Representation does not necessarily reduce threats to biodiversity: Australia's Commonwealth marine protected area system, 2012–2018

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Abstract

In 2012, Australia proclaimed a national marine protected area (MPA) system - the National Representative System of MPAs (NRSMPA). Following a change in federal government, the system underwent two major revisions: an independent review released in 2015, and a final plan designed by the Director of National Parks implemented in 2018. We used all three iterations of the NRSMPA, from 2012 to 2018, to compare: 1. the MPA zoning composition, using IUCN protected area categories; 2. the achievement of goals for representing biophysical features; and 3. the potential to mitigate threats to biodiversity from commercial fishing and offshore petroleum extraction. We found that protection levels in the NRSMPA were downgraded in 2018, compared to 2012 and 2015 iterations. Although each iteration met its qualitative goals, the lack of quantitative goals meant that representation of biophysical features was highly uneven and dominated by MPAs offering little protection against the impacts of extractive uses. Moreover, existing areas with value for pelagic longlining, demersal trawling, and offshore petroleum extraction were largely avoided by MPAs, irrespective of their biophysical features. MPAs, especially those with high protection, resulted in little forgone fisheries catch and revenue, likely providing few safeguards for species threatened by fishing. Changes in the NRSMPA over time have left more areas open to fishing, particularly pelagic fishing and notably in the Coral Sea. By focusing on meeting poorly defined representation goals instead of threat reduction, changes to the NRSMPA over time have increased the exposure of Australia's marine biodiversity to known threats.

Keywords

Representation; threats; Australia; marine protected areas; fishing; petroleum

1. Introduction

Marine protected areas (MPAs) are defined as geographical spaces in which extractive uses, such as fishing and petroleum extraction, are regulated or removed to achieve biodiversity conservation goals (Edgar et al. 2007; Lubchenco et al. 2003). In the 1990s, conventional fisheries management tools were found to be inadequate for both managing stocks and conserving marine biodiversity (Bohnsack and Ault 1996; Dayton 1998; Pauly et al. 1998). Since then, the extent of spatial protection for biodiversity has increased (e.g. Pauly et al. 2002). Global conservation targets further fuelled widespread implementation of MPAs, particularly Aichi Target 11 under the Convention on Biological Diversity, which calls for a minimum of 10% of marine and coastal areas to be protected using ecologically representative protected areas by 2020[1]. The extent of MPAs increased substantially from two million km^2 in 2000 (0.7% of the ocean) to 27 million km^2 (7.4% of the ocean) in November 2019 (UNEP-WCMC 2019). However, an increasing number of scientists have questioned whether the rapid growth in MPA coverage means adequate representation and protection of marine biodiversity from threats (Chape et al. 2005; De Santo 2013; Jantke et al. 2018; Pressey et al. 2015; Pressey et al. 2017; Roberts et al. 2018).

Protected areas are representative of a region when they sample a set of selected biodiversity features (Margules and Pressey 2000). In the absence of detailed inventories of species and ecosystems, representation is often applied to surrogate features, which are defined by abiotic characteristics and meant to reflect patterns in the distribution of species (Pressey 2004). Examples of marine surrogates are bioregions in the Great Barrier Reef Marine Park (Fernandes et al. 2005) and ecoregions globally (Spalding et al. 2007). The objective of planning with surrogates is usually to represent a specified minimum percentage of each within protected areas. Explicit objectives associated with representation are, in principle, an improvement over ad hoc MPA designation, which is commonly based on either political opportunity or maximising areal extent. However, designing MPAs solely based on representation, particularly in the absence of explicit quantitative objectives, has been criticised for allowing biased and uneven protection among biophysical features (Barr and Possingham 2013; Devillers et al. 2015; Jantke et al. 2018) and for placing MPAs in remote areas that least need protection from existing threats (Devillers et al. 2015). With or without explicit objectives, representation can be achieved without directly preventing or mitigating threats to biodiversity, which should be a primary purpose of MPAs (Pressey et al. 2017).

In the 1990s, several policies and processes contributed to establishment of a National Representative System of MPAs (hereafter ‘MPA system’) in Australia (discussed in Vince 2018). The ratification in 1994 of the 1982 United Nations Convention of the Law of the Sea required nations to effectively manage the resources in their exclusive economic zones (Vince 2006). In 1998, Australia’s Ocean Policy (Commonwealth of Australia 1998) committed to accelerating the creation of a national MPA system. Around the same time, guidelines (ANZECC 1998) and an action plan (ANZECC 1999) for implementing the MPA system were finalised, identifying ‘comprehensiveness’, ‘adequacy’, and

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[1] https://www.cbd.int/sp/targets/default.shtml

‘representativeness’ (CAR) as principles that would guide the process. At the 2002 World Summit on Sustainable Development, the Australian Government committed to implementing a CAR system of MPAs by 2012 (Cochrane 2016). The major part of this system was to be implemented in Australia’s Commonwealth waters, extending from three to 200 nautical miles offshore.

In 2012, Australia’s federal Labor government proclaimed the first iteration of the MPA system in Commonwealth waters, including internal zonings, anticipated to come into effect in July 2014 (Appendix Fig. 1A). In 2013, the new Liberal government implemented an independent review of the MPA system, involving consultation with regional communities and a review of the available science. The review’s Bioregional Advisory Panel and Expert Scientific Panel released their revised zoning in late 2015 (Appendix Fig. 1B) (Bioregional Advisory Panel 2015). The revised zoning was further amended by the Director of National Parks and implemented in July 2018 (Fig. 1). The original MPA system and subsequent changes were controversial and highlighted the contrasting values of scientists, fishers, environmentalists, politicians, and the tourism industry (Horrobin 2015; Karp 2018; Perez 2018; Prendergast 2019; Pressey 2013; Readfearn 2018).

During development of the MPA system, representation and extent were used as goals for biodiversity conservation (ANZECC 1998, 1999). Despite meeting qualitative representation goals, the 2012 MPA system was highly uneven in representing biophysical features (Devillers et al. 2015; Roberts et al. 2018), with representation biased toward offshore, tropical environments (Roberts et al. 2019). Further, the 2012 MPA system largely avoided the potential threats associated with fishing and entirely avoided threats from petroleum extraction (Devillers et al. 2015; Hunt 2013). Species distribution modelling of bycatch species in the Eastern Tuna and Billfish Fishery showed the 2012 and 2015 iterations made little contribution to minimising shark bycatch (Welch et al. 2018).

Major revisions to MPA systems remain an unexplored topic in the global MPA literature. We explore this topic here by assessing revisions to zoning plans of the National Representative System of MPAs, which reflect intensifying commercial and political constraints on marine conservation in Australia. Our study provides insights into the question of whether meeting representation goals is sufficient to achieve conservation of marine biodiversity. Australia’s Commonwealth MPA system is useful as a case study because it is based on representation goals and had three iterations in its design, allowing comparisons of how representation and threat mitigation were achieved by different zoning schemes. International Union for Conservation of Nature (IUCN) categories were used in planning the MPA system and are used here to assess changes to zoning schemes. Although we recognise that Australia has misapplied and misinterpreted IUCN categories, specifically in regard to zones in which recreational and industrial fishing can and cannot occur (Day et al. 2019; Fitzsimons 2011), we establish the extent and broad configuration of IUCN zones according to interpretations and applications of the MPA system planners. Then, we examine how the representation goals of the MPA system goals were met, including unevenness and bias, across the three iterations. Next, we examine mitigation of potential threats to biodiversity from fishing and offshore petroleum extraction by measuring changes in the spatial overlap of MPAs with commercial fishing and potential offshore extraction of solid, liquid, and gaseous hydrocarbons (hereafter “petroleum”). We conclude by considering the need for MPAs to mitigate potential threats from fishing by highlighting uncertainties around management of Australian Commonwealth fisheries.

2. Methods

2.1. Study area

The MPA system includes Commonwealth, State and Territory waters. We focus on the Commonwealth component for three reasons: the significant planning changes it has undergone in the past decade; its very large extent compared to all non-Commonwealth MPAs combined (CAPAD (2018): 20 times larger); and the readily available spatial data on MPA zones and extractive uses compared to data in State and Territory waters (e.g. Tulloch et al. 2020). Planning for the MPA system divided Commonwealth waters into six regions: North, Coral Sea, Temperate East, South-east, South-west, and North-west (Fig. 1). Planning started with the South-east region, leading to the proclamation of an MPA system in 2007. Management plans for the South-east were completed in 2013, implementing the proclaimed zoning (Director of National Parks 2013b). The remainder of the MPA system was proclaimed in November 2012, reviewed in December 2015, and implemented in July 2018. The Coral Sea region excludes the existing Great Barrier Reef Marine Park, created in 1975 and rezoned in 2004. The MPA system planners used IUCN classification of protected areas in all iterations (e.g. Director of National Parks 2013a), and we grouped those categories into three broad zones (Table 1). Changes after 2012 did not alter the boundaries of the proclaimed marine parks but led to changes in internal zones and associated regulations.

The four stated goals of the MPA system[2] focused on the representation of biophysical features, aiming to: (1) represent each provincial bioregion (38 across all planning regions); (2) cover the entire depth range in each planning region; (3) include examples of benthic and demersal biological features (29 in total); and (4) include all types of seafloor features (e.g. seamounts, canyons, and plains, 21 in total). Provincial bioregions were defined by the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) (Commonwealth of Australia 2006). All 50 features relevant to goals three and four are contained in a spatial dataset termed ‘key ecological features’. The wording of the third goal is significant. It appears to relate to broad types of benthic and demersal features, not necessarily to all recognised features within each type. This interpretation is supported by our quantitative results (section 3.2, below).

2.2. Analysis

Spatial analyses were conducted using ArcGIS (v10.4.1). We measured the composition of each iteration of the MPA system in terms of the broad zones in Table 1. We then converted vector layers of each iteration to 1km^2 raster grids to calculate changes over time in broad zones (I -

[2] https://parksaustralia.gov.au/marine/management/resources/scientific-publications/goals-and-principles-establishment-national-representative-system-marine-protected-areas/

II; IV; VI) at the scale of planning regions. A Sankey diagram in Displayr was used to calculate the total area of each broad zone that changed to another type of broad zone in 2012, 2015 and 2018. We measured the spatial overlap, in each iteration, between broad zones and biophysical features to assess how representation outcomes changed over time. Biophysical features included IMCRA provincial bioregions (IMCRA v4.0 2006), key ecological features (Department of Sustainability, Environment, Water, Population and Communities 2015), and depth classes (Geoscience Australia 2009). In the discussion of depth classes (section 4.4) regarding State MPAs and Australia's continental shelf, the spatial overlap between Australia's national 2018 MPA system (CAPAD 2018) and geomorphic provinces (Heap and Harris 2008) was calculated. An index of protection equality (Barr et al. 2011) was used to measure the equality of percentage representation of biophysical features. The index ranges from zero to 100, with zero indicating that all protection is focused on one feature, and 100 indicating equal protection across all features. To assess how broad zones related to threats to biodiversity, we measured the overlap of broad zones with the three most recently available extractive use layers: Commonwealth pelagic longline and trawl effort (2011 to 2014) (National Environmental Science Program Marine Biodiversity Hub 2016) and offshore petroleum prospectivity (2008) (Geoscience Australia 2008a, b, c, d). Pelagic longlining and trawling were selected because they are major Commonwealth fishing methods and the only fishing effort datasets with extensive and recent spatial data. By using petroleum prospectivity we assumed that prospective areas are likely to be drilled. To strengthen the validity of this assumption we focused on 'medium – high' and 'high' prospectivity areas. When quantifying the overlap between broad zones and Commonwealth fishing effort for each iteration of the MPA system, we used the entire span of effort data (2011 to 2014). We supplemented our assessment of iterations and threats to biodiversity by analysing the biomass of fish catch per unit area (kg/km^2) in each planning region and by each broad zone in the ten years preceding each iteration. Further, using data from Larcombe and Marton (2018) and Mobsby (2018), we compared estimations of annual forgone fisheries catch and gross value of production for each iteration, with the reported Commonwealth fisheries catch and gross value of production of the year preceding each MPA system iteration. Details of datasets and spatial layers are in Appendix Table 1.

3. Results

3.1. Changes in zoning

From 2012 to 2018, the zoning composition of the MPA system changed substantially (Fig. 2). The 2012 MPA system had the largest percentage area covered by highly protected zones (I – II) (36.9%), but also by Multi-Use Zones (VI) (38.9%), wherein intensive seafloor extraction (trawling and petroleum) are generally allowed. In 2015, coverage of Habitat Protection Zones (IV) increased considerably from 24.2% to 40.8%. This was caused by a small portion of highly protected zones (7.6%) being downgraded and over a third of Multi-Use Zones being upgraded. Combined protection of ecosystems (I – II) and seafloor habitats (IV) was highest in 2015 (74.9%), when Multi-Use Zones were at their minimum (25.1%). In 2018, over a third of highly protected zones were downgraded to Habitat Protection Zones and Multi-Use Zones.

Thus, in 2018, Habitat Protection Zones had their greatest cover (45.7%) at the cost of highly protected zones. Between 2015 and 2018, Multi-Use Zones increased in cover from 25.1% to 31.9%, owing to downgrades from both highly protected zones and Habitat Protection Zones.

The MPA system review and management documents for the Coral Sea Marine Park show substantial zoning changes over time (Bioregional Advisory Panel 2015; Director of National Parks 2018). Highly protected zones (I – II) halved in cover, from 50.8% of the marine park in 2012, to 41.5% in 2015, and 24.1% in 2018. Conversely, Habitat Protection Zones (IV) more than doubled in cover from 29.2% in 2012, to 55.2% in 2015, to 69.2% in 2018. This broad increase corresponded to a decrease in special types of IV zones that add further fishing regulations, e.g. Habitat Protection Zone (Reefs)/(Coral Sea), such as protection against pelagic longlining. These zones greatly decreased in cover from 20.5% in 2012, to 2.8% in 2015, to 3.0% in 2018, thereby allowing longlining over much larger areas. Multi-Use Zones (VI) had 20.1% cover of the marine park in 2012, lowering to 3.3% in 2015, then increasing to 6.7% in 2018.

3.2. Meeting the representation goals of the MPA system

Goal 1: Represent each provincial bioregion – Parts of all provincial bioregions were covered by MPAs in all three iterations, achieving the first stated goal (Appendix Fig. 2). In each iteration, coverage of bioregions by any broad zone varied from 0.4% to 98.4%, the median being 26.8%. Nevertheless, high protection levels of bioregions were generally lacking. Median coverage of bioregions by highly protected zones (I – II) decreased from 3.7% in 2012, to 3.2% in 2015, and 1.8% in 2018 (Fig. 3A). All iterations left between four and five bioregions without highly protected zones. The decrease in coverage of bioregions by highly protected zones paralleled an increase by Habitat Protection Zones (IV) (Fig. 3A). Multi-Use Zones (VI) dominated bioregion cover in all iterations, although median cover fluctuated (Fig. 3A). Multi-Use Zones had the highest protection equality in all iterations, followed by highly protected zones, then Habitat Protection Zones (Fig. 3C).

Goal 2: Cover the entire depth range - All iterations of the MPA system covered the entire depth range within each planning region, achieving the second stated goal, but with a strong bias of higher protection toward remote, deeper waters (Fig. 4). The 2012 MPA system designated the most extensive highly protected zones, but these were poorly representative of depths < 500 m. The 2015 iteration represented the largest percentage of depths < 500 m in highly protected zones, despite allocating less overall high protection than in 2012. Bias in coverage of Multi-Use Zones (VI) was the opposite of that by highly protected zones. Depths < 500 m had between 20.1% and 22.8% cover by Multi-Use Zones among iterations, with coverage of deeper waters ranging from 7.2% to 14.3% (Appendix Fig. 3). Across iterations, depths ≥ 500 m had at least 3.5 times more cover in highly protected zones (I – II) (2018) than shallower depths, with seven times greater highly protected cover in 2012. Protection equality of depth classes was similar among iterations (65.2 – 78.3%) (Appendix Table 2).

Goals 3 and 4: Include examples of benthic and demersal biological features, and all types of seafloor features – Each iteration of the MPA system included parts of all seafloor features and examples of demersal and benthic biological features (i.e. key ecological features), reaching goals three and four. Coverage of key ecological features by MPAs of any broad zone ranged from 2.3% to 100%, with a median of 59.0% for each iteration (Appendix Fig. 4). Because only 'examples of' demersal and benthic biological features were required, as opposed to representation of all such features, seven out of the 29 key ecological features that were demersal or benthic biological features were not included in any iteration of the MPA system. It should be noted that two of these features were in the South-east planning region, where key ecological features were defined after an MPA system was implemented there, thus eliminating the opportunity for deterministic protection by the MPA system planners. Across iterations, between 12 and 13 out of 50 key ecological features had no coverage in highly protected zones (I – II). Of those included, median cover by highly protected zones was very low, with that of Multi-Use Zones (VI) an order of magnitude higher (Fig. 3B). Multi-Use Zones had the most equal cover of key ecological features, followed by highly protected zones and Habitat Protection Zones (Fig. 3D).

3.3. Broad zones in relation to potential threats to marine biodiversity

There was negligible overlap between Commonwealth managed commercial fishing area (2011 - 2014) and highly protected zones (I – II) in the three iterations of the. For pelagic longlining, the overlap ranged from 0.2% to 0.4%. In the Coral Sea Marine Park, zones permitting pelagic fishing (IV and VI) were designated in areas of pelagic longlining (2012, 2018: Fig. 5; 2015: Appendix Fig. 5). A minority of IV zones termed Habitat Protection Zones (Reefs)/(Coral Sea) and Conservation Park Zones do not permit pelagic fishing (Director of National Parks 2018). In the Temperate East planning region, MPAs mostly avoided pelagic longlining (2012, 2018: Fig. 5; 2015: Appendix Fig. 5). Similarly, Commonwealth trawling areas (2011 – 2014) had little overlap with any iteration of the MPA system (Appendix Table 3). Between 0.1% (2015, 2018) and 0.3% (2012) of trawling areas were protected by zones that prohibit trawling (I – II and IV), with 98.5% of trawling area left unprotected.

Highly protected zones (I – II) were characterised by low previous fishing yield (Fig. 6). Summed fish catch (kg/km^2) for the 10 years preceding each iteration showed that between 60% (2018) and 80% (2012, 2015) of highly protected zones were designated in areas of lower catch compared to Habitat Protection Zones (IV) and Multi-Use Zones (VI). Highly protected zones were, over time, increasingly placed in areas characterised by lower preceding fish catch in the North-west, Coral Sea, and Temperate East (e.g. Temperate East 2012: 6.3 kg/km^2; 2015: 3.8 kg/km^2; 2018: 1.1 kg/km^2). In contrast, between 60% (2015) and 80% (2012, 2018) of Multi-Use Zones had the highest preceding catch relative to other broad zones. Apart from the Coral Sea, where the entire planning region was placed in MPAs, areas with the highest fish catch preceding MPA designation were left unprotected. These unprotected areas had catch ranging from nine to 100 times greater than that of highly protected zones within the same planning regions. For instance, in the South-west, summed catch was 1.9 kg per km^2 in areas that were proclaimed as highly protected zones in 2012. Areas of the South-west that remained unprotected in the 2012 iteration, had 122.3 kg per km^2 summed catch.

All iterations of the MPA system resulted in negligible forgone fisheries catch and value (Fig. 7). The 2012 MPA system was estimated to annually forgo 2.4% of 2011–12 Commonwealth fisheries catch and 2.7% of 2011–12 Commonwealth fisheries gross value of production. The 2015 iteration lowered these values to 1.4% of 2014–15 catch and 1.3% of 2014–15 gross value of production. In 2018, these values again decreased to 1.1% of 2016–17 catch and 1.0% of 2016–17 gross value of production (most recent Commonwealth fisheries data).

Each MPA system iteration covered a small percentage of areas that were promising for petroleum extraction in 2008, measured by 'petroleum prospectivity' (Geoscience Australia 2008a, b, c, d). In the North and North-west planning regions, where most offshore petroleum extraction occurs, zones that exclude petroleum extraction (I – II and IV) covered around 0.3% of 'high' and 'medium–high' prospectivity across all iterations (2012, 2015: Appendix Fig. 6; 2018: Fig. 8). Nationally, around 4.5% of 'high' and 'medium–high' prospectivity were protected from petroleum extraction. Most of that protection was in a Habitat Protection Zone (IV) in the Coral Sea Marine Park covering the Townsville Basin, a 'medium–high' prospectivity area.

4. Discussion

After two decades of policy development and planning, Australia's first national MPA system was implemented in Commonwealth waters in 2018, following its proclamation in 2012 and revision in 2015. Protection levels of the 2018 MPA system were downgraded when compared to both the 2012 and 2015 iterations. This was evidenced by the substantial loss of highly protected zones (I – II) in 2018, replaced either by zones protecting only seafloor habitats, i.e. Habitat Protection Zones (IV), or zones offering little biodiversity protection, i.e. Multi-Use Zones (VI). Despite these changes, all the MPA system iterations met their qualitative representation goals. Unevenness and bias were evident in meeting these goals in all iterations, particularly towards higher coverage of biophysical features by the least protective Multi-Use Zones and lower coverage by highly protected zones. All iterations of the made negligible, and progressively smaller, reductions in the exposure of marine biodiversity to threats posed by commercial fishing and petroleum extraction.

4.1. Achievement of representation goals

The goals for representation of biophysical features were met by each MPA system iteration. This might seem surprising given the substantial variation in representation among individual bioregions and key ecological features, ranging from none to total. Only Multi-Use Zones (VI), in which intensive extraction via trawling and petroleum extraction are generally permitted, had comparable protection equality to the global median in 2011 (Barr et al. 2011)**.** Bioregions, depths < 500 m, and key ecological features were mostly covered by Multi-Use Zones, exposing them to the potential threats of intensive extraction. In contrast, those features had low coverage by highly protected zones (I – II), and a few bioregions and key ecological features had no high protection, compounding the poor protection offered by Multi-Use Zones.

All iterations designated a large portion of high protection in remote waters deeper than 500 m. This pattern was identified previously in the 2012 MPA system (Devillers et al. 2015) and the South-east region of the MPA system (Williams et al. 2009), indicating that Australia is following the global tendency towards marine protection in remote waters that are exposed to minimal human pressures (Jones & De Santo 2016; Stevenson et al. 2019). Australian State MPAs do not compensate for this pattern within their jurisdictions. In 2018, State MPAs covered 10.3% of Australia's continental shelf, compared to Commonwealth MPAs that covered 29.0% (of which 11.1% is in the Great Barrier Reef Marine Park). Additionally, State MPAs have, and will likely continue to face, similar issues in terms of downgrading planned or actual protection levels (Booth and Turnbull 2018) (South Australian MPAs under review at time of writing), increasing the need for Commonwealth MPAs to provide high levels of protection in shallow waters.

The low, and in a few cases complete lack of, protection (especially high protection) and clear biases in representation of biophysical features were facilitated by the wording of the representation goals. There were three notable aspects of this wording. First, all goals were qualitative, lacking any quantitative minimum amounts of features to be represented. In contrast, quantitative representation goals for the Great Barrier Reef Representative Areas Program (Fernandes et al. 2005) explicitly required at least 20% coverage of each bioregion in highly protected zones. This limited the capacity for biased designation of reserves, although not preventing it entirely (Grech and Coles 2011), and represented features that were unknown at the time of rezoning (Bridge et al. 2016), clearly showing the value of a transparent process when planning MPAs and using quantitative goals. The lack of explicit, quantitative goals in the MPA system contradicts a basic requirement of systematic conservation planning for both representation and adequacy of protection (Margules and Pressey 2000).

The second aspect of the wording of representation goals was the term 'examples of' demersal and benthic biological features, bypassing the need to cover parts of all of these features and allowing zero coverage of some.

The third aspect of wording was the failure to address coverage of features by a broad range of zones, which should ideally specify more highly protected zones for features more exposed and/or sensitive to extractive uses (Mills et al. 2011; Pressey et al. 2007). The use of low protection MPAs to represent features has been termed 'cryptic under-representation' (Avery 2003) and creates an overestimation of protection in the public eye (Roberts et al. 2020), potentially undermining trust in future MPA planning (Agardy et al. 2011). Cryptic under-representation is exacerbated within the MPA system because of Australia's misinterpretation and misapplication of IUCN zoning guidelines to MPAs (Fitzsimons 2011). Zone types IV and VI confer notably less protection than presented in the latest IUCN guidelines, which stipulate no industrial fishing or mining in either (Day et al. 2019).

Combined, these three aspects of the MPA system goals conferred considerable political expediency in all iterations while implying that biophysical features can be adequately protected by very small percentages under high protection. Such an implication requires careful justification based on the best available evidence, although this was notably lacking in all iterations of the MPA system (and see 4.3 below).

4.2. Mitigation of threats to biodiversity

The 2012 MPA system largely avoided threats from fishing (Devillers et al. 2015), with the 2015 and 2018 iterations further increasing avoidance. The clearest example of threat avoidance was the Coral Sea Marine Park, containing the five most represented bioregions, along with the second and sixth most represented key ecological features. Despite these accomplishments, in all iterations, this marine park avoided protecting areas potentially threatened by Commonwealth pelagic longlining. The substantial zoning changes to this marine park made little apparent difference to threat avoidance, even though half the area of highly protected zones was downgraded between 2012 and 2018, thereby opening more area to pelagic longlining. The 2012 Coral Sea Marine Reserve, covering 1.3 million km^2, contributed minimally to reducing overfishing of overfished tuna species and bycatch of protected species (Hunt 2013). Several protected species are threatened by longlining, including elasmobranchs, cetaceans, and seabirds (AFMA 2012; Barry Baker and Wise 2005), with the threat to the latter under-estimated by under-reporting (Brothers et al. 2010). It is not apparent that any MPA system iteration has mitigated threats to these vulnerable taxa, for example by closing areas with high fishing bycatch. It is worth noting that the Coral Sea is the only marginal tropical sea where human impacts are, in a global context, low (Ceccarelli et al. 2013). Thus, there is high value in protecting some unfished, lower impact areas here. Nevertheless, this does not justify complete avoidance of areas potentially threatened by current fishing. There are arguments against the use of MPAs for protection of pelagic, mobile species (e.g. Hilborn et al. 2004), but also arguments for their utility (Game et al. 2010). Alpine and Hobday (2007) demonstrated that only 13% of the pelagic area in eastern Australia waters would be necessary to protect 20% of the annual distribution of 40 important pelagic species and major physical processes. Furthermore, spatial protection can be dynamic in time and space by tracking abiotic and biotic factors, which can be more appropriate for pelagic species (Welch et al. 2020). Although these studies did not directly measure threat reduction to pelagic biodiversity, they support the concept that MPAs can be used, where appropriate, to protect pelagic, mobile species.

Trawling can have substantial impacts on benthic communities and habitats (Hiddink et al. 2017; Pusceddu et al. 2014; Rijnsdorp et al. 2015; Schratzberger and Jennings 2002; Simon et al. 2001). Nonetheless, successive iterations of the MPA system did very little to reduce these impacts, despite reaching their representation goals. Trawling has resulted in habitat degradation in Australia (Althaus et al. 2009; Svane et al. 2009), with recovery time-frames beyond ten years in sensitive habitats (Williams et al. 2010). A 2007 ecological risk assessment of the Northern Prawn Fishery found, conservatively, over 40% of habitats to be at medium risk from prawn trawling, including corals, sponges, and seagrasses (Griffiths et al. 2007). A subsequent report found almost 30% of habitats assessed to be at high risk of impacts from otter board trawling in the Commonwealth trawl sector (Corrie 2015). Aside from habitat damage, trawling is characterised by high biomass and species richness of bycatch, even in well managed Australian fisheries (Griffiths et al. 2007). Bycatch species with long generation times, such as sharks, are at particular risk of decline by trawling (Foster et al. 2015; Savina et al. 2013). Bycatch risk assessments are undertaken in relatively data-rich fisheries, such as the Northern Prawn Fishery, which have revealed bycatch of several at-risk protected species including elasmobranchs (AFMA 2008; Zhou 2011; Zhou et al. 2007), but also regions of lower impact to bycatch (Zhou et al. 2015). Nevertheless, many Australian trawl fisheries lack robust data concerning bycatch species abundances. Without such data, it is precautionary to assume that trawling is a threat to many potential bycatch species.

A small amount of area promising for offshore petroleum extraction in 2008 was protected by each iteration of the MPA system. Most of this area was in the Townsville Basin within the Coral Sea Marine Park. However, petroleum operations have not been permitted there by any MPA system iteration (Bioregional Advisory Panel 2015; Director of National Parks 2013a, 2018). We did not find a clear reason behind this limitation on petroleum operations, although it is possibly an unofficial extension of the petroleum drilling moratorium established in the Great Barrier Reef region in 1970 (Kriwoken 1991). Off north-western Australia, where most offshore petroleum extraction occurs nationally, prospective areas have been largely avoided by the MPA system iterations. The prospectivity data were collected between four and ten years prior to iterations. However, our conclusions are supported by Devillers et al. (2015), who found that the 2012 iteration avoided high protection of offshore wells, acreage release, and petroleum titles. Offshore petroleum extraction, at a minimum, poses a short-term and localised threat to marine biodiversity, with the long-term, cumulative impacts unknown (Evans et al. 2016). In Australia, offshore drilling has caused declines in some benthic organisms and medium-term (>11 months) changes to benthic communities (Currie and Isaacs 2005). Fish communities can be harmed, with wastewater from drilling having adverse physiological impacts, such as elevated stress and damage to DNA (Gagnon 2011). Petroleum operations also have diffuse impacts from marine seismic exploration. Seismic activity can cause auditory damage, stress responses, avoidance behaviours in marine fauna several kilometres away (Gordon et al. 2003; McCauley et al. 2000; McCauley et al. 2003), and has been linked to mass stranding of marine mammals (Ketten 2012). There is much uncertainty about such impacts, however, exemplified by Miller and Cripps (2013) who found no effect of marine seismic surveys on fish abundance and diversity on Scott Reef, Australia. The weight of evidence indicates that offshore petroleum extraction can be threatening, at least locally, to marine faunal communities and habitats, with potential for more extensive diffuse impacts. By avoiding prospective petroleum areas, iterations have not protected the biodiversity of those areas from the potential threats of offshore extraction.

4.3. When can avoidance of fishing be justified?

Iterations of the MPA system were consistent in avoiding areas of extractive uses. This was evident, not only spatially, but in the designation of higher protection in areas of lower fishing catch and value, and vice versa. Such bias can be justified in two circumstances. First, an area of negligible fishing catch or value is established as an MPA to proactively protect it against foreseeable future fishing. Advancing fishing technology could allow previously inaccessible/unprofitable areas to become accessible and economically viable for fishing (Eigaard et al. 2014), thus justifying the use of MPAs to protect biodiversity from possible future fishing impacts. Nevertheless, because there are very few new fishing grounds being opened, this is highly unlikely to be occurring. Second, this would be applicable if the long-term ecosystem impacts of fishing were demonstrably sustainable, which is contradicted by the evidence. Considerable uncertainty surrounds the effectiveness of fisheries management in mitigating five broad types of impacts in Australian waters (Table 2).

Australian Commonwealth fisheries are generally claimed to be sustainable in terms of the target stocks (Patterson et al. 2018). Nevertheless, in 2017, over 25% of stocks were uncertain with regard to fishing mortality and/or biomass (Patterson et al. 2018), highlighting the need for more data. Further, the generality of the sustainability claims has been challenged recently by analysis of fishery-independent data, showing declining decadal trends for populations of fish species that are assessed as 'not overfished' (Edgar et al. 2018; Edgar et al. 2019). In fishery sustainability assessments, the risks of overfishing populations are often estimated based on conceptually simple surrogate measures, such as biomass of the fished species that generate maximum sustainable yield or maximum economic yield. However, the ecological risks of fishing are only weakly estimated by such measures, and by risk assessment procedures. As a result, fisheries management is not sufficiently precautionary with respect to the highly uncertain effects of a number of pressures on stocks, including declining extent and quality of inshore habitats important for spawning or recruitment of juveniles, changes in climate, or complex interactions between target species and their predators and prey (see trophic impacts, Table 2). Data on the extent and severity of such impacts and how they affect the fishery could, in principle, become available, and collection of such data is beginning. Examples include: the extent of coastal habitat types correlates with catch per unit effort of nearby fished species in Queensland (Meynecke et al. 2008); summer sea surface temperature correlates with density and catch of blacklip abalone (*Haliotis rubra*) in south-eastern Australia (Young et al. 2020); and aquatic vegetation and nutrient inputs likely affect biomass of blue crabs (*Callinectes sapidus*) in Chesapeake Bay, USA, and thus their availability to the crab fishery (Ma et al. 2010). However, increased collection and synthesis of such intensive data, and development of effective consequent management controls, are likely cost-prohibitive relative to the commercial value of the fishery products. Management decisions in fisheries are therefore often made with little recognition of the need for high precaution in such ecological matters, and reserves have been long recognised (Ward 2004) as an option for more efficient (lower cost) and effective (achieving specific population management targets) than use of weakly estimated fishery targets as surrogates for achievement of ecological outcomes (Edgar et al. 2018; Edgar et al. 2019).

Recent assessments have found many byproduct (minor commercial species) and bycatch (non-commercial discards) species to be at high risk of impacts from Commonwealth fisheries (AFMA 2012; Corrie 2015; Griffiths et al. 2007; Wayte et al. 2007a; Wayte et al. 2007b). This includes protected species (Allen et al. 2014) with spatial management recommended in some instances, for example to mitigate the sub-population extinction risk to Australian sea lions (Goldsworthy and Page 2007). High-level MPAs (I – II) protect faunal communities against the impacts of bycatch and, in some cases, can benefit fisheries that involve bycatch of sensitive species (Hastings et al. 2017). With risk and/or uncertainty to byproduct and bycatch species, such MPAs have an important protective role, together with the development of regular bycatch risk assessments and minimum limits for estimated bycatch species abundances.

The impacts of Commonwealth fishing on habitats and ecological assemblages remain uncertain in many instances and lack specific fisheries policy (AFMA 2017). Notably, recent ecological risk assessments have found many habitats to be at high risk of degradation from Commonwealth fishing, particularly trawling, although the risks to ecological assemblages usually remain unidentified and unquantified (Griffiths et al. 2007; Wayte et al. 2007a; Wayte et al. 2007b). Considering these risks, it is difficult to justify the avoidance by MPA system iterations of Commonwealth trawling areas. It is commendable that ecological risk assessments are being applied to Commonwealth fisheries, but full assessment of the multiple risks of fishing impacts on habitats and assemblages is necessary, followed by subsequent integration of protection measures into fisheries management. MPAs are an appropriate tool for protecting and promoting recovery of habitats and assemblages (Friedlander et al. 2003; Mellin et al. 2016; Russell et al. 1999) and can be combined with improvement of ecological risk assessment tools and specific fisheries policy.

The cumulative risks of fisheries, i.e. the combined impacts of adjacent or overlapping fisheries and other system-level pressures on the same stocks or ecosystems, need to be quantified to achieve fishing sustainability. Cumulative impacts are mentioned only qualitatively in ecological risk assessments (e.g. AFMA 2012; Wayte et al. 2007a; Wayte et al. 2007b). Cumulative fishing impacts can be substantial. They are a risk to short-beaked common dolphins in southern Australia (Bilgmann et al. 2014) and difficult to predict (Kaplan et al. 2013), especially because catch data from non-Commonwealth fisheries are often unavailable (AFMA 2017). Quantifying cumulative impacts is a stated future direction for Commonwealth fisheries (AFMA 2017) and we encourage movement in this direction. Furthermore, cumulative impacts of fishing and other major anthropogenic stressors on fish populations, such as climate change, habitat degradation, invasive species, and pollution, must be accounted for to achieve ecological sustainability of fishing. Provided that spatial zoning can be used to manage cumulative impacts (Halpern et al. 2008), it would be prudent to implement MPAs in overlapping areas of fisheries and other stressors.

In light of these considerable risks and uncertainties, the burden of proof for adequate management of marine biodiversity lies with those who argue that highly protected marine reserves are unnecessary and with those who relegate such highly protected areas to residual places where fishing has been absent or at a low level. Clearly, there is a need for highly protected marine reserves in some of the areas that are now fished. Although this will result in some degree of displacement of fishing effort to other areas (Stevenson et al. 2013), the current threats and uncertainties likely outweigh those posed by near-future fishing displacement, especially if fishery managers account for displacement in determining fishing regulations and harvest controls. Such reserves will assist both fisheries and biodiversity conservation with greater certainty than the low-precaution present-day management structures outside reserves.

5. Conclusion

Our analysis demonstrates that representation goals can be achieved without mitigating threats to marine biodiversity from extractive uses. Despite differences in zoning, all the MPA system iterations achieved qualitative goals for representing biophysical features and, more importantly, were consistent in avoiding areas of extractive uses. This avoidance can only be justified where robust, long-term evidence of sustainable extraction exists. Although Commonwealth fisheries have made commendable progress in building this evidence, large uncertainties remain about the sustainability of fishing on targeted, byproduct, and bycatch species. Moreover, ecological risk assessments have shown that many habitats and bycatch species are at medium or high risk of impacts from fishing. Notably, assemblage-level and cumulative impacts are currently unquantified and remain major uncertainties to be managed in fisheries. We encourage the acceleration of progress towards ecological sustainability by managers of fisheries, coastal ecosystems, and marine parks. However, with the inherent uncertainties and risks outlined, avoidance of designating highly protected MPAs in areas potentially threatened by fishing cannot be justified. This avoidance was facilitated in the MPA system by using qualitative representation goals, highlighting the problems with: (a) not using quantitative goals with minimum requirements for representation; and (b) the lack of focus on reducing threats to biodiversity in all the MPA system iterations by failing to appropriately apply precaution. MPAs are primarily intended to protect biodiversity from the threats posed by extractive uses but, in Australia's Commonwealth MPA system, have clearly not been implemented for that purpose. MPA planners, in Australia and globally, must frame their goals in a manner that explicitly and quantifiably provide for effective mitigation of the range of threats to biodiversity.

In-text figure and table captions

Figure 1. Australia's 2018 National Representative System of MPAs (NRSMPA), showing broad zones based on International Union for Conservation of Nature categories (Table 1). In Australia, marine jurisdiction is divided among the states, the Northern Territory, and the Commonwealth. Commonwealth waters generally extend from three nautical miles to 200 nautical miles offshore, reaching the boundary of Australia's exclusive economic zone. The NRSMPA is a Commonwealth MPA system that also includes State and Territory waters; here we analyse the Commonwealth component that has been the subject of major revisions and comprises the vast majority of Australia's MPA estate. **2 columns.**

Table 1. International Union for Conservation of Nature categories, their definition (Parks Australia 2018) and grouping within broad zones used in this paper. **2 columns.**

Figure 2. Percentages of the 2012, 2015 and 2018 iterations of the National Representative System of MPAs covered by the three broad zones in Table 1. Coloured flows between iterations indicate exchanges of areas between broad zones. **2 columns.**

Figure 3. Representation of biophysical features over time. Median percentage cover of **A.** provincial bioregions, and **B.** key ecological features by each broad zone (*green:* I – II; *yellow:* IV; *blue:* VI). Protection equality by broad zones among **C.** provincial bioregions, and **D.** key ecological features. Protection equality ranges from zero to 100, with zero indicating all protection focused on one feature and 100 indicating equal protection across all features. **2 columns.**

Figure 4. Depth distribution of highly protected zones (I - II) in the 2012, 2015, and 2018 iterations of the National Representative System of MPAs. **1.5 columns.**

Figure 5. Overlap of Commonwealth pelagic longlining effort hours (2011 - 2014) with broad zones in the Coral Sea Marine Park and Temperate East planning region **A.** proclaimed 2012 National Representative System of MPAs, and **B**. implemented 2018 National Representative System of MPAs. **2 columns.**

Figure 6. Recent Commonwealth fish catch in each planning region for the **A.** 2012 **B.** 2015 and **C.** 2018 iterations of the National Representative System of MPAs. In each planning region, MPAs are defined by broad zones or 'none' (where no MPAs were planned or established). Figures are summed fish catch per unit area (kg/km^2) for the ten years preceding each iteration. The South-east planning region was excluded because its MPAs were implemented in 2013 and did not change afterwards, unlike MPAs in the other planning regions. **2 columns.**

Figure 7. Forgone fisheries resulting from iterations of the National Representative System of MPAs (Larcombe and Marton 2018). Solid bars: Commonwealth fisheries catch (tonnes, 000s) and gross value of production (GVP) ($AUS, millions) for the year preceding each iteration (except for the 2018 iteration which used 2016 – 17 data, the most recent available) (Mobsby 2018). Hatched bars: **e**stimated annual forgone fisheries catch and forgone GVP. **1.5 or 2 columns.**

Figure 8. High and medium-high petroleum prospectivity areas (Geoscience Australia 2008b, c, d) and broad zones of the 2018 National Representative System of MPAs. The North-west and parts of the North and South-west planning regions are shown. **2 columns.**

Table 2. Documented impacts of fishing and associated uncertainties to be resolved, or otherwise treated with adequate levels of precaution, to achieve recognisable levels of ecological sustainability. **2 columns.**

Appendix figure and table captions

Figure 2. A. The 2012 and **B.** 2015 NRSMPA, categorised by broad zones. **2 columns.**

Table 1. Data set, source, type and resolution, and description. 'Measure' refers to what the dataset is a measure of. **2 columns.**

Table 2. Protection equality of broad zones within depth classes for each iteration of the NRSMPA. Protection equality ranges from zero to 100, where zero indicates that all protection focused on one feature, while a value of 100 indicates an equal protection among all features. **1 column.**

Figure 2. Percentage cover of provincial bioregions by broad zones in the **A.** 2012 **B.** 2015, and **C.** 2018 NRSMPA. Northeast Shelf Transition and Northern Shelf Province bioregions are substantially covered in the Great Barrier Reef Marine Park. **2 columns.**

Figure 3. Depth distribution of Multi-Use Zones (VI) among the 2012, 2015, and 2018 NRSMPA. **1.5 columns.**

Figure 4. Percentage cover of key ecological features (KEFs) by the **A.** 2012 **B.** 2015, and **C.** 2018 NRSMPA, categorised by broad zones. Note that some KEF names are cut-off. **2 columns.**

Table 3. Percentage overlap between Commonwealth trawling (2011 - 2014) and broad zones among all iterations of the NRSMPA. **1 or 1.5 columns.**

Figure 5. Overlap between Commonwealth pelagic longlining effort hours (2011 - 2014) with the Coral Sea Marine Park and Temperate East planning region as per the 2015 NRSMPA, categorised by broad zones. **2 columns.**

Figure 6. 'High' and 'Medium - high' petroleum prospectivity areas and the **A.** 2012 and **B.** 2015 NRSMPA, off north-western Australia. The NRSMPA is categorised by broad zones. **2 columns.**

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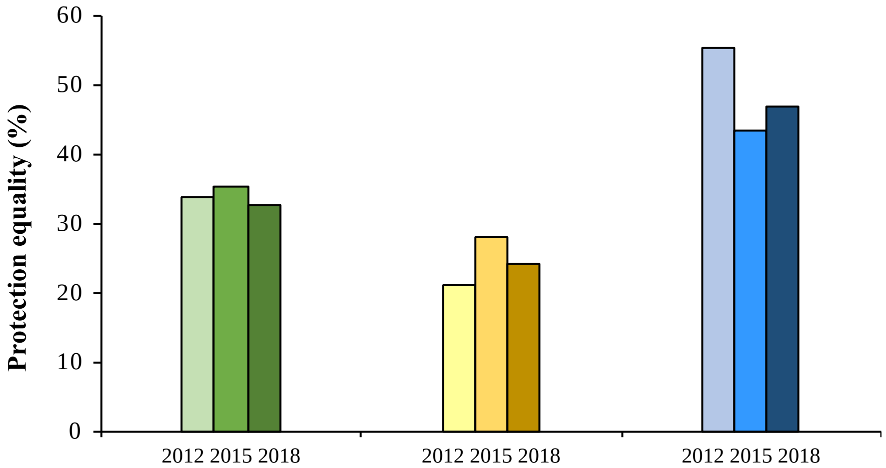
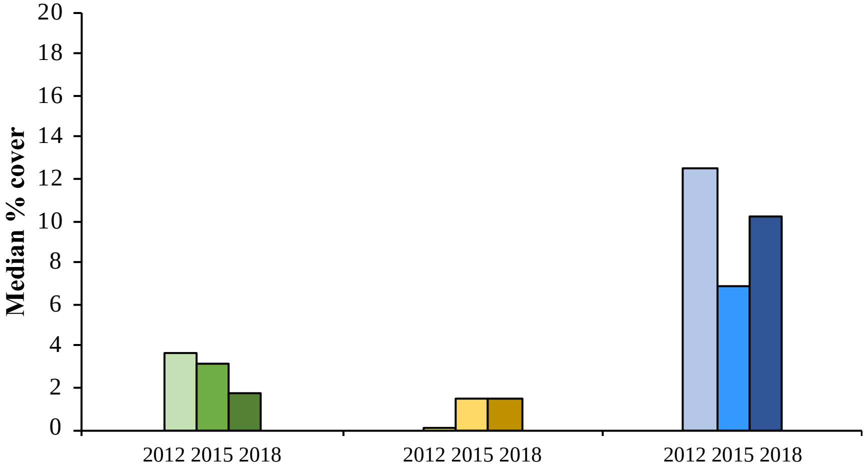
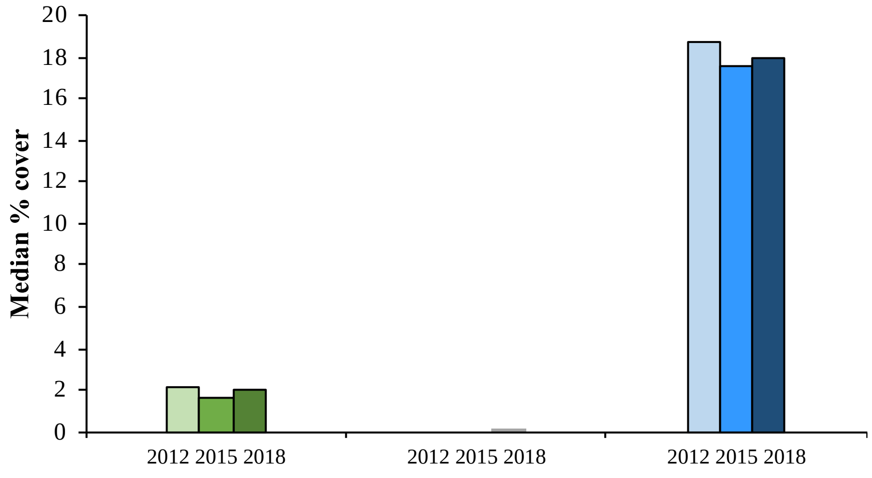
Dataset	Data source	Data type	Description	Measure
2012 NRSMPA	Department of the Environment and Energy (2014)	Vector	The proclaimed zoning for 2012 NRSMPA.	NA
2015 NRSMPA[1]	Bioregional Advisory Panel (2015)	Vector	The recommended changes of the Expert Scientific Panel and Bioregional Advisory Panel to the 2012 NRSMPA.	NA
2018 NRSMPA	Department of the Environment and Energy (2018)	Vector	Following changes by the Director of National Parks, the final NRSMPA that was implemented in 2018.	NA
Marine planning regions	Geoscience Australia (2012)	Vector	Spatial regions in which NRSMPA planning was broken down. These included: North, Coral Sea, Temperate East, South-east, South-west, and North-west.	NA
IMCRA Provincial Bioregions	IMCRA v4.0 (2006)	Vector	Spatial regions in which biophysical features are more similar relative to other regions, largely based on patterns of benthic fish diversity and the distribution of deep-water habitats. There are 41 in total (Commonwealth of Australia 2006); 38 being relevant to our analysis.	Representation (NRSMPA goal 1)
Key ecological features	Department of Sustainability, Environment, Water, Population and Communities (2015)	Vector	Components of a marine ecosystem that make a substantial regional contribution to biodiversity or ecosystem function and integrity. There are 50 in total.	Representation (NRSMPA goals 3 and 4)
Depth classes	Geoscience Australia (2009)	Raster (0.0025 degrees)	Australian Bathymetry and Topography Grid, June 2009.	Representation (NRSMPA goal 2)
Geomorphic units	Heap and Harris (2008)	Vector	Distribution of seafloor geomorphic features surrounding the Australian mainland and offshore territories. Spatial resolution of the bathymetry model was 250 m.	NA
Australian Commonwealth fisheries effort distribution 2011 - 2014	National Environmental Science Program Marine Biodiversity Hub (2016)	Raster (0.1 degree)	Commonwealth fishing effort hours were summaries of AFMA log book data on effort distribution from 2011 to 2014. Resolution was 0.1 degree where five or more vessels operated. Where less than five vessels operated, effort information is not disclosed, and resolution was 1 degree. Because of this, the effort distribution data used in the analysis was only where five or more vessels operated between 2011 and 2014.	Threat
Relative prospectivity of the East, North, North-west, and South-west planning regions	Geoscience Australia (2008 a, b, c, d)	Vector	Relative petroleum prospectivity is a measure of how promising an area is for petroleum extraction. Spatial data was not available for the South-east planning region. Note that the East planning region dataset includes the Coral Sea and Temperate East planning regions.	Threat

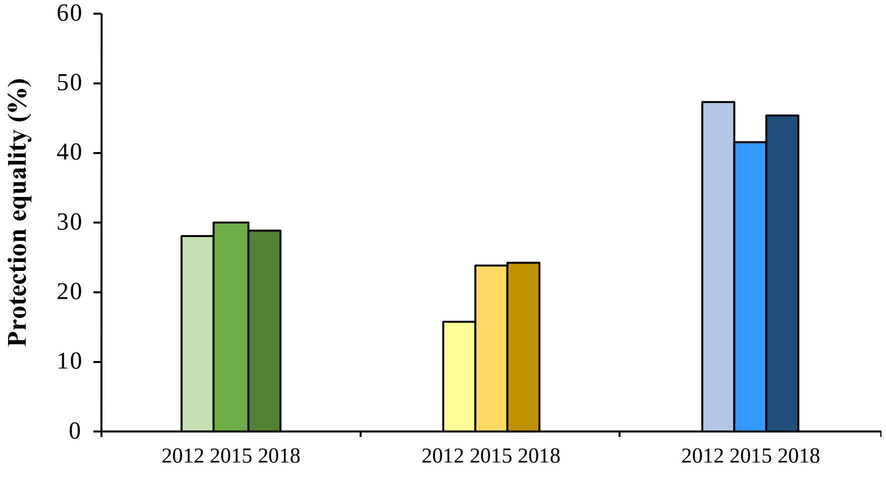
682 [1] South-east planning region not included. It was exported from another NRSMPA layer and then the 'Merge' tool was used to combine it with, and thus complete, the 2015 NRSMPA.

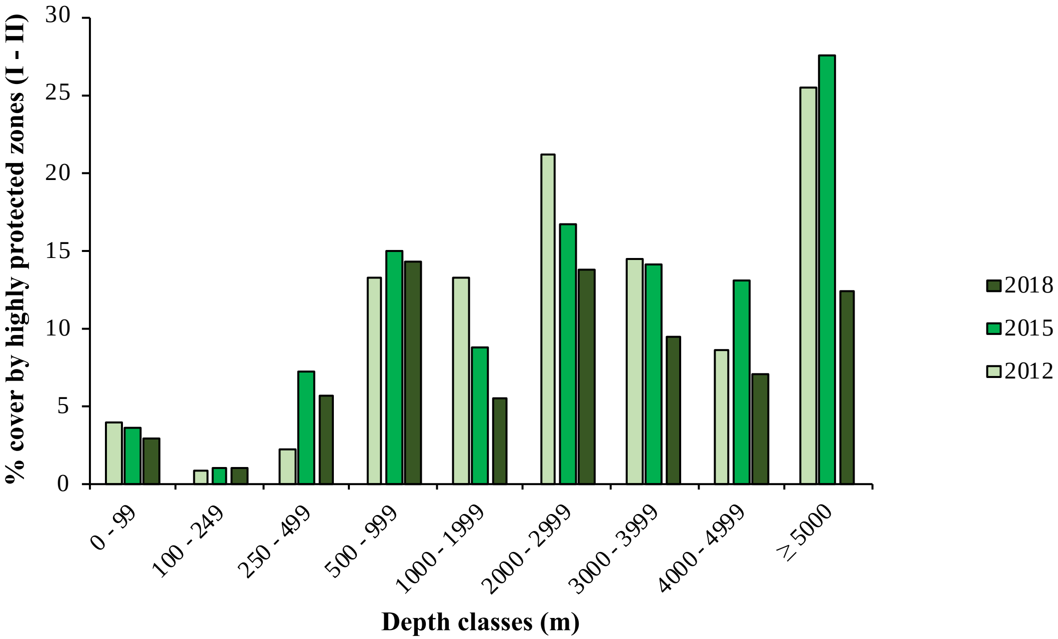
	I - II	IV	VI	No MPA
2012	0.26	0	1.26	98.48
2015	0	0.14	1.38	98.48
2018	0	0.14	1.38	98.48

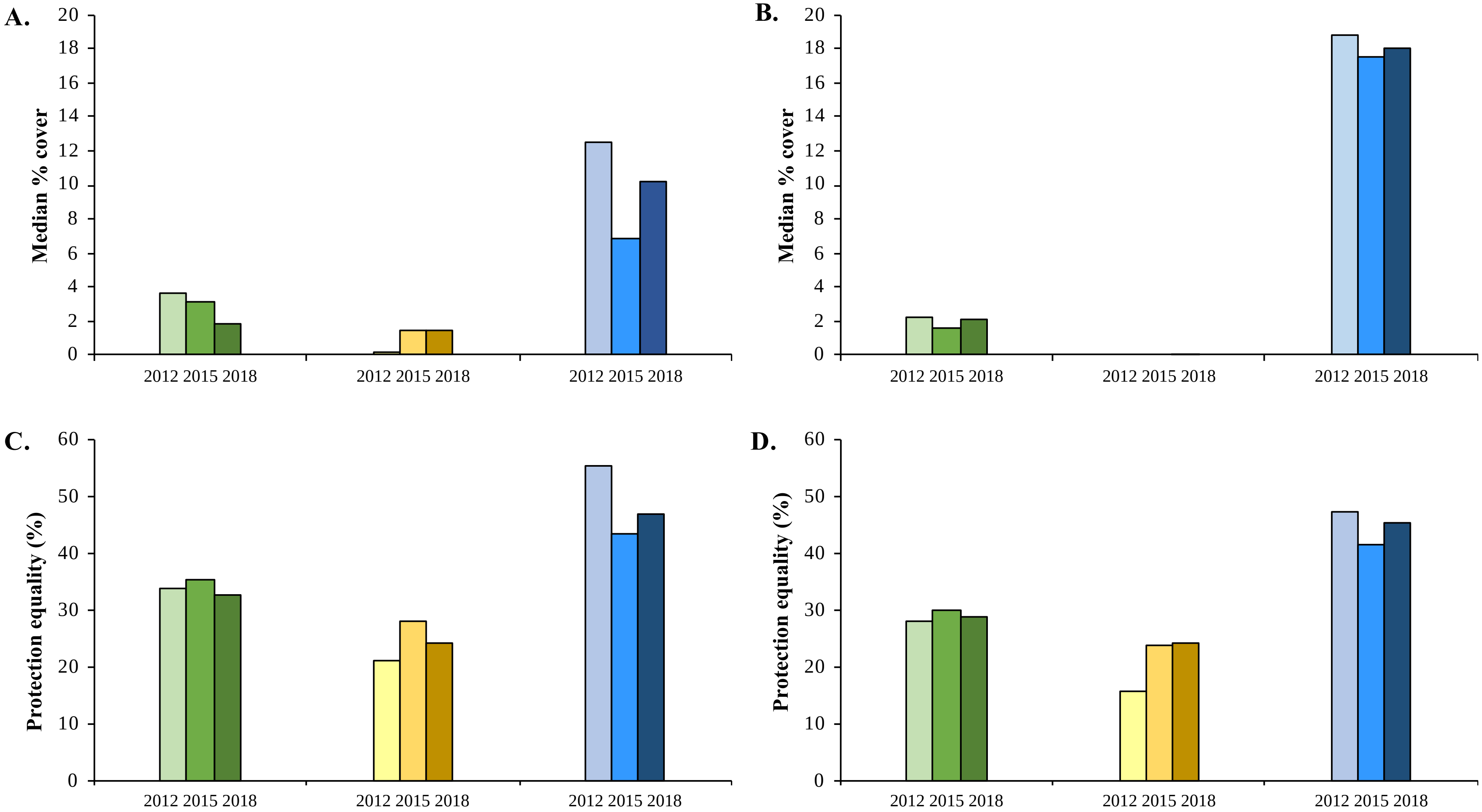



Median % cover
20
18
16
14
12
10
8
6
4
2
0
2012 2015 2018
2012 2015 2018
2012 2015 2018

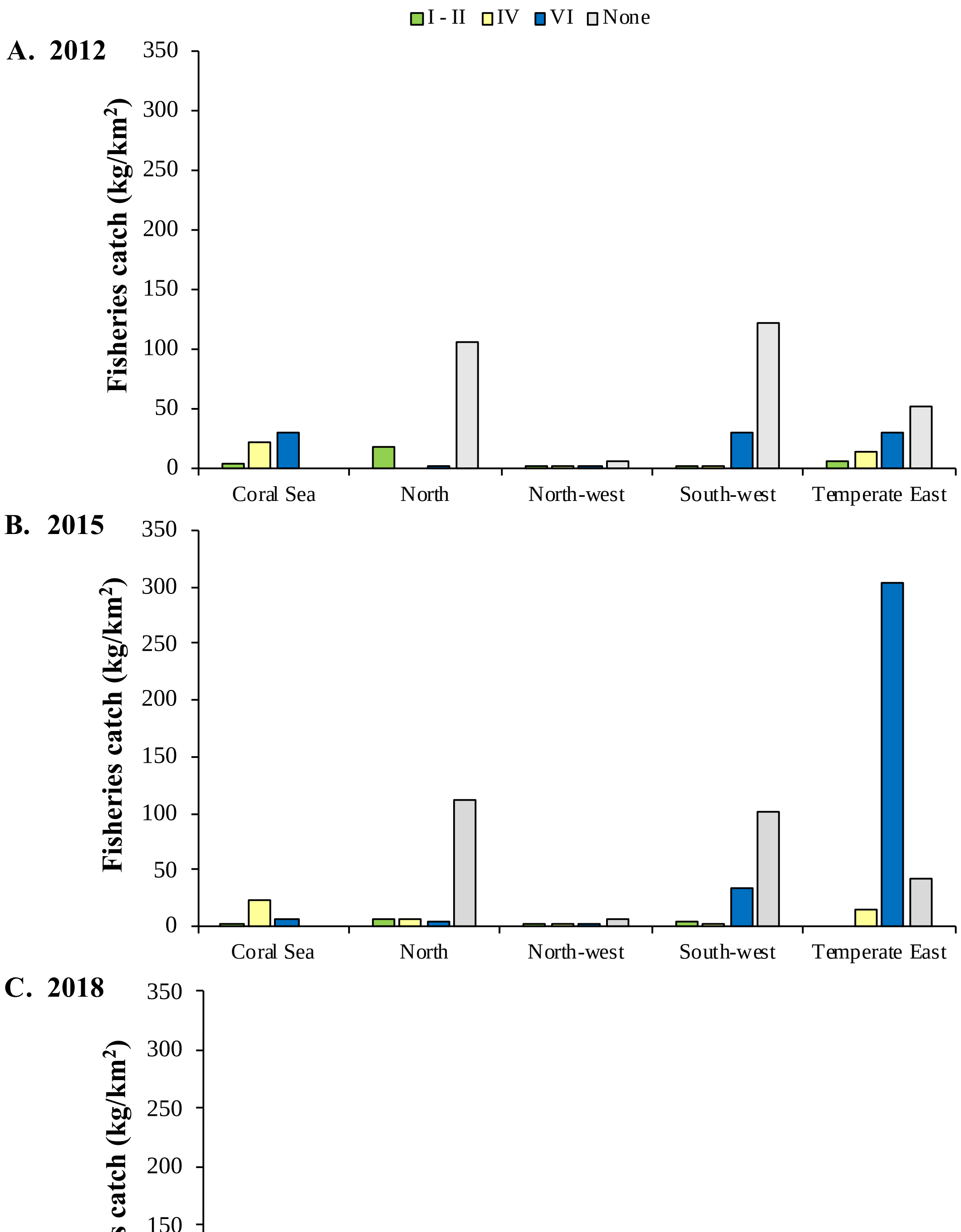

Median % cover
20
18
16
14
12
10
8
6
4
2
0
2012 2015 2018
2012 2015 2018
2012 2015 2018

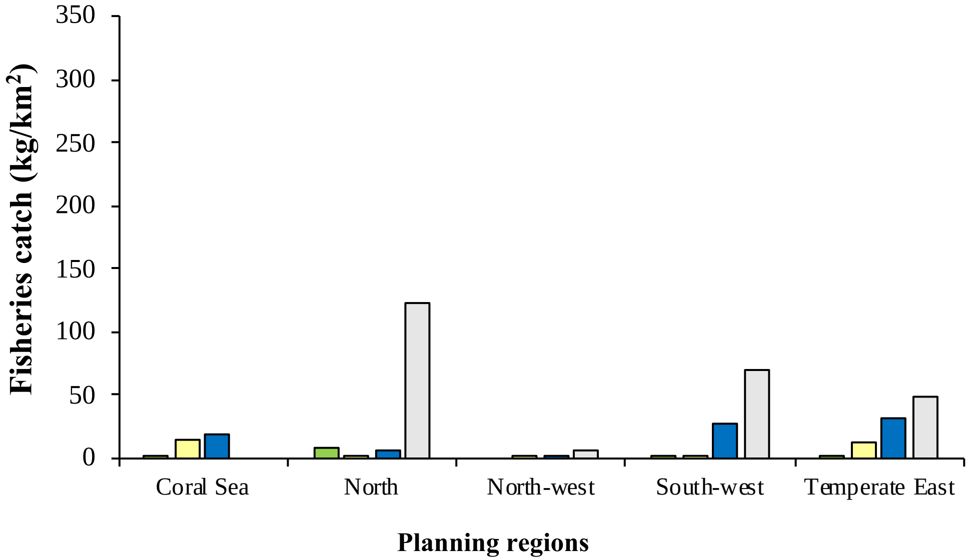

Protection equality (%)
60
50
40
30
20
10
0
2012 2015 2018
2012 2015 2018
2012 2015 2018

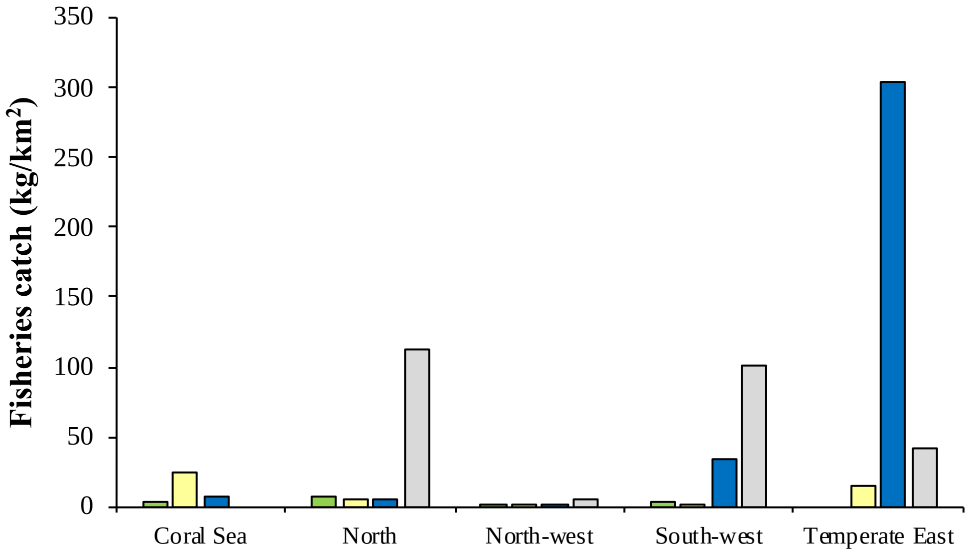

% cover by highly protected zones (I - II)
30
25
20
15
10
5
0
0 - 99
100 - 249
250 - 499
500 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
≥ 5000
Depth classes (m)
2018
2015
2012

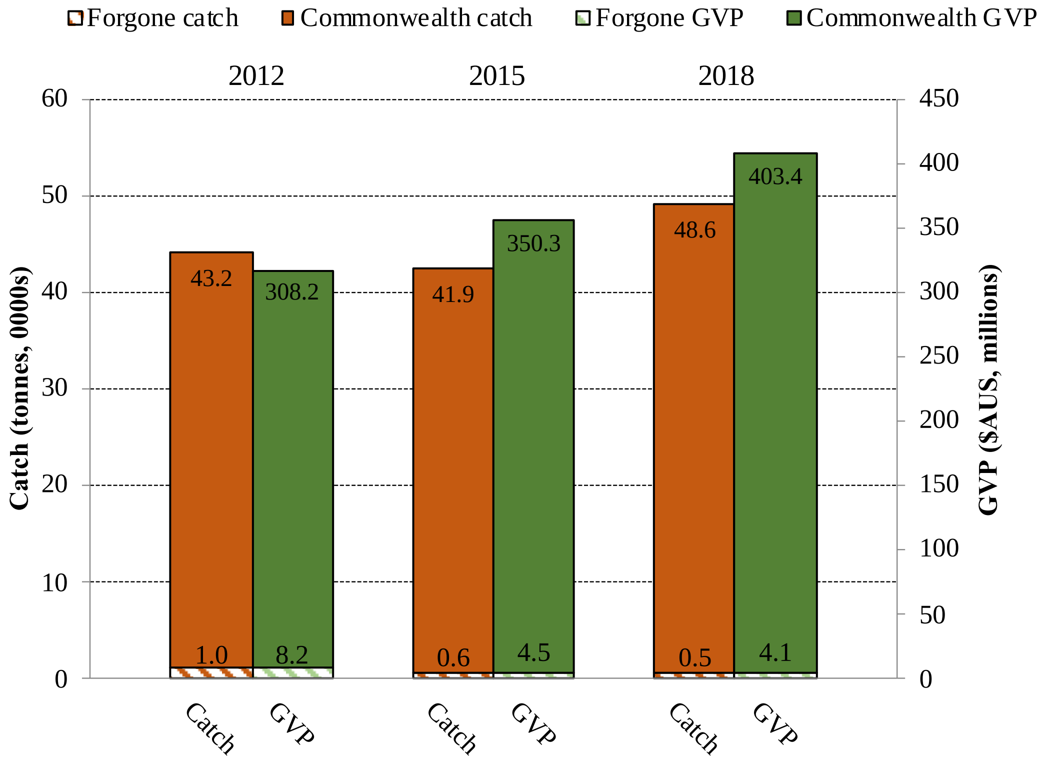

A.
B.
C.
D.
Median % cover
Protection equality (%)
0
2
4
6
8
10
12
14
16
18
20
30
40
50
60
2012 2015 2018

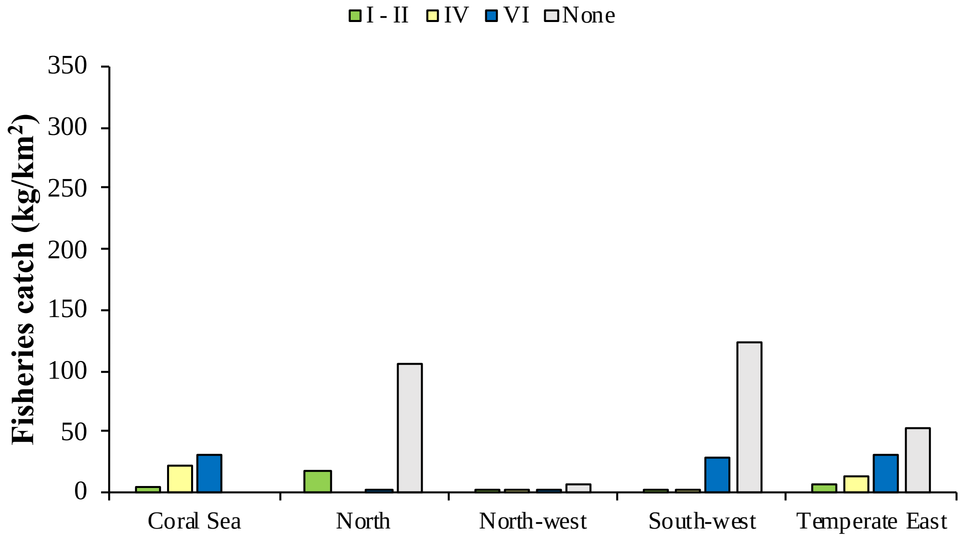
	I - II	IV	VI
2012	69.92	70.23	78.29
2015	65.77	65.20	70.52
2018	69.08	65.72	73.58


I - II
IV
VI
None
A. 2012
Fisheries catch (kg/km²)
350
300
250
200
150
100
50
0
Coral Sea
North
North-west
South-west
Temperate East
B. 2015
Fisheries catch (kg/km²)
350
300
250
200
150
100
50
0
Coral Sea
North
North-west
South-west
Temperate East
C. 2018
s catch (kg/km²)
350
300
250
200
150


Fisheries catch (kg/km2)
350
300
250
200
150
100
50
0
Coral Sea
North
North-west
South-west
Temperate East
Planning regions


Fisheries catch (kg/km^2)
350
300
250
200
150
100
50
0
Coral Sea
North
North-west
South-west
Temperate East

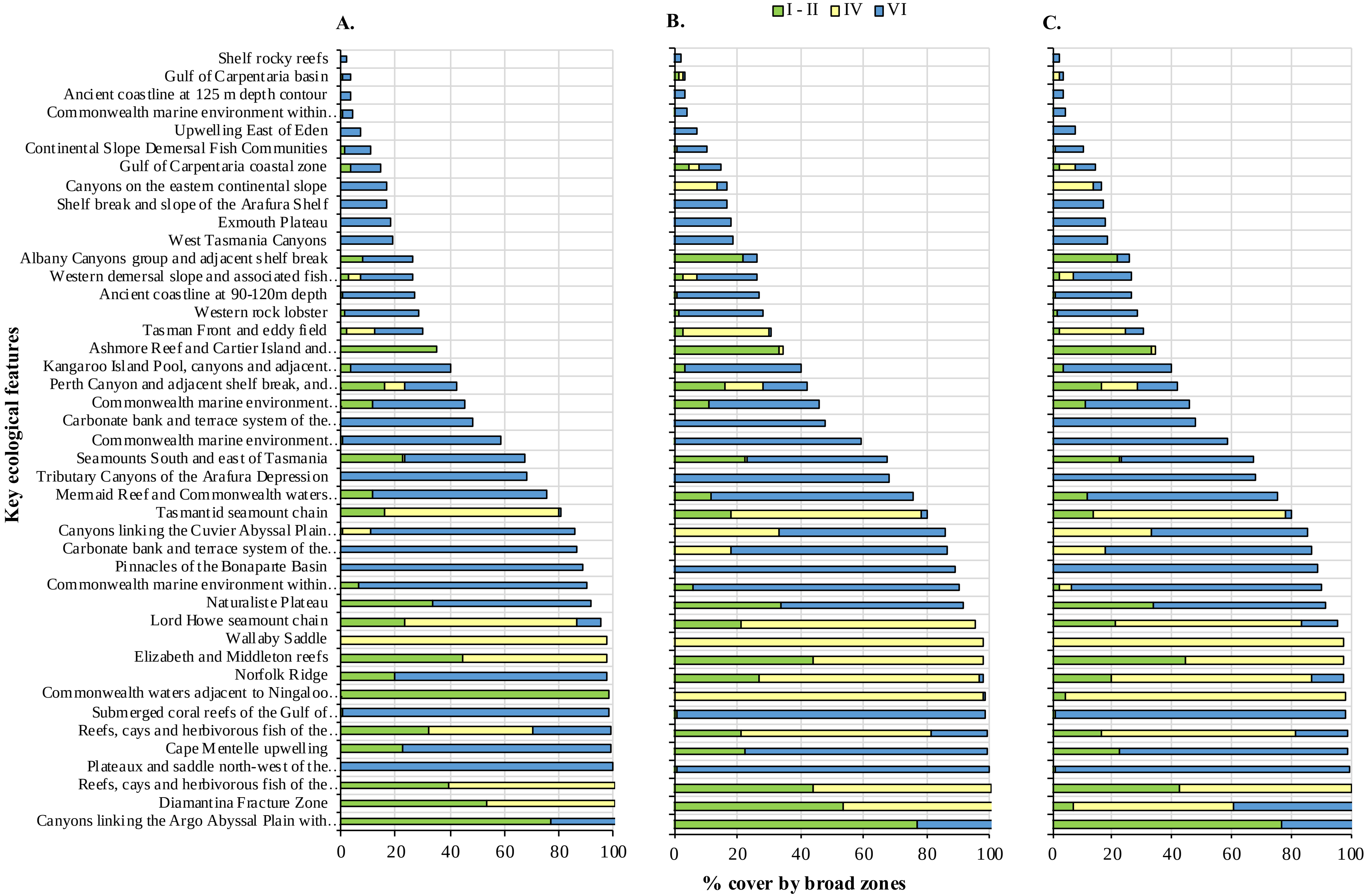

Forgone catch
Commonwealth catch
Forgone GVP
Commonwealth GVP
2012
2015
2018
Catch (tonnes, 0000s)
GVP ($AUS, millions)
60
50
40
30
20
10
0
450
400
350
300
250
200
150
100
50
0
43.2
308.2
41.9
350.3
48.6
403.4
1.0
8.2
0.6
4.5
0.5
4.1
Catch
GVP
Catch
GVP
Catch
GVP


I - II
IV
VI
None
Fisheries catch (kg/km^2)
350
300
250
200
150
100
50
0
Coral Sea
North
North-west
South-west
Temperate East

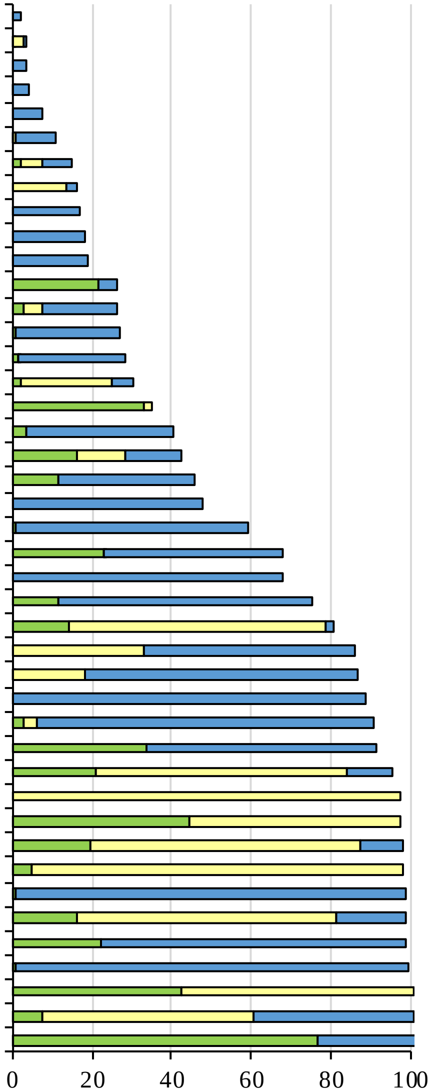
695

	Potential impacts of fishing	Management uncertainties
Target stocks	Depletion of target species abundance to levels that affect population structure, function, spatial distribution, and/or resilience (Edgar et al. 2018; Edgar et al. 2019; Hobday et al. 2007; Klaer 2001).	Management of target stocks should aim to maintain population sizes, structures, and distributions to a high level of assurance that populations will not be seriously depleted by fishing, or suffer reduced resilience to externalities such as climate-mediated shifts in productivity and ranges, pollution, loss of habitat quality or availability, or undocumented fishing. Given the scale of these complexities and uncertainties, only a widespread and highly precautionary approach to management, such as marine reserves, can achieve target stock sustainability.
Trophic impacts	Disruption amongst ecologically linked species (predators, prey) of distribution, population structure, and spatial and temporal behaviour patterns such as migration, feeding, and breeding nursery functions (Soler et al. 2018).	Trophic effects of fishing are best understood in simple predator-prey systems, and some small-bodied species are now identified as 'forage' species to reflect their utilitarian role as food for target species, irrespective of their ecological predator-prey role for other species (seabirds, mammals, etc). However, assessing the structure and scale of trophic impacts of fishing is complex and expensive and, in practice, highly limited.
Bycatch: retained (byproduct) or discarded	Depletion of non-target or non-economic species populations (AFMA 2012; Wayte et al. 2007a; Wayte et al. 2007b).	Management of bycatch should aim to maintain ecological functions of non-target species populations, including adequate population sizes, structures, and functions. Uncertainties arise from lack of data compared to target species, especially for indirect and remote impacts resulting from various forms of ecological connectivity/interactions (across spatial, temporal, and trophic relationships) (Thrush et al. 2015).
Habitat modification	Deployment of fishing gear commonly interacts with the ecosystem being fished, either through direct physical damage or behavioural effects on habitat-forming species (Griffiths et al. 2007; Svane et al. 2009; Wayte et al. 2007a; Wayte et al. 2007b).	Management to minimise habitat modification should aim to reduce the impacts of some gear types (such as trawls, gillnets, demersal longlines, traps, pots) with approaches such as avoiding specific times and places, including avoidance of sensitive habitats such as sponge beds and deep-water corals. Such management is intensive and expensive, and compliance with such fine-scale management rules in many fisheries can be highly uncertain, and open to unscrupulous activities.
Cumulative impacts	Overlapping impacts – not only different fisheries (e.g. federal, state, charter, recreational, indigenous), but also fishing	The aim of management should be to limit fishing impacts, especially in complex ecosystems, so that populations of ecologically linked species (predator, prey, habitat-forming) are not seriously affected by the reduction of fished species,

IUCN category	NRSMPA regulations	Broad zone
Sanctuary Zone (Ia)	Strict protection. Scientific access and research only.	Highly protected zone (I – II)
National Park Zone (II)	No extractive uses permitted (e.g. no fishing or petroleum extraction), whilst allowing for non-extractive uses (e.g. tourism and recreation).	
Habitat Protection Zone (IV)	Activities that do not disturb the seafloor are permitted (e.g. no demersal fishing methods or petroleum extraction).	Habitat Protection Zone (IV)
Recreational Use Zone (IV)	Recreational fishing is permitted, but not commercial fishing.	
Multi-Use Zone (VI)	Managed for sustainable resource use by permitting a range of extractive uses.	Multi-Use Zone (VI)
Special Purpose Zone (VI)	Managed for sustainable resource use by permitting a limited number of extractive uses.	



I - II
IV
VI
A.
B.
C.
Key ecological features
Shelf rocky reefs
Gulf of Carpentaria basin
Ancient coastline at 125 m depth contour
Commonwealth marine environment within..
Upwelling East of Eden
Continental Slope Demersal Fish Communities
Gulf of Carpentaria coastal zone
Canyons on the eastern continental slope
Shelf break and slope of the Arafura Shelf
Exmouth Plateau
West Tasmania Canyons
Albany Canyons group and adjacent shelf break
Western demersal slope and associated fish..
Ancient coastline at 90-120m depth
Western rock lobster
Tasman Front and eddy field
Ashmore Reef and Cartier Island and..
Kangaroo Island Pool, canyons and adjacent..
Perth Canyon and adjacent shelf break, and..
Commonwealth marine environment..
Carbonate bank and terrace system of the..
Commonwealth marine environment..
Seamounts South and east of Tasmania
Tributary Canyons of the Arafura Depression
Mermaid Reef and Commonwealth waters..
Tasmantid seamount chain
Canyons linking the Cuvier Abyssal Plain..
Carbonate bank and terrace system of the..
Pinnacles of the Bonaparte Basin
Commonwealth marine environment within..
Naturaliste Plateau
Lord Howe seamount chain
Wallaby Saddle
Elizabeth and Middleton reefs
Norfolk Ridge
Commonwealth waters adjacent to Ningaloo..
Submerged coral reefs of the Gulf of..
Reefs, cays and herbivorous fish of the..
Cape Mentelle upwelling
Plateaux and saddle north-west of the..
Reefs, cays and herbivorous fish of the..
Diamantina Fracture Zone
Canyons linking the Argo Abyssal Plain with..
0
20
40
60
80
100
% cover by broad zones



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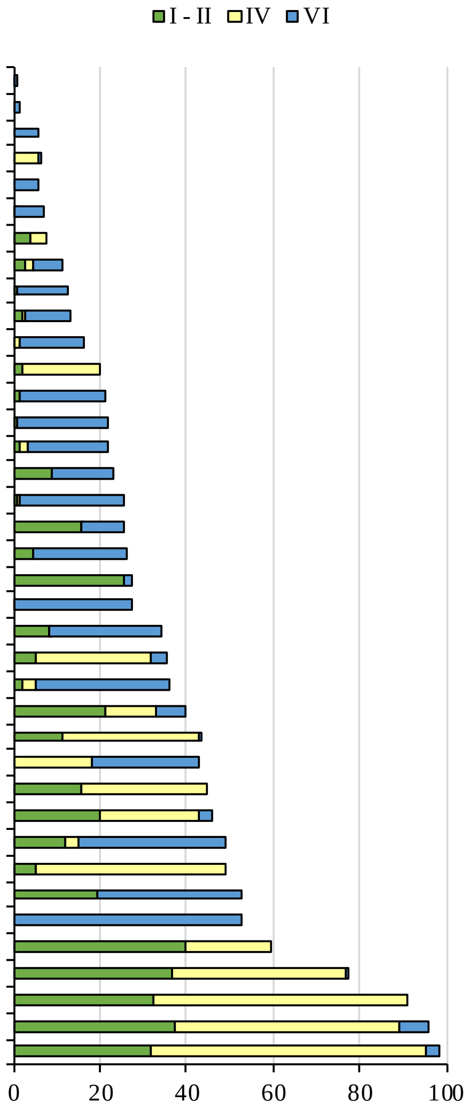
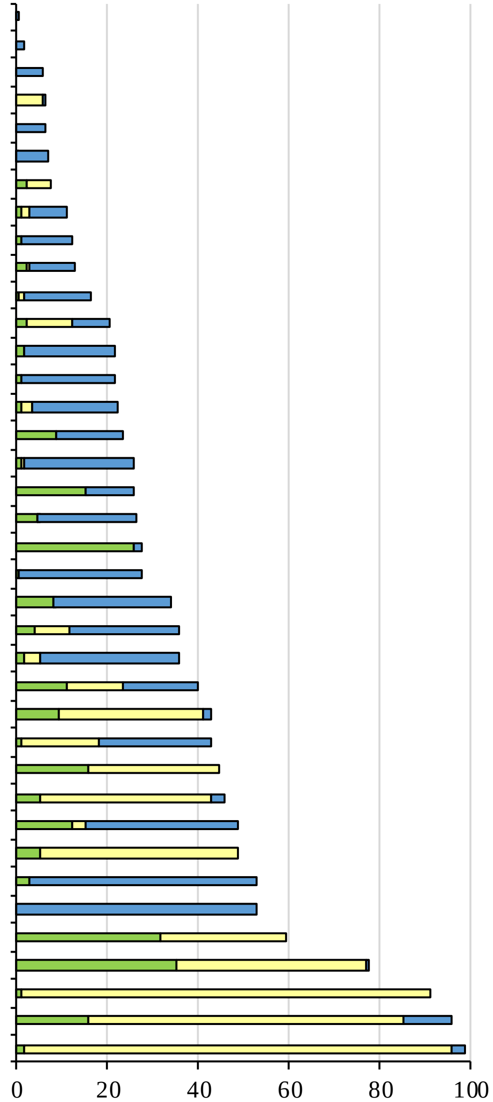


700



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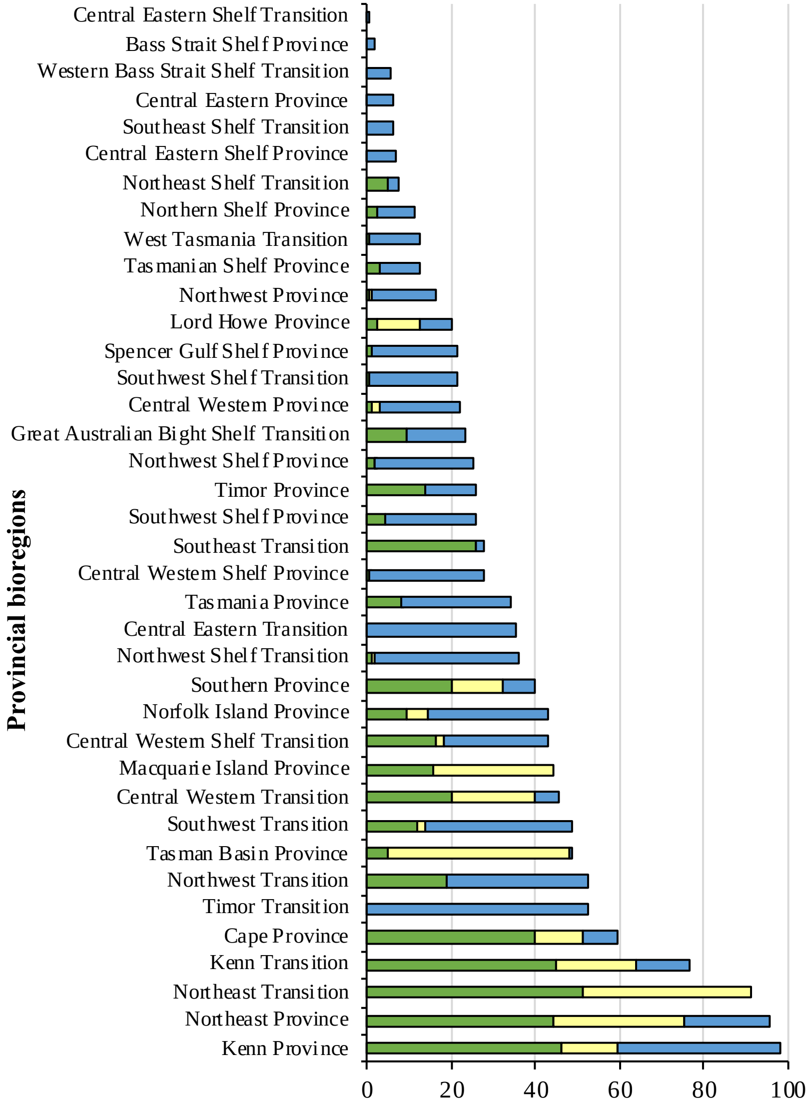
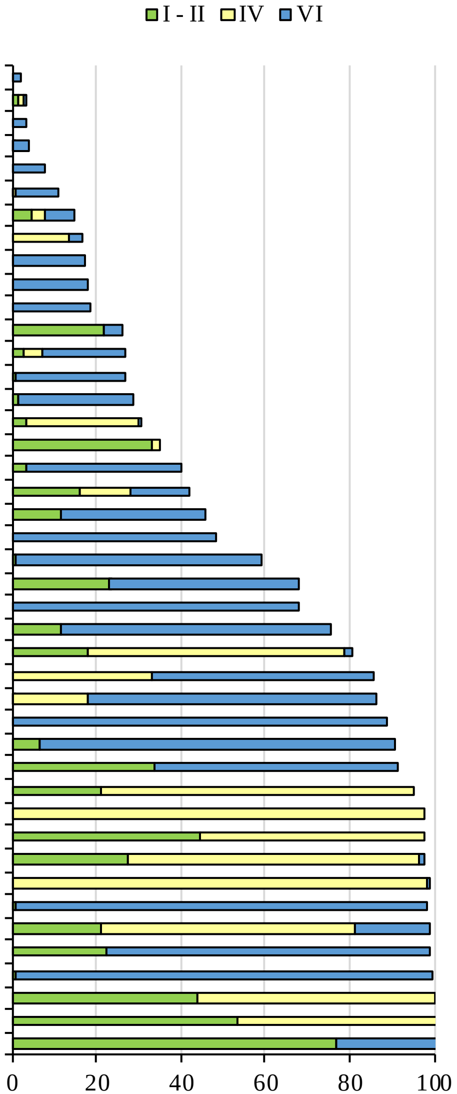
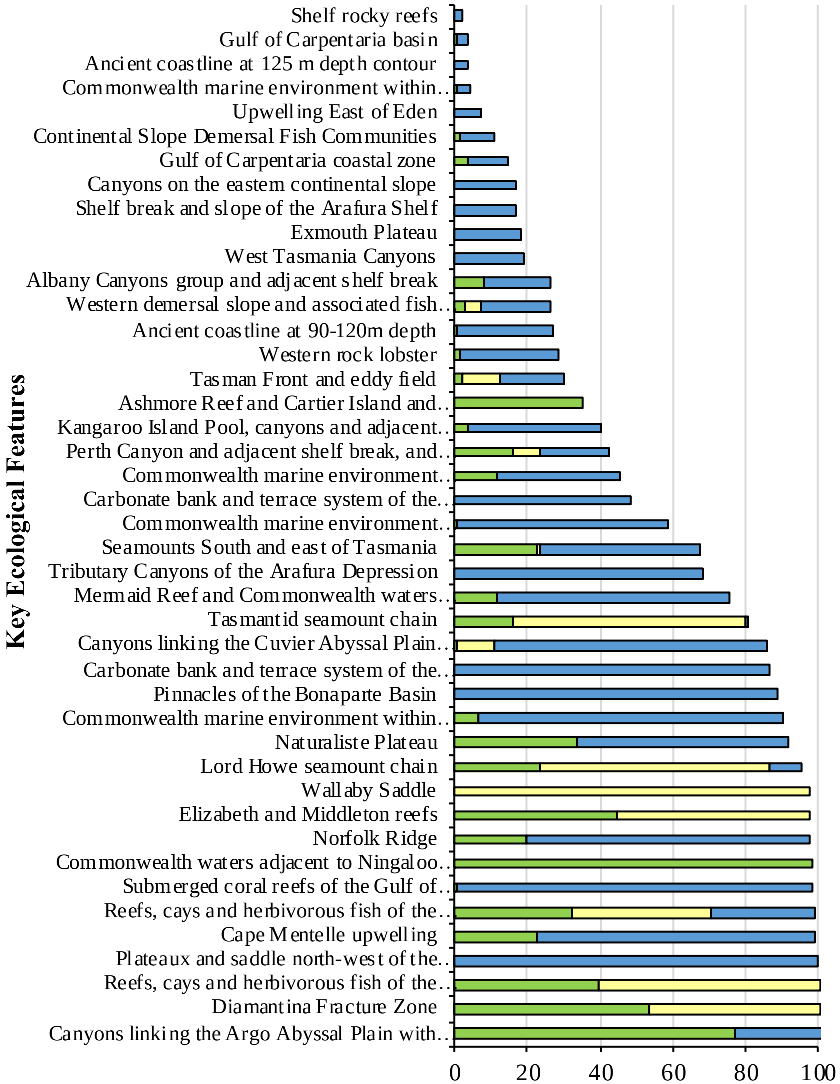

Central Eastern Shelf Transition
Bass Strait Shelf Province
Western Bass Strait Shelf Transition
Central Eastern Province
Southeast Shelf Transition
Central Eastern Shelf Province
Northeast Shelf Transition
Northern Shelf Province
West Tasmania Transition
Tasmanian Shelf Province
Northwest Province
Lord Howe Province
Spencer Gulf Shelf Province
Southwest Shelf Transition
Central Western Province
Great Australian Bight Shelf Transition
Northwest Shelf Province
Timor Province
Southwest Shelf Province
Southeast Transition
Central Western Shelf Province
Tasmania Province
Central Eastern Transition
Northwest Shelf Transition
Southern Province
Norfolk Island Province
Central Western Shelf Transition
Macquarie Island Province
Central Western Transition
Southwest Transition
Tasman Basin Province
Northwest Transition
Timor Transition
Cape Province
Kenn Transition
Northeast Transition
Northeast Province
Kenn Province
Provincial bioregions
0
20
40
60
80
100

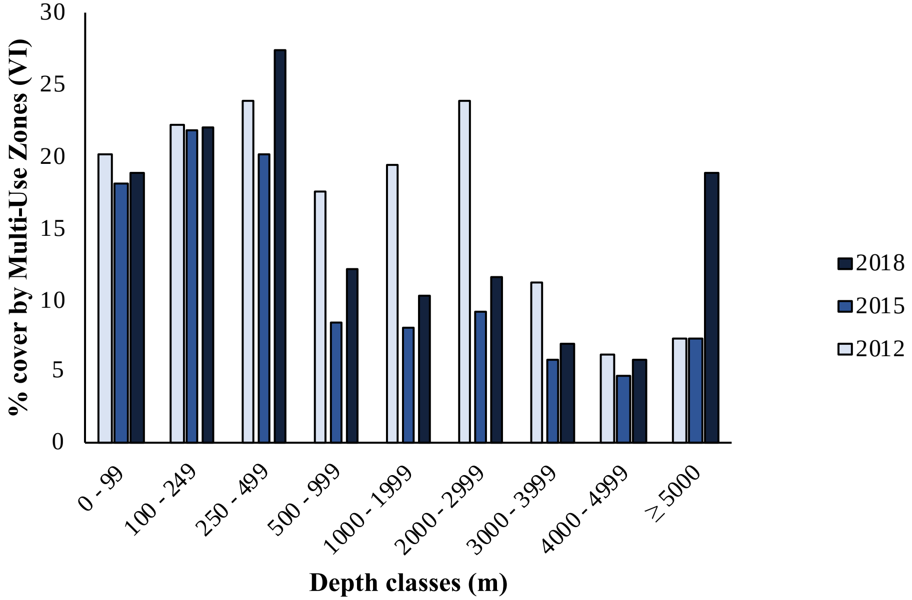
702

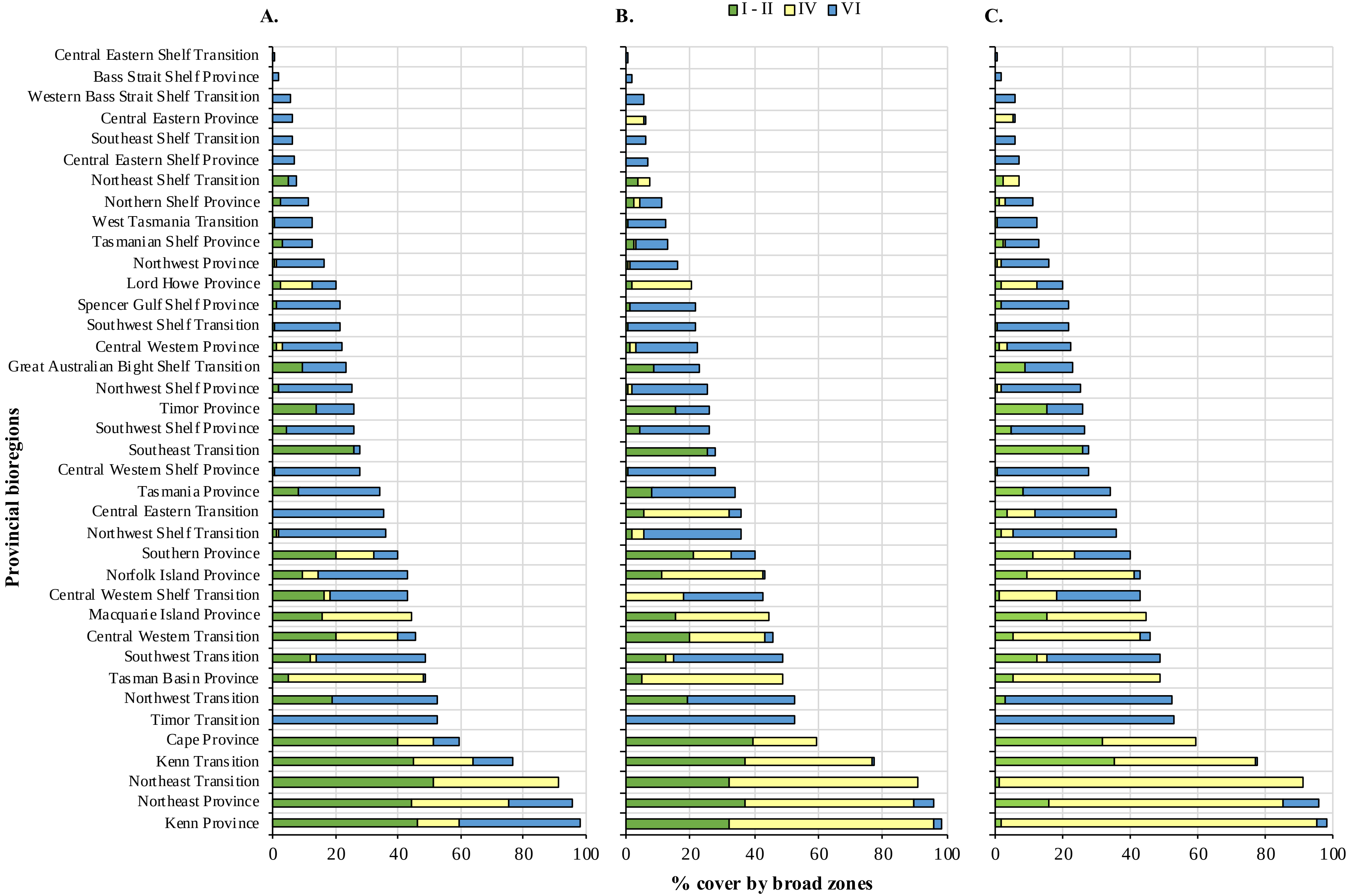


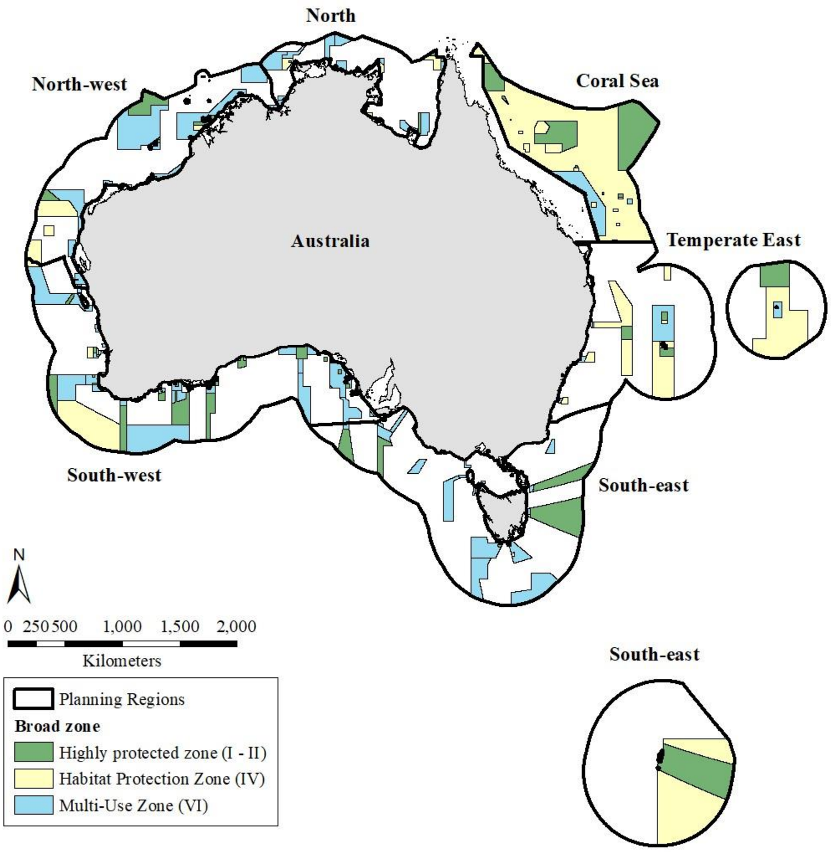
703

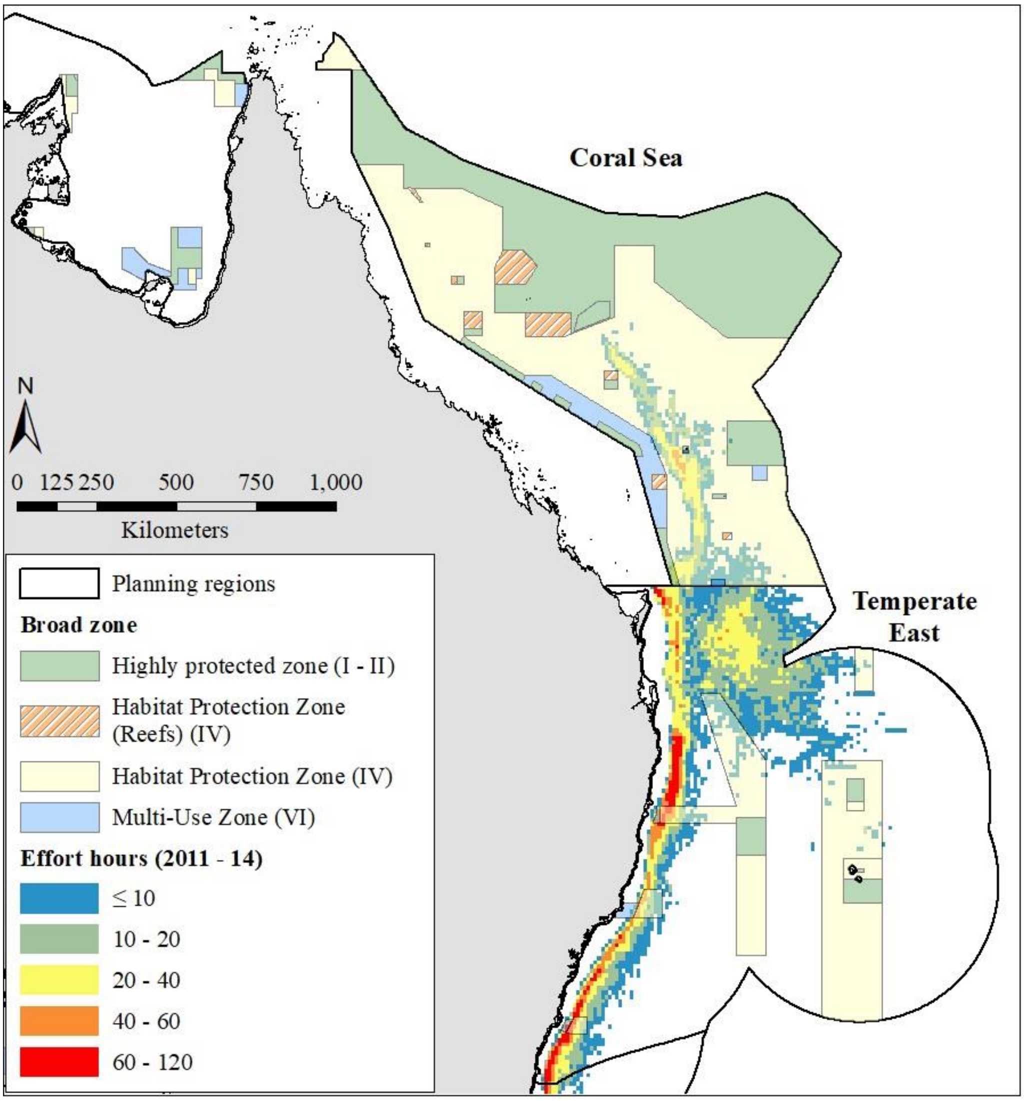

Key Ecological Features
Shelf rocky reefs
Gulf of Carpentaria basin
Ancient coastline at 125 m depth contour
Commonwealth marine environment within…
Upwelling East of Eden
Continental Slope Demersal Fish Communities
Gulf of Carpentaria coastal zone
Canyons on the eastern continental slope
Shelf break and slope of the Arafura Shelf
Exmouth Plateau
West Tasmania Canyons
Albany Canyons group and adjacent shelf break
Western demersal slope and associated fish…
Ancient coastline at 90-120m depth
Western rock lobster
Tasman Front and eddy field
Ashmore Reef and Cartier Island and…
Kangaroo Island Pool, canyons and adjacent…
Perth Canyon and adjacent shelf break, and…
Commonwealth marine environment…
Carbonate bank and terrace system of the…
Commonwealth marine environment…
Seamounts South and east of Tasmania
Tributary Canyons of the Arafura Depression
Mermaid Reef and Commonwealth waters…
Tasmantid seamount chain
Canyons linking the Cuvier Abyssal Plain…
Carbonate bank and terrace system of the…
Pinnacles of the Bonaparte Basin
Commonwealth marine environment within…
Naturaliste Plateau
Lord Howe seamount chain
Wallaby Saddle
Elizabeth and Middleton reefs
Norfolk Ridge
Commonwealth waters adjacent to Ningaloo…
Submerged coral reefs of the Gulf of…
Reefs, cays and herbivorous fish of the…
Cape Mentelle upwelling
Plateaux and saddle north-west of the…
Reefs, cays and herbivorous fish of the…
Diamantina Fracture Zone
Canyons linking the Argo Abyssal Plain with…
0
20
40
60
80
100

704

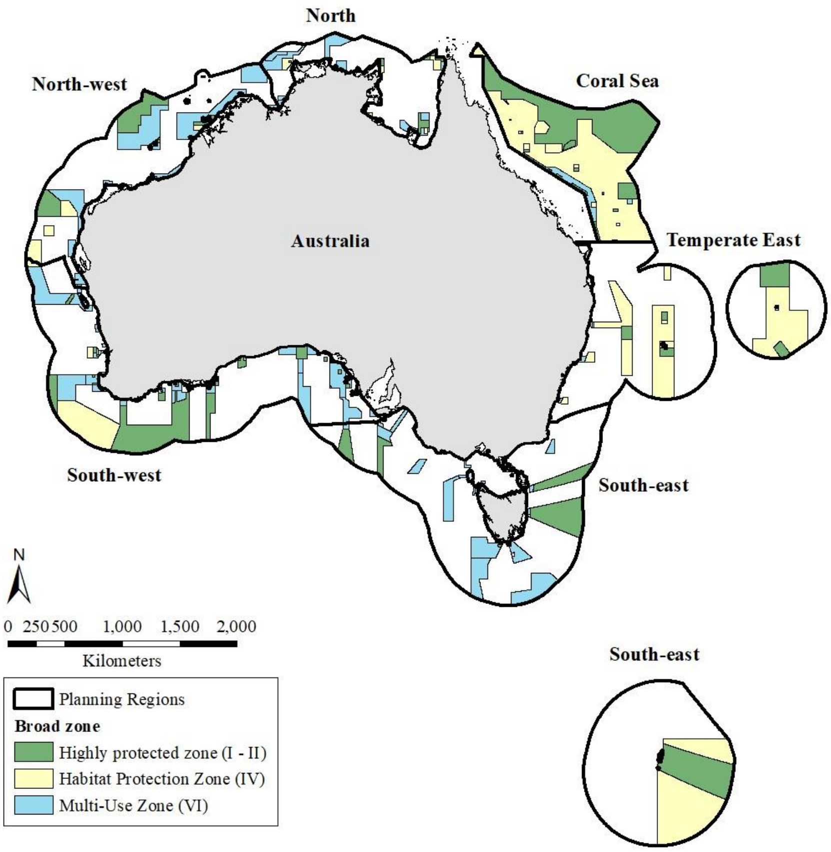

% cover by Multi-Use Zones (VI)
30
25
20
15
10
5
0
0 - 99
100 - 249
250 - 499
500 - 999
1000 - 1999
2000 - 2999
3000 - 3999
4000 - 4999
≥ 5000
Depth classes (m)
2018
2015
2012

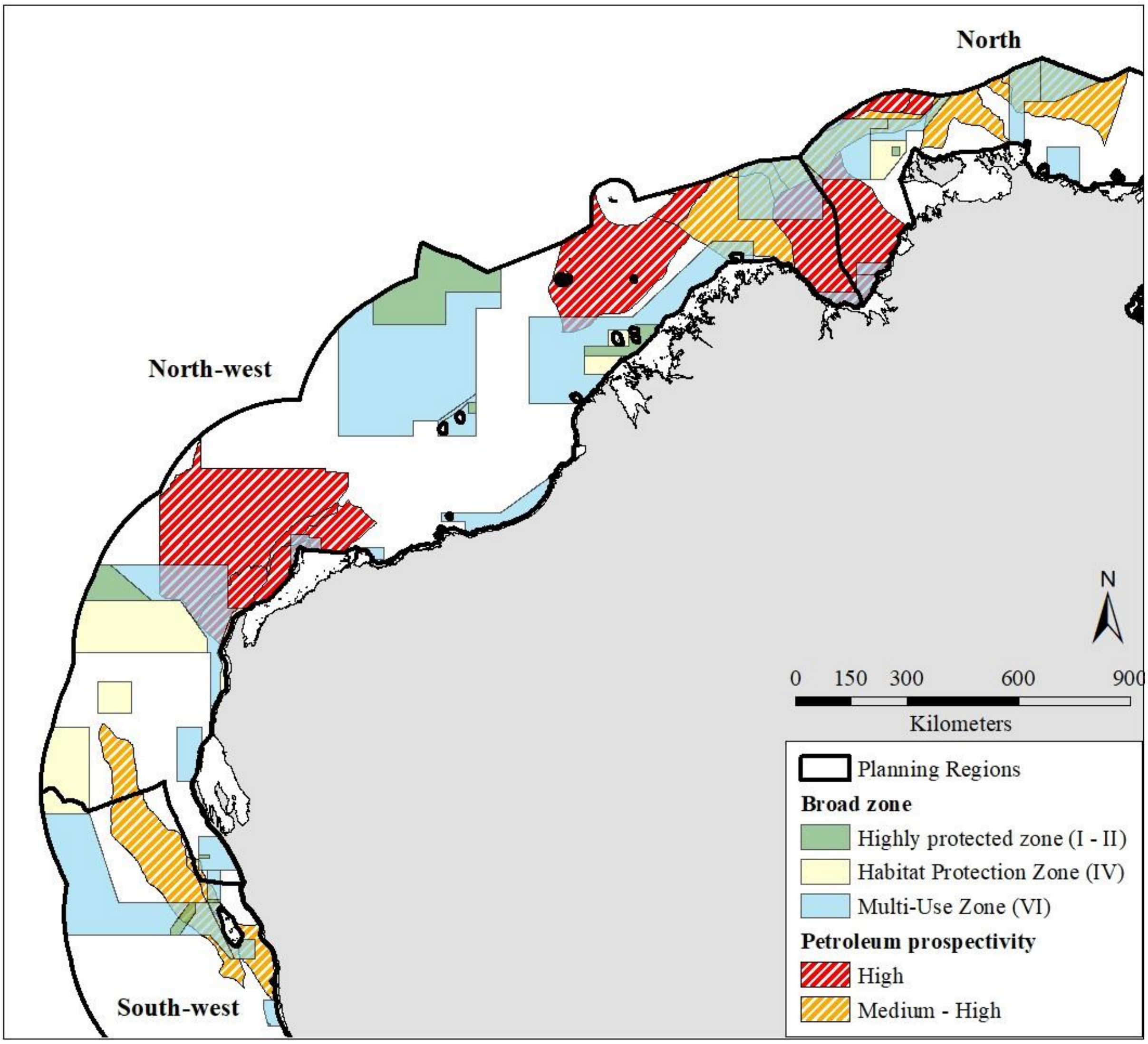

A.
B.
C.
I - II
IV
VI
Provincial bioregions
Central Eastern Shelf Transition
Bass Strait Shelf Province
Western Bass Strait Shelf Transition
Central Eastern Province
Southeast Shelf Transition
Central Eastern Shelf Province
Northeast Shelf Transition
Northern Shelf Province
West Tasmania Transition
Tasmanian Shelf Province
Northwest Province
Lord Howe Province
Spencer Gulf Shelf Province
Southwest Shelf Transition
Central Western Province
Great Australian Bight Shelf Transition
Northwest Shelf Province
Timor Province
Southwest Shelf Province
Southeast Transition
Central Western Shelf Province
Tasmania Province
Central Eastern Transition
Northwest Shelf Transition
Southern Province
Norfolk Island Province
Central Western Shelf Transition
Macquarie Island Province
Central Western Transition
Southwest Transition
Tasman Basin Province
Northwest Transition
Timor Transition
Cape Province
Kenn Transition
Northeast Transition
Northeast Province
Kenn Province
0
20
40
60
80
100
% cover by broad zones

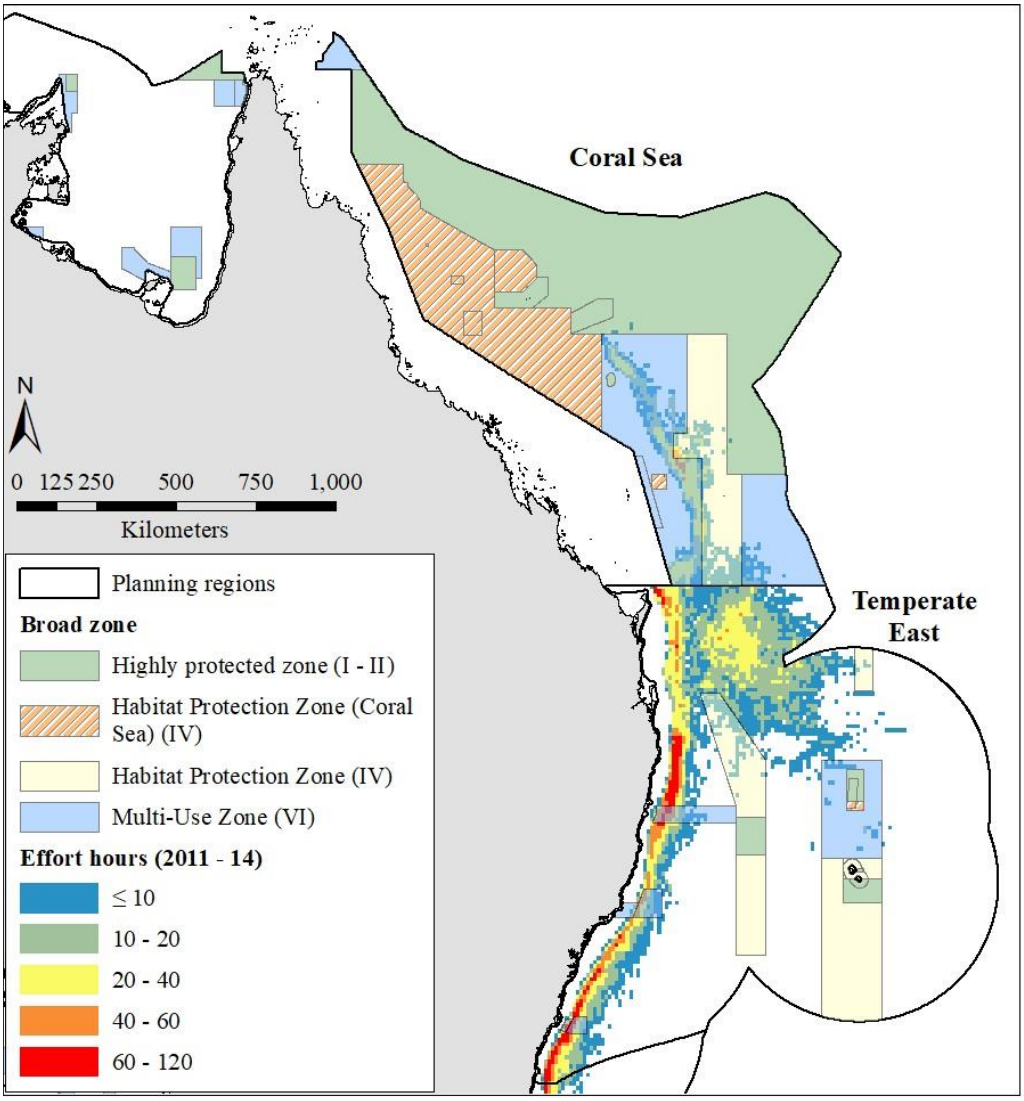

North
North-west
Coral Sea
Australia
Temperate East
South-west
South-east
N
0 250 500 1,000 1,500 2,000
Kilometers
Planning Regions
Broad zone
Highly protected zone (I - II)
Habitat Protection Zone (IV)
Multi-Use Zone (VI)
South-east



Coral Sea
Temperate East
N
0 125 250 500 750 1,000
Kilometers
Planning regions
Broad zone
Highly protected zone (I - II)
Habitat Protection Zone (Reefs) (IV)
Habitat Protection Zone (IV)
Multi-Use Zone (VI)
Effort hours (2011 - 14)
≤ 10
10 - 20
20 - 40
40 - 60
60 - 120


North
North-west
Coral Sea
Australia
Temperate East
South-west
South-east
N
0 250 500 1,000 1,500 2,000
Kilometers
Planning Regions
Broad zone
Highly protected zone (I - II)
Habitat Protection Zone (IV)
Multi-Use Zone (VI)
South-east


North
North-west
South-west
N
0 150 300 600 900
Kilometers
Planning Regions
Broad zone
Highly protected zone (I - II)
Habitat Protection Zone (IV)
Multi-Use Zone (VI)
Petroleum prospectivity
High
Medium - High


Coral Sea
Temperate East
N
0 125 250 500 750 1,000
Kilometers
Planning regions
Broad zone
Highly protected zone (I - II)
Habitat Protection Zone (Coral Sea) (IV)
Habitat Protection Zone (IV)
Multi-Use Zone (VI)
Effort hours (2011 - 14)
≤ 10
10 - 20
20 - 40
40 - 60
60 - 120