Area-based conservation in the 21st century

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Abstract

Humanity will soon define a new era for nature – one that seeks to transform decades of underwhelming responses to the global biodiversity crisis. Area-based conservation efforts, which include both protected areas and other effective area-based conservation measures (OECMs), are likely to extend and diversify. But persistent shortfalls in ecological representation and management effectiveness diminish the potential role of area-based conservation in stemming biodiversity loss. Here we show how protected area expansion by national governments since 2010 has had limited success in increasing the coverage across different biodiversity elements (ecoregions; 12,056 threatened species; Key Biodiversity Areas; wilderness areas) and ecosystem services (productive fisheries; carbon services on land and sea). To be more successful post-2020, area-based conservation must contribute more effectively to meeting global biodiversity goals – ranging from preventing extinctions to retaining the most intact ecosystems – and better collaborate with the many Indigenous, community groups and private initiatives that are central to successful biodiversity conservation. The long-term success of area-based conservation requires Parties to the Convention on Biological Diversity to secure adequate financing, plan for climate change and make biodiversity conservation a far stronger part of land, water and sea management policies.

Introduction

Governments, policy makers and much of the conservation community have long heralded protected areas as a fundamental cornerstone of biodiversity conservation[1,2]. The importance of other effective area-based conservation measures (OECMs) is also beginning to be recognised[3,4]. OECMs were defined by the Convention on Biological Diversity (CBD) in 2018 as places outside the protected area estate that deliver effective biodiversity conservation, such as government-run water catchment areas, territories conserved by Indigenous peoples and local communities some private conservation initiatives (Box 1). Both protected areas and OECMs (collectively referred to herein as area-based conservation measures) are acknowledged in the CBD and the 2030 Agenda for Sustainable Development[5]. In particular, the CBD's current ten-year Strategic Plan for Biodiversity[6] – agreed by 168 countries in 2010 – had an explicit target (Aichi Target 11) that stipulated "at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and OECMs, and integrated into the wider landscape and seascape" by 2020. This target has dominated the area-based conservation agenda for the past decade.

Between 2010 and 2019, protected areas expanded from covering 14.1% to 15.3% of global land and freshwater environments (excluding Antarctica) and from 2.9% to 7.5% of the marine realm[7] (Fig 1). While it is not yet possible to track their global extent systematically, OECMs have emerged as a category of area-based conservation since 2010[8]. However, despite these encouraging efforts, some disconcerting spatial dynamics in the global protected area estate are becoming more apparent. One recent analysis showed that on average 1.1 million km^2 of land and sea were recorded as removed from the global protected area estate annually between 2006 and 2018[9]. There is also concern that nations are paying less attention to the qualitative elements of Aichi Target 11, including the need for representative and connected protected areas that are equitably governed and managed[10-16]. Moreover, some long-standing issues, including poor resourcing and low management effectiveness, continue to compromise the ability of protected areas to conserve biodiversity and ecosystems[17-23]. As a consequence, there is a risk that humanity could fail to deliver on the overall strategic goal for which the target was established – to "improve the status of biodiversity by safeguarding ecosystems, species, and genetic diversity"[6].

A post-2020 Global Biodiversity Framework will be agreed upon at the fifteenth Conference of the Parties to the CBD. This new strategic plan could be humanity's last chance to prevent catastrophic global biodiversity loss[24]. The urgency to act has emboldened calls for a substantial expansion of area-based conservation globally[25-28] and fundamental changes in how environmental targets are framed and implemented[17,22,29,30]. It is therefore timely to assess the achievements and failures of area-based conservation efforts over the past decade and place these findings within the wider context of the global biodiversity crisis.

The performance of protected areas since 2010

In this section, we provide an up to date temporal analysis (between 2010 to 2019) of how the recent expansion of protected areas globally has affected the net coverage of the qualitative components of Target 11 (see Supplementary Methods for details of methodology and calculations). We omit reference to OECMs in this section as a database showing the global extent of these sites is not yet available.

Protected areas being ecologically representative

The concept of being ecologically representative has been interpreted as the coverage of species or ecoregions (areas containing geographically distinct assemblages of species[31,32]), especially those that are threatened with extinction[10,13,33,34]. We analysed how expansion of the global protected area estate between 2010 and 2019 affected coverage of 12,056 species listed as Vulnerable, Endangered or Critically Endangered (herein 'threatened' species) on the IUCN Red List[35] (Fig. 2). Between 2010 and 2019, the percentage of species with some portion of their geographic range protected increased from 86% to 87.6% (n=10,563). However, only 21.7% (n = 2,618) of species assessed had adequate representation inside protected areas in 2019 (up from 18.9% in 2010), where adequacy targets for individual species were set according to their geographic range[34].

The proportion of threatened reef-forming corals with adequate representation grew rapidly over the last decade from 9.1% to 44.0%. The proportion of species with adequate coverage also increased for threatened mangroves (to 50.0%), seagrasses (to 50.0%), marine mammals (to 43.2%), marine bony fishes (to 42.1%) and cartilaginous fishes (to 32.4%) in this time. However, no threatened marine reptiles had adequate levels of protection in 2019. On land, the proportion of species with adequate coverage grew by <3% for birds (to 33.6%) and <2% for amphibians (to 10.9%), reptiles (to 13.6%), mammals (to 37.0%) and freshwater species (to 19.0%) in the last decade (Table S1; Table S2). It remains that 78.3% (n = 9,438) of all threatened species assessed had inadequate protection as of 2019, with at least 1,493 (12.4%) remaining without any coverage at all.

We further assessed progress toward adequacy targets of 17% protection for terrestrial ecoregions and 10% for marine ecoregions or pelagic regions. We found that 42.6% (n = 361) of terrestrial ecoregions were adequately protected in 2019 (up from 38.8% in 2010) (Fig. 2; Table S3). We also found that one-fifth (20.6%) of land protected since 2010 covered tropical and subtropical grassland ecoregions – a critically endangered biome[31] (Table S4). However, 32.9% of land protected since 2010 covered dry or desert ecoregions, which are relatively species poor and well represented in the global protected area estate[31]. The percentage of marine ecoregions with adequate coverage increased to 45.7% (n = 106) last decade (from 31.8% in 2010) (Table S5), with much of this growth occurring over in the Southern Ocean around Antarctica (0.7 million km^2; 4.2% of all new marine protected area). Despite attracting 81.3% (14.7 million km^2) of all new protected since 2010, coverage in pelagic regions remains low, with only 10.8% (n = 4) adequately protected in 2019 (up from 2.7% in 2010) (Fig 2; Table S6). Protected area expansion in pelagic regions was particularly concentrated in waters between Australia and South America, which enjoyed 36.6% of all new marine protected area (6.0 million km^2) in the past decade.

Coverage of areas of particular importance for biodiversity

The Key Biodiversity Area (KBA) approach[36] offers a global standard for identifying marine, terrestrial and freshwater sites that contribute significantly to the global persistence of biodiversity. Over 15,000 KBAs have been identified so far (83.1% of which are Important Bird Areas - the avian subset of KBAs)[37]. Host nations are encouraged to ensure that these sites are managed in ways that ensure the persistence of biodiversity, although this does not necessarily mean inclusion within a protected area[36]. Our analysis showed average coverage of terrestrial KBAs was 45.9% in 2019 (up from 43.6% in 2010) and 43.3% for marine KBAs (up from 37.9% in 2010) (Fig 2). Overall, some 4,900 KBAs (33.0%) remained without protected area coverage in 2019.

Wilderness areas are ecologically intact land and seascapes that are predominantly free of human-driven biophysical disturbance[38,39]. They underpin planetary life-support systems[40] and are critical for the long-term persistence of imperilled species[41], especially in a time of climate change[42]. Over half (55.6%) of all wilderness overlaps with the geographic range of at least one threatened species, yet wilderness areas are also quite spatially discordant from KBAs – only 1.2% of all land and sea on Earth is simultaneously recognised as both a KBA and wilderness area (Fig S1). Our analysis shows coverage increased for both terrestrial (from 19.7% to 22.1%) and marine wilderness (2.0% to 8.5%) areas during the past decade (Fig. 2).

Coverage of ecosystem services

The carbon sequestered and stored in terrestrial ecosystems plays a pivotal role in mitigating anthropogenic climate change[43]. We therefore assessed coverage of global above-ground biomass and soil carbon stocks[44]. Coverage of above-ground biomass increased from 22.6% in 2010 to 23.7% (99.0 petagrams of carbon (Pg C)) in 2019. Coverage of global soil carbon stocks was lower on average and increased less in the past decade, from 13.9% in 2010 to 14.6% (400.5 Pg C) in 2019. Large unprotected repositories of soil carbon are prevalent across north-east North America, Russia and south-east Asia (Fig S2). However, maps of terrestrial organic carbon, particularly in peatlands and tropical rainforests, are continually being refined[45], which may influence our future understanding of carbon storage in particular areas.

The 'biological pump' – carbon fixed by phytoplankton in the world's oceans being exported to the deep ocean[46,47] – also plays a key role in mitigating climate change because it removes carbon from the ocean and atmosphere systems for decades to millennia[48]. We estimate that 0.21 Pg of particulate organic carbon (POC)[49] and 0.17 Pg of dissolved organic carbon (DOC)[50] is exported inside marine protected areas each year (Table S7; Table S8). We note, however, that the factors that drive carbon export in the world's oceans vary seasonally[51] and the relative value of marine protected areas in carbon export may vary through time.

Around three billion people rely on wild-caught or farmed seafood as their primary source of protein, making the sustained provision of seafood a globally-important goal[5]. We compared protected area coverage of the most and least productive marine regions for fisheries catch in the world's oceans, finding that coverage of the least productive exclusive economic zones (EEZs) (i.e. those within the bottom 20% for annual fisheries catch per unit area; Table S9) was on average three times greater than coverage of the most productive EEZs (i.e. those within the top 20% for annual fisheries catch per unit area; Table S10) (31.2% versus 9.8%). Moreover, average coverage of the most productive EEZs has not changed notably since 2010 (Fig 2). We also found that the seven most productive pelagic regions for fisheries catch have no formal protected area coverage (Table S11).

Protected areas being well connected

Well-connected ecosystems are critical for maintaining important ecological and evolutionary processes, including species migration and gene flow, especially when species face rapid climatic and environmental changes[52,53]. Connectivity among marine protected areas further helps to replenish and maintain fish populations, including on fished reefs[54,55]. A previous study showed that, in 2016, only 30% of terrestrial ecoregions were at least 17% covered by protected areas that were within the potential dispersal distance of terrestrial vertebrates[56]. A subsequent study showed that the percentage of connected terrestrial protected areas increased from 6.5% to 7.7% between 2010 and 2018[57]. However, these assessments did not account for the permeability of unprotected land between protected areas. There have been no global-scale assessments of connectivity among marine or freshwater protected areas, but regional-scale studies show them to have limited connectivity, especially for species with a dispersive larval stage[58].

Protected area management effectiveness

Over the past few decades, four broad approaches have been used to evaluate area-based conservation efforts (Table 1). Three of these approaches pertain to management effectiveness, the first of which – herein termed input evaluation – evaluates the adequacy of management resources for area-based conservation. A recent study corresponding to ~23% of terrestrial protected area found 47% of protected areas suffer from inadequate staff and budget resources, with poor resourcing especially noticeable in the Neotropics[21]. Similarly, a study of 433 marine protected areas showed 65% to have insufficient budget for basic management needs and 91% to have on-site staff capacity that is inadequate or below optimum[20]. Related inputs, including weak enforcement of protected area regulations[59], have also been implicated in poor management effectiveness.

A second evaluation approach – herein termed threat reduction evaluation – asks if area-based conservation effectively reduces threats to biodiversity persistence. The majority of these evaluations show that protected areas slow but fail to completely halt human pressures within their borders. For example, human pressures increased inside 55% of protected areas on land between 1993 and 2009[60], while in the marine realm, 94% of protected areas created before 2014 permit fishing activities[61,62]. However, terrestrial protected areas have been found to reduce rates of deforestation and forest degradation below those observed in nearby unprotected areas[63], including in the Amazon[64,65], and marine protected areas can reduce fishing vessel traffic[66] and the negative effects of some non-native species[67].

The third evaluation approach – herein termed outcome evaluation – asks if the goals of area-based conservation are being achieved relative to no intervention taking place. A recent controlled study showed some 12,000 protected areas were ineffective at reducing human pressures inside their borders between 1995 and 2010[68]. However, several studies have reported beneficial impacts of protected areas on biodiversity. For example, a controlled study of 359 terrestrial protected areas showed species richness to be 10.6% higher and abundance 14.5% higher inside protected areas than outside, with the effects of protection most prominent in human-dominated land uses in the tropics (e.g. cropland, plantations)[69]. Similarly, a controlled study of 218 marine protected areas found that, on average, fish biomass is nearly double inside protected areas than in non-protected sites[20]. Marine protected areas can also promote the recovery of commercial fish species[70,71]. No-take marine reserves, in particular, can effectively increase species richness, density and biomass in both tropical and temperate systems[20,72-74], as well as being effective at restoring trophic function[75,76] and lowering levels of coral disease[77]. Finally, several studies have reported on the social impacts of protected areas. For example, a controlled study corresponding to 603 protected areas found households near protected areas with tourism opportunities had higher wealth levels (by 17%) and a lower likelihood of poverty (by 16%) than similar households living far from protected areas[78].

Equitable governance and management in protected areas

Social equity in the context of protected areas has multiple dimensions, including distributional equity (e.g. people agree on a scheme for sharing benefits and burdens), procedural equity (e.g. decision-making that is transparent, accountable and participatory) and recognition (e.g. respect for cultural identities, customary rights and traditional management practices)[79]. A recent survey corresponding to 225 protected areas showed the majority of conservation managers, staff and community representatives believe protected area benefits are shared equally[15]. Yet the study also showed decision-making was not equitable in many cases and that local stakeholders perceived a general loss of rights over natural resources after protected area establishment[15].

Despite limited evidence of progress toward social equity, protected areas that do integrate local communities as stakeholders often result in better socioeconomic and conservation outcomes[14,80]. A review of 27 marine protected areas found stakeholder engagement, surveillance, leadership, political will and the existence of sanctioning and conflict resolution mechanisms were key factors related to achieving ecological objectives[81]. No-take, well-enforced, and longer established marine protected areas not only show conservation success[82], but also positive economic and governance outcomes for dependant human communities[83]. Furthermore, community-managed terrestrial protected areas are often more effective than nationally-designated protected areas at reducing deforestation pressures, including in Peru, Brazil, Australia and Namibia[84,85].

Lessons learned and priority actions for area-based conservation

National governments collectively made some progress toward Aichi Target 11 in the past decade, particularly in the marine realm. However, it is clear that nations have as yet failed to meet this target. The rate of terrestrial protected area expansion needed to be double what was observed in the past decade in order to achieve 17% coverage for land and freshwater environments. Moreover, 78.3% of known threatened species and more than half of all ecosystems on land and sea remained without adequate protection in 2019. A clear lesson from this assessment is that nations must expand area-based conservation efforts and better ensure they contribute meaningfully to global goals for species and ecosystem conservation, which range from stopping extinction[86] to keeping ecosystems intact[87]. The past decade has also shown that many protected areas are poorly managed, due predominantly to chronic resource shortages, and that many Indigenous and community groups are inadequately or inequitably represented in land, water and sea conservation plans. In light of these lessons, we identify three urgent challenges that must be acted upon by governments, scientists, policy makers and other stakeholders as they embark on the next decade of area-based conservation (Table 2).

Making other effective area-based conservation measures count

There are now expanding opportunities to formally recognise places outside state-run protected areas that can conserve biodiversity. In addition to protected areas governed privately[88] and by Indigenous peoples[84], other effective area-based conservation measures

(OECMs) are being increasingly recognised. The importance of OECMs was formally recognised in Aichi Target 11 in 2010, but their guiding principles and criteria for identification were not agreed until November 2018 (Box 1). This delay likely contributed to OECMs being overlooked in most national biodiversity policies and strategies over the last decade. With a formal definition now agreed[89], nations and managing bodies look set to operationalise OECMs more rapidly. The challenge now for the conservation community is to ensure OECMs contribute meaningfully to biodiversity conservation.

Other effective area-based conservation measures could help address representation shortfalls in the global protected area estate. One recent study shows that 566 unprotected Key Biodiversity Areas are at least partly covered by one or more potential OECMs[4], and compared with nationally-designated protected areas, OECMs may prove to be more socially acceptable in productive land and seascapes (which are hotspots for poorly protected threatened species[10,11]). Recognising OECMs in inshore marine habitats, farmlands and managed forests could also enhance the connectivity of area-based conservation efforts, provided natural ecological functions can be restored and maintained in such areas[90,91]. Wider recognition of OECMs should also help make area-based conservation management more equitable given they are managed by and for the benefit of a diverse set of actors. A recent study showed Indigenous-managed lands in Australia, Brazil and Canada support similar concentrations of vertebrate species to nationally-designated protected areas[92], which exemplifies the importance of working with Indigenous Peoples to recognise OECMs in their territories.

To deliver on their potential, however, governments, private industry and the conservation community must immediately mobilise support for OECMs to overcome issues faced by many protected areas, including inadequate reporting and resourcing. A reporting platform for OECMs[8=] was released in December 2019 and has potential to make assessments of progress toward the successor of Aichi Target 11 more accurate if countries make use of it. The success of OECMs will also depend on governments and conservation actors upholding human rights and social safeguards, particularly in Indigenous and community areas. In cases where meeting OECM criteria will require some adaptation to livelihoods, great care must be taken to develop alternative livelihood opportunities that deliver tangible benefits to resource users[93]. Alternative livelihood schemes must also be mindful to retain the biodiversity benefits of OECMs[94].

Tracking the increasing dynamism of area-based conservation

Recent studies show protected areas are more dynamic in space and time than previously thought[9]. Decisions to remove, shrink or relax protected areas are poorly documented, making it difficult to assess which ecosystems are most susceptible to such dynamics or how they affect the overall quality of area-based conservation networks. The challenge for the conservation community is to have protected area dynamics reported more transparently – especially when they compromise biodiversity outcomes.

Many removals from the protected area estate can be attributed to protected area downgrading, downsizing, and degazettement (PADDD) events. Over 1,500 PADDD events affected over one-third of Australia's protected area network (416,740 km^2) between 1997 and 2014[95]. Moreover, 23 PADDD events have affected natural World Heritage Sites – protected areas with "outstanding universal value" (e.g. Virunga, Serengeti and Yosemite National Parks)[96]. PADDD events can accelerate forest loss and fragmentation[97] and most

(62%) are associated with activities that are in stark conflict with biodiversity conservation, including industrial-scale resource extraction and infrastructure development[98]. Potentially of greatest concern, however, are the many PADDD events that are going undocumented, particularly in marine systems[99] and on private lands[100].

To improve the transparency of area-based conservation decisions, we encourage governments and the conservation community to engage more with global PADDD tracking platforms (e.g. padddtracker.org). We also believe that integrating PADDD tracking data with existing area-based conservation databases (e.g. World Database on Protected Areas[7]) would vastly improve their utility and aid global reporting. Dynamism in area-based conservation could signal attempts to expand or enhance protected areas, either through improved resourcing and management[101,102], or by enacting more restrictive regulations[103]. As such, there is also a clear need to better incentivise and track the continuum of changes to protected areas that can improve their ability to conserve biodiversity. We suggest that such changes be characterised collectively as Protected Area Gazettement, Expansion and Enhancement (PAGEE). Clear, transparent tracking around both PADDD and PAGEE events will ensure we address, and not exacerbate, current shortfalls in area-based conservation.

Outcome-orientated evaluation of area-based conservation

The numerous approaches developed to evaluate area-based conservation efforts all have merit, but the conservation community remains too reliant on types of evaluation that focus on management inputs or threat reduction[104] (Table 1). Adopting evaluation techniques that more effectively capture the biodiversity and socio-economic outcomes of area-based conservation is currently a substantial challenge.

The Global Database on Protected Area Management Effectiveness (GD-PAME) provides information on many protected area processes, including the existence of a management plan or the adequacy of law enforcement activities[105]. Yet the majority of GD-PAME methodologies were not developed to quantify the effects of protected area management activities on species and ecosystems[105] and therefore cannot be used to evaluate progress toward the effective conservation of biodiversity. High resolution maps of ecological change across land and seascapes, including forest cover change[106] and changes in cumulative human pressure[107,108], enable more outcome-orientated conservation evaluations. But ecological changes across land and seascapes do not always explain local biodiversity patterns[109]. The temporal resolution of cumulative human pressure mapping also lags behind that of forest cover mapping efforts and some maps of human pressure are at spatial resolutions (e.g. 77sqkm[108]) that preclude assessments of many small (i.e. <1 km^2), but crucially important[110], protected areas.

To make area-based conservation evaluations more outcome-orientated, we suggest making robust outcome evaluation techniques – both ex-ante to help site areas[111] and ex-post to report on outcomes[112] – a standard reporting requirement for all organisations involved in area-based conservation. Conservation agencies must then better fund long-term and well-designed biodiversity monitoring programs. It will be especially important for such programs to monitor control sites that match protected areas in terms of ecological and anthropogenic conditions, so as to isolate any confounding effects[113,114]. We also encourage governments and communities to engage more with citizen science initiatives that use techniques such as camera traps, drones and acoustic monitors to increase the coverage and frequency of biodiversity data[115]. Combining advances in remote sensing and field campaigns (e.g. the

European Space Agency's Biomass Earth Explorer) with in situ reporting of protected area management capacity and biodiversity trends could also make outcome evaluations much more accurate and reliable.

Future-proofing area-based conservation

While the three challenges discussed above are immediate priorities, broader policy changes can ensure area-based conservation can contribute meaningfully to longer-term goals held by the CBD, namely that "by 2050 humanity live in harmony with nature"[116] (Table 2). In this final section, we outline a set of necessary pre-conditions – adequate financing, being climate-smart and mainstreaming biodiversity across national policy frameworks – that require action by governments now to ensure the long-term success of area-based conservation strategies.

Secure adequate financing

The global funding available for species protection has more than halved in the past two decades, from approximately $200 million USD per year in the 2000s to <$100 million USD per year in the 2010s[117]. Compounding resource shortfalls at existing sites are the costs associated with expanding area-based conservation efforts. One estimate suggests protecting and effectively managing a more taxonomically comprehensive terrestrial protected area network would cost US$76.1 billion annually[118]. As such, a conservative estimate of the current financial shortfall for area-based conservation likely exceeds the multi-billion dollar mark. This shortfall is unlikely to be fully addressed in the coming decade, but reducing it must become an immediate priority for governments and private industry.

Current and future resourcing needs could be met if the contribution of area-based conservation to national economies was fairly recognised. The direct value generated by visits to protected areas is valued at $600 billion USD per year[119]. Governments must therefore better account for the contribution of area-based conservation efforts to national economies. When budgeting for area-based conservation, we suggest governments use predictive measures of funding requirements and impacts[120] and that they consider under-appreciated cost-saving benefits of effective biodiversity conservation. For example, it would be useful to compare the costs arising from the socio-economic devastation caused by zoonotic diseases such as SARS or COVID-19 with those needed to effectively manage area-based conservation networks in a way that reduces supply to illegal wildlife markets[121]. There is also an urgent need to better harness industry and philanthropic contributions to area-based conservation through, for example, improved funding guidelines that ensure involvement from private interests do not compromise the siting or management of area-based conservation[122-124].

Being climate-smart

Anthropogenic climate change will become an increasingly strong mediator of the success of area-based conservation this decade[125], with many predicted biological responses to climate change already underway[126]. A recent study showed that under a business-as-usual scenario for greenhouse gas emissions (RCP8.5), mean sea-surface temperatures within marine protected areas are projected to increase by 2.8°C by 2100[127]. We overlaid climate change projections under a more moderate emissions scenario (RCP4.5) on the terrestrial protected area network and found that temperatures in the warmest quarter will increase on average by 2.9°C on protected land by 2050, with higher increases occurring in European nations (Fig

S2; Table S12). We also found that by 2050 some biodiverse nations, including Suriname and Guyana, can expect 30-40% less rainfall on protected land during dry months (Fig S3; Table S13). Such changes in bioclimatic conditions are likely to dramatically alter ecological networks[128] and imperil some species and ecosystems[129]. Even the relatively moderate RCP4.5 greenhouse gas emission scenarios are likely drive the elimination of most warm-water coral reefs by 2040–2050[130].

There are now well-established ways to incorporate climate change into area-based conservation plans[131], including safeguarding, or where possible, restoring the integrity of ecosystems around protected areas so as to ensure ecological connectivity[132,133]. Ensuring that managers have the knowledge and capacity to implement realistic climate adaptation policies is also paramount[134]. Greater enforcement of conservation regulations[135] and accounting for human responses to climate change[136] are also likely to enhance the climate resilience of area-based conservation efforts. However, targeting protected areas in sites where bioclimatic changes may be small (i.e. refugia) must be done with caution because predicted changes can be spatially discordant[127] as can the biotic response. For example, only 3.5% of marine protected areas co-occur with refugia for both sea-surface temperature and oxygen concentration[127]. In such cases, decision-support tools (e.g. value of information analysis[137]; systems modelling[138]) can evaluate the benefits of resolving uncertainty about ecological responses to climate change before implementing conservation action, and hence lead to more robust management decisions.

Make biodiversity conservation mainstream

No matter how well-sited, resourced or managed, area-based conservation can only act on a subset of threats to biodiversity persistence. The amelioration of large-scale distal threats requires other interventions that are triggered by broader land, water and sea management policies[139,140]. China is the first major economy to formulate a national policy – known as the Ecological Redline Policy – that mandates municipality and provincial governments to establish biodiversity and ecosystem service assessments in land use planning[141]. It is hoped that the Ecological Redline Policy extends to China's planned activities beyond their national boundaries, including the Belt and Road Initiative, which could impact on may areas of critical conservation concern[142]. However, most national land, water and sea management policies are subservient to economic development[143] or contain loopholes that lead to perverse environmental outcomes[144]. Governments must recognise that getting these policies right is essential and will ease the strain on area-based conservation strategies in the long term.

Two cross-cutting changes could improve the efficacy of national land, water and sea management policies. First, we suggest nations adopt an overarching goal for biodiversity that is bold – to have a net positive impact on biodiversity, for example[29] – and then agree a set of socio-economic and environmental targets that can contribute proportionally to this overarching goal. Targets should then be made mutually conditional whereby environmental targets (e.g. protect 30% of land) cannot be considered met if progress toward socio-economic targets (e.g. eliminate incentives harmful to biodiversity) is found wanting. Improving biodiversity accounting protocols could also enhance the efficacy of land, water and sea management policies. One example of this is switching from biodiversity impact offsetting protocols that simply displace conservation funding or entrench rates of biodiversity loss (e.g. ‘averted loss offsetting’) to emerging protocols that align compensation with desired trajectories for imperilled species or ecosystems (e.g. ‘target-based compensation’)[145].

Conclusions

Area-based conservation will remain the cornerstone of biodiversity conservation long into the 21st century. But governments have dramatically underinvested in protected areas and OECMs and been weak in legally protecting them. In addition to addressing existing shortfalls, conservation organisations need to adopt more impact-orientated evaluation measures and promote governance and management equity. Organisations must also improve the transparency of decisions that result in spatial and resource dynamics and ensure that OECMs can contribute meaningfully to biodiversity conservation. Finally, governments must future-proof area-based conservation by securing adequate financing, being climate-smart and mainstreaming biodiversity across environmental and socio-economic policies.

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Data availability

The World Database on Protected Areas (http://www.protectedplanet.net)[7], the World Database of Key Biodiversity Areas (http://keybiodiversityareas. org)[37], ecoregions on land[31] and sea[32,146], wilderness on land[39] and sea[38], geographic distributions of non-avian[35] and avian[147] threatened species and bioclimatic projections[148] are publically available online. Maps of fisheries catch[149], particulate organic carbon[49] and dissolved organic carbon[50] export, and biomass and soil carbon[44] can be obtained from their creators. Source Data for Supplementary Fig 3 and 4 are provided with the paper. Source Data for Fig 1 and 2 and all data tables found in the Supplementary Information in are available in an online digital repository at 10.5281/zenodo.3894431

Code availability

Spatial analysis was conducted using in ESRI ArcGIS Pro v2.4.0. The workflow we used to process the World Database on Protected Areas is available in the Supplementary Information.

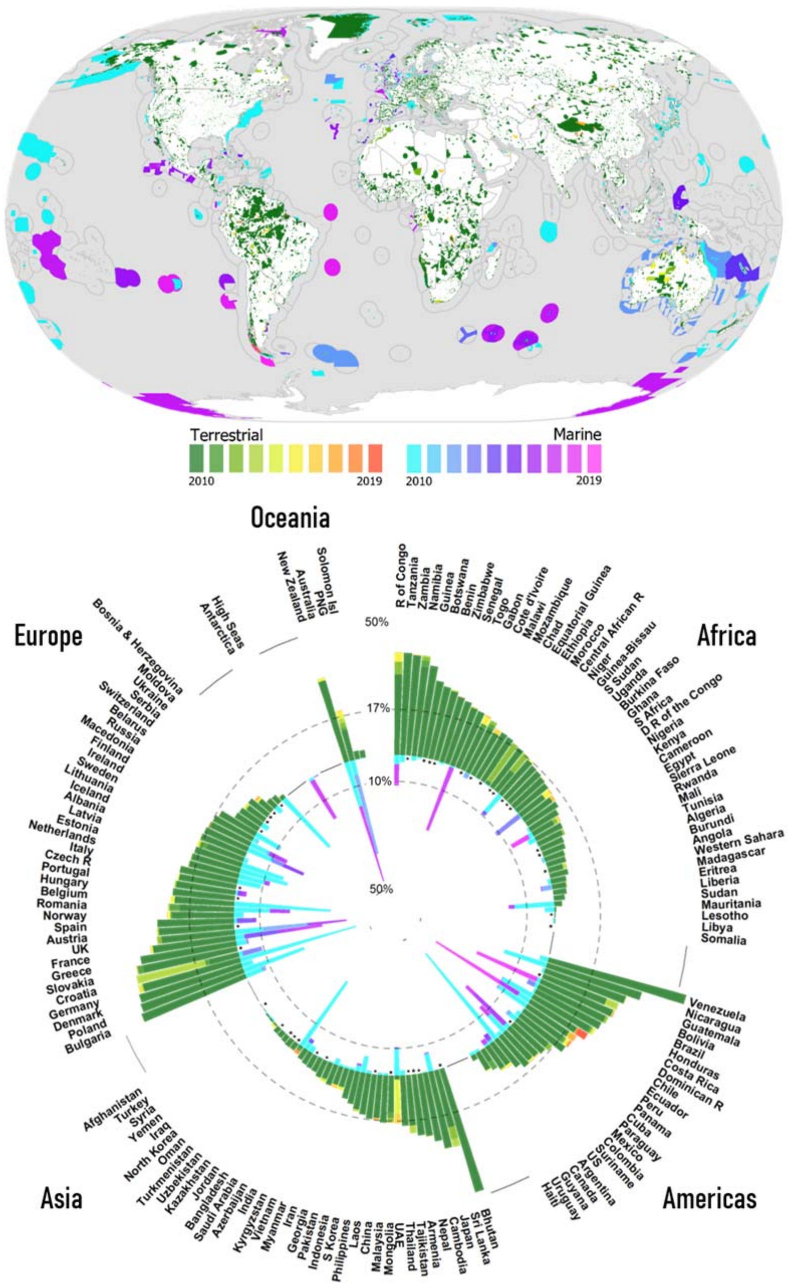


Fig. 1. Growth in the global protected area estate between 2010 and 2019. Global map shows annual expansion of protected areas across marine (blue to pink colours) and terrestrial (green to red colours) realms on Earth. Circular plot shows increases in areal coverage (%) per year for marine and terrestrial protected area estates for countries >25,000 km^2 in size. Landlocked countries are marked with an asterisk (*). Progress toward the globally agreed target - to have 17% of land and inland waters and 10% of coastal and marine areas protected by 2020 - is promising but incomplete. Data for figure sourced from[7].

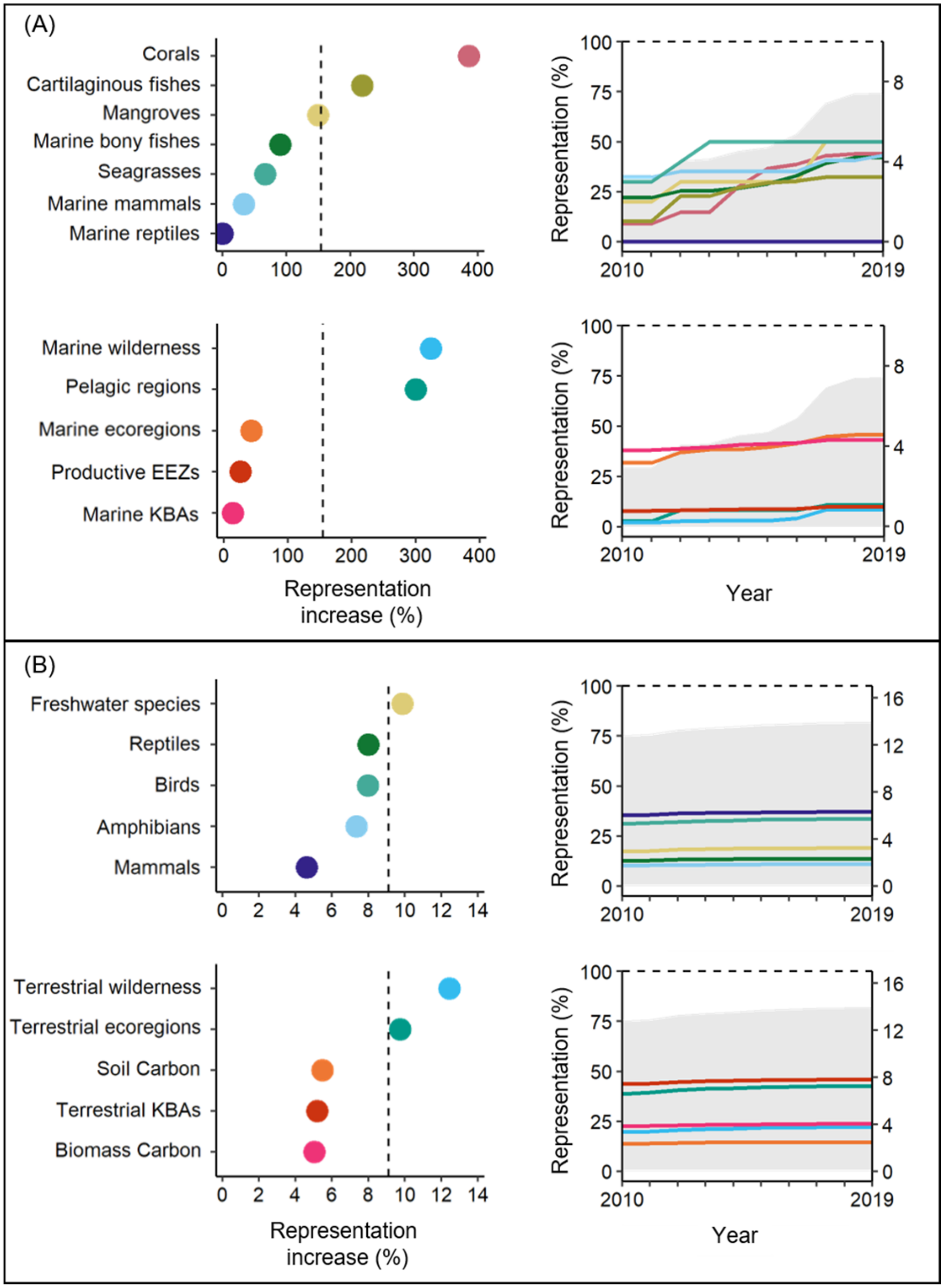
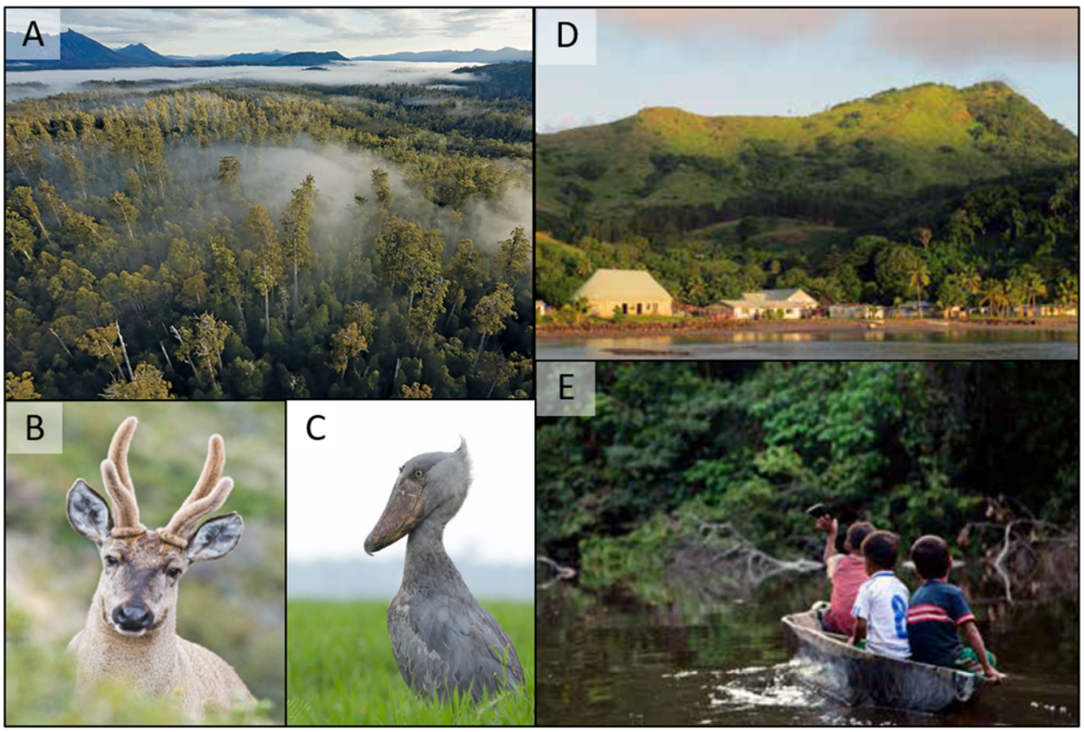

(A)
Corals
Cartilaginous fishes
Mangroves
Marine bony fishes
Seagrasses
Marine mammals
Marine reptiles
0 100 200 300 400
Representation (%)
100 75 50 25 0
8 4 0
2010 2019
Marine wilderness
Pelagic regions
Marine ecoregions
Productive EEZs
Marine KBAs
0 100 200 300 400
Representation increase (%)
Representation (%)
100 75 50 25 0
8 4 0
2010 2019
Year
(B)
Freshwater species
Reptiles
Birds
Amphibians
Mammals
0 2 4 6 8 10 12 14
Representation (%)
100 75 50 25 0
16 12 8 4 0
2010 2019
Terrestrial wilderness
Terrestrial ecoregions
Soil Carbon
Terrestrial KBAs
Biomass Carbon
0 2 4 6 8 10 12 14
Representation increase (%)
Representation (%)
100 75 50 25 0
16 12 8 4 0
2010 2019
Year

Fig. 2. Temporal trends in biodiversity and ecosystem service representation within the global marine (A) and terrestrial (B) protected area estates. Left-hand plots show increases in representation of values (coloured dots) compared with percent growth in protected area estates between 2010 and 2019 (dotted vertical lines). Coloured dots to the right of dotted vertical lines show when an increase in representation was greater than the growth in the protected area estate, suggesting these values benefited most from recent expansion of area-based conservation efforts. Right-hand plots show change in biodiversity and ecosystem service representation (coloured lines; left axis) as the terrestrial and marine protected area estates expanded between 2010 and 2019 (grey shading; right axis). For taxonomic groups, trend lines show the proportion of threatened species with adequate representation. Trend lines for ecoregions and pelagic regions show the proportion of these features that are at least 17% protected (for terrestrial ecoregions) or at least 10% protected (for marine ecoregions or pelagic regions). Trend lines for all other values, including Key Biodiversity Areas (KBAs), wilderness areas, biomass carbon, soil carbon and exclusive economic zones (EEZs) within the top 20% for annual fisheries catch per km^2, represent global averages. See Supplementary Information for data sources and methods.

Nationally designated protected areas	Other effective area-based conservation measures (OECMs)
"A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values"[2]	"A geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and, where applicable, cultural, spiritual, socioeconomic, and other locally relevant values"[89]



Box 1. Protected areas and other area-based conservation measures (OECMs) are complementary area-based conservation measures. Their distinguishing feature is that a protected area has a primary conservation objective whereas an OECM delivers the effective in-situ conservation of biodiversity, regardless of its objectives. Protected areas are playing a central role in conserving (**A**) wilderness areas in Tasmania, Australia (Credit: Nik Lopoukhine), the Patagonian Huemul (*Hippocamelus bisulcus*) in Chile and (**C**) the Shoebill stork (*Balaeniceps rex*) in Uganda (Credit: Daniel Field). OECMs have been recognised at (**D**) a locally managed marine area on Totoya Island, Fiji (Credit: Stacy Jupiter) and (**E**) a conservation concession in Loreto Region, Peru (Credit: Bruno Monteferri).

Table 1 Approaches for evaluating area-based conservation. The different approaches imply different measurements and are subject to strengths and weakness. Design, input and threat reduction evaluations all measure means to an end, whereas outcome evaluation measures progress toward the ultimate goals of area-based conservation. Globally we have limited capacity to perform outcome evaluation for area-based conservation.

Type	What is Measured	Strengths (+) and Weaknesses (-)	Examples
Design evaluation	1. Coverage of species 2. Coverage of ecoregions 3. Coverage of important areas for biodiversity and ecosystem services 4. Protected area connectivity	+ Broad spatial data on environmental variables readily available + Robust methods to identify if siting decisions for area-based conservation are influenced by competing interests (e.g. agricultural suitability) + Can include Traditional Ecological Knowledge where available - Coarse scale assessments might not be adequate of local planning - Subject to inaccuracies in global data sets	10,11
Input evaluation	1. Budget shortfalls 2. Capacity shortfalls 3. Social equity shortfalls	+ Global database established + Assessment frameworks that can be conducted rapidly - Taxonomic or geographic biases in datasets	18,21
Threat reduction evaluation	1. Change in human pressures 2. Change in environmental state (e.g. pollution, forest cover)	+ Human pressures are often useful proxies for broad-scale biodiversity impacts + Cheap and non-invasive (e.g. derived from satellites) - Often miss important drivers of biodiversity loss (e.g. disease, pollution, poaching) - Do not always explain local or regional biodiversity patterns	20,60,105
Outcome evaluation	1. Species abundance and richness 2. Extinction risk 3. Socio-economic outcomes	+ Account for what would have happened in the absence of conservation intervention + Provides the most robust foundation for decision-making - Counterfactual studies can exclude from impact evaluation sites that are small, surrounded by other conservation interventions or do not have an biophysically similar site that is unprotected - Data to quantify progress toward goals of area-based conservation (e.g. avoiding extinctions) in the absence of conservation action often unavailable	20,86,150

Table 2. Synthesis of current progress toward targets for area-based conservation and how acting on key challenges could improve its performance in the 21st century. Progress toward targets assessed as "Good" (substantial positive trends at a global scale relating to most aspects of the element), "Moderate" (the overall global trend is positive but insubstantial or insufficient, or there may be substantial positive trends for some aspects of the element but little or no progress for others, or the trends are positive in some geographic regions but not in others), "Poor" (little or no progress toward the element or movement away from it; although there may be local, national, or case-specific successes and positive trends for some aspects, the overall global trend shows little or negative progress) or "Unknown" (insufficient information to score progress). Challenges and suggested actions shaded orange represent immediate discrete priorities, while those shaded green are overarching pre-conditions that require action by governments to ensure the long-term success of area-based conservation strategies. Figure partially adapted from ref. ([24]) and ([151]).

Global targets for area-based conservation	Good	Moderate	Poor	Unknown	Challenges to improve progress	Potential actions to address challenges
Conserve:					• Dynamism of area-based conservation are made more transparent	• Utilise PADDD tracking platforms and integrate with WDPA • Better track Protected Area Gazettement, Expansion and Enhancement (PAGEE) events
• 17% terrestrial and inland water		!				
• 10% coastal and marine areas		!				
Capture important places for biodiversity and ecosystem services, such as:					• Other effective area-based conservation measures (OECMs) contribute substantively to biodiversity conservation	• Engage with OECMs reporting platforms • Mobilise support for OECMs to overcome reporting and resourcing issues • Ensure that OECMs be managed by a diverse set of actors
• KBAs		!				
• Wilderness areas		!				
Be effectively managed by:					• More impact-orientated evaluation of area-based conservation	• Collect better temporal biodiversity data, including through citizen science initiatives • Make robust impact evaluation a standard reporting requirement
• Having adequate resources			×			
• Abating human pressures		!				
• Having positive biodiversity impacts				?		
Be equitably managed		!			• Secure adequate resourcing	• Fund the contribution of area-based conservation to national economies • Better harness industry and philanthropic contributions
Be ecologically representative					• Be climate smart	• Safeguard ecological integrity • Utilise decision support tools to make robust decisions
• Cover 17% of all terrestrial ecoregions		!				
• Cover 10% of all marine ecoregions		!				
• Cover 10% of all pelagic regions			×			
Be well-connected and integrated		!			• Make biodiversity conservation mainstream	• Adopt an overarching goal for biodiversity that is bold • Adopt biodiversity accounting protocols that align compensation with desired trajectories for imperilled species or ecosystems

Supplementary figures and tables

Figure S1. Global spatial overlap in key biodiversity variables and the protected area estate.

Figure S2. The terrestrial protected area network overlaid on a global map of biomass and soil carbon.

Figure S3. Mean and interquartile rage of change in temperature (□) during the warmest quarter within national terrestrial protected area networks under a moderate emissions scenario (RCP4.5).

Figure S4. Mean and interquartile rage of change in precipitation (millimeters) during the driest quarter within national terrestrial protected area networks under a moderate emissions scenario (RCP4.5).

Table S1. Proportion of threatened species from different taxonomic groups with adequate representation in the global protected area estate 2010 and 2019.

Table S2. Proportion of threatened freshwater species from different classes with adequate representation in the global protected area estate 2010 and 2019.

Table S3. Protected area coverage (%) of terrestrial ecoregions in 2010 and 2019.

Table S4. Location of terrestrial protected areas established between 2010 and 2019 by biome.

Table S5. Protected area coverage (%) of marine ecoregions in 2010 and 2019.

Table S6. Protected area coverage (%) of off-shelf pelagic regions in 2010 and 2019.

Table S7. Export of particulate organic carbon (POC) at approximately 100m in protected and unprotected waters in global marine regions.

Table S8. Export of dissolved organic carbon (DOC) at approximately 100m in protected and unprotected waters in global marine regions.

Table S9. Protected area coverage (%) between 2010 and 2019 of exclusive economic zones (EEZs) within the bottom 20% for annual fisheries catch (in tonnes) per unit area.

Table S10. Protected area coverage (%) between 2010 and 2019 of exclusive economic zones (EEZs) within the top 20% for annual fisheries catch (in tonnes) per unit area.

Table S11. Annual fisheries catch (tonnes per km^2) and protected area coverage between 2010 and 2019 (%) of pelagic regions.

Table S12. Current (average for 1950–2000) and future (average for 2041–2060) mean temperatures (□) during the warmest quarter within national terrestrial protected area networks.

Table S13. Current (average for 1950–2000) and future (average for 2041–2060) precipitation rates (millimetres) during the driest quarter within national terrestrial protected area networks.

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