleum exploration and extraction. The outer boundary of Commonwealth waters marks the limit of the Exclusive Economic Zone. Inshore from the inner Commonwealth boundaries are state (Western Australia) and territory (Northern Territory) waters. Orange polygons within Commonwealth waters show overlap between category VI MPAs (red) and petroleum titles (pale yellow). (B) Summed national percentages of petroleum titles, offshore petroleum acreage release areas, and offshore wells covered by category VI MPAs. There are no petroleum titles, offshore petroleum acreage release areas, or offshore wells within IUCN category I, II and IV MPAs.

Australia, around 6% of MPAs categorized as VI overlap petroleum titles and 72% overlap 2011 and 2012 petroleum acreage release areas (Figure 7(B)), indicating that Australian MPAs have been categorized or configured to provide no obstacle to oil and gas development, notwithstanding the adverse impacts of these developments on marine biodiversity (SoE, 2011).

## REGIONAL PICTURE: GREAT BARRIER REEF MARINE PARK

Marine protection was assessed in the Great Barrier Reef (GBR) Marine Park, established in 1975 and rezoned in 2004. Today the main objective of the Marine Park is ‘to allow for the long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region’ (Commonwealth of Australia, 2011). With a total size close to 350 000 km$^2$, the park is divided into zones with different levels of protection. The initial zoning plans were strongly residual, with no-take zones concentrated in remote areas and largely absent from soft-bottom ecosystems suitable for trawling and other extractive uses (Day, 2008). The 2004 rezoning of the park increased no-take zones from 4.6% to 33.3% of the total area. The new zones also represent at least 20% of each of the 70 marine bioregions defined for the exercise (Fernandes *et al.*, 2005; Day, 2008). Other objectives were also used to identify the zones, such as having at least three replicate samples within each bioregion, setting minimum sizes for new no-take zones, protecting minimum amounts of known habitats, and protecting unique and special sites. The five-year rezoning process involved significant consultations with the public and key stakeholders, including recreational and commercial fishers. Despite diverging levels of satisfaction with the rezoned marine park among stakeholders (Lédée *et al.*, 2012; Sutton and Tobin, 2012), the 2004 GBR rezoning is recognized worldwide as a major achievement in marine conservation (Gaines *et al.*, 2010).

Data used in the rezoning process included spatial information on commercial uses (e.g. fishing and tourism) and non-commercial uses (e.g. recreational fishing and diving). The Great Barrier Reef Marine Park Authority (GBRMPA) used a systematic conservation planning approach to achieve quantitative objectives for multiple biodiversity features, guided by biophysical operating principles, while minimizing the opportunity costs to users, including commercial and recreational fishers. The process involved an initial draft zoning plan followed by public comment, allowing GBRMPA to propose revised zones for a second phase of public consultations that further minimized the impact on existing uses while maintaining a minimum representation of all bioregions.

Spatial data on trawling effort were central to the design of the final zones (Figure 8). This analysis found that early draft no-take zones in 2003 largely avoided important trawling areas. After public consultation on the draft and access to VMS trawl effort data (Good *et al.*, 2007), the location of no-take zones further changed relative to trawl effort. There is a 73% overlap in no-take zones between the 2003 and final (2004) zoning plans (a 27% change in draft no-take zones),

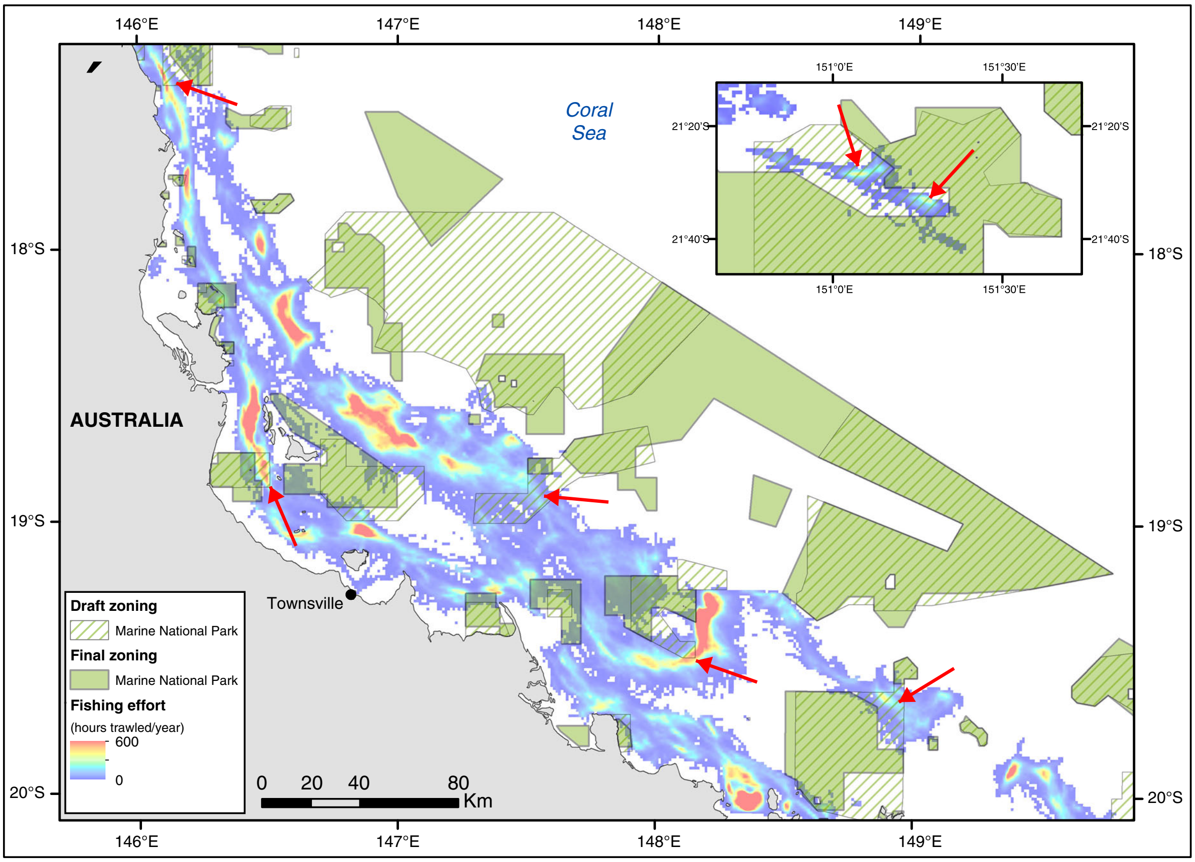


Figure 8. Changes in marine national park zones (no-take zones) between the initial 2003 Great Barrier Reef draft zoning plan (hatched) and the 2004 final zones (solid green), in relation to average estimated trawling effort in 2002 and 2003. The inset (top-right) shows another area located to the south-east of the main map. Red arrows indicate examples of areas initially proposed for closure but finally left open to trawling.

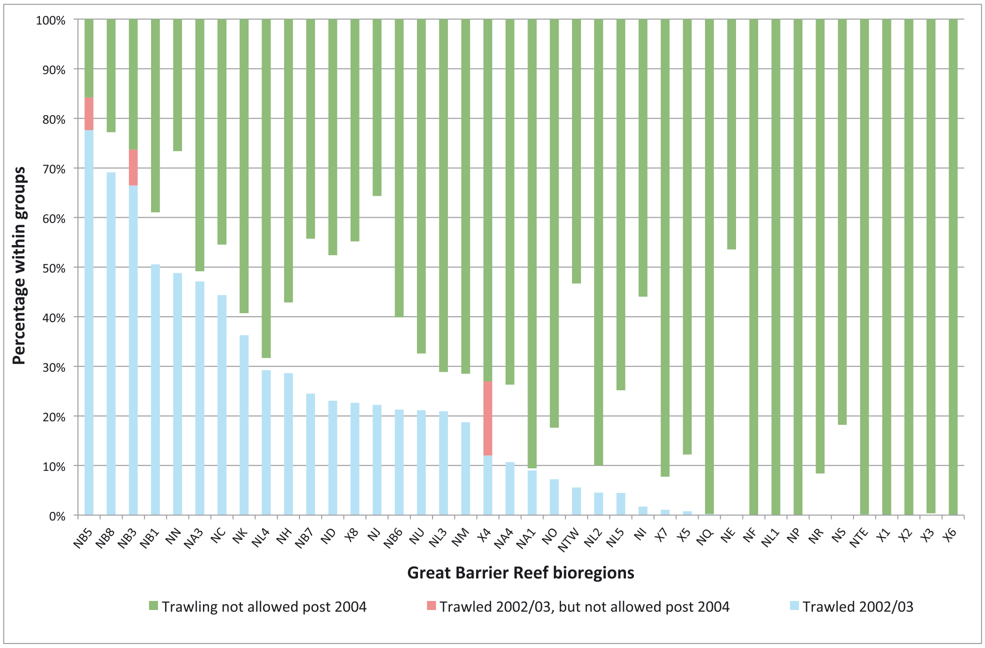


Figure 9. Extent of non-trawl zones in the Great Barrier Reef Marine Park in relation to previous trawling. Percentages trawled of the Great Barrier Reef soft-bottom bioregions in 2002/03 (blue + red), and percentages of bioregions closed to trawling in the 2004 rezoning (green + red). Bioregions listed are nonreef bioregions. Red portions of bars indicate previous trawled percentages closed to trawling by the rezoning. Areas closed to trawling consist of the following 2004 zones: Habitat Protection, Conservation Park, Buffer, Scientific, Marine National Park and Preservation. Data on 2002/03 trawling are the same as those in Figure 8, but the figures here refer to the entire extent of the Marine Park. Descriptions of bioregions in relation to codes used here can be found at http://www.soetownsville. org/data/coastal/marine-bioreg/bioregions_description.pdf

allowing a further 49% reduction in the impact on trawling. Grech and Coles (2011) found that, while the area available for trawl fishing in the GBR decreased from 51% to 34% with the final 2004 rezoning, the rezoning caused the loss of only 4.8% of the area actually trawled in 2003, and just 0.82% of the area trawled more than once in 2003.

Minimizing opportunity costs to trawling in the Great Barrier Reef rezoning meant that protection of soft-bottom bioregions from trawling was greatest in areas with the lowest trawl effort (Figure 9). Protection was least (albeit with the required minimum of 20% coverage by no-take zones) for bioregions that had been more extensively trawled before the rezoning, leaving large portions (up to 78%, Figure 9) of some bioregions exposed to trawling. The implications for the region's biodiversity have not been assessed, although adverse impacts of trawling in the region persist (Pears *et al.* (2012), and note uncertainties and caveats for many species outside high-risk categories, along with crude estimates of population sizes and reductions attributable to trawling). Key unanswered questions for future planning in the region are what percentages of bioregions are necessary to represent their biota (Desmet and Cowling, 2004; Metcalfe *et al.*, 2013) and how these percentages should be distributed to afford adequate protection from trawling.

Among the 70 marine bioregions that underpinned the 2004 rezoning, many were very large, with some extending over hundreds of kilometres (Lewis *et al.*, 2003). The objectives that guided the rezoning allowed considerable flexibility in the placement of no-take zones. It is unclear, however, whether this approach shifted no-take zones to parts of bioregions that were different, physically and biologically, from parts that remained open to trawling. Trawling is far from uniform within the GBR's soft-bottom bioregions (Figure 9), suggesting heterogeneity with respect to suitability for trawling (and see Burridge *et al.*, 2003). This heterogeneity could be related to distance from ports, inherent characteristics such as sediment type or hard structures that impede nets, or investment in preparing areas by initial trawling to remove megabenthos, making such areas suitable in terms of bottom type and target species. While information about benthic biodiversity was made available to GBRMPA for the rezoning (Pitcher *et al*., 2002), this information was generally not sufficient to understand heterogeneity of biodiversity within bioregions. Whether minimizing opportunity costs to trawling led to residual protection of physical and biological variation within bioregions remains an open question.

## DISCUSSION AND CONCLUSIONS

The establishment of MPAs around the world has been extensive and is rapidly expanding, but the effectiveness of many MPAs is regularly questioned (Mora and Sale, 2011; Rife *et al*., 2013; Bergseth *et al*., in press). Much of the criticism of MPAs relates to allowed activities, poor enforcement, and alienation of stakeholders. However, there is a fundamental question that has seldom been asked (but see Spalding *et al*., 2013): How effectively are MPAs separating marine biodiversity from processes that threaten its persistence? This question relates to the basic purpose of any protected area. Too often, the establishment of protected areas is seen as equivalent to effective protection, and very often this conflation of ideas is mistaken. Protected areas fail in their basic purpose to the extent that they are residual to extractive uses. A strong focus on minimizing the opportunity costs of MPAs, combined with limited biological data and highly generalized conservation objectives, entails the considerable risk of pushing 'protection' into residual parts of the ocean (Figure 1).

### Another look at the four questions related to minimizing opportunity costs of MPAs

At the outset four questions were posed (Figure 1) that decision makers should be able to answer about the implications of minimizing opportunity costs when designing MPAs and no-take zones. The evidence that minimizing the opportunity costs of MPAs and no-take zones has had perverse outcomes for marine biodiversity globally, in Australian waters, and in the Great Barrier Reef Marine Park is now discussed. This assessment involves a slight rephrasing of questions 2–4 by replacing 'Should' – for statements of intent in Figure 1 – with 'Do' – for assessment of outcomes here. Table 2 summarizes the assessments of this study, beginning with three alternative answers. 'Yes' indicates that the evidence for a positive answer outweighs negative evidence. 'No' indicates the opposite. 'Uncertain' indicates mixed or scarce evidence. The lens for these assessments is shaped by current scientific thinking about the location and configuration of MPAs. In the case of the Great Barrier Reef Marine Park, rezoned in 2004, using this lens therefore draws to some extent on hindsight. Hopefully, this assessment provides some lessons for the next rezoning of that region, whenever that occurs, and also for MPA planning in other regions that would seek to emulate what was, in 2004, world's best practice.

*Question 1*: *Are MPAs/no-take zones intended to protect biodiversity?*

At the global level, the intent to protect marine biodiversity using MPAs and no-take zones is stated explicitly in policy (e.g. WSSD, 2002[4]; IUCN World Parks Congress, 2003[5]; CBD COP, 2010[6]) and in IUCN's definition of MPAs as primarily focused on conservation outcomes (Fitzsimons, 2011; Day *et al*., 2012). Nationally, Australia's in-principle commitment to the conservation of marine biodiversity through MPAs is clearly stated. Principles for expanding the Australian MPA system to represent and promote the persistence of biodiversity have long been established (ANZECC, 1998). Goals, apparently qualitative, underpinning the recent bioregional planning exercises in Australian waters also indicate a policy commitment to conserving marine biodiversity. For

[4]2002 World Summit on Sustainable Development (WSSD) Agenda 21, available online: http://www.unep.org/Documents.Multilingual/Default.asp?documentid=52

[5]2003 International Union for the Conservation of Nature (IUCN) World Parks Congress, available online: https://cmsdata.iucn.org/downloads/14_2lowres.pdf

[6]Convention on Biological Diversity (CBD) Conference of Parties (COP) tenth meeting, decision X/2 Strategic Plan for Biodiversity 2011 - 2020, available online: http://www.cbd.int/decision/cop/?id=12268

Table 2. Analysis of patterns of marine protected areas globally, in the Australian marine jurisdiction, and in the Great Barrier Reef region, in relation to the four questions posed in Figure 1

| | Global | Australia | Great Barrier Reef |
|---|---|---|---|
| 1. Are MPAs/no-take zones intended to protect biodiversity? | Yes: Indicated by definitions of MPAs and high-level policy statements. | Yes: Indicated by national policy statements and qualitative goals for the design of MPAs established in 2007 and 2012. | Yes: Indicated by enabling legislation and operating principles for the 2004 rezoning. |
| 2. Do developing systems of MPAs/no-take zones give precedence to more threatened biodiversity features? | No: Trend is toward very large, remote MPAs with little potential for extractive uses and distant from most serious threats. | No: Strong biases away from commercial activities indicate an extensive system of MPAs that is clearly residual. | Uncertain: Available data on threatened species and ecosystems shaped the 2004 rezoning, but there were only marginal reductions in the extent of trawling, which continues to affect large parts of some soft-bottom bioregions, with some species still at risk. |
| 3. Do MPAs/no-take zones adequately represent all biodiversity features of interest? | No: MPAs currently occupy too small a percentage of the world's oceans to be adequately representative. There are no agreed quantitative objectives, and trends in representation suggest increasing bias toward remote parts of the ocean with least exposure to threatening processes. | No: Absence of quantitative objectives for representing features despite previous policy initiatives for systematic planning. Representation was highly uneven, and in some cases very poor, for features mapped in preparation for the bioregional planning exercises that led to extensive new MPAs in 2007 and 2012. | Uncertain: Representation in 2004 was adequate within the limits of political tolerance, and based on explicit objectives and operating principles. Refinement of objectives might improve protection, and the model of uniform requirements for representation should not be emulated. |
| 4. Do MPAs/no-take zones adequately represent more threatened examples of features that are different from less threatened examples? | No: No evidence that within-feature variation is a consideration. Very poor and residual representation of extensive features indicates that representation of within-feature variation in relation to threats is not possible. | No: Some evidence that within-feature variation related to biodiversity and threats was not accounted for. No evidence that within-feature variation was an important consideration in the design of MPAs, in spite of long-established national policy relevant to this issue. | Uncertain: Within-bioregion variation linked to suitability for trawling did influence the representation of bioregions. Corresponding within-bioregion variation in biodiversity is unknown. |

the Great Barrier Reef, both the enabling legislation (Commonwealth of Australia, 2011) and operating principles for the 2004 rezoning (Fernandes *et al.*, 2005) are explicit about the primacy of biodiversity conservation in the region. In summary, it appears that governments and international NGOs have promoted, for the three case study contexts, the important role of MPAs and no-take zones in achieving biodiversity conservation. If the effectiveness of MPAs in protecting biodiversity is often questionable, one reason is the lack of resources for management and compliance (Mora and Sale, 2011; Rife *et al.*, 2013). But another important factor determining the effectiveness of MPAs and no-take zones is their location relative to biodiversity features that need protection from threatening processes, addressed in the questions that follow.

*Question 2*: *Do developing systems of MPAs/no-take zones give precedence to more threatened biodiversity features?*

The rationale for giving precedence to biodiversity features that are most threatened (and with fewest spatial options for protection, Margules and Pressey, 2000) is that such a scheduling strategy will minimize the extent to which conservation objectives are compromised by threatening processes while systems of MPAs are being assembled. Globally, the emerging trend is toward very large MPAs in remote parts of the ocean with limited potential for extractive uses and distant from the most serious threats to marine biodiversity (and see Spalding *et al.*, 2013). There is little evidence that large, remote MPAs are the best way of averting the decline in marine biodiversity. This approach appears to be shaped more by political pragmatism and by the explicit emphasis of some conservation NGOs than by insights into effective ways of maximizing the long-term persistence of biodiversity. Large and remote MPAs are in many cases the only way countries can meet, at minimal cost and political risk, their international conservation commitments. At the same time, despite possible benefits, the contribution of these very large MPAs to the most urgent conservation priorities in the world's oceans can be questioned (Agardy *et al.*, 2003; Cressey, 2011; Anon., 2012; De Santo, 2013; Dulvy, 2013; Spalding *et al.*, 2013).

For Australia there is no evidence that more threatened biodiversity features (e.g. coastal waters or Key Ecological Features) have been given precedence, and strong evidence for the opposite pattern. Australia's MPA system in Commonwealth waters is now so extensive (at 3.1 million $km^2$) that residual patterns are clearly evident. Indirect evidence consists of very uneven representation of provincial bioregions and strong spatial biases, particularly of no-take MPAs, toward deeper waters distant from the mainland. More direct evidence relates to biases away from areas valuable for commercial fishing and extraction of oil and gas, particularly in the case of no-take MPAs. Both of these activities are known to have impacts on and to pose future risks to Australia's marine biodiversity (SoE, 2011), and some poorly protected species and ecosystems are in decline (SoE, 2011).

For the Great Barrier Reef, precedence of threatened features was, in one sense, not an issue. The whole zoning system, after protracted design and public consultation, was enacted simultaneously, so a sequence of protection was irrelevant (although whether the zoning system is 'complete' remains open to debate). The rezoning did, however, consider ecosystems and species known at the time to be threatened, including marine turtles and dugong (Fernandes *et al.*, 2005, 2009). The assessment 'Uncertain' in Table 2, is influenced by two considerations. First, the rezoning had only a marginal effect on the extent of pre-existing trawling in soft-bottom bioregions (Figure 9, and see Grech and Coles, 2011). Second, there was a clear tendency for no-trawling zones to be configured around previous trawling activities, albeit with a minimum of 20% protection of all bioregions in no-take zones (Figure 9). This underlines the need for conservation objectives for bioregions and other features in the region to be scaled according to exposure to extractive uses. It is also acknowledged that the rezoning was preceded by a trawl management plan in 2001, although this plan was not focused on maintaining the region's biodiversity. Importantly, trawling is currently permitted over extensive parts of some bioregions (up to 78%, Figure 9).

In summary, there is an emerging residual pattern of MPAs globally, a strongly established residual pattern in Australian waters (and see Pressey, 2013), and some indications of residual protection in the Great Barrier Reef. At least for Australia and the Great Barrier Reef, these patterns have clearly been shaped by an emphasis on minimizing opportunity costs. Globally, the distribution of MPAs strongly suggests the influence of minimizing opportunity costs, perhaps by the political expedient of avoiding conflict with resource extractors in near-shore, heavily used waters. Moreover, the effectiveness of zoning and management of some very large, remote MPAs is questionable (Cressey, 2011; Dulvy, 2013).

*Question 3*: *Do MPAs/no-take zones adequately represent all biodiversity features of interest?*

The global MPA system covers a small percentage of the world's oceans, so representation, even at the coarse resolution of marine ecoregions and pelagic and benthic provinces, is inevitably poor (Spalding *et al.*, 2013). This limitation is reinforced by the fact that MPAs are rarely no-take zones, spanning a broad range of protection types that do not necessarily avert threats to biodiversity. The commitment by governments and large NGOs to filling gaps in global representation remains uncertain despite explicit international policy statements about representation (e.g. Aichi Biodiversity Targets[7]). While policies aimed specifically at establishing very large, remote MPAs help to increase the world's MPA coverage and protect large, relatively pristine areas, they accelerate the already strong trend towards large and remote MPAs (De Santo, 2013; Spalding *et al.*, 2013) and uneven representation. Across a sequence of international conventions and conferences, there have been occasional proposals for quantitative objectives usefully framed in relation to marine ecoregions and habitats (De Santo, 2013), but there appears to be no international consensus on such objectives. Also, vagueness about the spatial context for objectives (such as Aichi's '10% of coastal and marine areas') and objectives framed for national jurisdictions (CBD COP, 2010[8]) could be counterproductive by encouraging politically expedient, highly biased protection (Agardy *et al.*, 2003; Melick *et al.*, 2012; De Santo, 2013).

Nationally, well considered principles for expanding the Australian Commonwealth MPA network (ANZECC, 1998) appear to have been discarded in designing the 2007 (Nevill and Ward, 2009) and 2012 MPAs. These very extensive MPAs were apparently not based on any quantitative objectives and, by any standards, failed to adequately represent many of the environmental features that had been mapped specifically for the bioregional planning process. Biases in representation were stronger for no-take MPAs than for all MPAs combined. Regionally, the 2004 rezoning of the Great Barrier Reef Marine Park remains one of the world's best examples of representing marine biodiversity, as well as attempting to promote the persistence of key processes (Fernandes *et al.*, 2005). With hindsight, however, the 20% representation objective for all bioregions in no-take zones, although testing political will at the time, could now be improved. More sophisticated, variable objectives for individual ecosystems and species are needed to reflect factors such as spatial turnover of species within ecosystems, genetic heterogeneity within species, and exposure of features to threatening processes.

In summary, representation is very poor globally and hindered by the lack of explicit objectives. In Australia, the lack of objectives for recent bioregional planning was a retrograde step, with representation remaining uneven and, for some features, very poor. The approach to representation in the Great Barrier Reef, exemplary in 2004, would benefit from refinements. All three case studies indicate that uneven representation is related to

[7]Convention on Biological Diversity (CBD) Conference of Parties (COP) tenth meeting, decision X/2 Strategic Plan for Biodiversity 2011 - 2020 including the Aichi Biodiversity Targets, available online: http://www.cbd.int/sp/targets/

[8]Convention on Biological Diversity (CBD) Conference of Parties (COP) tenth meeting, decision X/2 Strategic Plan for Biodiversity 2011 - 2020, available online: http://www.cbd.int/decision/cop/?id=12268

minimizing opportunity costs in the form of short-term financial and political liabilities.

*Question 4*: *Do MPAs/no-take zones adequately represent more threatened examples of features that are different from less threatened examples?*

Globally, there is little information on variation within marine ecoregions or pelagic and benthic provinces; regardless, given the scale of intra-habitat variability in ecological features, it is likely that heterogeneity of both biological composition and extractive potential will be high in many such extensive features. Given the very poor and increasingly residual representation of many of these features, it is not possible for within-feature variation to be adequately addressed by MPAs in relation to threats. Among the principles for MPA expansion previously established in Australia (ANZECC, 1998) is one that concerns the representation of physical and biological variation within mapped features such as provincial bioregions. The available evidence indicates that within-feature representation is not high in the new Commonwealth MPAs, despite many of the mapped features, such as provincial bioregions, being very extensive and probably very heterogeneous. Williams *et al.* (2009a) demonstrated that geomorphic units used for planning MPAs in the South-east region were heterogeneous physically and biologically and that MPAs, and particularly no-take MPAs, covered a biased (least threatened) portion of this variation. The configuration of MPAs, especially no-take MPAs, around commercial uses in the Australian marine jurisdiction offers little promise that more threatened within-feature variation has been represented. For the Great Barrier Reef, it is clear that pre-existing trawling influenced the distribution of no-take and other protective zones designed to achieve objectives for marine bioregions. What remains unclear is whether this bias is associated with variation in biodiversity within bioregions. In summary: within-feature variation is poorly known globally and certainly not represented; in Australia, the few published analyses and residual biases at the feature level strongly suggest poor representation of threatened within-feature variation; and in the Great Barrier Reef it is unknown whether within-bioregion suitability for trawling is also associated with variation in biodiversity.

Overall, Table 2 indicates clearly that, globally and in Australia, a commitment to protecting marine biodiversity with MPAs has not been matched by action. Minimizing opportunity costs is leading to perverse outcomes for marine biodiversity. Protection is concentrated on ecosystems and associated species under least threat, while much biodiversity exposed to threats remains so, and is declining as a consequence. For the Great Barrier Reef, perverse outcomes of minimizing opportunity costs are possible. Objectives for the Reef's features need to be refined, partly in relation to exposure to threatening processes, and the implications for the Reef's biodiversity of minimizing costs to trawling are not understood.

## Challenges for science and policy

Thirty years of systematic conservation planning have contributed greatly to designing effective systems of MPAs, and influenced policy and practice. Principles developed in Australia for establishment of MPAs, shaped strongly by systematic planning, include comprehensiveness, adequacy and representativeness (ANZECC, 1998). But the recent exercise in designing very extensive MPAs in Australian waters demonstrates that principles once endorsed by government can be abandoned when they would lead to politically unacceptable conflicts with resource users. Put another way, it seems that the opportunity costs of a comprehensive, adequate and representative system of MPAs in Australia were too high for the Australian Government to pay. Despite the small impact on existing extractive activities of the MPAs announced in 2012, the Australian government elected in 2013 started a review of the MPAs, suspending their management plans. This problem is similar to that faced by many conservation initiatives around the world that have to confront political and economic realities. The solution is often to aim for the 'low hanging fruit' in an attempt to demonstrate willingness to establish protected areas, even if the long-term costs – to society in the form of lost biological heritage as well as biodiversity – of continuing declines of ecosystems and species under extractive pressures are not assessed.

More extensive application of the principles of systematic conservation planning would help reverse the weaknesses of MPA systems described in Table 2. However, despite well known success stories in the application of systematic planning (Fernandes *et al.*, 2009; Gleason *et al.*, 2010), more effective systems of MPAs would also benefit from further development of systematic methods in at least three areas, each of which will require translation into policy.

First, representation of ecosystems and species – a foundation of systematic planning (Margules and Pressey, 2000) – is necessary but not sufficient. Reviewing systems of MPAs only in terms of representation (Barr and Possingham, 2013) ignores the relative urgency for protection of species and ecosystems. Chronological analyses of the development of terrestrial reserve systems have shown that progressive increases in representation reflect 'protection' of less threatened features while more threatened features remain exposed to further attrition (Pressey and Taffs, 2001b; Pressey *et al.*, 2002). Measures of representation per se therefore need to be refined to reflect urgency for protection, and preferably complemented with estimation of conservation impact (Ferraro and Pattanayak, 2006). Importantly, impact refers to outcomes for conservation attributable to protected areas relative to the counterfactual of no intervention, considering the potential decline of unprotected features. Measuring impact therefore addresses the ultimate goal of conservation, whereas representation (and especially extent of protected areas) falls short in this respect. Retrospective analyses of the impact of protected areas on land are now operational (Andam *et al.*, 2008; Nolte *et al.*, 2013), providing lessons for the future. Predictive analyses to maximize future impact are also being developed on land (Withey *et al.*, 2012). Both approaches need adaptation and application in the marine realm.

Second, a growing literature on using spatially variable costs in systematic conservation planning (Ban and Klein, 2009) has not come to terms with the risks entailed in minimizing the costs of achieving conservation objectives. The risks to biodiversity of minimum-cost conservation solutions are strongly related to the spatial resolution and heterogeneity of features identified for representation. But the risks to biodiversity might persist even when using relatively finely defined features such as the 70 marine bioregions in the Great Barrier Reef Marine Park. Among the unanswered questions related to costs are: 1. To what extent do apparent 'win-win' solutions that achieve objectives at minimum cost disadvantage biodiversity features most exposed to threats posed by extractive activities? 2. How do perverse outcomes from minimizing costs relate to the resolution at which conservation features are defined, relative to the resolution of cost data? 3. What measures best promote the persistence of features that are most costly to protect? 4. To what extent must society forgo economic gain or incur economic losses if the commitment to conservation is real?

Third, the respective benefits and risks of large MPAs in remote areas with little current threat and smaller MPAs in imminently threatened and heavily used waters remain poorly understood (but see Spring *et al.*, 2007 for a terrestrial analysis). While this situation prevails, the debate will be shaped more by belief systems than real understanding, and the prospects will remain poor for designing balanced portfolios of MPAs that maximize long-term outcomes for marine biodiversity. Claims that remote, residual MPAs are good investments for the future are valid only if it can be demonstrated that this strategy gives better long-term outcomes for biodiversity than an alternative strategy based on addressing urgent priorities in relation to threat. There is a pressing need for the assumptions involved in advocacy for both strategies to be laid out and examined, and the implications of these assumptions being wrong to be identified. With this foundation, it will be possible to better understand the long-term conservation impact of shifting the balance of protection between remote and inshore marine areas. Assessments of the long-term outcomes of short-term decisions also need the context of climate change. Latitudinal shifts in species are already observed in many terrestrial (Chen *et al.*, 2011) and marine (Cheung *et al.*, 2009) ecosystems, and changes in ocean temperature and acidity will affect species and ecosystems in both coastal and remote oceanic environments.

This study has explored the residual nature of MPAs at different geographic scales, a consequence of the complex trade-offs between ecological, socio-economic and political considerations. The study demonstrates that reaching targets defined by the extent of MPAs, or even targets related to representation of marine features, can give governments, NGOs and the public a false sense of achievement for conservation, with potentially perverse outcomes for marine biodiversity. To expose and help reduce such residual tendencies of MPAs, we proposed a series of four questions or retrospective assessments that funders and planners should be able to address in the interests of accountability. Navigating these questions and assessments requires scientists and practitioners to develop a more explicit view of the consequences of minimizing the opportunity costs of marine conservation.

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