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Making protected areas effective for biodiversity, climate and food

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Abstract

The spatial extent of marine and terrestrial protected areas (PAs) is amongst the most intensely debated issues in the post-2020 Global Biodiversity Framework of the Convention on Biological Diversity. Positive impacts of PAs on habitats, species diversity and abundance are well documented in many locations. Yet, biodiversity loss continues unabated despite efforts to protect 17% of land and 10% of the oceans by 2020. This casts doubt on whether extending PAs to 30% or even 50% would achieve hoped for biodiversity benefits. Critically, the focus on area coverage overshadows the need to focus on PA effectiveness and overlooks concerns about PAs impacts on food security and other sustainability objectives. Given that the choices made now about PAs could tip the balance towards either negative or positive outcomes for biodiversity and people, we propose a simple means of visualising the complex relationships between PA area coverage and effectiveness and their effects on biodiversity conservation, nature-based climate mitigation and food production. Our analysis illustrates how achieving a 30% PA global target could be beneficial for biodiversity, climate and food. It also highlights several important caveats: i) achieving lofty area coverage objectives will likely be of little benefit for biodiversity or climate without concomitant improvements in effectiveness, ii) there could be tradeoffs with food production particularly for high levels of coverage and effectiveness and iii) important differences in terrestrial and marine systems should be taken into consideration when setting and implementing PA targets. The CBD's call for a significant increase in protected area would need to be accompanied by clear PA effectiveness goals to reduce and revert dangerous anthropogenic impacts on socio-ecological systems and biodiversity.

Introduction

Biodiversity loss and climate change are progressing at an alarming rate[1,2]. In response to this challenge, terrestrial and marine protected areas (PAs) are increasingly recognised as being central to biodiversity conservation[3-6]. Aichi Biodiversity Target 11 of the Convention on Biodiversity (CBD) was formulated with the aim of protecting 17% of the terrestrial surface and 10% of oceans by 2020. PAs are generally not only more species rich than neighbouring areas, they also contribute to avoiding species extinctions, habitat loss and degradation (i.e., also supporting the objectives in Aichi Biodiversity Targets 5, 6, 12, 14, 15). It is not surprising, therefore, that PAs feature prominently in the CBD's post-2020 Global Biodiversity Framework (GBF)[7]. As most of the Aichi targets have not been achieved[1], this new framework seeks to increase global efforts towards biodiversity protection for the periods to 2030 and 2050 (https://www.cbd.int/conferences/post2020/wg2020-03/documents, CBD/WG2020/3/3).

The first draft of the GBF calls for a very ambitious increase to at least 30% of land and marine areas to be protected by 2030, and while this objective is still under negotiation, a coalition of 78 governments is strongly supporting its adoption. The UN Framework Convention on Climate Change has also recognised the co-benefits of PAs for climate change mitigation in regions where biodiversity-rich and carbon-rich ecosystems correspond[8,9]. Conversely, concerns have been voiced that a large expansion in PAs could compromise climate change adaptation in human societies and the provisioning of a broader set of ecosystem services, food in particular, due to PAs competing for space with other human uses[10-12].

PA coverage is a relatively easily measurable indicator of conservation effort. However, the effectiveness of PAs is critical for conservation success[13,14]. Ignoring the two-dimensional space that defines PAs (that is: area *and* effectiveness) will limit their contribution to successful biodiversity outcomes. The first draft of the GBF includes a call for 'effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures'; however, i) progress towards these objectives set in the Aichi targets was weak and ii) effectiveness is difficult to measure.

The nature's Green Shoots framework and visualisation

The approach outlined here to visualise the synergies and trade-offs arising from protected areas and their impacts on biodiversity, climate change mitigation and food production is inspired by the "Burning Embers" diagrams that are used to synthesise and communicate climate change risks for natural and human systems in assessment reports of the Intergovernmental Panel on Climate Change (IPCC)[15,16]. Nothing similar exists for the biodiversity crisis. By focusing on risks, the Burning Embers do not identify the possible policy levers and sets of actions to reduce these risks. We propose, therefore, nature's 'Green Shoots', as a complementary approach to inform international biodiversity and climate change policies that goes beyond the identification of risks towards the analysis of solutions.

The y-axis in *Figure 1* gives the global surface of terrestrial or marine ecosystems within PAs. The analysis is separated into terrestrial and marine realms because of their different pressures, functioning and governance structures. When assessing solutions, a second dimension is required. The x-axis thus gives the "effectiveness" of PAs, which is defined here as a combination of three important enabling conditions: *where* PAs are sited, *how* PAs are run, and the ability or capacity *per se* to *implement* them.

The colours in the graphics represent the outcomes of PA coverage and effectiveness for selected sustainable development objectives: in this case, biodiversity, climate and food. The colour gradient is set from grey, indicating the poorest outcome, to green that indicates the most positive outcome (see *Supplement* and *Shoots_PA.xls* for a further description of the method; an alternate colour scale is provided in the *Supplementary Figures SI-1 and SI-2*, recognising colour vision deficiencies). The method assumes that PA coverage (y-axis) and PA effectiveness (x-axis) are independent in determining the overall outcome.

The colour transitions chosen are qualitative, and involve judgements made by the authors, informed by outcomes of assessment reports of the IPCC and IPBES[1,2,17] and by a large literature review (see text and *Supplementary Tables S1 and S2*). Colours represent the outcome of a change in PA in relative terms, the default colour transition is linear but can be non-linear if supported by the literature. As one moves from the current status to areas towards the green end of the gradient the outcomes are considered to substantially improve for biodiversity conservation, climate change mitigation or food provisioning. As one moves towards the grey end of the gradient, outcomes are considered to become considerably worse. The Green Shoots approach allows exploration and visualization to communicate alternative scenarios of PA coverage and effectiveness that are widely discussed in the literature. For instance, 30% and 50% PA coverage may well be reached without overcoming the barriers that affect current effectiveness levels (e.g. resources, knowledge, political will; examples indicated by '1' and '2' in *Figure 1*). Likewise, 30% and 50% PA coverage may be reached whilst overcoming current barriers to PA effectiveness (indicated by '3' and '4', *Figure 1*). Note that the level of uncertainty in colour attribution rises for global PA coverage and effectiveness as they depart from current levels. We assess moderate-low uncertainties with identifying present-day conditions, and with the direction of the response (i.e., whether the implementation of a measure would lead to an overall positive or negative impact) reflecting the paucity of quantitative information at a global-scale level regarding biodiversity and ecosystem responses to the measures addressed in this review.

Our analysis focuses on the global scale. Likewise, the judgements underpinning colour transitions are made without considering other changes such as human population growth or climate change impacts, which would influence how PAs interact with biodiversity, food production, or carbon uptake and storage. The Green Shoots are designed flexibly (*Shoots_PA.xls*) to allow such additional aspects to be factored in and may also be applied at regional or national scales, given that synergies and trade-offs arising from increasing PA coverage and effectiveness will differ between social-ecological contexts and geographic regions.

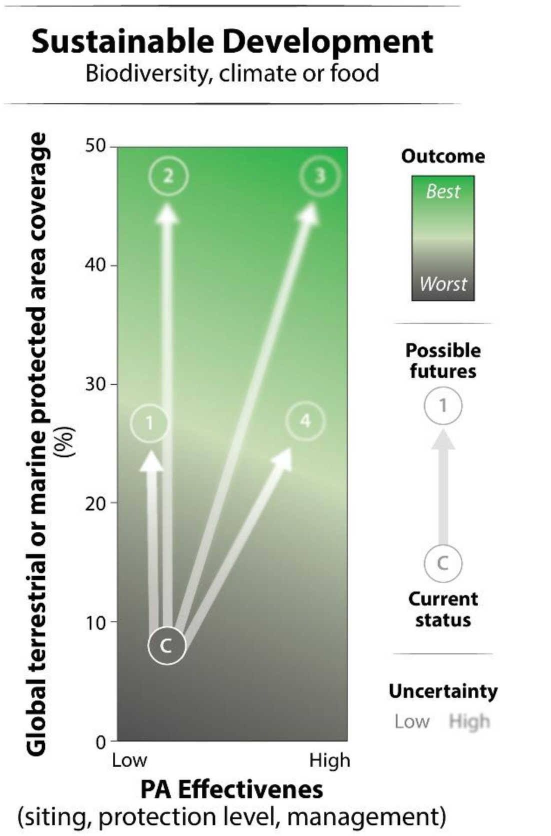

Figure 1: 'Green Shoots' template as used for the analyses shown in Figure 2. The y-axis gives the global surface terrestrial or marine ecosystems in PAs (as a percentage) where the scale ranges from 0% to a maximum of 50%, which is the highest commonly cited figure for maximum global PA coverage [18,19]; the x-axis ranges from low to high level of effectiveness. "High" on the effectiveness scale indicates that most PAs are optimally sited, under strict protection (sensu IUCN PA categories I and II), well managed and adequately resourced. "Low" indicates that most PAs are sited in areas of low biodiversity value, have low levels of protection (sensu IUCN PA categories V and VI), are poorly managed and have insufficient financing. An encircled 'c' is used to represent the current global status of PA coverage and estimated effectiveness. Numbers '1' and '2' represent cases where (close to) 30% and 50% PA coverages are approached, respectively, without overcoming the barriers that affect current effectiveness levels. Numbers '3' and '4' represent cases where 30% and 50% PA coverage are approached, respectively, whilst overcoming current barriers to PA effectiveness. Increasing uncertainty of location of colour transitions are indicated by increasing fuzziness in the circles. Arrows are included here to guide the eye. Additional information: see Supplementary text and figures and Shoots_PA.xls.

Current status of Protected Areas

Terrestrial protected areas (TPA) currently cover about 15% of the Earth's ice-free, land surface and achieving this coverage by 2020 was one of the very few near successes of the Aichi Biodiversity Targets set in 2010[20]. However, the current TPA network is insufficient to cover a significant amount of the geographical range of most known plant and animal species[13,21]. For todays' TPA network, one estimate is that <70% of bird and mammal species, <35% of reptiles and amphibians have adequate representation[22]. Of vertebrates threatened with extinction, only 19% of their range is represented on average[23].

The overall success of TPAs in terms of nature conservation is reduced by inadequate management and siting[21]. TPAs are often placed in areas with limited human-use potential, rather than areas of high biodiversity value[21,24]. Earlier estimates of average management effectiveness varied between 45% and 55%[4,25]. Others have found that less than 25% of TPAs have adequate financial and staff capacity to achieve their objectives, resulting in only 4-9% of terrestrial mammals, amphibians and birds having ranges that were protected by those TPAs that have sufficient resources[26]. For forests, when shortcomings in effectiveness are taken into account, only 6.5% can be considered protected[27]. While there is agreement that TPAs have been somewhat effective in avoiding land conversion and that species diversity is higher inside than outside TPAs[4], our overall assessment of today's effectiveness is of the order of 20% between lowest and highest (*Figure 2, 'c'*).

Likewise, evidence from the literature shows that the global network of marine protected areas (MPAs) underperforms and therefore sits at the low end of the effectiveness scale, similar to the TPAs (*Figure 2*). Observed MPA coverage is presently about 7.5% of coastal and marine waters[28], but with at most only half being truly implemented[28-30]. Among these, only 71% were found to be effective to some extent[29,31]. The current system of MPAs falls short in providing adequate coverage of species geographical ranges[5,32,33] and the diversity of ecosystems[28]. In addition, a significant proportion of those MPAs do not have the sufficient levels of size and protection[34,35], management capacity[29] or enforcement[36] to be fully effective (*Supplementary Material, Tables S1 & S2*).

Protected Area Targets for 2030-2050

Increasing both the coverage and effectiveness of TPA and MPAs over the coming decades would help to slow the loss of biodiversity. There are, however, on-going debates about i) the emphasis on increased area *vs*. improved siting, protection levels and management[34], ii) the fraction of land or ocean that would be desirable to include in protected areas[13,19], and (iii) the contribution of other effective, area-based conservation measures[37,38].

Some argue that as much as half of the Earth's ice-free land surface should be set aside for PAs to ensure adequate protection of species and ecosystems[18]. The argument behind 'Half Earth' draws on studies showing that 85% of plant species could be protected in this way[39], which others extended to ca. 85% of all species based on relationships between species and required habitat area[18]. There is considerable debate about the degree of protection that should be conferred on these areas: proposals include relatively strict protection from human activities, while others suggest an approach that would allow for sustainable use of biodiversity alongside agricultural activities[19,37,40,41]. Under some assumptions, even at the highest level of effectiveness, a TPA of 50% would not cover all plants [24] and all mammals (which potentially would require 60% of all land[42]).

While these estimates in themselves are controversial[24,43] the importance of increasing today's TPA effectiveness and need to overcome shortcomings regarding financing, management or placement is still not central to the debate[13,24,44], although some studies have argued that the primary emphasis indeed should be on increasing effectiveness given limited land resources[45-47]. With a focus on TPA effectiveness, protection of up to about a third of land has been estimated to provide major improvements in coverage of all species (including non-vertebrates) and ecoregions [13,23,48-51], and this corresponds to the ambition to set-aside 30% of land for TPAs by 2030, as specified in the action targets of the first draft of the GBF.

With respect to siting, different perspectives on biodiversity (e.g., species diversity, endemism, ecosystem intactness) can lead to very different PA configurations, which will result in different sets of co-benefits and trade-offs. Nevertheless, siting of TPA networks could acknowledge different biodiversity priorities through improved spatial planning to prioritize areas of high biodiversity value jointly with ecological representativeness[45-47]. We reflect these views in *Figure 2* such that at high effectiveness, protection of biodiversity rapidly improves with increasing TPA coverage, but with diminishing returns[13,52] (smaller benefits as TPA percentage increases above ca. 30%; *Figure 2, Shoots_PA.xls in the Supplement*). Such a diminishing return is expected as, for example, increasing

TPA coverage results in higher levels of connectivity[53,54], and TPAs increasingly capture whole foodwebs and communities (rather than species)[55]. However, if resources to establish and manage TPAs remain limited, expanding to 30% or even 50% TPA coverage will barely enhance biodiversity protection, and even be poorer than 20% TPA coverage with resources dedicated to increased effectiveness. The minimum value is set to occur at 0% protected areas; while the maximum value (dark green) occurs at 50% protected areas with high effectiveness.

As with TPAs, MPAs can lead to significant conservation outcomes such as increases in fish density, size, and biomass[48], as well as in species richness and functional rarity[49], and restore food webs and habitats[50,51]. While the literature on TPAs focuses mostly on impacts on species richness or abundance, protected biomass is most commonly used in marine studies as an indicator for evaluating MPA performance (*Figure 2; Shoots_PA.xls*). The biodiversity benefits of MPAs vary greatly in magnitude depending on coverage or effectiveness. As for TPAs, siting[30] and management[29] play a major role. MPA effectiveness has also been shown to be strongly dependent on the MPA levels of protection[56], with positive outcomes mostly observed for fully or highly protected areas (high end of effectiveness axis) and barely observed for lower levels of protection (low end of effectiveness axis)[35]. Hence, if the levels of protection are too low[35,57], the management capacity insufficient[29], or MPAs poorly placed[32], MPAs barely deliver positive outcomes, even at large coverage of 30% or even 50%.

When considering well-functioning MPAs, positive biodiversity outcomes generally increase locally with MPA size[6] and regionally with overall coverage[58,59]. A recent synthesis proposed that at least 30% of the oceans should be covered by PAs to efficiently protect biodiversity, ensure population connectivity among MPAs and population persistence[59], and minimize the risk of fisheries and population collapse and ensure population persistence[59]. Achieving 30% protection would also help mitigate the adverse evolutionary effects of fishing, maximize or optimize fisheries value or yield, and thus satisfy multiple stakeholders[59]. The rate of biomass increase within MPAs is expected to be sharp up to 30% global coverage with a lower increase for higher coverage, up to 50%[57,59].While increasing MPA coverage up to 50% of the global oceans is being debated, this target so far lacks a strong scientific basis for a proven increase in performance.

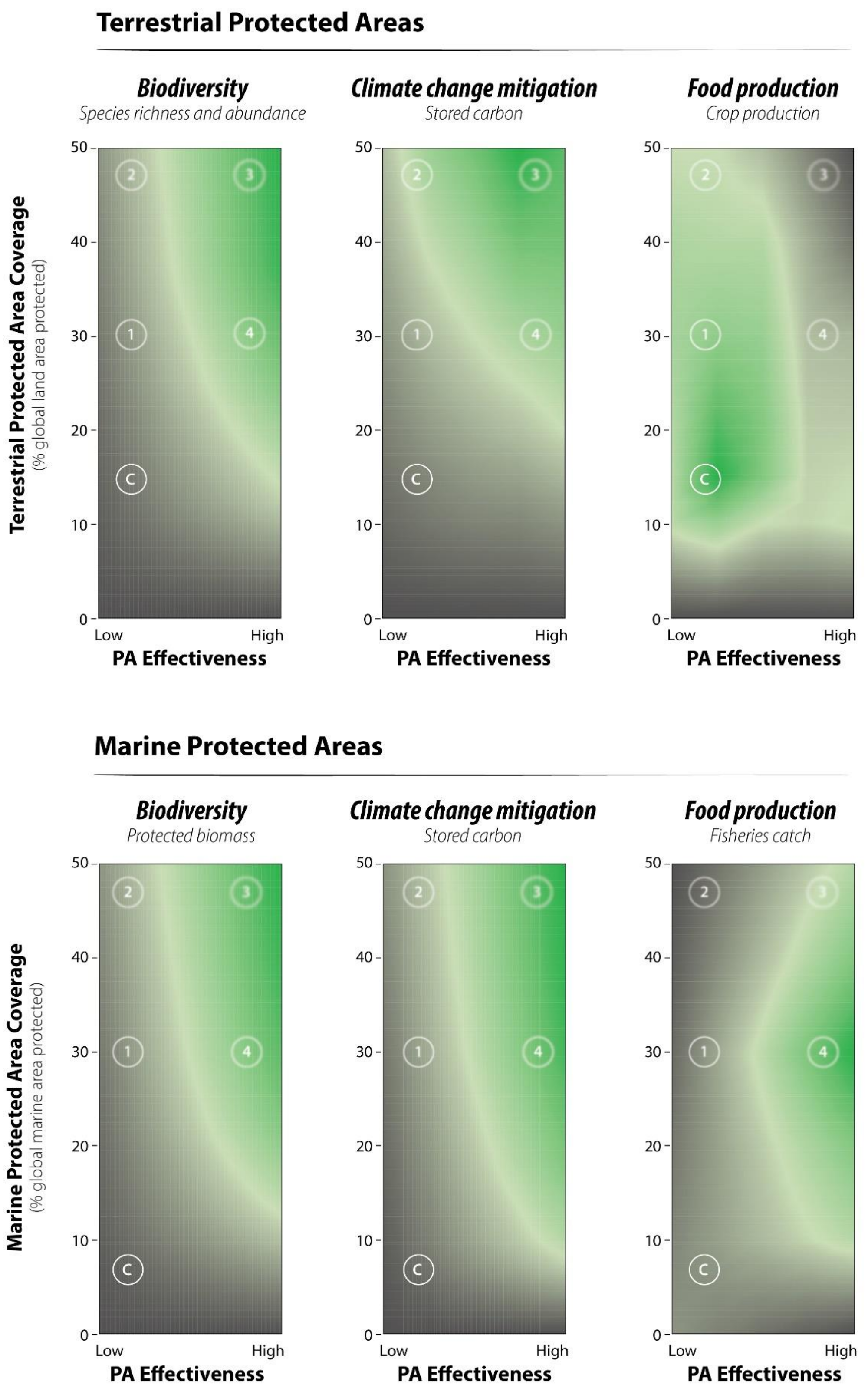

Figure 2: Impacts of terrestrial (top) and marine (bottom) protected areas on biodiversity, climate and food. The y-axis is the percent of global surface terrestrial or marine ecosystems in PAs where the scale ranges from 0% to a maximum of 50%. The x-axis, effectiveness: represents i) siting (i.e., how well PAs are sited based on biodiversity criteria alone), ii) protection level (i.e., how well the type and amount of impacting human activities are regulated within the PA), and iii) management effectiveness. Today's status is indicated by a 'c'. 'Biodiversity': intends to integrate across all domains of biodiversity, but

most terrestrial literature relates to species diversity or abundance, whereas most marine studies use protected biomass as the most common indicator. 'Climate': climate change mitigation through maintenance of marine or terrestrial ecosystems and increase of ecosystem carbon stocks. 'Food': estimated by fishing yield per effort (marine) and land area available for crop production (terrestrial). Colour transitions are based on an assessment of the literature (see manuscript text and S.I.), uncertainties for the present day are medium-low and increase when moving towards higher area coverage and, especially, higher effectiveness. Uncertainty in the Green Shoots is largest in the top right corner of each diagram, which is farthest from the situation today.

PA impacts on carbon uptake and storage, and food production and fisheries

On land, areas of high biodiversity and high carbon stocks generally correspond, notably in many pristine forests, wetlands and savannahs[8,51]. Protection of valuable areas that are still largely intact creates therefore climate change mitigation co-benefits by avoiding potentially large carbon losses while also maintaining substantial, extant carbon sinks[8,60-62]. Conservation actions that target biodiversity-rich areas that are already under threat can provide additional biodiversity-carbon co-benefits, albeit at a smaller scale[8]. Avoiding further conversion of these areas into land used for agricultural production is important given that only between 12% and 21% (depending on the choice of biodiversity indicator) of joint carbon and biodiversity "hotspots" are currently protected, while carbon losses from the conversion of natural land continue to be substantial ('current', *Figure 2*)[8,63]. The restoration of ecosystems will achieve further positive synergies for both species and carbon pools, if both goals are pursued simultaneously[64]. That is why an increase in TPAs to, for example, 30% may only provide modest climate mitigation benefits at current levels of effectiveness, since little protection of carbon stocks and sinks would be provided. Positive impacts increase rapidly as the effectiveness of protection increases[12]. However, if the selection of TPAs is based on strict biodiversity considerations (i.e., highest effectiveness), the carbon benefits would not be equivalent since biodiversity and ecosystem carbon sinks are not perfectly co-located across all world regions [8,64]. Even at 50% TPA, carbon sequestration would be expected to be somewhat lower when e.g., biodiversity hotspots are given priority, compared to siting that accounts for the co-location benefits[8,55]. As such, the optimal solutions for climate would be large areas being protected at, from a biodiversity perspective, medium-to-high effectiveness (*Figure 2*).

Protected areas can hamper the ability to produce, harvest and trade food and fiber, especially if these activities are fully excluded from PAs[65,66]. Given that considerably more than 50%, of the ice-free land surface is already used for food, feed, fiber and timber production, and millions of people remain undernourished[17], conflict with expanding TPAs is inevitable. While new TPA could all be placed in unproductive regions this would be contradictory with the goal of improved TPA siting. Relatively low TPA coverage reduces global competition for land, which is advantageous for food production. However, TPAs provide watershed protection and habitat for pollinators, support traditional farming systems and act as reservoirs for genetic resources[65,67-69], such that absence of TPAs would diminish global food production (*Figure 2*). Current land use has developed with a primary focus on agricultural productivity. Today's TPAs do not limit production, while providing benefits to surrounding agricultural regions and therefore are represented as broadly beneficial ('current', *Figure 2*) for global production. At very low TPA efficiency, their beneficial roles are unlikely to be realised even with high PA coverage, even though land area competition is modest in 'paper parks'[70].

The level of protection but also the location affects the resulting trade-offs. Protection of primary ecosystems stops agricultural expansion into these areas but does not require reconfiguration of the current food system (i.e. changes in existing demand or production). However, the extent of such ecosystems not already protected is limited, and the ongoing biodiversity loss requires expanding TPAs in productive agricultural regions. Conflicts over land resources therefore will likely become acute if PA coverage were to increase substantially, especially if the level of protection increased and/or if protected areas were placed where both agricultural and biodiversity values are high[11,12,71,72]. Food could, in principle, be produced on less agricultural land by increasing the intensity of agricultural production (i.e. land sparing [73]). But the impacts of TPAs on food security at very high levels of coverage (i.e. both 30% and 50% TPAs) with a strong conservation focus (i.e. strict protection) could increase food price increases and food insecurity[11,12,74], reflecting higher costs of inputs arising from production intensification. Higher food prices would be most severe for poorest globally and add to rates of malnutrition[11,74]. Increasing agricultural water withdrawals and pollution from greater fertiliser and pesticide use[11,12,40,75] would have negative biodiversity and societal consequences in the remaining agricultural areas[11,40,75].

The climate change mitigation benefits of establishing MPAs are mostly the result of protected and enhanced marine carbon pools, commonly referred to as Blue Carbon[76-78]. So far, only three marine ecosystems (mangroves, seagrasses and tidal saltmarshes) have been officially recognized by the IPCC as blue carbon sinks, and can count towards countries Nationally Determined Contributions (NDCs). These are also biodiversity-rich ecosystems. However, other important carbon pools such as marine animals and marine sediments are receiving increasing attention[78-80]. MPAs can contribute to climate change mitigation by increasing blue carbon pool sizes, which occurs when protection allows ecosystems to recover. Just as for other MPA outcomes, climate benefits heavily depend on MPA effectiveness. Indeed, low levels of protection fail to protect sediments and the sequestered carbon from trawling[81,82], and fail to increase fish biomass[35], an essential link to export carbon to deeper waters and seafloor sediments[83]. For the effect of area coverage on carbon sinks, it is expected that strong gains would be obtained with a small coverage of strategically placed MPAs on specific carbon pools. Indeed, an estimated 3.6% of ocean protection would allow protection of most of the currently trawled area[30], and coastal vegetated ecosystems only cover 0.2% of the ocean surface[84]. Additionally, the most carbon rich sediments are concentrated in the shallow seas, which represent only 21% of the ocean area[85]. However, several species-rich marine ecosystems, such as coral reefs, do not store substantial amounts of carbon. Hence, the overall positive climate outcome of MPAs would be somewhat diluted if MPAs were sited only according to biodiversity considerations. As such, the response curve of carbon sequestration benefits to the level of effectiveness has similarities with that of biomass benefits, such that little or no benefits are obtained at low levels of protection, steep increases are expected with increasing level of protection and effectiveness, and slower increases after the 30% coverage is met, when all Blue Carbon ecosystems are protected.

The proportion of overexploited (34.2%) and maximally sustainably exploited marine fish stocks (59.6%) has reached unprecedented levels[86], illustrating once more that both coverage and effectiveness of today's MPAs are insufficient to contribute to food security (point 'c', *Figure 2*). In most cases, food production, expressed here as fisheries catch, increases as MPA coverage increases because of the spill-over of adults and the export of eggs and larvae outside of MPAs[87] – unless the level of protection effectiveness is too low to significantly reduce fishing mortality. Larger fish inside MPAs produce more offspring per unit of body mass than smaller fish and export of this increases production outside of an MPA resulting in much higher yields for fishing fleets in neighbouring areas [88]. MPA benefits for food are expected to be the highest at around 30% coverage, where increased catches outside MPAs can offset lost fishing grounds. At higher coverage, catches are expected to decrease due to a squeezing effect, where fishing effort concentrates in reduced fishing grounds[89]. However, if political and socioeconomic constraints are prioritized over biodiversity considerations in MPAs, some studies point to the possibility of fully protecting the whole areas beyond national jurisdiction – 62% of the surface of the global ocean. Given that more than half of the high-seas fisheries would not be profitable without government subsidies, this could be achieved by removing subsidies[90-92], but studies to estimate the gains for biodiversity, climate and food of such a measure are required.

Synergies and tradeoffs between biodiversity, climate, and food

Reversing the loss of biodiversity, mitigating climate change, and sustainably feeding a growing human population are three critical and highly interlinked challenges. Since the magnitude of the problem is well understood, the scientific community is increasingly tasked with identifying solutions to support international policies[93,94]. The Green Shoots visualisations in *Figure 2* are intended to synthesise information across a range of challenges and indicators and thus to provide a globally-integrated means of evaluating the usefulness of a policy measure in achieving multiple environmental or societal goals at the biodiversity-climate-food nexus.

From the literature, we assess the overall biodiversity response of TPAs and MPAs to increases in both extent and effectiveness to be broadly similar (*Figure 2*). TPAs and MPAs with weak management clearly are of little or no help in protecting biodiversity[13,23,32,35,44,56], which underpins the importance of committing resources and political will to improve PA effectiveness. The first draft of the GBF, which proposes to increase both TPA and MPA targets to 30% of the land area and coastal and marine waters, is supported by scientific evidence only if PAs are implemented in an effective way. The significant disconnect that exists at present between what is being pledged by governments in terms of resources to do so, and what is available in reality for implementing conservation measures[95] is therefore of concern.

The Green Shoots as presented here support the growing consensus of better integration of the CBD and UNFCCC policy targets. 30% or 50% PAs with high effectiveness can contribute substantially to climate change mitigation. It is important to note, however, that nature-based solutions for climate change mitigation, such as maintaining and enhancing carbon uptake and storage in marine and land ecosystems, are not alternatives to phasing-out fossil-fuels[2].

Synergies between increased PA coverage and food production exist, but trade-offs are unavoidable, with differences emerging between MPAs and TPAs concerning effectiveness and total PA coverage. In the ocean, at the lowest levels of effectiveness, MPA area-benefits for food supply will be negligible, while TPAs that are not protected well allow agricultural activities – even though TPA-crop yield benefits arising from e.g., pollinator protection may be small. At very high levels of effectiveness, and high coverage, PAs can negatively impact food security – the trade-off in this case being markedly greater for TPAs than MPAs. The combination of 30% PA coverage at high levels of effectiveness is highly beneficial for the supply of seafood, but already compromises food production on land. The challenges arising from the competition for land between nature protection and food production could, however, be addressed by reducing food losses and wastes and by changing diets[96,97]. This would also contribute to more equitable global food distribution[96]. Reducing food waste and striving for globally equitable supply would also have benefits for marine systems, and the societies that depend on them.

The trade-offs between biodiversity and food production are strongly influenced by how PA coverage is increased. TPA expansion into areas that are still predominately natural would have relatively little impact on food production, but PA expansion through ecosystem restoration on agricultural land would have large impacts on food. Given the need to feed a growing population, large-scale, ecosystem restoration on agricultural land is challenging, although for some national contexts PA expansion through restoration may be relevant, at smaller scales.

The choices made now about PA extent can tip the balance toward either negative or positive outcomes across nexus challenges – such as demonstrated here for biodiversity, food and climate. Urgent action is needed to avoid dangerous levels of anthropogenic interference both in the climate and socio-ecological systems, but it is important to get these actions 'right', especially since some of the benefits will accrue only with time. Our analysis in principle supports 30% PA as a global target, as currently drafted in the GBF. For such a target, cross-nexus co-benefits are achievable if PA effectiveness and coverage are prioritized equally. It will be essential, however, to adopt additional measures to avoid losses or overconsumption in the food system. Given siting, protection level, and management effectiveness, national and global policy could foster the much-needed compromise between PA expansion through restoration and increased protection of remaining natural ecosystems. The former will have immediate impacts on food production on land while carbon and biodiversity benefits will only increase with time. The latter will have immediate biodiversity and carbon benefits, while impacts on food systems depend on many factors such as future population growth and the capacity to maintain or enhance production from existing agriculture and fisheries sustainably. For both restoration and protecting natural ecosystems, increasing PA effectiveness is as important, if not more so, than increasing PA coverage. Specifying, and even hitting, targets defined only in terms of area will not achieve biodiversity goals, nor will they create synergies with other sustainability objectives.

To reflect these findings, the area-target in the GBF would need to be accompanied by a target that specifies the aspired effectiveness, along the lines of 'the majority of these areas should strive for highest levels of protection' – e.g. equivalent to the current IUCN categories I and II. As with area targets, measures will need to be put in place to monitor effectiveness targets. Such measures could combine remote sensing and in-situ species monitoring, as used for area-based targets, with information on PA management plans, dedicated spending and the involvement of local communities to ensure societal engagement. Given the potential for trade-offs in the climate-biodiversity-food nexus, the most appropriate assessment of PA success would need to combine ex-post measures with regular ex-ante analyses and modelling in order to identify the dynamic changes in management that would be required in response to, for example, future socio-economic trends or climate change.

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