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## **Making protected areas effective for biodiversity, climate and food**

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## 1 **Abstract**

2 The spatial extent of marine and terrestrial protected areas (PAs) is amongst the most intensely  
3 debated issues in the post-2020 Global Biodiversity Framework of the Convention on Biological  
4 Diversity. Positive impacts of PAs on habitats, species diversity and abundance are well documented in  
5 many locations. Yet, biodiversity loss continues unabated despite efforts to protect 17% of land and  
6 10% of the oceans by 2020. This casts doubt on whether extending PAs to 30% or even 50% would  
7 achieve hoped for biodiversity benefits. Critically, the focus on area coverage overshadows the need to  
8 focus on PA effectiveness and overlooks concerns about PAs impacts on food security and other  
9 sustainability objectives. Given that the choices made now about PAs could tip the balance towards  
10 either negative or positive outcomes for biodiversity and people, we propose a simple means of  
11 visualising the complex relationships between PA area coverage and effectiveness and their effects on  
12 biodiversity conservation, nature-based climate mitigation and food production. Our analysis illustrates  
13 how achieving a 30% PA global target could be beneficial for biodiversity, climate and food. It also  
14 highlights several important caveats: i) achieving lofty area coverage objectives will likely be of little  
15 benefit for biodiversity or climate without concomitant improvements in effectiveness, ii) there could  
16 be tradeoffs with food production particularly for high levels of coverage and effectiveness and iii)  
17 important differences in terrestrial and marine systems should be taken into consideration when setting  
18 and implementing PA targets. The CBD's call for a significant increase in protected area would need to  
19 be accompanied by clear PA effectiveness goals to reduce and revert dangerous anthropogenic impacts  
20 on socio-ecological systems and biodiversity.

21

## 22 **Introduction**

23 Biodiversity loss and climate change are progressing at an alarming rate<sup>1,2</sup>. In response to this  
24 challenge, terrestrial and marine protected areas (PAs) are increasingly recognised as being central to  
25 biodiversity conservation<sup>3-6</sup>. Aichi Biodiversity Target 11 of the Convention on Biodiversity (CBD) was  
26 formulated with the aim of protecting 17% of the terrestrial surface and 10% of oceans by 2020. PAs  
27 are generally not only more species rich than neighbouring areas, they also contribute to avoiding species  
28 extinctions, habitat loss and degradation (i.e., also supporting the objectives in Aichi Biodiversity  
29 Targets 5, 6, 12, 14, 15). It is not surprising, therefore, that PAs feature prominently in the CBD's post-  
30 2020 Global Biodiversity Framework (GBF)<sup>7</sup>. As most of the Aichi targets have not been achieved<sup>1</sup>,  
31 this new framework seeks to increase global efforts towards biodiversity protection for the periods to  
32 2030 and 2050 ([https://www.cbd.int/conferences/post2020/wg2020-03/documents,  
33 CBD/WG2020/3/3](https://www.cbd.int/conferences/post2020/wg2020-03/documents,CBD/WG2020/3/3)).

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

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

## 49 **The nature's Green Shoots framework and visualisation**

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

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

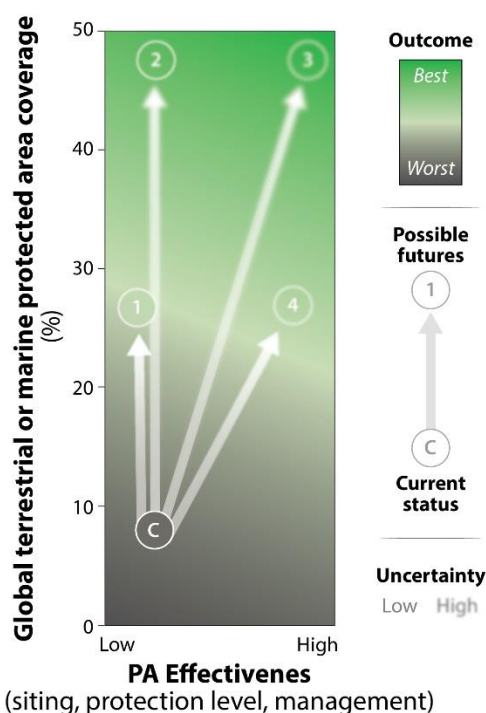
64 The colours in the graphics represent the outcomes of PA coverage and effectiveness for  
65 selected sustainable development objectives: in this case, biodiversity, climate and food. The colour  
66 gradient is set from grey, indicating the poorest outcome, to green that indicates the most positive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

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

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

## Sustainable Development

Biodiversity, climate or food



96

97

98 *Figure 1: 'Green Shoots' template as used for the analyses shown in Figure 2. The y-axis gives the*  
99 *global surface terrestrial or marine ecosystems in PAs (as a percentage) where the scale ranges from*  
100 *0% to a maximum of 50%, which is the highest commonly cited figure for maximum global PA coverage*  
101 *<sup>18,19</sup>; the x-axis ranges from low to high level of effectiveness. "High" on the effectiveness scale indicates*  
102 *that most PAs are optimally sited, under strict protection (sensu IUCN PA categories I and II), well*  
103 *managed and adequately resourced. "Low" indicates that most PAs are sited in areas of low biodiversity*  
104 *value, have low levels of protection (sensu IUCN PA categories V and VI), are poorly managed and*  
105 *have insufficient financing. An encircled 'c' is used to represent the current global status of PA coverage*  
106 *and estimated effectiveness. Numbers '1' and '2' represent cases where (close to) 30% and 50% PA*  
107 *coverages are approached, respectively, without overcoming the barriers that affect current*  
108 *effectiveness levels. Numbers '3' and '4' represent cases where 30% and 50% PA coverage are*  
109 *approached, respectively, whilst overcoming current barriers to PA effectiveness. Increasing*  
110 *uncertainty of location of colour transitions are indicated by increasing fuzziness in the circles. Arrows*  
111 *are included here to guide the eye. Additional information: see Supplementary text and figures and*  
112 *Shoots\_PA.xls.*

113

114

### 115 Current status of Protected Areas

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

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

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

141

#### 142 **Protected Area Targets for 2030-2050**

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

148 Some argue that as much as half of the Earth's ice-free land surface should be set aside for PAs  
149 to ensure adequate protection of species and ecosystems<sup>18</sup>. The argument behind 'Half Earth' draws on  
150 studies showing that 85% of plant species could be protected in this way<sup>39</sup>, which others extended to ca.  
151 85% of all species based on relationships between species and required habitat area<sup>18</sup>. There is  
152 considerable debate about the degree of protection that should be conferred on these areas: proposals  
153 include relatively strict protection from human activities, while others suggest an approach that would  
154 allow for sustainable use of biodiversity alongside agricultural activities<sup>19,37,40,41</sup>. Under some  
155 assumptions, even at the highest level of effectiveness, a TPA of 50% would not cover all plants<sup>24</sup> and  
156 all mammals (which potentially would require 60% of all land<sup>42</sup>).

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

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

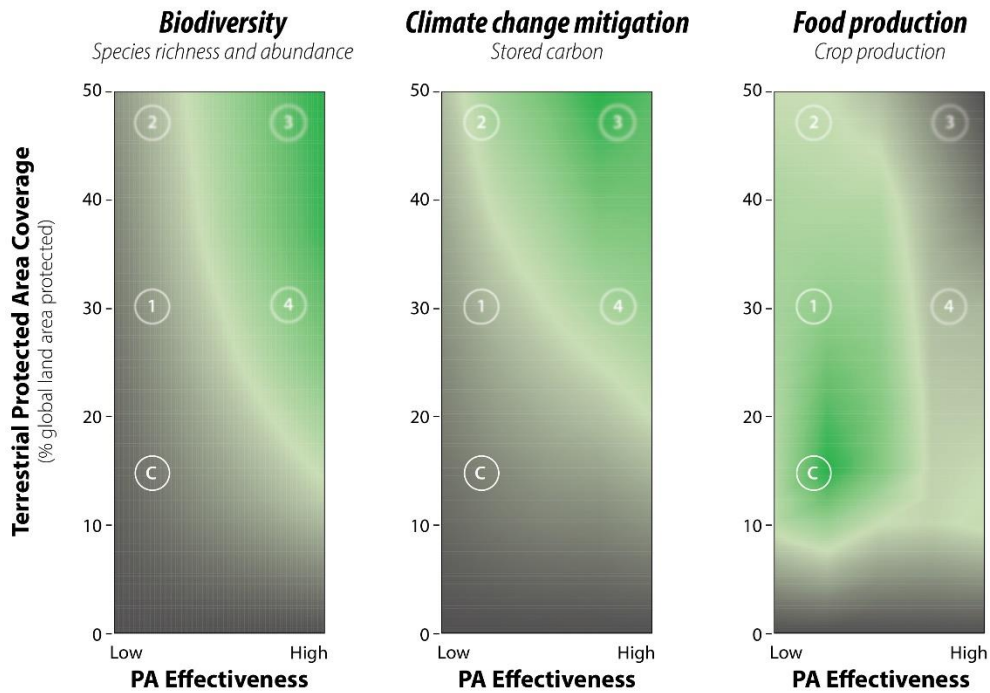
173 TPA coverage results in higher levels of connectivity<sup>53,54</sup>, and TPAs increasingly capture whole  
174 foodwebs and communities (rather than species)<sup>55</sup>. However, if resources to establish and manage TPAs  
175 remain limited, expanding to 30% or even 50% TPA coverage will barely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

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

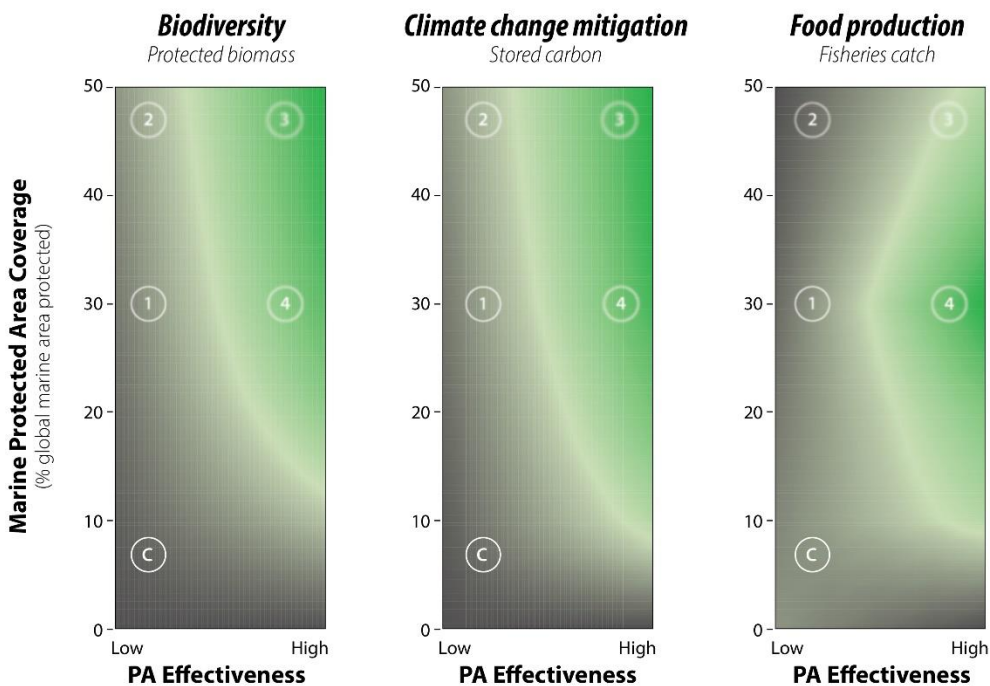
190 When considering well-functioning MPAs, positive biodiversity outcomes generally increase  
191 locally with MPA size<sup>6</sup> and regionally with overall coverage<sup>58,59</sup>. A recent synthesis proposed that at  
192 least 30% of the oceans should be covered by PAs to efficiently protect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

200

## Terrestrial Protected Areas



## Marine Protected Areas



201  
202

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



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

217  
218

### 219 **PA impacts on carbon uptake and storage, and food production and fisheries**

220 On land, areas of high biodiversity and high carbon stocks generally correspond, notably in  
221 many pristine forests, wetlands and savannahs<sup>8,51</sup>. Protection of valuable areas that are still largely intact  
222 creates therefore climate change mitigation co-benefits by avoiding potentially large carbon losses while  
223 also maintaining substantial, extant carbon sinks<sup>8,60-62</sup>. Conservation actions that target biodiversity-rich  
224 areas that are already under threat can provide additional biodiversity-carbon co-benefits, albeit at a  
225 smaller scale<sup>8</sup>. Avoiding further conversion of these areas into land used for agricultural production is  
226 important given that only between 12% and 21% (depending on the choice of biodiversity indicator) of  
227 joint carbon and biodiversity “hotspots” are currently protected, while carbon losses from the conversion  
228 of natural land continue to be substantial (‘current’, *Figure 2*)<sup>8,63</sup>. The restoration of ecosystems will  
229 achieve further positive synergies for both species and carbon pools, if both goals are pursued  
230 simultaneously<sup>64</sup>. That is why an increase in TPAs to, for example, 30% may only provide modest  
231 climate mitigation benefits at current levels of effectiveness, since little protection of carbon stocks and  
232 sinks would be provided. Positive impacts increase rapidly as the effectiveness of protection increases<sup>12</sup>.  
233 However, if the selection of TPAs is based on strict biodiversity considerations (i.e., highest  
234 effectiveness), the carbon benefits would not be equivalent since biodiversity and ecosystem carbon  
235 sinks are not perfectly co-located across all world regions<sup>8,64</sup>. Even at 50% TPA, carbon sequestration  
236 would be expected to be somewhat lower when e.g., biodiversity hotspots are given priority, compared  
237 to siting that accounts for the co-location benefits<sup>8,55</sup>. As such, the optimal solutions for climate would  
238 be large areas being protected at, from a biodiversity perspective, medium-to-high effectiveness (*Figure*  
239 *2*).

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

253 The level of protection but also the location affects the resulting trade-offs. Protection of  
254 primary ecosystems stops agricultural expansion into these areas but does not require reconfiguration of  
255 the current food system (i.e. changes in existing demand or production). However, the extent of such  
256 ecosystems not already protected is limited, and the ongoing biodiversity loss requires expanding TPAs  
257 in productive agricultural regions. Conflicts over land resources therefore will likely become acute if  
258 PA coverage were to increase substantially, especially if the level of protection increased and/or if

259 protected areas were placed where both agricultural and biodiversity values are high<sup>11,12,71,72</sup>. Food could,  
260 in principle, be produced on less agricultural land by increasing the intensity of agricultural production  
261 (i.e. land sparing<sup>73</sup>). But the impacts of TPAs on food security at very high levels of coverage (i.e. both  
262 30% and 50% TPAs) with a strong conservation focus (i.e. strict protection) could increase food price  
263 increases and food insecurity<sup>11,12,74</sup>, reflecting higher costs of inputs arising from production  
264 intensification. Higher food prices would be most severe for poorest globally and add to rates of  
265 malnutrition<sup>11,74</sup>. Increasing agricultural water withdrawals and pollution from greater fertiliser and  
266 pesticide use<sup>11,12,40,75</sup> would have negative biodiversity and societal consequences in the remaining  
267 agricultural areas<sup>11,40,75</sup>.

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

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

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309 **Synergies and tradeoffs between biodiversity, climate, and food**

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

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

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

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

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

350 The choices made now about PA extent can tip the balance toward either negative or positive  
351 outcomes across nexus challenges – such as demonstrated here for biodiversity, food and climate. Urgent  
352 action is needed to avoid dangerous levels of anthropogenic interference both in the climate and socio-  
353 ecological systems, but it is important to get these actions ‘right’, especially since some of the benefits  
354 will accrue only with time. Our analysis in principle supports 30% PA as a global target, as currently  
355 drafted in the GBF. For such a target, cross-nexus co-benefits are achievable if PA effectiveness and  
356 coverage are prioritized equally. It will be essential, however, to adopt additional measures to avoid

357 losses or overconsumption in the food system. Given siting, protection level, and management  
358 effectiveness, national and global policy could foster the much-needed compromise between PA  
359 expansion through restoration and increased protection of remaining natural ecosystems. The former  
360 will have immediate impacts on food production on land while carbon and biodiversity benefits will  
361 only increase with time. The latter will have immediate biodiversity and carbon benefits, while impacts  
362 on food systems depend on many factors such as future population growth and the capacity to maintain  
363 or enhance production from existing agriculture and fisheries sustainably. For both restoration and  
364 protecting natural ecosystems, increasing PA effectiveness is as important, if not more so, than  
365 increasing PA coverage. Specifying, and even hitting, targets defined only in terms of area will not  
366 achieve biodiversity goals, nor will they create synergies with other sustainability objectives.

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

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378

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