**Title: Effective coverage targets for ocean protection**

**Running Title: Effective targets for ocean protection**

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**Abstract:**

The UN's globally adopted Convention on Biological Diversity coverage target for marine protected areas (MPAs) is ≥10% by 2020. In 2014 the World Parks Congress recommended increasing this to ≥30%. We reviewed 144 studies to assess whether the UN target is adequate to achieve, maximise or optimise six environmental and/or socio-economic objectives. Results consistently indicate that protecting several tens-of-percent of the sea is required to meet goals (average 37%, median 35%, modal group 21-30%), greatly exceeding the 2.18% currently protected and the 10% target. The objectives we examined were met in 3% of studies with ≤10% MPA coverage, 44% with ≤30% coverage and 81% with more than half the sea protected. The UN's 10% target appears insufficient to protect biodiversity, preserve ecosystem services and achieve socio-economic priorities. As MPA coverages generated from theoretical studies inherently depend on scenario(s) considered, our findings do not represent explicit recommendations but rather provide perspective on policy goals.

**Main Text:**

## Introduction

Global concern regarding environmental degradation and anthropogenic impacts on marine ecosystems has led to urgent calls to increase the global coverage of marine protected areas (MPAs), the aim being to preserve and recover what remains of ecosystems and prevent further declines. The Convention on Biological Diversity (CBD) target currently commits signatory governments to conserving ≥10% of marine environments by 2020 through "ecologically representative" protected area networks (Convention on Biological Diversity 2010). The 2014 World Parks Congress called for at least 30 percent of each marine habitat to be included within highly protected MPAs, increasing a previous recommendation for 20-30% coverage made in 2003 (World Parks Congress 2014).

Marine protected areas are one of the principal tools advocated to preserve and maintain biodiversity and ecosystem services, and to mitigate negative effects of anthropogenic activities (e.g. Angulo-Valdés and Hatcher 2010; Halpern et al. 2010; Lubchenco et al. 2003; Roberts 2012). They are areas where human activities have been restricted to varying degrees with the aim of protecting living and non-living resources and, while most commonly established for conservation purposes, they are also recognised as a tool for commercial fish stock management and recovery (FAO 2011; Rice et al. 2012; Roberts and Hawkins 2012; Vandeperre et al. 2011).

Although protected area coverage targets have been controversial (Carwardine et al. 2009), they have driven international and national policy and collective action to increase conservation both on land and for the sea (Botsford et al. 2014; Gleason et al. 2013; Jenkins and Joppa 2009; Watson et al. 2014). While undoubtedly political, such targets should be based on robust scientific evidence if they are to meet their environmental objectives. Given the recent adoption by the UN of a Sustainable Development Goal for the oceans, with the 10% MPA goal embedded within it (Goal 14: Conserve and sustainably use the oceans, seas and marine resources), and of the upcoming CBD Conference of Parties in 2016, it is timely to evaluate the evidence base for effective MPA coverage.

Previous reviews in 2003 (N=40 studies, Gell and Roberts 2003) and 2010 (N=33 studies, Gaines et al. 2010) suggested that 20-40% coverage is warranted. In view of the large disconnect between the UN 10% MPA target and the results of these studies, a broader synthesis of current research is required. We investigate six objectives of MPAs that together encompass the results of all studies examined: (1) protect biodiversity; (2) ensure population connectivity among MPAs; (3) minimise the risk of fisheries/population collapse and ensure population persistence; (4) mitigate the adverse evolutionary effects of fishing; (5) maximise or optimise fisheries value or yield; and (6) satisfy multiple stakeholders (i.e. studies contain analyses designed to identify the required percentage coverage to minimise trade-offs between stakeholders and maximise value (e.g. Boncoeur et al. 2002)). These objectives were chosen following an initial scoping study and represent objectives orientated towards conservation goals (objectives 1, 2 and 4), socio-economic priorities (objective 5) or elements of both (objectives 3 and 6).

Here we conduct an assessment of scientific literature to determine whether existing targets for ocean protection are adequate to achieve, maximise or optimise the various objectives expected from MPAs, as appropriate to the goals considered.

**Methods**

*Selection of articles*

An intensive search of peer-reviewed scientific literature was undertaken in Web of Science and Scopus. In addition, we conducted a bibliographic search of all relevant review articles identified in our searches to ensure all relevant articles were identified. Initial searches were undertaken in December 2014 in Web of Science and subsequently updated in March and October 2015 in Web of Science and Scopus. Subsequent updates restricted searches in Web of Science to articles published during or after 2014 or 2015 respectively and undertook new searches in Scopus without date restriction. Search terms were identified by reference to articles cited in relevant reviews (Gaines et al. 2010; Gell and Roberts 2003), consultation with subject experts within the review group and simplified trial searches. Table S1 details the combinations of the search terms used. Only English language articles were assessed.

*Study inclusion criteria*

We established an a-priori protocol for the search strategy and criteria for inclusion and exclusion of studies in our review. Included studies were required to contain the following elements: *Population*: Any marine environment. Studies considering protected areas in estuarine, freshwater or terrestrial environments were excluded; *Intervention*: Included studies should consider the proportion of the sea that should be protected within MPAs to achieve, maximise or optimise the objectives they investigated. Studies that used an inadequate sample size to enable investigation of appropriate coverage were excluded (i.e. scenarios should assess a minimum of 4 percent coverage values across a range and results should clearly indicate where objective(s) were achieved/maximised/optimised); *Time and*

*Place*: Studies produced at any time and using any location as a case study were included, as were those using theoretical mathematical modelling approaches with numerical illustration; and *Outcomes*: Included studies must contain results that indicate a percentage, or range of percentages, of MPA coverage to achieve, maximise or optimise the objective(s) investigated within each study. Objectives may be related to environmental or socio-economic impacts, including but not restricted to: ecosystem functioning [biodiversity, abundance, connectivity] and human health and wellbeing [income, employment, fisheries yield]. Note that this percentage may be zero and that overall coverage can be calculated from appropriate size and spacing recommendations, e.g. an MPA size of 20 km width with spacing recommendations of 40 km would give a coverage of 33%. Studies that consider the design (size, spacing, shape, etc.) of MPAs but not overall coverage and where overall coverage cannot be calculated were excluded.

*Article screening*

The first 100 hits (based on sorting of relevance of results) from each search in Web of Science were screened. All articles identified in Scopus were screened. The results from each search were combined in a single Endnote library file and duplicates removed. All articles retrieved were assessed for inclusion in our review based on a hierarchical assessment of relevance by screening article titles, then abstracts of articles with relevant titles, followed by the full text of potentially relevant articles. Studies were considered relevant based on the inclusion criteria. If the relevance of articles was unclear at title and abstract stages they were included and assessed at full text. The aim of this process was to systematically remove articles that did not contain relevant information to our study. A schematic showing the processes involved in this review and numbers of articles and studies moving between stages is shown in Fig. S1.

*Data handling and analyses*

Data extracted from each relevant article included the full reference and the percentage(s) of area or stock protected which achieved, optimised or maximised the investigated objective(s).

Percent coverages were recorded according to each objective as either a range or single value depending on results reported within each study. Where multiple individual percent coverages were reported we recorded these as a range (i.e. the minimum and maximum values reported were recorded) to encompass the full spread of results. Analyses were undertaken based on the median of the range, or the single value reported by each assessed article. Equal weighting was assigned to each study contained within this synthesis as included studies are essentially theoretical and therefore no a-priori reason exists for weighting one study more highly than another. Each study was assigned to one or more objectives as appropriate. As results for each objective inevitably consisted of different sample sizes, numerically dominant groups will therefore be over-represented in combined results. Coverages for different objectives were statistically compared using the Kruskal-Wallis H test to ensure overall results were representative of all objectives. To further test for possible bias resulting from uneven sample sizes, equal weighting was assigned to each objective by calculating the proportion of studies within each MPA coverage class (0-10%, 11-20%, etc.), i.e. each objective totals to one, and then averaging results across objectives. For these data, the mean, median and modal group were estimated to enable comparison with our unweighted results. We used Mann-Whitney U to test for differences between required coverages in temperate and tropical ecosystems.

**Results**

We identified 126 relevant articles published between 1995 and 2015 (Fig. S2); 96.8% of which used modelling approaches (including numerical simulations, decision-support tools, species-area relationships and GIS modelling) with the remainder using literature review techniques (N=2) or expert/stakeholder driven processes (N=2). These articles collectively contributed 144 studies (i.e. data points) to our analysis, given some papers addressed multiple objectives. Included studies are detailed in Table S2. Considerable variability in required MPA coverage amongst studies was found however mean and median results were highly consistent across a diverse range of objectives, converging between 30-40% (Fig. 1 and Table S3). There was no significant difference in required coverage among the five different goals with sufficient sample sizes to offer adequate statistical power (protect biodiversity, ensure connectivity, avoid collapse, fisheries value and multiple stakeholder satisfaction: Kruskal-Wallis $H=2.59$, 4 d.f., $p=0.63$).

On average, the required coverage for protection to achieve, maximise or optimise the objective(s) investigated was 37% of the sea (median 35%, modal group 21-30%). Over half of all studies (56%) indicate that >30% of the sea should be protected to meet the goal they investigated (Fig. 2). 81% of goals were met with >50% coverage, but only 3% of goals were met with ≤10% coverage (Fig. 2). When equal weighting was applied to each MPA objective, it had minimal effect on the results (equal weighting of objectives: mean 35% coverage, median 32%, modal group 21-30%; Fig. S3). Table S3 provides summary statistics for each of the six objectives investigated and overall results. We also found no significant difference in required MPA coverage between studies undertaken with specific regard to either tropical (mean 34%, N=33 studies) or temperate (mean 38%, N=47 studies) ecosystems (Mann-Whitney U=726, Z=0.48, $N_1$=47, $N_2$=33, 1 d.f. p=0.63).

**Discussion**

Marine protected areas are a critical part of the toolkit for biodiversity conservation and fisheries management (Roberts et al. 2005). However, while observational evidence detailing their many potential benefits exists (e.g. Baskett and Barnett 2015; Caselle et al. 2015; Fenberg et al. 2012; Huijbers et al. 2015; Lester et al. 2009) it is not practical to experimentally answer how much of the sea requires protection to safeguard biodiversity, preserve ecosystem services and ensure socio-economic priorities. Consequently, syntheses of theoretical research examining aspects of this question are required.

Previous reviews (Gaines et al. 2010; Gell and Roberts 2003) have suggested between 20% and 40% of the sea should be protected to achieve MPA goals. We update, expand and increase the rigour of these analyses, identifying an additional 93 articles previously not considered and discounting a further 41 articles previously included on the basis of those articles not being sufficiently thorough to meet our inclusion criteria. Our findings suggest that the objectives we examined are rarely secure with MPA coverage in single percentage figures – the status quo – and the picture was little improved with ≤10% coverage. While achieving 10% coverage by 2020 is extremely ambitious politically, our research strongly indicates that 10% is only a waypoint towards effective ocean protection and governance, not the endpoint. Even the more ambitious target of ≥30% protection called for by the 2014

World Parks Congress (World Parks Congress 2014) may not be enough to meet all of the multiple objectives expected of MPA networks (e.g. Angulo-Valdés and Hatcher 2010), particularly if surrounding areas are not subject to good management (e.g. Micheli et al. 2004; Rodwell and Roberts 2004; White et al. 2010). However, improving management outside protected areas should ease the performance burden for MPAs and lower the eventual target coverage to be attained (e.g. Rodwell and Roberts 2004; White et al. 2010).

MPA coverages generated from any theoretical study inherently depend on the scenario(s) considered (e.g. species' life history characteristics, conservation objectives, MPA design characteristics, management outside the MPA(s), etc.) and most studies identify a range of coverages for protection rather than a specific fraction. In addition, it should be noted that none of the studies included within this analysis explicitly set out to address the question of how much of the sea should be protected globally but rather considered the implementation of MPAs within the scenario and/or case study area examined. Our findings do not therefore represent explicit recommendations for what global targets should be but rather offer perspective on political targets.

The evidence we examined showed that MPA coverages required to achieve objective(s) within individual studies varied substantially, largely due to the different scenarios considered (e.g. protection of rare species versus optimizing a fishery for a highly mobile species). Indeed, the range of values reported by studies illustrates the theoretical potential for optimal management to either exclude MPAs entirely (e.g. Holland and Stokes 2006) or to restrict human activities to very small areas of the sea and protect the remainder (e.g. Tanner 2001). The former example focused on the application of an MPA in a well-managed (fished at or below maximum sustainable yield) and previously unexploited fishery, while the latter identified maximum harvest in a prawn trawl fishery with the majority of the fishing ground protected and a very small area heavily exploited. The level of MPA coverage required can vary considerably from one place, habitat type or species to the next depending on their characteristics and the specific goals (e.g. representation of particular species or habitat or rebuilding overexploited fisheries, etc.) and management outside the MPA. Extreme values like 0% or 98% MPA coverage generally arose in studies considering single, narrow objectives. Given that MPA networks are always designed to achieve multiple objectives, with significant trade-offs between them, mean and median values of coverage will be more representative of those needed in practice than the extremes. Nonetheless, while there is strong consensus in the findings justifying global targets of the order of tens-of-percent MPA coverage, one should always consider specific circumstances at local scales.

The CBD target does not stipulate how much protection MPAs should have. Countries could therefore meet this target with MPAs that offer little protection from extractive or damaging activities. Estimates vary, but according to the authoritative MPAtlas (Marine Conservation Institute 2016) only just over 1% of the sea out of 2.18% in MPAs can be considered as highly protected[1]. While partially protected areas have been shown to provide some benefits to species' density and biomass (Sciberras et al. 2013), highly protected MPAs, also known as "marine reserves" or "no-take zones", have much greater benefits for habitats and species of conservation concern (Sciberras et al. 2013). Some MPA benefits may be achievable only with near complete protection (e.g. conservation of fragile

[1] Including currently proposed MPAs would result in this coverage increasing to 2.4% no-take MPAs out of 5.7% MPAs (Marine Conservation Institute 2016).

habitats, or of highly vulnerable species) while others would likely require a greater coverage of partially-protected MPAs to achieve the same outcomes. Highly protected MPAs also offer important contributions to fishery management goals (Vandeperre et al. 2011) and, if cooperatively designed and managed, may act to reduce conflict among stakeholders in multiple use areas (e.g. Mazor et al. 2014; Ruiz-Frau et al. 2015).

Some critics have argued that different design principles and MPA coverage are necessary for different environmental settings, or to meet different objectives such as biodiversity conservation versus fisheries enhancement (Hilborn et al. 2004). We found required MPA coverages of several tens of percent to be highly consistent across a diverse range of objectives (Fig. 1) and in temperate vs tropical settings (Table S3). This convergence of results reveals the considerable opportunities for strategic designs to achieve many objectives simultaneously.

Percentage based targets have been criticised for several reasons. Some people consider them to be based on little scientific evidence or ecological knowledge or to imply guaranteed protection if targets are met regardless of enforcement and additional management measures for the matrix surrounding MPAs (Carwardine et al. 2009). In addition, the significant areas indicated by this study may be considered politically unachievable (Carwardine et al. 2009). However, while the 10% target is simpler politically, the evidence suggests it is highly unlikely to generate the benefits aspired to by the CBD. In the rush to fulfil targets, there is also concern that MPAs will be designated in areas with low biodiversity value or few human activities to increase social and political acceptability. Likewise there is the risk of creating networks of paper parks where management and enforcement is negligible if it exists at all. Both these outcomes would limit effectiveness. Having said that, establishing MPAs to protect intact environments in areas of limited human activity to prevent degradation before it occurs, such as seen in the recent creation of many very large, remote MPAs (Wilhelm et al. 2014), will make a highly valuable contribution to a global MPA network and is comparable to the wave of designation of large and intact terrestrial protected areas that occurred decades ago (Cantú-Salazar and Gaston 2010; Naughton-Treves et al. 2005).

All management strategies have drawbacks. However, establishing a global MPA target has many advantages which we, and others, believe outweigh such shortcomings: they are simple to convey, politically tractable and explicitly incorporate the ecosystem approach (Carwardine et al. 2009); they help mobilise support for conservation and generate political will (Wood 2011); and, if designed appropriately, they provide measurable objectives and a clear purpose (Wood 2011). Based on our review, we conclude the UN 10% target is too low and that the 2014 World Parks Congress call for ≥30% of the sea in highly protected MPAs is strongly supported by existing evidence.

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## Figure Legends

**Fig. 1.** Tukey boxplot showing the range of required coverage for each MPA objective: (1) protect biodiversity (N=29, median 32%, range 9-80%); (2) ensure population connectivity (N=9, median 27%, range 13-68%); (3) minimize the risk of fisheries/population collapse and ensure population persistence (N=20, median 46%, range 10-76%); (4) mitigate the evolutionary effects of selective fishing (N=4, median 35%, range 25-59%); (5) maximise or optimise fisheries value or yield (N=58, median 40%, range 0-98%); and (6) satisfy multiple stakeholders (N=24, median 33%, range 10-80%). Outliers shown by open circles.

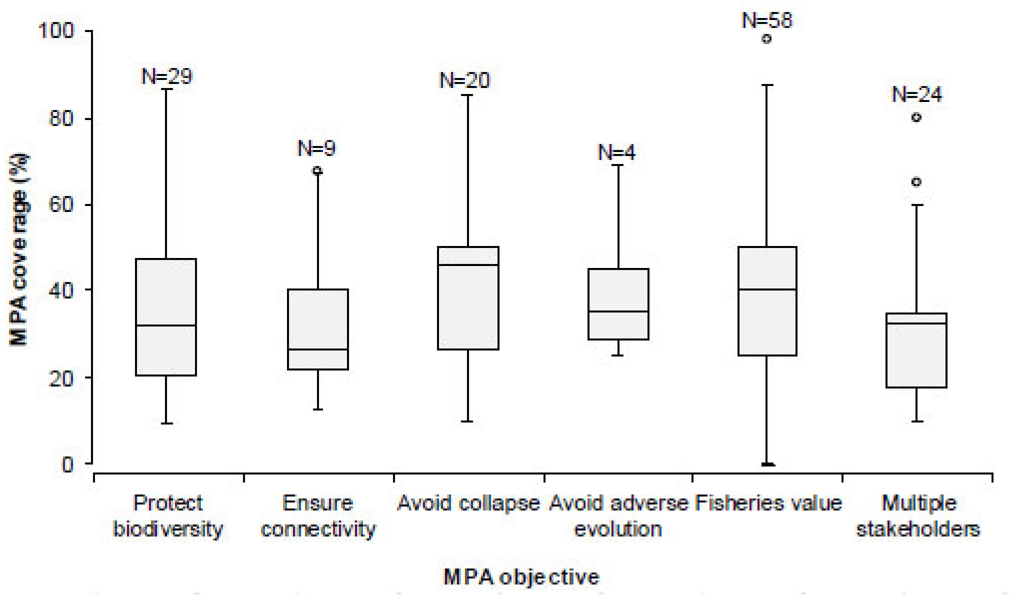

**Fig. 2.** Frequency distribution of the required coverage for protection to meet MPA objectives based on 144 studies. Cumulative frequency (solid line) showing the percentage of studies that consider MPA goals will be met at each coverage level.