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LETTER

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Poor ecological representation by an expensive reserve system: Evaluating 35 years of marine protected area expansion

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Abstract

Global areal protection targets have driven a dramatic expansion of the marine protected area (MPA) estate. We analyzed how cost-effective global MPA expansion has been since the inception of the first global target (set in 1982) in achieving ecoregional representation. By comparing spatial patterns of MPA expansion against optimal MPA estates using the same expansion rates, we show the current MPA estate is both expensive and ineffective. Although the number of ecoregions represented tripled and 12.7% of national waters was protected, 61% of ecoregions and 81% of countries are not 10% protected. Only 10.3% of the national waters of the world would be sufficient to protect 10% of each ecoregion if MPA growth since 1982 strategically targeted underrepresented ecoregions. Unfortunately 16.3% of national waters are required for the same representative target if systematic protection started in 2016 (an extra 3.6% on top of 12.7%). To avoid the high costs of adjusting increasingly biased MPA systems, future efforts should embrace target-driven systematic conservation planning.

KEYWORDS

Aichi target 11, conservation planning, Convention of Biological Diversity, marine protected area, protection equality, protection gap, representation, spatial prioritization

1 | INTRODUCTION

The need to conserve marine biodiversity using site-based strategies like protected areas (PAs) has been increasingly recognized over the last four decades (Halpern, 2003; Klein et al., 2015; Roberts, 1997). When marine protected areas (MPAs) are well resourced, well placed, and well managed they halt many threats to biodiversity and the unsustainable use of the ocean, such as destructive fishing practices, overharvesting, and coastal engineering (Edgar et al., 2014; Lester et al., 2009; Watson, Dudley, Segan, & Hockings, 2014). The first global PA target, 10% ecoregion coverage, was announced at the 1982 World National Parks Congress (McNeely & Miller, 1983). A similar target was placed in the most recent Strategic Plan for Biodiversity 2011–2020, with Aichi target 11 calling for effective, area-based protection of "at least […] 10% of coastal and marine areas" (CBD, 2010). The UN Sustainable Development Goals, adopted in 2016, also mandate the conservation of "at least 10% of coastal and marine areas" by 2020 (United Nations, 2015).

These targets have driven huge expansion of the global MPA estate, with 25.3 million km^2 (6.97%) of the ocean under protection as of December 2017 (UNEP-WCMC & IUCN, 2018). Despite this considerable expansion, the global MPA estate does not adequately represent most marine biodiversity, and remains insufficient to conserve it (Klein et al., 2015; Mora et al., 2006; Mouillot et al., 2016; Spalding, Fish, & Wood, 2008). Given the insufficiency of the current MPA estate, and limited funds available for conservation, it is crucial that investments in marine conservation are made as strategically and efficiently as possible (Leslie, 2005; Lourie & Vincent, 2004). Although systematic conservation planning methods and tools have been available since the 1980s (Kirkpatrick, 1983; Margules & Pressey, 2000; Moilanen, Wilson, & Possingham, 2009), their impact on the efficiency of past MPA expansion has never been assessed. Furthermore, the degree to which strategic MPA expansion could have improved representation and efficiency of the current global MPA estate is unclear.

Along with a lack of data around the efficiency of MPA expansion, measures of progress towards global conservation targets have focused on simplistic areal assessments, such as "country X has conserved Y% of its Exclusive Economic Zone," despite requirements for ecological representation (CBD, 2010; Tittensor et al., 2014; Watson et al., 2016). Addressing the representation elements of Aichi target 11 has been a problem due to a lack of adequate indicators (Boonzaier & Pauly, 2015; Di Marco, Watson, Venter, & Possingham, 2016; Watson et al., 2016). However, newly developed representation metrics such as "protection equality (PE)" (Barr et al., 2011; Chauvenet, Kuempel, McGowan, Beger, & Possingham, 2017) and "mean percentage gap" (Sutcliffe, Klein, Pitcher, & Possingham, 2015) provide a timely opportunity to address this challenge.

Here we present the first assessment of how effectively past MPA expansion (1982–2016) has addressed the representation goal of international conventions. We simulate strategic planning of fully representative reserve networks for this period to evaluate the performance of the current MPAs, to identify missed opportunities for biodiversity in past expansion, and to quantify the benefits of starting strategic conservation planning as early as possible. The development of post-2020 targets presents an opportunity to improve upon existing global marine conservation targets, and we provide specific information on strategic MPA expansion to inform this process.

2 | METHODS

2.1 | Study region and data

2.1.1 | Study region

Our study covers the global marine area under national jurisdiction excluding Antarctica. We included 277 Exclusive Economic Zones (EEZ) in our study, consisting of 226 territories, 20 joint areas, and 31 disputed areas (Claus et al., 2016). Joint and disputed areas were excluded from analyses specifically targeted at territories (hereafter termed countries).

2.1.2 | Protected areas

We obtained data on the global distribution of MPAs from the 2017 World Database on Protected Areas (WDPA) (UNEP-WCMC & IUCN, 2017). We only included sites with the status "designated," "inscribed," or "established." For MPAs without polygonal representation, we included only those with reported area and created a circular buffer equal to the reported area around the point. We excluded terrestrial parts of MPAs, all MPAs with no establishment year, as well as UNESCO Man and Biosphere Reserves.

2.1.3 | Ecoregions

We obtained spatial data on marine regions from the Marine Ecoregions and Pelagic Provinces of the World dataset (The Nature Conservancy, 2012). This dataset shows a biogeographic classification of the world's coastal and shelf waters and the oceans, targeted at capturing generic patterns of biodiversity across habitats and taxonomic groups. The study region captures 258 of the 269 marine regions (hereafter termed ecoregions).

2.1.4 | Planning units

We created a planning unit (PU) layer of 30 × 30 minute grid cells covering the global marine area under national jurisdiction, which matches the scale of the fish catch rate data used to determine opportunity cost. We intersected the PU layer with the PA layer to determine the fraction of each PU under protection, f_p, for each year from 1982 to 2016.

2.1.5 | Fisheries opportunity cost

We used fish catch data from Watson (2017) as a surrogate for opportunity cost of MPAs. To calculate an opportunity cost metric for each PU, r_p, we averaged the catch for small and large scale fisheries from 1962 to 1982 and summed these values, for each PU. Because MPAs are generally smaller than the PUs, the opportunity cost of an MPA is proportional to the area of the PU covered by the MPA, with fish catch data assumed to be uniform within each PU. We thereby assume that MPAs have fisheries regulations in place that limit or exclude fishing once a PA is established, but do not stop illegal fishing activity. We used catch data from the period prior to 1982 to avoid the catch data being influenced by existing MPAs.

2.2 | Assessment of observed MPA expansion

We analyzed ecological representation in the global MPA system for a 35-year period from 1982 to 2016 by calculating PE, mean percentage gap, and opportunity cost for each year. We considered the year 1982 as the starting point of strategic and target-driven planning for PAs due to the emergence of the first PA coverage target (to protect 10 % of each of the world's ecological regions) (McNeely & Miller, 1983).

2.2.1 | Protection equality

We applied the proportional PE metric developed by Chauvenet et al. (2017) to capture the development of representation of ecoregions and countries in the global MPA estate. By measuring how equally conservation features, that is, ecoregions or countries, are protected, the PE metric provides a distinct indicator of the representativeness of the global MPA system, moving beyond simply reporting on area protected. It gives a value between 0 and 1, with 0 indicating a completely inequitable coverage of conservation features by a PA network and 1 indicating a perfectly equitable coverage.

2.2.2 | Mean percentage gap

Following the methodology by Sutcliffe et al. (2015), we calculated the mean percentage gap (MPG) of the global MPA system in each year, that is, the mean gap in protection for achieving the 10% PA coverage target for each ecoregion and country. This metric unveils shortfalls in representation that are masked by reporting on total area protected alone and is given by:

$$\sum\nolimits_{1\ldots N}^{i} \frac{\left(\frac{p_i}{t_i}\right)}{N} \times 100,$$

where p_i is the amount that country or ecoregion i is less than the target area t_i required for protecting 10% of each country or ecoregion and N is the total number of countries or ecoregions, respectively.

2.2.3 | Opportunity cost

The total fisheries opportunity cost of the observed MPA system in year t is:

$$\sum\nolimits_{1=N}^{p} (f_{p,t} c_p),$$

where $f_{p,t}$ is the fraction of PU p that is protected in year t and c_p is the catch per PU p.

2.3 | Simulation of strategic MPA expansion

We used integer linear programming to design an optimal reserve system that meets a 10% protection target for each ecoregion while minimizing the total cost while accounting for the existing reserve system for a particular year (starting in 1982). To simulate optimal MPA planning starting post 1982, we repeated this prioritisation analysis for every year from 1982–2016. For each year, MPAs designated in or before that year were "locked in," and our 10% targets remained the same.

We used the software Gurobi (version 5.6.2) to solve this minimum set conservation planning problem. For details on the programming approach we refer to Beyer, Dujardin, Watts, and Possingham (2016), appendix C.3.

3 | RESULTS

3.1 | Assessment of observed MPA expansion

3.1.1 | Protection equality

Total protection of the global marine area under national jurisdiction has increased 16-fold since 1982 from 0.78% to 12.7%, fulfilling the areal component of Aichi target 11. While representation as measured by PE does not necessarily increase with more area under protection, we found a tripling of ecoregional representation levels (3.4-fold increase) since 1982, and a doubling of country-level representation (2.3-fold increase) (Figure 1). This is a considerable increase, although representation of ecoregions and countries within the MPA estate remain poor (PE = 0.31 for ecoregions, PE = 0.16 for countries). As the MPA estate has expanded since 1982, ecoregional representation has been consistently higher than country-level representation, with the proportion of adequately represented ecoregions almost double that of countries in the current MPA estate.

3.1.2 | Mean percentage gap

To analyze the level of MPA coverage across ecoregions and countries, we use the MPG metric, where a value of 100 indicates no MPA coverage in any ecoregion and 0 indicates ≥10% MPA coverage in all ecoregions. We found that current representation of most ecoregions is poor (MPG = 44%), but has improved substantially since 1982 (MPG = 86%, Figure 1b). Despite massive expansion of the MPA estate since 1982, only 39% of ecoregions currently meet 10% coverage targets (Figure 2a). Representation of territorial waters is even poorer (MPG of 70%) and has seen only marginal improvement since 1982 (MPG = 97%), with just 19% of countries meeting 10% coverage targets (Figure 2b). While a quarter of all ecoregions and almost half of all countries

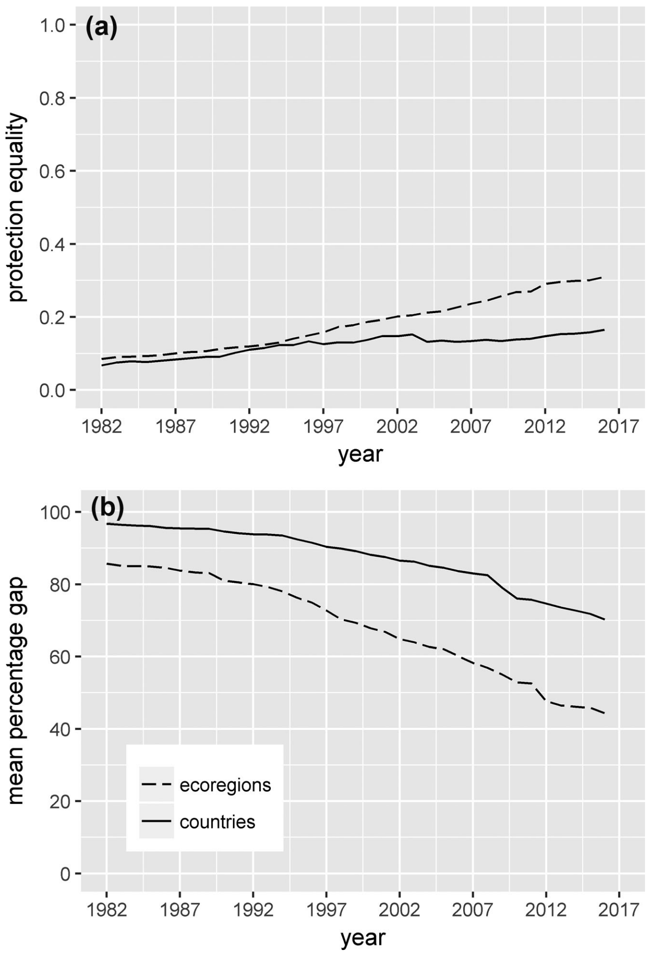

FIGURE 1 Protection equality (a) and mean percentage gap (b) of ecoregions and countries in the global MPA estate

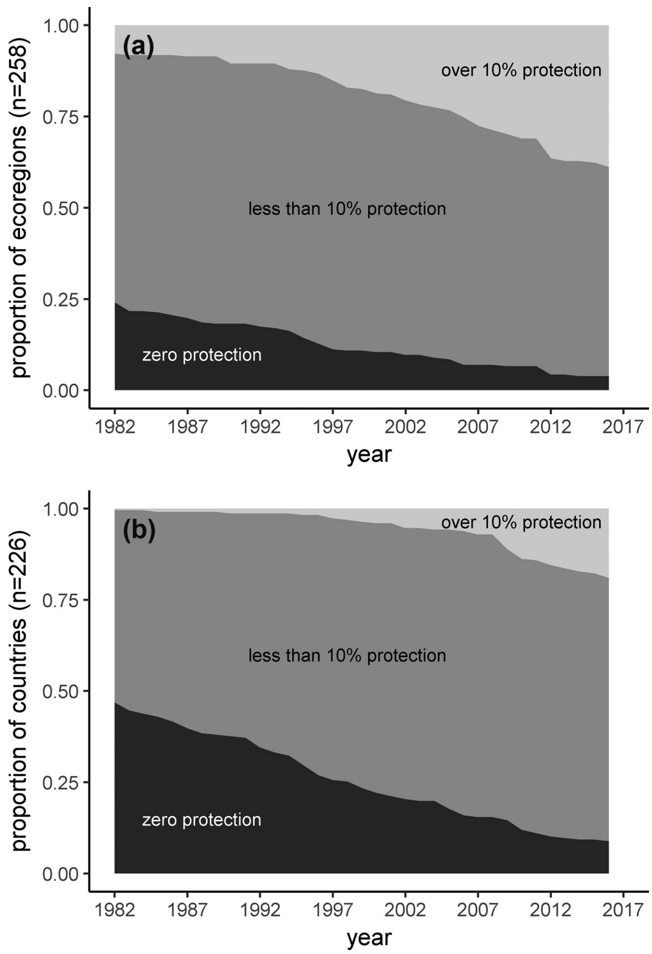

FIGURE 2 Development of shortfalls and target achievement of ecoregions (a) and countries (b)

were completely unprotected in 1982, by 2016 this dropped to 4% and 9%, respectively. Although most ecoregions have some level of protection, some very large ecoregions, such as the Guinea Current (c. 620,000 km^2) off the tropical West African coast, and the Malvinas Current (c. 320,000 km^2) off the southeast coast of South America, still have zero protection (Figure 3).

3.2 | Simulation of strategic MPA expansion

If MPA growth since 1982 had strategically targeted underrepresented ecoregions while minimizing opportunity costs to fisheries, 10.3% of the world's EEZ area would have been sufficient to protect 10% of each ecoregion (Figure 4a). Starting planning strategically from later years, especially from the mid-2000s on, would have required a much larger fraction of the marine area. Until 2011, systematic planning could have resulted in a fully representative MPA system covering less area than the current actual MPA system. Starting systematic protection based on the current MPA system (as of December 2016) will require 16.3% of total EEZ area and thus an additional 5 million km^2 to represent each ecoregion to a 10% level (Figure 4).

Due to inefficient historical MPA placement, the later systematic planning started in our simulations, the more costly a representative MPA estate becomes (Figure 4b). If efficient expansion of the MPA estate to meet 10% representation targets for ecoregions started from the 1982 MPA estate, rather than the 2016 MPA estate, the total cost of the final MPA estate could be more than halved. Starting strategic expansion in 2002, when the World Summit on Sustainable Development committed to establishing a representative network of MPAs, could have led to a fully representative MPA system with fisheries cost 16% lower than the current MPA estate. A strategically planned MPA system could also have achieved a substantially higher protection equality of ecoregions (up to a value of PE = 0.8, Figure 5a). If strategic planning had started in or before 2011, a fully representative network could have been achieved using at most the same total protection area as the 2016 MPA estate (Figure 5b).

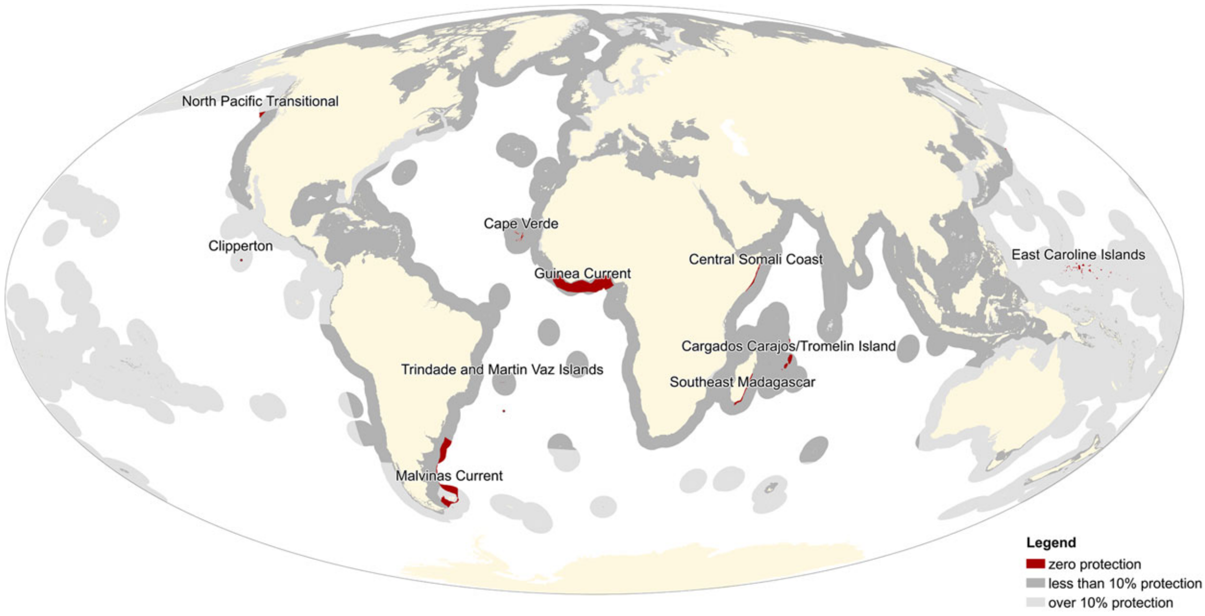

FIGURE 3 MPA coverage of ecoregions in 2016

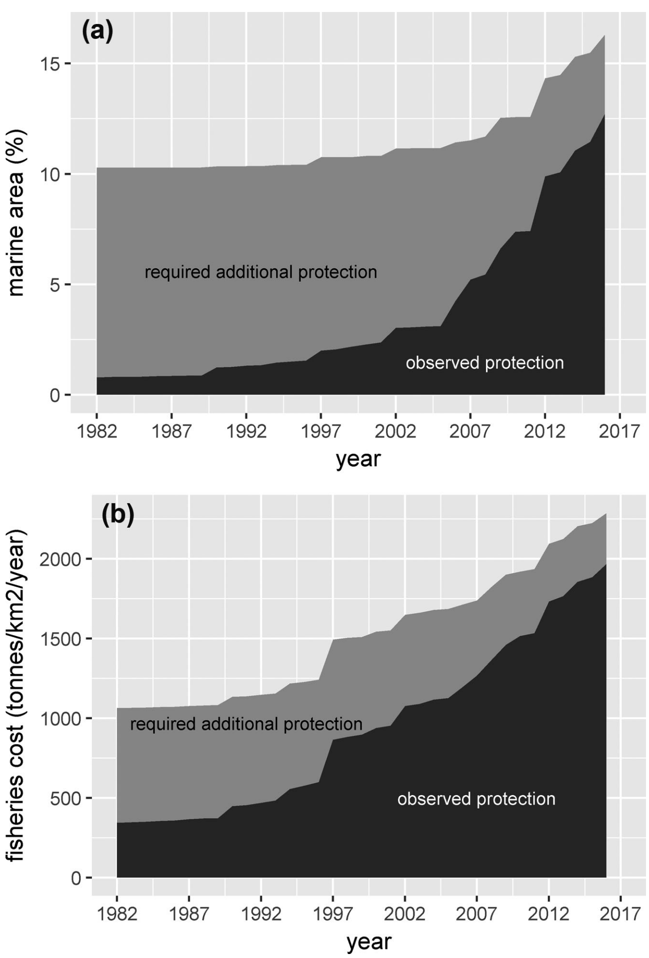

FIGURE 4 Observed and optimal area requirements (a) and fisheries opportunity cost (b) of MPA systems for different starting years of strategic planning

4 | DISCUSSION

Since the emergence of the first PA coverage target of 10% of each of the world's ecoregions in the year 1982, more than 12% of the global marine area under national jurisdiction has been designated as an MPA. While this 16-fold increase in MPA areal extent is one of conservation's greatest success stories (Watson et al., 2014), we found that MPAs have not been placed cost-efficiently and that expansion has not systematically targeted underrepresented ecoregions. One startling result shows that simply starting strategic expansion in 2011 could have led to a fully representative MPA estate with the same area as the 2016 MPA estate, which only adequately represents 39% of ecoregions. If strategic planning had started in 1982, a fully representative MPA system with high protection equality could have been established using far less area and cost than the current MPA system. The lack of strategic planning in past MPA expansion can be regarded as a massive lost opportunity for conservation.

In the past, poor representation of species and ecosystems in PA networks has been attributed to weaknesses in planning methods (Pressey, 1994; Stewart, Noyce, & Possingham, 2003). However, our analysis shows that MPA expansion has remained extremely inefficient over the past three decades, despite the rapid development of conservation prioritization techniques (Moilanen et al., 2009; Wilson, McBride, Bode, & Possingham, 2006). This is likely due to the numerous other considerations that dictate MPA placement beyond biodiversity value. These include intense opposition MPAs often face from fisher people and the fossil fuel industry, and consequently, a lack of political will to place MPAs where they will be most effective for conservation

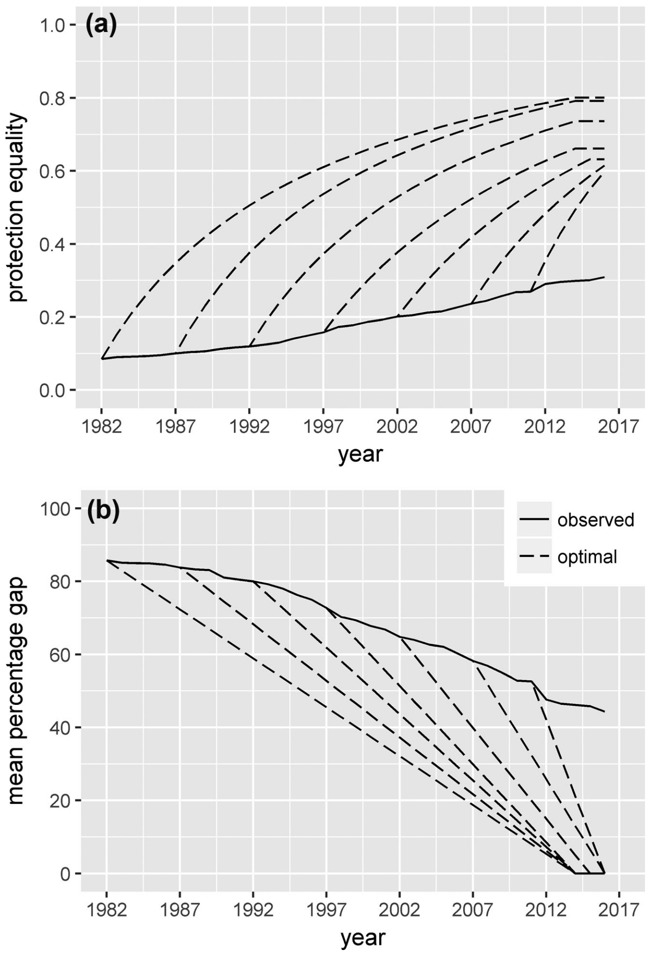

FIGURE 5 Observed and optimal trajectories of (a) protection equality and (b) mean protection gap of ecoregions in the global MPA system. Optimal trajectories are provided for different starting years of systematic planning. A mean percentage gap of 0 means that 10% of each ecoregion is protected

(Plasman, 2008; Voyer, Gladstone, & Goodall, 2014). Although there are some MPA networks, which were developed with the support of systematic conservation planning tools (e.g., the Great Barrier Reef Marine Park in Australia), the global MPA estate remains highly residual (i.e., placed in areas unsuitable for other uses) (Barr & Possingham, 2013). In addition to the poor placement of MPAs, the level of effective marine protection is likely to be much lower than the current 12.7% currently included in marine reserves, due to poor management effectiveness and the low proportion of total MPA area made up of no-take reserves (Gill et al., 2017; Robb, Bodtker, Wright, & Lash, 2011).

To improve marine conservation efforts, it is crucial that nations allocate adequate resources to MPAs, and strategically expand their MPA estates to achieve ecoregional representation. To encourage nations to do so, measuring progress towards global conservation targets must go beyond area-based reporting (Watson & Venter, 2017). New metrics, such as protection equality and mean percentage gap, allow thorough analyses of representation of biodiversity features such as ecoregions, ecosystems, and species. In the marine case, such analyses reveal that even though ecoregional representation of the global MPA estate as measured by protection equality tripled (to PE = 0.31) since 1982, current representation is still poor relative to PE levels found for specific marine sites such as the Great Barrier Reef (PE = 0.80–1.00; Barr & Possingham, 2013) and the Coral Triangle region (PE = 0.38–0.44; Chauvenet et al., 2017) as well as for terrestrial ecoregions (median PE across terrestrial ecoregions for 83 countries = 0.42; Barr et al., 2011). Transparent reporting on the ecological condition of MPAs is also essential, as intense human activity in MPAs may compromise their conservation benefits, by reducing species richness and abundance (Edgar et al., 2014; Rife, Erisman, Sanchez, & Aburto-Oropeza, 2013).

We show that inefficient historical MPA placement has led to a costly reserve network with poor ecological representation, but our work is subject to inevitable limitations. While representation could be measured in multiple ways, we focus on ecoregions as broad-scale surrogates for biodiversity, as this is how representation is measured in global conservation agreements (e.g., Aichi target 11; CBD, 2013). It is important to recognize that at smaller scales, MPAs are often designated to protect critical habitat and irreplaceable sites, and that our global broad scale analysis of representation misses this nuance. Our cost efficiency analysis is based on the assumption that MPAs have fisheries regulations in place to limit or exclude fishing. Although often essential for successful marine reserves, such regulations are frequently absent or not enforced (Campbell et al., 2012; Robb et al., 2011). Therefore, we are likely overestimating the true level of protection MPAs offer biodiversity. Our fisheries data from the period prior to 1982 do not capture recent changes in fisheries effort. While using different, for example, dynamic, cost layers would modify the MPA estate cost figures, our main conclusion—the current MPA estate is both expensive and ineffective—would not change. Further, we limited our analysis to national waters because current MPAs are concentrated in these areas, designation of MPAs is legally straightforward, and the coastal shelves hold most of the known marine biodiversity and fisheries productivity (Pauly et al., 2002). We did not account for the high seas, which make up 61% of ocean area, but currently have only 0.25% coverage by MPAs. We missed marine protection that exists through local rules, laws and practices, but without formally gazetted MPAs and we did not include MPAs without an establishment year in the WDPA dataset.

5 | CONCLUSION

It is clearly in nations' interests to start strategic conservation planning as early as possible to avoid costly and imbalanced reserve systems that are hard and expensive to adjust later. Global conservation targets are likely to increase post-2020 (Larsen, Turner, & Mittermeier, 2015; O'Leary et al., 2016; Wilson, 2016) and this research has provided a timely reminder of the large efficiency gains that strategic conservation planning can deliver during a period of MPA expansion, in terms of both biodiversity and minimizing reserve network cost. Future conservation strategies must call for implementing rigorous habitat and ecoregion-based target-driven planning in the process of establishing representative PA networks.

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