1 **Assessing ambitious nature conservation strategies within a 2 degree warmer and food-secure**

2 **world**

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6 **Abstract**

7 Global biodiversity is projected to further decline under a wide range of future socio-economic

8 development pathways, even in sustainability oriented scenarios. This raises the question how

9 biodiversity can be put on a path to recovery, the core challenge for the CBD post-2020 global

10 biodiversity framework. We designed two contrasting, ambitious global conservation strategies, 'Half

11 Earth' (HE) and 'Sharing the Planet' (SP), and evaluated their ability to restore terrestrial and

12 freshwater biodiversity and to provide ecosystem services while also mitigating climate change and

13 ensuring food security. We applied the integrated assessment framework IMAGE with the GLOBIO

14 biodiversity model, using the 'Middle of the Road' Shared Socio-economic Pathway (SSP2) with its

15 projected human population growth as baseline.

16 We found that both conservation strategies result in a reduction in the loss of biodiversity and

17 ecosystem services globally, but without additional measures to achieve effective climate mitigation

18 they will be insufficient to restore biodiversity. The HE strategy performs better for terrestrial

19 biodiversity protection (biodiversity intactness (MSA), Red List Index, geometric mean abundance) in

20 currently still natural regions, reflecting global conservation priorities. The SP strategy yields more

21 improvements for biodiversity in human-used areas, aquatic biodiversity and for regulating

22 ecosystem services (pest control, pollination, erosion control), reflecting regional priorities. However,

23 'conservation only' scenarios show a considerable increase in food security risks (especially in Sub-

24 Saharan Africa) compared to the baseline and limited reduction of global temperature increase. Only

25 when conservation strategies are combined with climate change mitigation efforts and additional

26   actions especially in the agricultural and energy system into a portfolio of 'integrated sustainability

27   measures', both conservation strategies result in restoring biodiversity to current values or even

28   some improvement, while keeping global warming below two degrees and keeping food security

29   risks below baseline. Minimizing food wastes and reducing consumption of animal products will be

30   crucial.

31   **Keywords:** Conservation, Half Earth, Sharing the Planet, Climate Change, Food Security, Solution-

32   oriented scenarios, Biodiversity, Ecosystem Services

33

1. Introduction

34

35 The decline of biodiversity continues despite global commitments under the UN Convention on

36 Biological Diversity (CBD). In 2020 the CBD Strategic Plan 2010-2020 will come to an end and

37 countries have to renew their commitments. In view of limited progress in realising CBD goals and

38 targets (Tittensor et al., 2014; IPBES, 2019, sCBD, 2020), countries need to design and agree upon a

39 new and more effective global biodiversity framework for the coming decades to realise the 2050

40 vision of the CBD. This new framework needs to be part and parcel of the broader sustainable

41 development agenda, especially the internationally agreed Agenda 2030 and its Sustainable

42 Development Goals (SDGs) (UN GA, 2015). Agenda 2030 emphasizes the need to develop biodiversity

43 conservation strategies that are consistent with other SDGs – and sustainable development in

44 general – reflecting the increasing acknowledgement of the importance of biodiversity and natures

45 contributions to people for human well-being (Blicharska et al., 2019; IPBES, 2019; Lucas et al., 2014).

46 A variety of scenario-based analyses and modelling approaches (IPBES, 2016) can help to understand

47 future impacts of drivers of biodiversity loss and to explore the potential of various measures to

48 achieve global goals and targets. Current explorative scenario-projections, covering a wide range of

49 plausible socio-economic pathways, indicate that global biodiversity will continue to decline, even

50 under more optimistic scenarios oriented towards sustainability (Shin et al., 2019; Schipper et al.

51 2020; Pereira et al., 2020). Moreover, despite the 2015 Paris Agreement to limit global warming to

52 well-below 2 degrees, the world is currently heading towards a global temperature increase of 3.2

53 degrees (UNEP, 2019), and more than 800 million people are still food insecure (FAO, 2019). This

54 raises the question of how to put nature on a path to recovery, while also halting climate change and

55 contribute to ending hunger and feeding a growing and wealthier global population.

56 To answer this question, scenario analysis recently shifted to consider ambitious objectives for

57 nature conservation and desirable nature futures (Rosa et al., 2017; Pereira et al., 2020). Recent

58 papers have assessed what efforts are necessary to put nature on a path to recovery (Mace et al.,

59   2018; Leclere et al., 2018, 2020 (accepted); Tickner et al., 2020), building on earlier work to halt the

60   loss of biodiversity and meet the Aichi targets (van Vuuren et al., 2015; Kok et al., 2018; Visconti et

61   al., 2016). Challenges remain, however, to include all relevant drivers of biodiversity loss, apply

62   multiple perspectives to area-based conservation and to integrate biodiversity outcomes with other

63   relevant SDGs, while considering multiple visions for nature (Rosa et al., 2020). Furthermore, efforts

64   need to be put to examine how nature supports socio-economic development and human well-being

65   (Rosa et al., 2017). Ultimately, there is a need to understand which ambitious long-term conservation

66   strategies can restore nature and contribute to meeting other societal goals, such as, in this analysis,

67   food security and climate objectives (Allan et al., under review; IPBES, 2019, p. 56; Rosa et al., 2017).

68   We aim to fill these gaps by applying a solution-oriented, model-based scenario-analysis to evaluate

69   two alternative, ambitious conservation strategies, labelled 'Half Earth' and 'Sharing the Planet'. We

70   evaluate both strategies for their realisation of internationally agreed goals for biodiversity (the 2050

71   Vision and the emerging post-2020 global biodiversity framework being developed under the CBD),

72   climate change (UNFCCC Paris Agreement) and food security (SDG 2 End hunger).

73   In response to recent calls, our scenarios include multiple perspectives on conservation (Bhola et al.,

74   2020; Immovilli and Kok, 2020) and values of nature (Pascual et al., 2017; Pereira et al., 2020; Rosa et

75   al., 2017; van Zeijts et al., 2017). Including these different perspectives helps to show how different

76   valuations of nature may be reflected in different conservation strategies and pathways. This in turn,

77   also helps to show how different approaches to conservation can become contested not only

78   between conservation points of view, but also from for example food security and equity

79   perspectives (Ellis and Mehrabi, 2019; Mehrabi et al., 2018, Otero et al., 2020; Schleicher et al.,

80   2019).

81   The 'Half Earth' (HE) strategy emerges from a focus on protecting nature for its intrinsic value.

82   Several proposals have been made for ambitious area-based conservation efforts, including

83   conserving half of the earth's surface (Wilson, 2016; Pimm et al., 2018), nature needs half (Locke,

84   2013) and the global deal for nature (Dinerstein et al., 2017, 2019). Despite differences in methods

85   applied, proponents agree on the need to promote wilderness and separating human influence from

86   nature as the most important solution to halt biodiversity loss. To achieve such bold targets, these

87   approaches rely on extending protected areas, conserving other remaining natural areas and

88   restoration efforts as their main strategies, while recognizing that the strategy would be applied

89   differentially to different regions (Locke et al., 2019). A consequence of setting aside large areas for

90   nature conservation is that it limits space for producing food and other agricultural and forestry

91   products, requiring massive improvement of agricultural productivity.

92   The 'Sharing the Planet' strategy is underpinned by the principle of 'living with nature' (Hinchliffe,

93   2006; Turnhout et al., 2013) and entails both instrumental and relational valuations of nature.

94   Conservation is 'convivial' insofar as it aims to maintain biodiversity and create value at a local level,

95   it does not seek to separate humans from nature and it addresses structural social inequalities and

96   injustices (Büscher & Fletcher, 2020). Protecting and supporting nature's contributions to people

97   (NCP) are therefore the main objectives of this perspective. With this regard, proposals have been

98   made to prioritize the multifunctionality of a landscape and the delivery of multiple benefits through

99   ecosystem services. Thus, biodiversity conservation is one of the many benefits a landscape can

100   provide, along with others such as food security, poverty alleviation, sense of identity, etc. (Kremen

101   & Merenlender, 2018; Perfecto & Vandermeer, 2016). Agriculture production is part of the

102   integrated and productive landscapes.

103   The impacts of both HE and SP conservation strategies on biodiversity and food security are

104   evaluated in scenarios where climate change mitigation is consistent with currently committed global

105   mitigation efforts (expected to result in a global warming of 3.2 °C in 2100 (UNEP, 2019) and in

106   scenarios where global warming is limited to 2°C and thus additional sustainability measures in the

107   food and agricultural system are applied. To the former we refer as 'conservation only' scenarios, to

108   the latter as 'integrated sustainability' scenarios. The scenarios are evaluated against, the 'Middle of

109   the Road' scenario of the Shared Socio-economic Pathways (SSP2) (Riahi et al., 2017). SSP2 describes

110   a world in which social, economic, and technological trends do not shift markedly from historical

111   patterns. We project the scenarios to 2070 and report results also for two intermediate years (2030

112   and 2050). We do not address the governance needed to realise these strategies, nor does the

113   model-framework allow us to explore feedbacks of these strategies on economy, production systems

114   or population (see Rosa et al., 2017, 2020). The integrated assessment model IMAGE (Stehfest et al.,

115   2014) and the global biodiversity model GLOBIO (Schipper et al., 2020; Janse et al., 2015) are applied

116   to evaluate the outcomes of these pathways in terms of various metrics of biodiversity, ecosystem

117   services, climate change and food security and to assess the efforts needed for this.

118

119   **2. Methods**

120   **2.1 Conservation strategies**

121   As a starting point of the scenario analysis, we elaborated consistent narratives for two contrasting

122   global conservation strategies, 'Half Earth' and 'Sharing the Planet', based on literature review and

123   recent debates in the context of CBD's post-2020 global biodiversity framework (see S.1 and

124   Immovilli and Kok, 2020 for more elaborate descriptions, see also Bhola et al., 2020).

125   In the 'Half Earth' strategy, nature is valued for its intrinsic value. The concept of wilderness and

126   naturalness are central to this strategy, to be protected from human pressures (Kopnina, 2016;

127   Wuerthner, 2014). In order to retain the naturalness of ecosystems, Protected Areas (PAs) and other

128   area-based conservation measures are cornerstones of this strategy. Ecosystem services and natures

129   contributions to people are considered as a co-benefit, but not prioritized. This conservation strategy

130   requires a land sparing approach for agriculture, based on sustainable intensification aiming at

131   closing the yield gaps (Garnett et al., 2013; Phalan et al., 2016). This type of intensification draws

132   upon wide technological developments and innovations, such as more efficient irrigation and

133   nutrient use, pest management and genetic modification, and aims for eco-efficiency and reduction

134   of externalities. There is less reliance on bio-energy. Also other pressures besides agriculture (like

135   hydropower) are restricted in the protected half. In river basins, new hydropower dams would be

136   only allowed in the 'non-protected half', while in the 'protected half' measures will be taken to partly

137   restore the flow of water and reduce river fragmentation.

138   In the 'Sharing the Planet' strategy, conservation measures that support and enhance the provision

139   of ecosystem services and nature's contributions to people are prioritized. This strategy premises on

140   the concept of 'living with nature' (Turnhout et al., 2013; Buscher and Fletcher, 2020). In agriculture,

141   the dominant landscape is a heterogenous mosaic, comprising a combination of natural habitat

142   patches and agriculture, a so-called agro-ecological matrix, resulting in improved provision of

143   ecosystem services (Kremen & Merenlender, 2018; Perfecto & Vandermeer, 2016). Food production,

144   carbon storage, pollination, water and nutrient retention, biodiversity conservation and other

145   services are achieved within the mosaic landscape following the path of ecological intensification.

146   This type of intensification is concerned with the optimization of ecosystem benefits and it primarily

147   relies on ecological knowledge, labor-intensive or smart mechanization systems, as applied in

148   agroecology, organic farming, agroforestry and diversified farming systems (Tittonel, 2014). There is

149   less reliance on bio-energy, and additional hydropower capacity is only possible while respecting

150   ecological flow requirements and minimizing further river fragmentation.

151

152   **2.2 Defining scenarios**

153   The Half Earth (HE) and Sharing the Planet (SP) strategies were translated into four quantitative

154   scenarios (Table 1), including 'conservation only' scenarios (HE-co and SP-co) and 'integrated

155   sustainability' scenarios combining conservation with measures to limit global warming to 2⬚°C and

156   additional sustainability measures in the food and agricultural system (HE-is and SP-is). We created

157   global maps of potential conservation areas consistent with the HE and SP narratives as the starting

158   point of the analysis (see S. 2 for further details).

159

160   To assess the impacts of 'conservation only' strategies on biodiversity and food security, we

161   evaluated the HE and SP strategies in a situation where climate change is hardly mitigated (RCP 6.0)

162   and in which no further measures in the food and agricultural system are taken. The RCP 6.0 scenario

163   is close to the SSP2 baseline result at a radiative forcing of 6.0 W m^{-2}, and is consistent with currently

164   committed global mitigation efforts (UNEP, 2019). Next, we combined the HE and SP conservation

165   strategies with measures to limit global warming to 2 °C (RCP 2.6; Van Vuuren et al., 2011) and

166   measures in the food and agricultural system needed to safeguard global food security. These

167   'integrated sustainability' pathways combine area-based conservation and restoration with changes

168   in land use, agricultural production and food consumption to mitigate climate change (e.g., reducing

169   food waste, reducing animal product consumption and further increasing agricultural productivity).

170   We adjusted some assumptions regarding the energy system compared to the standard SSP2, RCP

171   2.6 energy-mix, notably with respect to biomass and hydropower, to take into account biodiversity

172   concerns (Table 1).

173

174   TABLE 1 Key assumptions in the SSP2 baseline and the four scenarios*

	SSP2	Half Earth	Sharing the Planet
Conservation		Conservation in HE-co and HE-is	Conservation in SP-co and SP-is
Conservation / Land use regulation	Protected areas are restricted to achieve the Aichi target of 17% of the terrestrial area by 2050	Global conservation area is extended to cover at least 50% of all terrestrial and freshwater ecoregions, in 2050 (See S.I. 2). No expansion of urban and agricultural areas allowed in	For ES optimization, high carbon forests, riparian zones, areas functioning as water towers, peatlands and urban green spaces are added to the current Protected Areas and Key

		conservation areas. Activities causing encroachment are reduced over time.	Biodiversity Areas, to cover 30% of the global terrestrial area in 2050 (see S.I. 2). No expansion of urban and agricultural areas allowed in conservation areas.
Trade	Current tariffs and subsidies.	Current tariffs and subsidies.	Introduction of a 10% import tax for all agricultural products by 2050.
Urban expansion	Based on HYDE, with expansion as a function of population and urbanization (Klein Goldewijk et.al. 2011)	Follows the baseline, no expansion in conservation areas.	Follows the baseline, while protecting current urban green spaces and maintain close proximity to green spaces in expanding urban areas (see S.I. 2)
Diffuse nutrient emissions to water	Nutrient use efficiency largely following FAO agricultural outlook. No additional measures to protect watercourses.	No additional measures	20% higher nutrient use efficiency in agriculture (following SSP1). [&] Implementation of natural vegetation riparian buffer zones on large (300m) and medium (150m) rivers (see S.I. 2), contributing to reduction of nutrient loading to water
Urban	Baseline SSP2: 61% sewerage	Follows the baseline	Improved wastewater

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wastewater	connection, 29% nutrient removal (global averages)		treatment (following SSP1): 75% sewerage connection, 43% nutrient removal (global averages) [&]
Hydropower	80% increase until 2050	Baseline increase only outside conservation areas, restoration of natural river flow in 25% of the locations in conservation areas	No increase
Land and food system		**Additional measures HE-is:**	**Additional measures SP-is:**
Agricultural practices and productivity	Productivity increase following largely FAOs agricultural outlook and a relation to GDP (Doelman et al. 2017)	'Sustainable intensification' with high crop yield increase following SSP1 (Doelman et al. 2017); higher fertilizer and irrigation efficiency, following SSP1.	Productivity increase 10% lower than in HE ; agro-forestry in tropical biomes and mixed cropland-nature patterns (70/30) in temperate biomes; higher fertilizer and irrigation efficiency, following SSP1.
Food losses	Current levels of food losses	Reduction of food losses by 50%	Reduction of food losses by 50%
Consumption of animal products	Medium - endogenous model outcome	Consumption of animal products 50% lower than endogenous outcome by 2070. [#]	Consumption of animal products 50% lower than endogenous outcome by 2070. [#]
REDD (Reducing	No REDD.	REDD, protecting all forest	REDD, protecting all forest

emissions from deforestation and forest degradation)		with carbon density > 100 t C/ha.	with carbon density > 100 t C/ha.
Biofuels	Endogenous SSP2 results	Reduced reliance on biofuels, only residues, no dedicated biofuels	Reduced reliance on biofuels only residues, no dedicated biofuels

175 * All scenarios follow SSP2 population and GDP projections, and all assumptions are as SSP2, if not specified

176 otherwise here.[#] Applied for all regions, except for low income regions with low animal product consumption

177 (North Africa, West Africa, East Africa, Rest of South Africa, India, Rest South Asia, and Indonesia). [$] Irrigation

178 efficiency increases by 0.1%/yr for all irrigated areas and fertilizer use efficiency 20% higher than SSP2,

179 efficiency decreases in countries with nutrient mining (settings according to SSP1).

180

181

182 **2.3 IMAGE and GLOBIO models and indicators**

183 We applied the integrated assessment model IMAGE (Stehfest et al., 2014) and the biodiversity

184 model GLOBIO (Schipper et al., 2020, Janse et al., 2015) to evaluate the four scenarios. IMAGE

185 assesses global environmental change under future socio-economic development scenarios. It

186 includes a set of connected models describing the energy, the agricultural economy and land use,

187 natural vegetation and the climate system. For our analysis we particularly used the MAGNET model

188 for calculating changes in agricultural demand, production and trade (Woltjer et al., 2014); relied on

189 earlier calculations of TIMER for changes in the energy system and the demand for bioenergy and

190 hydropower (van Vuuren, 2007); the GNM model for calculating nutrient loads in water systems

191 (Beusen et al., 2015) and LPJmL for carbon, water, crop and grass yields, and vegetation dynamics

192 (Schaphoff et al., 2018, Müller et al. 2016); the GISMO model to asses impacts on food security

193 (Lucas et al., 2019). Socio-economic processes, especially in MAGNET and TIMER, distinguish 26

194   world regions, while land use and all biophysical processes are resolved at a 5 x 5 arcminutes and 30

195   x 30 arcminutes resolution.

196   The GLOBIO model includes four main components: 1) GLOBIO for assessing terrestrial biodiversity

197   intactness (Schipper et al., 2020), 2) GLOBIO-Aquatic for assessing freshwater biodiversity intactness

198   (Janse et al., 2015), 3) GLOBIO-Species for assessing the distribution and abundance of vertebrate

199   species, based on the INSIGHTS modelling framework (Visconti, 2016; Baseiro, 2020, see also S. 3),

200   and 4) GLOBIO-ES for assessing ecosystem services (Schulp et al., 2012). Indicators assessed with

201   GLOBIO are a function of multiple human pressures: land use, fragmentation, road disturbance,

202   encroachment by hunting, climate change, atmospheric nitrogen deposition, nutrient emissions to

203   water and hydrological disturbance. IMAGE scenario outcomes are used to quantify various of these

204   pressures. We downscaled changes in land use calculated in the IMAGE model downscaled to a 10

205   arcseconds resolution (~300x300meter at the equator) by the land use allocation module integrated

206   in GLOBIO (Schipper et al., 2020). GLOBIO also uses estimates on global temperature change,

207   fertilizer use and nitrogen deposition from IMAGE. Nutrient loads to water were calculated by GNM

208   (Beusen et al., 2015) and river discharge by LPJmL (Biemans et al., 2011) and PCR-GLOBWB

209   (Sutanadjaja et al., 2018). Road infrastructure data were used from the GRIP database (Meijer et al.,

210   2018).

211   Based on the indicators available in GLOBIO and IMAGE and following the proposal by Mace et al.

212   (2018), we quantified three complementary biodiversity indicators representing trends in

213   populations, extinctions and integrity (functional diversity) (Table 2): 1) the geometric mean

214   abundance (GMA; Visconti et al. 2016), 2) the Red List Index (RLI; Butchart et al., 2007) and 3) the

215   mean species abundance (MSA; Schipper et al. 2020; Janse et al. 2015). To cover ecosystem services

216   or nature's benefits to people, we include six terrestrial ecosystem services (crop production, grass &

217   fodder production, pest control, pollination, carbon sequestration and erosion control) and four

218   aquatic ones (water scarcity reduction, flood risk reduction, natural water purification and health and

219   recreational value of lakes).

220   As indicator for the impact on climate change we use the cumulative emissions from agriculture,

221   forestry and other land use. Food security impacts were analysed in terms of food availability, food

222   prices and people at risk of hunger. While food security has many more aspects, most global

223   modelling studies rely on these indicators (Hasegawa et al. 2018, Van Meijl et al. 2020).

224   TABLE 2 Overview of indicators (see also S. 4)

Indicator		Description	Model
Biodiversity	Mean Species Abundance (MSA)	Local biodiversity intactness indicated by abundance of original species compared to an undisturbed situation [dimensionless].	GLOBIO and GLOBIO-Aquatic
	Geometric Mean Abundance (GMA)	Ratio between total population size of a species at time t compared to its population size at a reference time, equivalent to the Living Planet Index [dimensionless]. Here only mammals are included.	GLOBIO-Species
	Red List Index (RLI)	Trend in aggregated extinction risk of species, as measured using the categories of the IUCN Red List of Threatened Species [dimensionless]. Here only mammals are included.	GLOBIO-Species
Ecosyste	Crop production	Total crop production [kcal per year]	IMAGE

13

	Grass/Fodder production	Total grass and fodder production [Mg biomass/year]	IMAGE
	Pest control	Proportion of cropland covered by natural pest control [dimensionless].	IMAGE
	Pollination	Proportion of cropland of pollinator-dependent crops covered by pollinators [dimensionless].	GLOBIO-ES
	Carbon sequestration	Proportion relative to C-emission [dimensionless]	IMAGE
	Erosion control	Risk reduction by natural vegetation relative to the proportion of vulnerable land that would benefit from natural vegetation cover to reduce erosion risk [dimensionless]	GLOBIO-ES
	Water scarcity reduction	Relative change in low-discharge of rivers	PCR-GLOBWB
	Flood risk reduction	Relative change in high-discharge of rivers	PCR-GLOBWB
	Natural water purification	The contribution of natural areas to a reduction of N and P load to (or concentrations in) water bodies [unit?]	GNM
	Healthy lakes	The proportion of lakes meeting the WHO standard for harmful algal blooms [dimensionless]	GLOBIO-Aquatic

14

		Cumulative emissions from land use	Combined cumulative emissions from agriculture and FOLU (Forestry and Other Land Use), for CO2, N_2O and CH_4 [Mtonne CO_2-eq].	IMAGE
Climate change	*mitigation*			
Food security		People at risk of hunger	Prevalence of undernourishment, based on average per-capita caloric consumption and a coefficient of variation reflecting distribution within population [Million people]	IMAGE/GISMO
		Food prices	Prices of food crops and animal products [index compared to 2015]	IMAGE/MAGNET
		Food energy supply	Per-capita availability of food crops and animal products [kcal/cap/day]	IMAGE/MAGNET

225

226　**3. Results**

227　**3.1 Overall results for biodiversity and ecosystem services, climate change and food security**

228　In this section we show the overall performance of the HE and SP pathways, compared to the

229　baseline (Figure 1), while detailed results are presented in sections 3.2 through 3.4 and additional

230　regional results in S.5.

231　In the baseline, environmental changes continue according to the current trends: land conversion

232　will still be significant as shown by the increase of agricultural land and continued climate change.

233　Due to scarcity of land and increased demand, global food prices will increase but the fraction of

234　people at risk of hunger will decline. A continuous decline of biodiversity is expected and most

235　regulating ecosystem services will decrease.

236   In the HE pathway, protecting 50% of the land surface combined with sustainable agricultural

237   intensification results in substantial reduction of agricultural area. Implemented as 'conservation

238   only' (HE-co), large benefits for biodiversity are expected and slightly better performance of

239   regulating ecosystem services, but only limited climate benefits and an increase in food security risks.

240   The SP pathway, with lower levels of protection and agriculture moving towards agro-ecological

241   approaches, shows less reduction in agricultural area and somewhat lower benefits for terrestrial but

242   better results for aquatic biodiversity than the HE-pathway. Implemented as 'conservation only' (SP-

243   co), limited climate benefits are expected and risks for food security still increase but less than in HE-

244   co. SP performs substantially better for most ecosystem services as well as for aquatic biodiversity.

245   Introducing integrated sustainability measures, in both pathways (HE-is, SP-is), reduces food security

246   risks and enables climate mitigation using land- and nature-based mitigation potential and creates

247   further benefits for biodiversity and ecosystem services.

248

Overview of the indicators in the 4 scenarios compared to the baseline
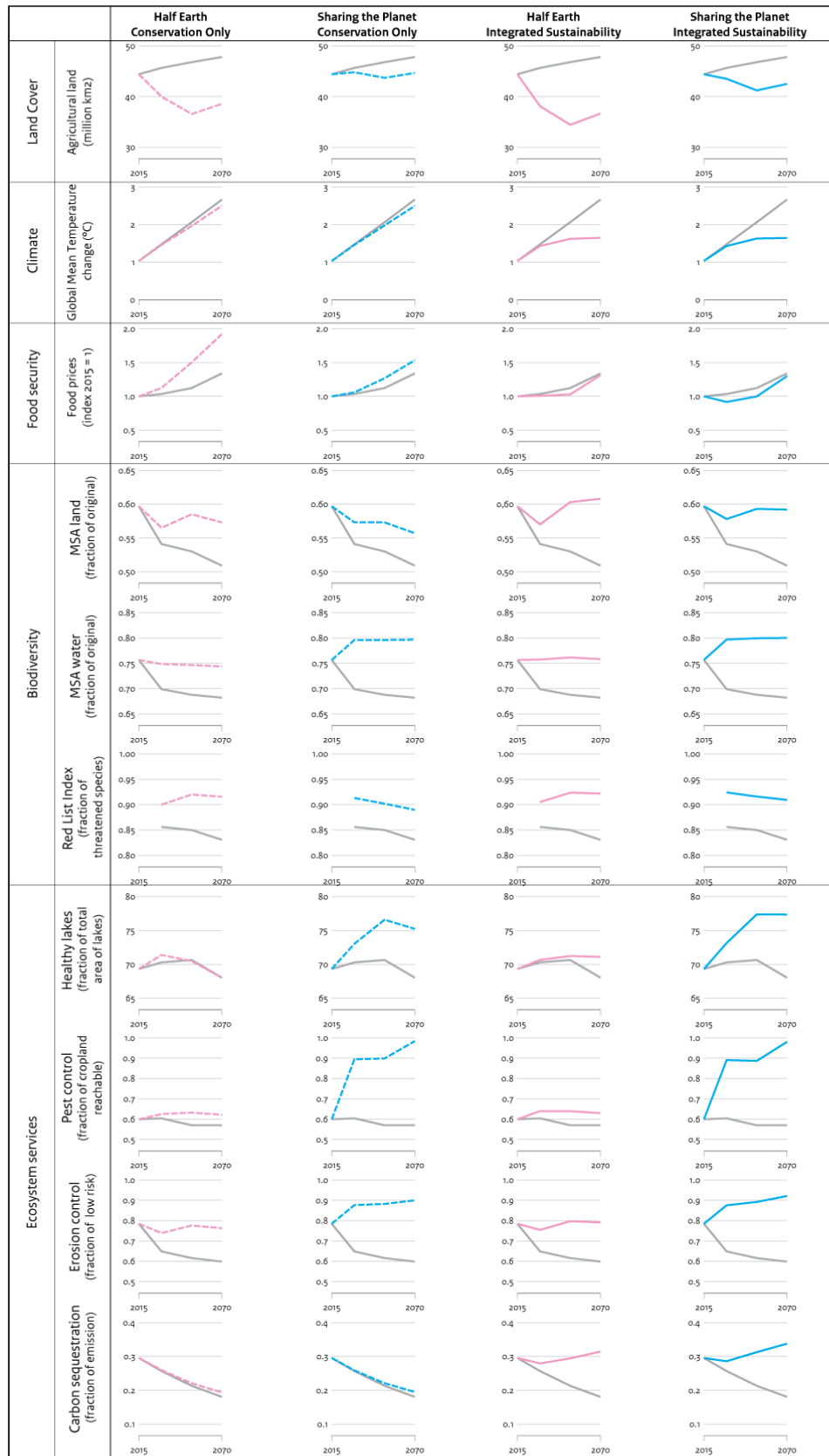
250   FIGURE 1: Overall global results for land use, climate change, food security, biodiversity and

251   ecosystem services for selected indicators (Baseline, HE-co, HE-is, SP-co, SP-is; 2015-2070).

252

3.2 Land use change, climate change mitigation and food security

254   The baseline scenario (SSP2) shows a continued expansion of agricultural areas by 8% up to 2070

255   (Figure 2). In contrast, the HE scenarios, with substantial expansion of protected areas, show declines

256   in cropland (5% and 17% for HE-co and HE-is respectively) and especially pasture (23% and 25% for

257   HE-co and HE-is respectively) by 2050 and again an expansion after that. The SP scenarios show

258   modest changes of agricultural land up to 2070 with mainly decrease of pastures in 2030-2050

259   (constant for SP-co and 4% decrease for SP-is), resulting from the intermediate position between the

260   baseline and the HE pathway with respect to agricultural productivity and expansion of protected

261   areas. The integrated sustainability measures in HE-is and SP-is stimulate agricultural productivity

262   even more than in the baseline and reduce food demand, due to waste reduction and dietary

263   changes. The recovery of mainly non-forest natural areas continues in both HE and SP until 2050.
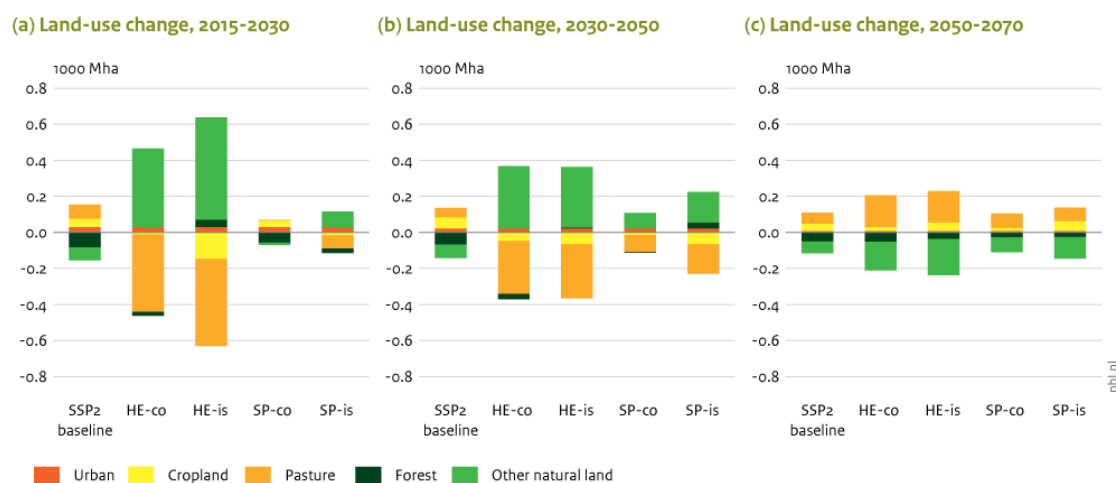

265   FIGURE 2: Land use changes in the periods (a) 2015-2030, (b) 2030-2050 and (c) 2050-2070 (SSP-2

266   baseline, HE-co, HE-is, SP-co, SP-is).

267   Land-use changes in conservation only scenarios (HE-co and SP-co) contribute only slightly to the

268   reduction of greenhouse gas emissions and to increased carbon sequestration, resulting in limited

269   climate change mitigation. The integrated measures in HE-is and SP-is include large mitigation efforts

270   achieved by industry and energy sectors. Figure 3a shows that the contributions of land-based

271   mitigation in relation to the full mitigation package in HE-is and SP-is will almost double. About 8% of

272   the total results is from implementing bio-energy (van Vuuren et al., 2015), and 4% via technological

273   abatement measures in agriculture such as nitrification inhibitors for N_2O from fertilizer application,

274   or farm-scale digesters for CH_4 from animal manure (Figure 3a). In the HE-is and SP-is scenarios,

275   emissions from agriculture and forests and other land use sectors are substantially reduced. The

276   cumulative emission reduction from land increases from 4 to 11 and to 13% through integrated

277   measures in HE-is and SP-is scenarios, respectively. In both scenarios, about a quarter of this

278   emission reduction arises from the conservation measures, mostly through avoided deforestation

279   and agroforestry carbon stocks (only SP). These emission reductions could be 'utilized' in two ways:

280   to allow a less-dramatic emission decline in energy and industry in the next decades (as illustrated in

281   Figure 3a), or to reach more ambitious climate targets than conventional mitigation projections (RCP

282   2.6) (Figure 3b). In this latter case, another 0.2 degree below the RCP2.6 scenario (consistent with 2

283   degrees) might be gained. It must be noted, however, that the land carbon sinks, like afforestation

284   and natural regrowth, are largely temporary, as carbon uptake levels off after some time, depending
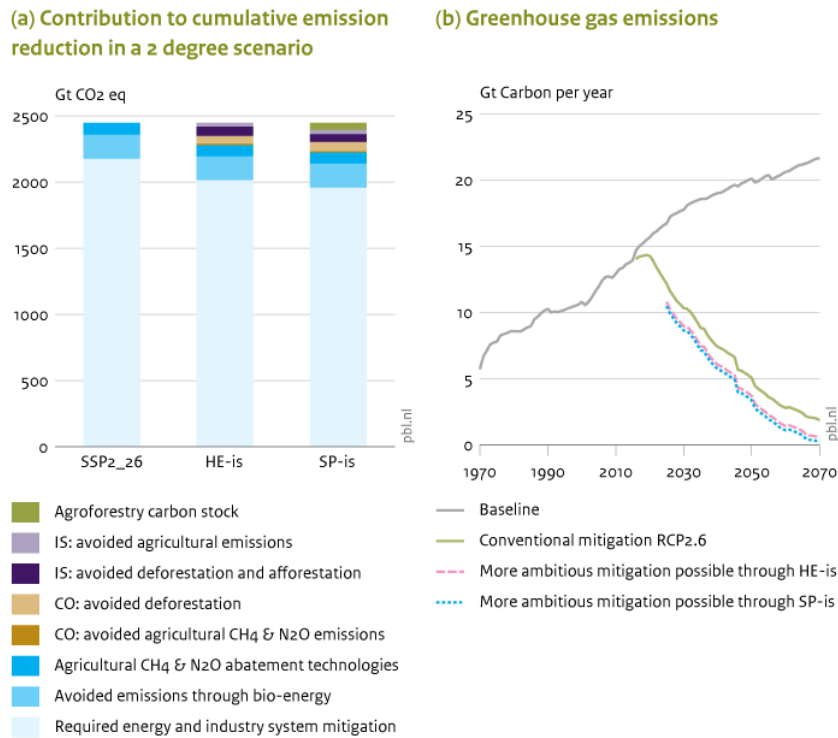
285   on the ecosystem.

(a) Contribution to cumulative emission reduction in a 2 degree scenario

(b) Greenhouse gas emissions

Legend (a):
- Agroforestry carbon stock
- IS: avoided agricultural emissions
- IS: avoided deforestation and afforestation
- CO: avoided deforestation
- CO: avoided agricultural CH4 & N2O emissions
- Agricultural CH4 & N2O abatement technologies
- Avoided emissions through bio-energy
- Required energy and industry system mitigation

Legend (b):
- Baseline
- Conventional mitigation RCP2.6
- More ambitious mitigation possible through HE-is
- More ambitious mitigation possible through SP-is

286

287   FIGURE 3: Greenhouse gas (GHG) emission reductions in the different pathways. (a) Contribution of

288   different measures to the required GHG emission reduction in a 2 degree scenario, for conventional

289   mitigation (SSP2 mitigation, based on Van Vuuren et al., 2017), and the HE-is and SP-is scenarios; (b)

290   GHG emissions for baseline and conventional mitigation, and additional mitigation achieved through

291   the HE-is and SP-is scenarios.

292   In the baseline, between 2015 and 2070, food security increases, as indicated by the fraction of

293   population at risk of hunger ('prevalence of undernourishment') being reduced from 10.1 to 2.8%

294   (figure 4a). In conservation only scenarios (HE-co, SP-co) food security risks also reduce, but to a

295   lesser extent, and result in 1.5 to 2 times higher number of people at risk of hunger by 2070

296   compared to the baseline. The increased scarcity of land, the required intensification (HE), or the

297   shift to agroecological methods (SP) will drive up food prices which reduces access to food for the

298   poor. The integrated sustainability scenarios (HE-is, SP-is) compensate the increased food security

299   risks from the 'conservation only' scenarios completely, by reducing both demands for food

300   production and food prices. Food prices are a little lower than to those in the baseline and people at

301   risk of hunger stabilizes just below the baseline SSP2 outcomes, with the SP-is scenario performing

302   better than HE-is. In all scenarios food security risks are most prevalent in Sub-Saharan Africa and
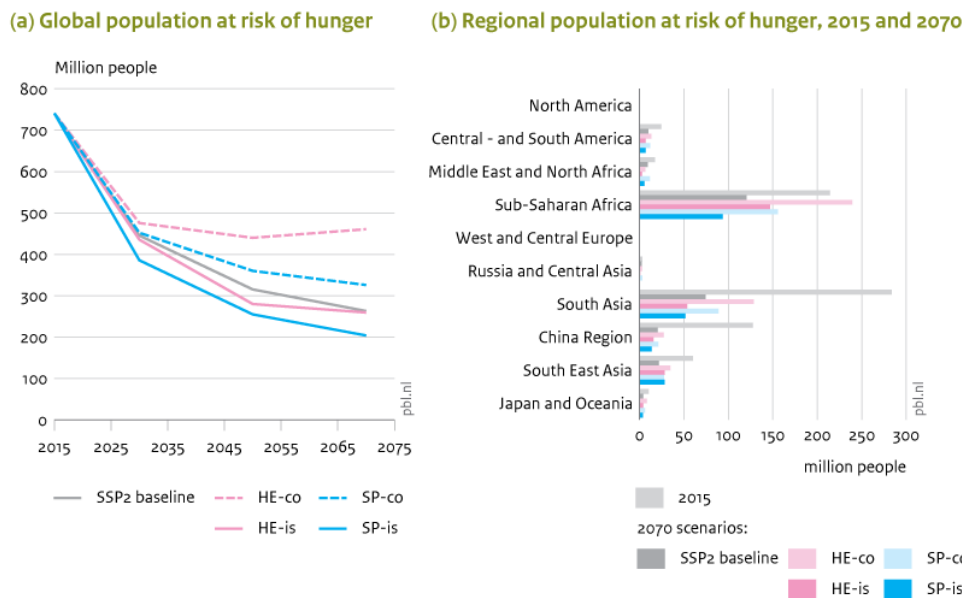
303   South Asia (figure 4b).

304

305

306   FIGURE 4: Impacts on food security (a) global and (b) regionally differentiated (Baseline, HE-co, HE-is,

307   SP-co, SP-is).

308

3.3 Projected changes in biodiversity and ecosystem-services

310   In the baseline scenario, a significant additional loss of biodiversity on land and in freshwater systems

311   is projected (Figures 1 and 5). Both conservation only scenarios (HE-co and SP-co) are able to prevent

312   a large share of the baseline loss of biodiversity. With additional sustainability measures (HE-is and

313   SP-is) global biodiversity shows further improvements as compared to the conservation only

314   scenarios to a level just above 2015 levels in terms of MSA (Figures 1 and 5). Ecosystem services

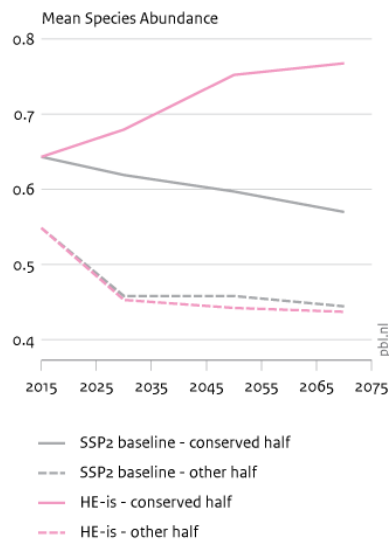315   improve especially in the SP scenarios.

21

316   The biodiversity indicators do, however, respond differently to the two conservation strategies.

317   While both HE-is and SP-is scenarios have similar overall global land MSA results, they show different

318   trends. In HE-is, MSA increases significantly in the protected half, but decreases in the non-protected

319   half, where it follows the baseline value (Figure 5a, see also Figure 6). Conversely, MSA results on

320   land are more equally distributed in the SP-is scenario, indicating that MSA is retained in many

321   regions, and both in natural and human dominated areas. The conservation and restoration of some

322   specific focus areas, supporting ecosystem services, in the SP scenarios will lead to significant

323   increases of MSA in these areas (Figure 5 b, see also Figure 6). The GMA improves in the conservation

324   only scenarios compared to the baseline. This is also reflected by the large number of currently

325   threatened species that increase in population size (Figure 1). The SP strategy, instead, results in a

326   stabilization of the current state, as indicated by the lack of change (or slight decrease) in GMA

327   values compared to current levels and by the fact that most of the threatened species do not change

328   (Figures 5e-f). Note that the impacts of climate change were not included in this analysis, and that

329   the outcomes cover mammals only.

330

331   While MSA in water decreases in the baseline, it increases in the SP scenarios and it stabilizes around

332   current values in the HE scenarios (Figure 1). The integrated sustainability scenarios (HE-is, SP-is),

333   result into similar MSA values in water as compared to conservation only scenarios (HE-co, SP-co).

334   This pattern is consistent for the three different water ecosystem types (lakes, rivers and wetlands,

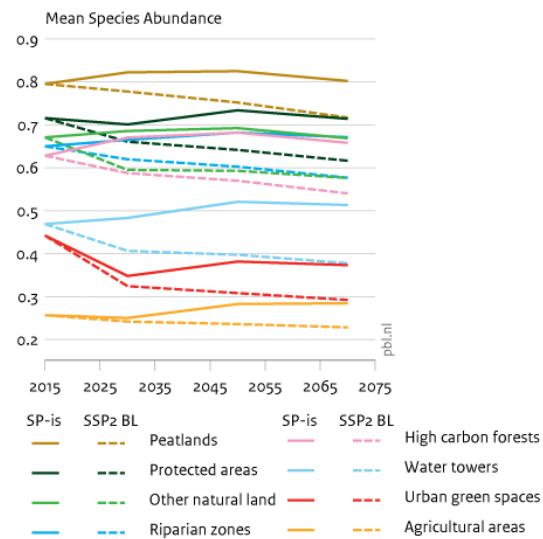335   but differs between regions (see details in S.5).

336

337   In the baseline scenario, provisioning services, such as crop and grass production, increase following

338   agricultural area expansion, but most regulating ecosystem services will decrease, such as erosion

339   control, carbon sequestration and, to a lesser extent, pest control, pollination and the percentage of

340   healthy lakes (figure 1 and 5c-d). This overall pattern in the baseline changes into a pattern of slightly

341   increasing provisioning and clearly increasing regulating services in both HE and SP scenarios, but

342   most pronounced in SP. Most ecosystem services improve due to changing agricultural, forest and

343   water management, however the carbon sequestration relative to the carbon emissions decreases in

344   HE-co and SP-co, and it only shows a slight increase in HE-is and SP-is, as not only the uptake of

345   carbon increases but the emissions decline simultaneously. Overall, most pathways indicate

346   diminishing trade-offs between these two ecosystem services categories (Figure 5c-d). For some

347   variables there are however large regional differences.

(a) MSA in focus areas under the Half Earth IS scenario

Mean Species Abundance

SSP2 baseline - conserved half
SSP2 baseline - other half
HE-is - conserved half
HE-is - other half

(b) MSA in focus areas under the Shared Planet IS scenario

Mean Species Abundance

SP-is	SSP2 BL		SP-is	SSP2 BL	
		Peatlands			High carbon forests
		Protected areas			Water towers
		Other natural land			Urban green spaces
		Riparian zones			Agricultural areas

(c) Change in provisioning ecosystem services

Change in % in 2070, compared to 2015

Food production   Grass and fodder production   Healthy lakes

SSP2 baseline   HE-co   SP-co
HE-is   SP-is

(d) Change in regulating ecosystem services

Change in % in 2070, compared to 2015

Pest control   Polli-nation   Erosion control   Carbon seq.   Water purification
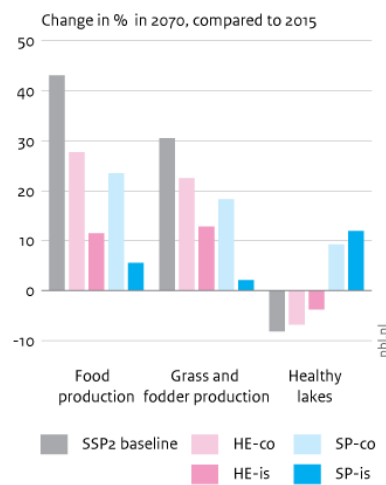
SSP2 baseline   HE-co   SP-co
HE-is   SP-is
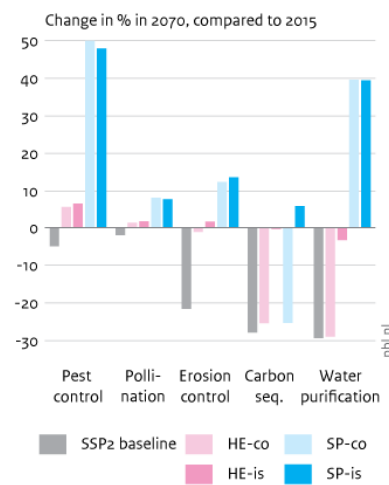
(e) Change in overall geometric mean abundance

Index (2015=1) for mammals

SSP2 baseline   HE-co   SP-co
HE-is   SP-is
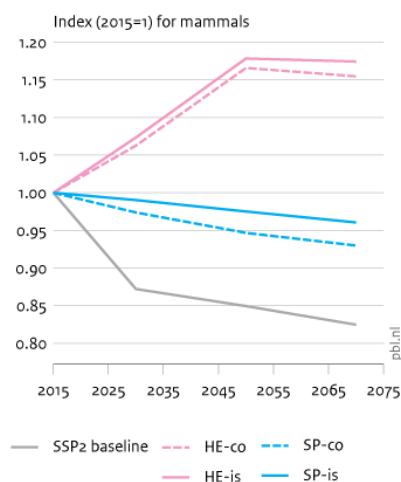
(f) Change in fraction of threatened mammal species

Fraction increasing or decreasing from 2015-2070

< -50%   -50 - 5%   -5 - 5%   5 - 50%   > 50%
Decrease   Constant   Increase

SSP2 baseline   HE-is
SP-is

348

24
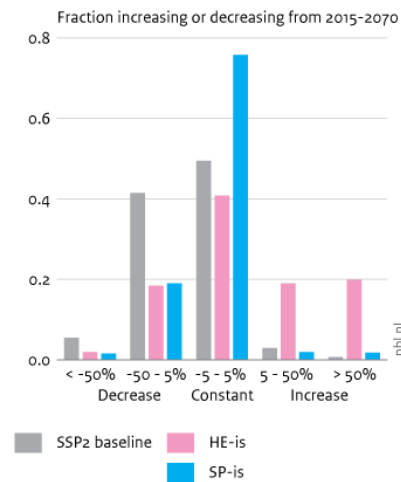
349   FIGURE 5 Changes in biodiversity and ecosystem services. (a) MSA under HE-is in protected and in

350   non-protected half; (b) MSA under SP-is for various ecosystems; (5c) Change in provisioning

351   ecosystem services; (c) Change in regulating ecosystem services, 2015-2070; (d) Change in overall

352   geometric mean abundance; (d) Change in fraction of threatened species; 2015-2070.

353   The differences between the pathways become more evident when looking at the regional results, as

354   shown in Figure 6 for the changes in MSA on land. MSA in 2015 shows low MSA in human dominated

355   areas and high MSA values in nature dominated parts of the world, including deserts, boreal forest

356   and tundra, and tropical forest areas. The SSP2 baseline results in predominantly decreasing MSA

357   trends in all regions, except for regions where MSA is already and remains low, such as South Asia,

358   Eastern China, Eastern USA and Europe. The largest MSA decreases are expected in regions that

359   currently still show high MSA values and with high demand for land, such as in Sub-Saharan Africa,

360   Central Asia, and the western parts of South and North America, as well as in Middle East and North

361   Africa and western Australia. Figure 6b illustrates the intra-regional dynamics of HE-is scenario.

362   Improvements in MSA resulting from conservation and restoration in the protected areas alternate

363   with large MSA decreases, following the baseline, from conversion of nature in non-protected areas

364   within the same region. Figure 6c shows the SP-is scenario protects important high MSA value areas

365   with pristine nature and results in improving MSA in mixed systems and areas supporting ecosystem

366   services (see also Figure 5b). This, overall limits large MSA decreases and provides a globally more

367   balanced outcome, compared to the HE-is and baseline scenarios. Overall, there are much greater

368   land use shifts projected in the HE and baseline scenarios than in the SP scenario.

369   Although in HE scenarios all regions are required to achieve high levels of conservation to meet the

370   goals of 50% protection of all ecoregions, efforts differ among regions compared to currently

371   protected areas. Especially in Central and South America a considerable expansion of conserved

372   areas is required (See figure S5.1). In 2050, West and Central Europe will be the region with the

373   lowest percentage change of protected areas compared to current protection level (+17%). The SP

374   scenarios require smaller levels of area conservation than HE scenarios across all regions, with the

375   exception of the South East Asia region that will conserve 51% of its area by 2050. 7 out of 10 regions

376   will expand area conservation by less than +12% compared to the current state. Only the South East

377   Asia (+29%), Central and South America (+19%) and North America (+17%) regions achieve higher
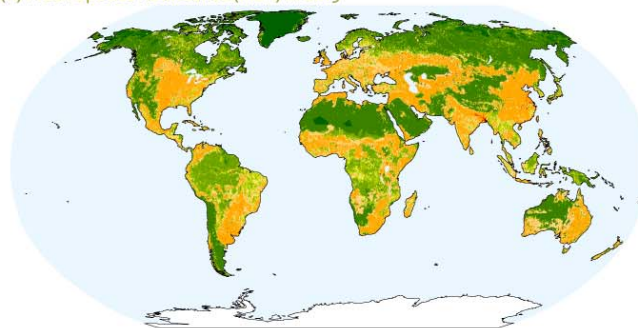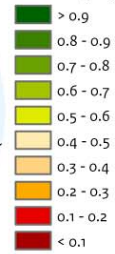
378   levels of area conservation.

379

380

381

382

(A) Mean Species Abundance (MSA) in 2015

Legend (map A and Sankey diagrams)
MSA category

The Sankey diagrams illustrate the change in share of the global land area in each MSA category. The flow colors reflect the MSA category outcome for the year 2050.
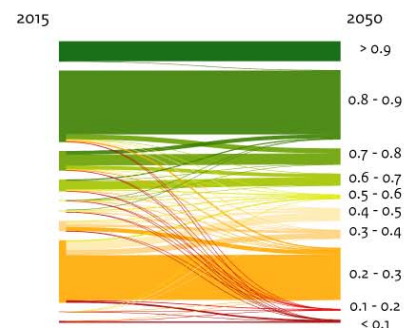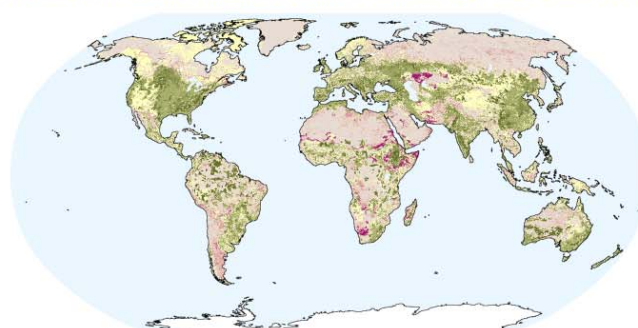
(B) Change in MSA under the SSP2 baseline 2015 - 2050: global map and Sankey diagram per MSA category
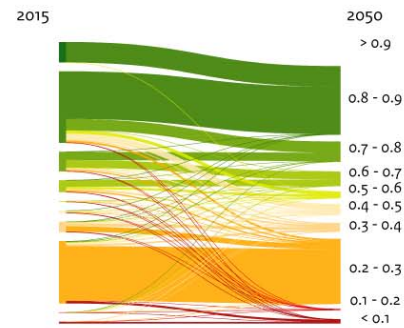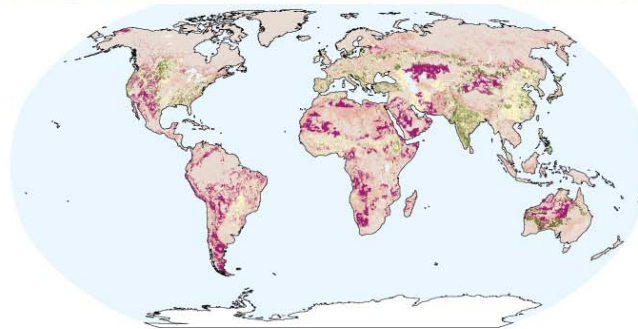
(C) Change in MSA under the Half Earth-IS scenario 2015 - 2050: global map and Sankey diagram per MSA category
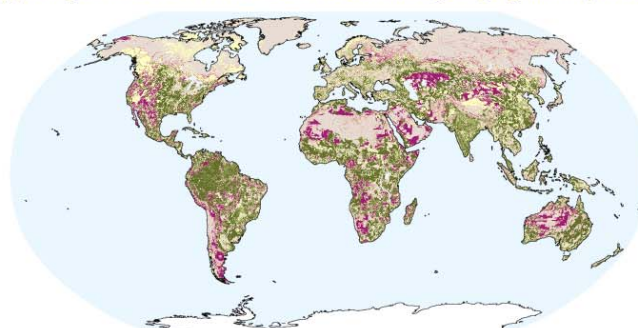
(D) Change in MSA under the Shared Planet-IS scenario 2015 - 2050: global map and Sankey diagram per MSA category

Legend (maps B, C and D)
Change in MSA

383

384

27

385   FIGURE 6 Regional results: (a) Mean Species Abundance in 2015; (b-d) Change in Mean Species

386   Abundance 2015-2050 baseline, HE-is and SP-is. The flow diagrams illustrate the changes in share of

387   global land area for each MSA category between 2015 and 2050.

388

389   **3.4 Contribution of actions to avoided loss of MSA**

390   Overall, for the global terrestrial MSA in 2050 the projected improvement compared to the baseline

391   is over 7% in the HE-is and over 6% in the SP-is scenario. These improvements can be attributed to

392   several actions resulting from the overall integrated measures on agricultural productivity and agro-

393   ecology, consumption changes and waste reduction. The MSA improvements are the outcome of (1)

394   conservation efforts in order to prevent baseline nature conversion, (2) the large scale rewilding and

395   restoration of natural areas that characterizes HE-is and (3) the improvement of nature in ecosystem

396   services supporting areas and mixed cropland/nature systems that is key in SP-is. Additionally,

397   reducing impacts from (4) fragmentation, infrastructure and encroachment. and climate mitigation

398   measures (5) contribute to the improvement of MSA compared to the baseline outcome in 2050 in
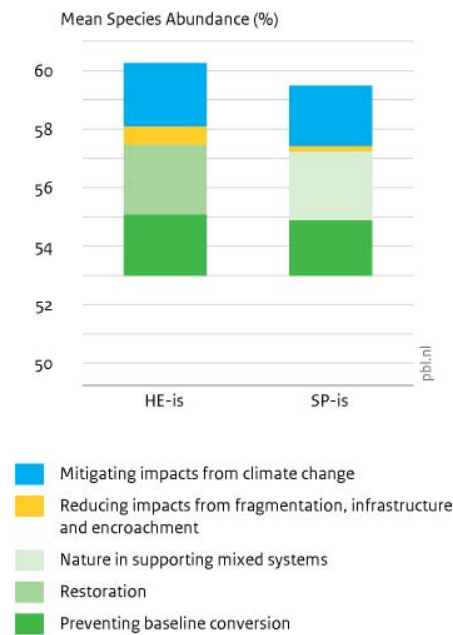
399   both scenarios.

400   For the global aquatic MSA (area-averaged over the different water types) the projected

401   improvement in 2050 in HE-is and SP-is compared to the baseline, is over 7% and 11% respectively.

402   These improvements can be attributed to: (1) prevented wetland conversion; (2) decreased adverse

403   effects on wetlands by human land-use in their catchment; (3) decreased pollution of lakes and rivers

404   from agricultural and/or urban sources; (4) decreased hydrological disturbance of rivers and

405   floodplain wetlands by restrictions on dams. The effect of climate change in itself is not included

406   because of current model restrictions. The attributions 1-3 contribute more in the SP pathway than

407   in HE, as the former emphasizes the catchment-scale processes and inland wetland conservation for

408   ecosystem services. The contribution of dam restrictions appears to be small on average, but it would

409   be larger if only rivers and floodplain wetlands were considered. This attribution contributes more in

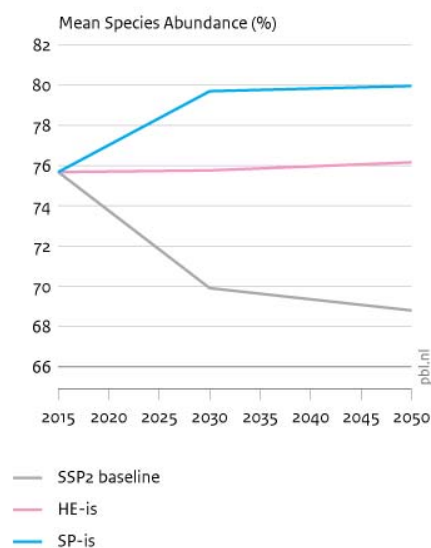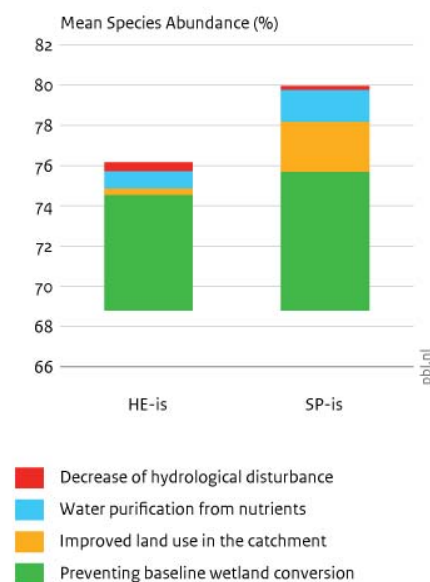410   HE as more emphasis is given to the conservation of pristine rivers.

411

412
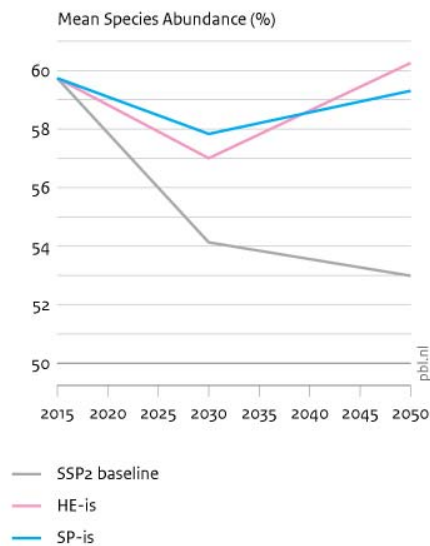
413   FIGURE 7: Measures contributing to reducing terrestrial (7.a and b) and aquatic (7.c and d)

414   biodiversity loss, globally (in MSA). Figure 7 describes the net contribution of the various actions in

415   halting the loss and restoring biodiversity compared to the SSP2 baseline outcome over the period

416   2015 - 2050. The overall difference for the timeline in global MSA between the SSP2 baseline and the

417   HE-is and SP-is is shown for terrestrial and aquatic MSA in figures 7a and 7c. Figure 7b and 7d show

418   how the projected improvement in MSA values in HE-is and SP-is in 2050 compared to the SSP2

419   baseline is attributed to the various measures in both pathways.

420

421   **4. Discussion**

422

423   **4.1 Nature, climate and food security**

424   This paper shows that two strong , but contrasting, conservation strategies, Half Earth and Sharing

425   the Planet, combined with an extensive set of sustainability measures, can achieve multiple

426   sustainability goals, including bending the curve for biodiversity, ensuring food security and keeping

427   global temperature change below two degrees. Strong conservation strategies alone will however

428   neither be sufficient to restore biodiversity, as indicated by still decreasing MSA values in both HE-co

429   and SP-co scenarios, nor ensure food security nor mitigate climate change below 2 degrees. Land-use

430   changes in both conservation scenarios (HE-co; SP-co) somewhat contribute to climate change

431   mitigation, but not much, whereas climate change still has impacts on biodiversity.

432   This confirms the need for strong climate mitigation efforts to be able to bend the curve for

433   biodiversity (Ohashi et al., 2019; Pereira et al., 2010; Soto-Navarro et al., 2020; Warren et al., 2013).

434   So far, current sustainability scenarios such as SSP1 have, however, been insufficient to 'bend the

435   curve' for biodiversity loss (Schipper et al., 2020; Pereira et al., 2020; van Vuuren et al., 2015; Kok et

436   al 2018). Leclere et al. (2020, in press) analyzed a very ambitious integrated action portfolio,

437   concluding that strong conservation and food system transformation are key for reversing

438   biodiversity decline. That analysis, however, did not include the impacts of climate change on

439   biodiversity. In this paper, we show that that bending the curve for biodiversity is still possible when

440   taking into account climate change, provided that ambitious climate change mitigation measures are

441   also included. Among these measures, demand reduction measures, will also have added benefits for

442   biodiversity.

443   To deal with potential trade-offs between biodiversity conservation and climate mitigation, we

444   limited bio-fuels (Behrman et al., 2015; Foley et al., 2011; Raghu et al., 2011) and hydropower use

445   (Ziv et al., 2012; Hermoso, 2017; Reid et al., 2019), did not include climate policy-driven afforestation

446   (Doelman et al., 2019), and maximized the potential gains of land use options (Griscom et al., 2017;

447   Nunez et al., 2020; Roe et al., 2019). Setting limits to applying these energy sources will have

448   consequences for the energy system, such as increased demand for other renewables like solar

449   energy, possibly higher costs, and increased need for improved energy efficiency and reduction of

450   energy demand (van Vuuren et al. 2018).

451   Furthermore, we show that, both conservation-only strategies and their related agricultural systems

452   will see a slower decrease of number of people at risk of hunger. This confirms possible trade-offs

453   between agricultural production, food security and conservation (Egli et al., 2018; Foley et al., 2011;

454   Mehrabi et al., 2018; Ramankutty et al., 2018) and emphasizes that either of the conservation-only

455   strategies HE-co and SP-co need to be combined with structural changes in both agricultural

456   production and food systems (Brussaard et al., 2010; Fisher et al., 2017; Garnett et al., 2013; Kremen,

457   2015; Leclere et al. accepted).

458   Ultimately, to restore nature and achieve food security and climate mitigation targets, both strong

459   area-based conservation and restoration efforts (Dinerstein et al., 2017, 2019; Locke, 2013; Visconti

460   et al., 2019; Wilson, 2016) as well as a broader sustainability measures, including reform of

461   agricultural and food systems, including bothsupply and demand, and other effective climate

462   mitigation, are needed to restore nature (Leclere et al., 2020; Mehrabi et al., 2018; Pereira et al.,

31

463 2010; Soto-Navarro et al., 2020; Warren et al., 2013). We show that limiting animal consumption,

464 reduction of food waste, and improved agricultural management, to both approaches (sparing and

465 sharing) is key to solve trade-offs between food production and biodiversity conservation, and also a

466 key element of greenhouse-gas emission reduction. This confirms earlier publications on the broad

467 action portfolio required for biodiversity conservation and food security (Foley et al., 2011; Garnett

468 et al., 2013; and Godfray, 2014; Mehrabi et al., 2018; Perfecto & Vandermeer, 2009; van Vuuren et

469 al., 2015, sCBD 2014,). Note, however, that our analysis does not account for socio-economic and

470 political dimensions that have an important role in ensuring food security (Fischer et al., 2017).

471

472 **4.2 Comparing conservation strategies**

473 While the HE and SP strategies show different outcomes with respect to biodiversity, they have also

474 some results in common. Firstly, there is an overlap in conservation areas, inevitably because both

475 strategies include existing protected and key biodiversity areas, but also because they tend to be

476 selected by the ecological criteria in HE (e.g. ecoregion representation, Range Rarity Index) and the

477 ecosystem service criteria in SP (e.g. high-carbon forests, riparian zones). Together the two strategies

478 have over 34 million km^2 of conserved area in common , indicating 51% and 80% of the total

479 conserved area for HE and SP respectively. When looking at MSA improvement, in both strategies,

480 28% of the land area (scattered globally, see Figure SI 5.6 in S.I.) shows at least 5 percent-point

481 improvement.

482

483 Secondly, the results for biodiversity and for regulating ecosystem services both point in the same

484 direction, although with differences in magnitude between the strategies. We do not find many

485 trade-offs between biodiversity conservation and regulating ecosystem services. Trade-offs with

486 provisioning services such as crop and grass production do occur (as shown by IPBES, 2019 and

487 Pereira et al., 2020), but they diminish in sustainability scenarios (such as SSP1), and even more in

488 the HE-is and SP-is scenarios we present here. Hence, we show that synergies between the two are

32

489   certainly possible in important respects, for instance in case of protection of carbon-rich, water-

490   conserving or soil-protecting ecosystems, riparian zones or adopting mixed farming systems. But no

491   doubt, in specific cases trade-offs between conservation goals and ecosystem services will occur

492   (Maes et al., 2012; Van der Biest et al., 2020).

493

494   There are, however, also large differences between the HE and SP strategies. HE includes ~20% extra

495   conservation areas compared to SP, while SP includes a number of biodiversity improvements in

496   agricultural areas. On average, HE performs better than SP on most terrestrial biodiversity measures,

497   but this varies among indicators and among regions. In general, HE greatly improves biodiversity in

498   the protected half but has hardly any effect in the non-protected half, while SP shows more evenly

499   distributed improvements. Especially the Amazon and Cerrado regions, Central Africa and South and

500   Southeast Asia improve most in HE-is. Some other regions score better MSA (hence biodiversity)

501   results under the SP-is scenario, such as the western part of North America, central and east Asia,

502   western Australia and scattered parts of Africa and South America. It appears that HE (compared to

503   SP) conservation strategies do not necessarily translate into higher regional MSA results, thereby

504   suggesting that a protection based primarily on wilderness might not be the optimal solution

505   everywhere (Ellis & Mehrabi, 2019; Pimm et al., 2018). Nevertheless, our results are consistent with

506   the conclusion by Riggio et al. (2020) that there are still low-impact areas available in the world that

507   provide opportunities for conservation. This is also in line with recent criticisms by Visconti et al.

508   (2019) and Jung et al. (2020) who, like Pimm et al., (2018), point at the importance of allocating the

509   right places for conservation. Our analysis suggests that a more differentiated approach is needed to

510   strike optimal results across different regions and the projected MSA improvement in a region will

511   depend on the initial MSA value (i.c. in 2015) in that region. Our findings align well with the concept

512   of the 'Three Conditions' as presented by Locke et al. (2019) that takes a middle position between HE

513   and SP. The 'Three Conditions' identify different regional conditions ranging from large wild areas, via

514   shared lands to cities and farmland, to enable the development of conservation responses and

515   production practices appropriate for each condition that can be informed by both HE and SP.

516

517   Another difference between the two conservation pathways is that aquatic MSA in general profits

518   more from the SP strategy than terrestrial MSA. This may be attributed to the fact that many aquatic

519   ecosystems are more connected with each other and with the surrounding or upstream land, e.g. by

520   flow of water and substances. This implies that general improvements in land management, including

521   the restoration of riparian buffer zones, have a broader effect than only locally, while on the other

522   hand local conservation measures might be less effective for aquatic ecosystems than for terrestrial

523   ones, unless whole landscapes or (sub)catchments are protected. This is in accordance with the

524   emphasis on catchment-based conservation measures for aquatic biodiversity recently put forward

525   by Tickner et al (2019) and Van Rees et al (2020). In addition, added benefits would be expected in

526   the SP strategy from the lower use of agrochemicals. On the contrary, HE scores better on the effect

527   of flow on biodiversity as more emphasis is put on river flow restoration (another recommendation

528   by Tickner et al (2019) and Van Rees et al (2020) due to more restrictions on hydropower. HE would

529   probably also score better for water bodies with many endemics ('reversed islands'), but this could

530   not be explored in this study as specific species models were not applied.

531   Comparing both conservations strategies with respect to land cover types, the HE strategy, requires

532   substantial changes in land use, especially grazing lands are expected to be abandoned and restored

533   towards natural grasslands, such as savannah and steppe systems, while there is less dynamics in

534   forest systems (see Figure 2). With respect to species, HE protects more areas important for the

535   conservation of threatened species, which yields decreasing number of species at risk of extinction

536   and higher RLI values, whereas in SP the human dominated landscapes will alter considerably,

537   improving the status of species that are adapted to these landscapes. This shows the value of using

538   different biodiversity indicators in parallel, the GMA and RLI providing information on species trends

539   and the MSA more on the ecosystem level.

34

540 A consequence of the large expansion of conserved areas, the HE scenario will directly affect a large

541 amount of people, and this could put nature against humans risk diminished acceptance of nature

542 conservation (Buscher & Fletcher, 2020; Ellis, 2019; Schleicher et al., 2019). Furthermore, a too-

543 narrow focus on achieving quantitative protection targets might not necessarily ensure that

544 biodiversity is actually conserved (Visconti et al., 2019). Attention should also be focused on the

545 management and governance of the conserved areas so as to ensure fair and effective protection.

546

547 **4.3 Actions and efforts needed**

548 The scenarios show that a portfolio of measures is needed to achieve nature, food and climate

549 targets in both the HE and SP conservation strategies. A transition towards more sustainable forms of

550 agriculture is a cornerstone for all strategies to halt biodiversity loss (Gross et al., 2019; Kremen,

551 2015; Phalan et al., 2011). Earlier analyses showed the importance of changes in agricultural

552 production to create space for area-based conservation and restoration (Kok et al., 2018; Leclere et

553 al., 2018, 2020; Mehrabi et al., 2018). Whether this is implemented by additional technological

554 intensification (Egli et al., 2018; Phalan et al., 2011) as in HE-is, or by a shift to agro-ecological

555 methods (Kremen, 2015, Tittonel, 2014) as in SP-is, both imply considerable changes in agricultural

556 systems. Optimal strategies for agriculture will differ regionally and can be aligned with different

557 kinds of conservation priorities (Locke et al., 2019).

558

559 This points at the need for improved spatial planning approaches to allocate conservation areas; not

560 only in the traditional form of Protected Areas, but also in new forms of conservation, such as the

561 recently internationally agreed Other effective Conservation Measures (Dudley et al., 2018; Garnett

562 et al., 2018; IUCN WCPA, 2019). Also new proposals for conservation are being suggested such as

563 'Promoted Areas' (Buscher & Fletcher, 2020). Improved spatial planning and management of

564 conservation areas may enhance the effectiveness of conservation areas also for freshwater

565 biodiversity (Hermoso et al., 2016; Reis et al., 2017; van Rees et al., 2020). All emphasize sustainable

566   use and the delivery of socially, economically and culturally relevant benefits next to conservation

567   objectives. The SP strategy comes close to these ideas where the implementation of a landscape

568   approach delivers conservation and Nature's Contribution to People (NCP) at the same time (Kremen

569   & Merenlender, 2018).

570

571   Crucially important elements in a portfolio of measures are reducing food waste (Kok et al., 2018;

572   Parfitt et al., 2010; Tscharntke et al., 2012) and reduced overall consumption of animal products,

573   (Machovina et al. , 2015; Stoll-Kleemann & Schmidt, 2016; Tilman & Clark, 2014, Springmann, 2018;

574   Willet et al., 2019, FAO et al, 2020). Improved human health and more attention to animal welfare

575   are important co-benefits of such diets that can be used as leverages for implementation. Reducing

576   food waste is also fundamental as according to FAO (2013) one third of produced food for human

577   consumption is lost. As food waste happens at different point of the supply chain for different

578   regions (low-income at agricultural production; middle-high income at retailer and consumer level)

579   (FAO, 2013; Tscharntke et al., 2012) this requires multiple interventions.

580

581   Effective climate change mitigation is an important condition to restore nature, especially in the long

582   term (after 2050) (e.g. Reid et al., 2019.) We have also shown that conservation measures can

583   contribute considerably to up to 134 and 309 Gt CO-2 equivalents (6 and 13% %) of required GHG

584   reductions, for conservation only and integrated strategies, respectively. This is lower than recent

585   estimates on the contribution of land or nature-based climate solutions to climate (Griscom et al.,

586   2018; Nunez et al., 2020; Roe et al., 2019). This can be explained by the fact that our study focusses

587   on biodiversity-related measures, and does not cover all land-related measures in agriculture,

588   grassland and wetlands, and afforestation as included by Griscom et al. (2018). The recent discussion

589   on the potential of afforestation (Bastin et al., 2019) triggered worries about delayed action in the

590   energy sector (Friendlingstein et al., 2019), and strong land-based mitigation may also affect food

36

591   systems. (Doelman et al., 2018). Furthermore, carbon uptake through restoration measures is

592   effective predominately in the short-term, though some long-term sinks exist in natural systems.

593

594

595   **4.4 Methodological reflections**

596   The analysis in this paper is based on the IMAGE and GLOBIO models. This allowed us to analyse

597   multiple pressures on biodiversity, as well as multiple indicators for biodiversity and ecosystem

598   services in both the terrestrial and freshwater domain. The analysis covers the most important

599   drivers and pressures on the global scale, but is not complete, as for instance the influence of

600   invasive species and of toxic stress are not included. Likewise, feedbacks of ecosystem services to

601   production sectors are not implemented, and the modelling of mixed farming systems could be

602   further improved. It would also be important in a next step to analyse these pathways using multiple

603   models. Although we did not explicitly analyse model- and scenario-uncertainties for this study,

604   together the two strategies span a solution space for possible pathways reflecting major

605   uncertainties. Projecting the scenarios towards 2070, thus going beyond the 2050 target year of the

606   CBD vision, shows that in the longer term integrated sustainability measures taken in the scenarios

607   are not enough to compensate for the projected growth in population and wealth in the baseline.

608   This again emphasizes the importance to address the indirect drivers of biodiversity loss such as

609   economy and population, as well as institutions, equity aspects and underlying value systems (IPBES,

610   2019; Buscher et al., 2017; Buscher & Fletcher, 2020; KC and Lutz, 2017; Otero et al., 2020; Pascual et

611   al., 2017; Perfecto & Vandermeer, 2009; Tscharntke et al., 2012).

612   So far, explorative scenario-analysis have mainly looked at achieving biodiversity objectives from a

613   climate perspective (Pereira et al., 2020; Riahi et al., 2017), and show the continued decline of

614   biodiversity. In this study, we bring ambitious biodiversity, together with climate objectives in

615   scenario-analysis (Dinerstein et al., 2019; Pereira et al., 2017, Titeux et al., 2017, Warren et al., 2013;

616   Soto-Navarro et al., 2020), and to put nature and our relationships with it at the center of

617   biodiversity scenarios (Rosa et al., 2017). As shown, this requires inclusion of important

618   considerations in scenarios such as criteria for conservation areas (Riggio et al., 2020), ecosystem

619   services (Soto-Navarro et al., 2019) or nature-inclusive forms of agriculture (Bommarco et al., 2018).

620   We aimed to build upon and contribute to the work of IPBES and their recent Nature Futures

621   Framework (IPBES-NFF) which provides guidance to elaborate scenarios with different types of

622   human-nature relations at the centre (Pascual et al., 2017; Rosa et al., 2017; Pereira et al., 2020).

623   Specifically, the HE scenario was envisioned to prioritize the intrinsic value of nature as it aims at

624   conserving nature's diversity and functions ('Nature for Nature' according to IPBES-NFF). The SP

625   scenario was envisioned to prioritize instrumental and relational values, ('Nature for Society' and

626   'Nature as Culture'). However, due to limitations in our models, only the 'Nature for Society' part

627   could be operationalized into the model. Efforts are underway that aim to include Nature as Culture

628   in global scenario-analysis. The way forward may be through a combination of quantitative and more

629   qualitative methods. The multiple ways people relate to and value nature could, in this way, become

630   evident and recognized in a conservation context (Chan et al., 2016; Martin et al., 2016; Pascual et

631   al., 2017, van Zeijts et al., 2017). Better inclusion of a plurality of values in scenario-analysis would

632   also help to better understand the equity dimensions of conservation, for example for people living

633   in or around the conservation areas, as put forward by Schleicher et al. (2019) and Büscher et al.

634   (2017), and to reconcile the conservation goals with local or regional benefits.

635

636   **4.5 Implications for post-2020 Global Biodiversity Framework**

637

638   The analysis in this paper has various implications for the post-2020 Global Biodiversity Framework

639   that is currently under negotiation. First and foremost, to meet long term goals for biodiversity,

640   climate change, food security (CBD, UNFCCC, SDGs), it will be necessary to advance a portfolio of

641   'integrated sustainability measures', that combines strong conservation efforts with addressing

642   direct and indirect drivers of biodiversity loss, especially land use change, agriculture and climate

643   change and increased attention to capturing the potential of nature's potential contribution to

644   resolving global challenges. These measures include strong area-based conservation and restoration

645   (Dinerstein et al., 2017, 2019; Locke, 2013; Visconti et al., 2019; Wilson, 2016), changes in

646   agricultural production and food consumption (e.g., reducing food waste, reducing animal product

647   consumption and increasing agricultural productivity) (Machovina et al., 2015; Stoll-Kleemann &

648   Schmidt, 2016; Tscharntke et al., 2012), as well as decarbonizing the energy system in ways that are

649   not detrimental to biodiversity and food security and benefit as much as possible from natural

650   climate solutions.

651

652   Conservation only efforts, without changes in consumption and waste and additional effective

653   climate mitigation, although resulting in avoiding a considerable part of the projected loss in

654   biodiversity, will not be able to restore nature and have a strong trade-off with food security

655   (Mehrabi et al., 2018). Furthermore it will be important to capitalize on the possible synergies

656   between conservation and climate mitigation policy by indicating the contribution strong

657   conservation efforts can make to bringing climate targets within closer reach (Dinerstein et al., 2019),

658   as well other contributions of nature to people (e.g. agriculture, clean water) (Diaz et al., 2018).

659

660   The two conservation strategies not only have different objectives but, in fact, show the effects of

661   protecting different types of nature over other and can be related to the goals and targets currently

662   under negotiation for the post-2020 Global Biodiversity Framework (CBD, 2020). The proposed target

663   of 30% protection by 2030 is coherent with both of the long term strategies analyzed, although each

664   may differ in the prioritization of areas to conserve. Evidently, the two strategies will lead to two

665   alternative futures with different urban, agricultural, forestry and fisheries systems. We do not to

666   advocate one strategy or the other, or present these as irreconcilable pathways, but rather we

667   present these findings to help open up a space where insights from different alternatives can be

668   deliberated.

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671

672   **Author contributions**

673   MK, RA, JM, JJ designed the research; MK, JM, MI, RA developed scenario-narratives and

674   conservation maps; JM, JH, JJ, MB, AS, RA ran GLOBIO; WJ, ES, AT ran IMAGE; all authors contributed

675   to analysis of results; MK, RA wrote first versions of this paper to which all authors contributed in

676   various iterations, MK and JM finalized the paper.

677   Authors declare no conflict of interest.

678

679   **Acknowledgements**

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