Article

Bending the curve of terrestrial biodiversity needs an integrated strategy

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Increased efforts are required to prevent further losses to terrestrial biodiversity and the ecosystem services that it provides[1,2]. Ambitious targets have been proposed, such as reversing the declining trends in biodiversity[3]; however, just feeding the growing human population will make this a challenge[4]. Here we use an ensemble of land-use and biodiversity models to assess whether—and how—humanity can reverse the declines in terrestrial biodiversity caused by habitat conversion, which is a major threat to biodiversity[5]. We show that immediate efforts, consistent with the broader sustainability agenda but of unprecedented ambition and coordination, could enable the provision of food for the growing human population while reversing the global terrestrial biodiversity trends caused by habitat conversion. If we decide to increase the extent of land under conservation management, restore degraded land and generalize landscape-level conservation planning, biodiversity trends from habitat conversion could become positive by the mid-twenty-first century on average across models (confidence interval, 2042–2061), but this was not the case for all models. Food prices could increase and, on average across models, almost half (confidence interval, 34–50%) of the future biodiversity losses could not be avoided. However, additionally tackling the drivers of land-use change could avoid conflict with affordable food provision and reduces the environmental effects of the food-provision system. Through further sustainable intensification and trade, reduced food waste and more plant-based human diets, more than two thirds of future biodiversity losses are avoided and the biodiversity trends from habitat conversion are reversed by 2050 for almost all of the models. Although limiting further loss will remain challenging in several biodiversity-rich regions, and other threats—such as climate change—must be addressed to truly reverse the declines in biodiversity, our results show that ambitious conservation efforts and food system transformation are central to an effective post-2020 biodiversity strategy.

Terrestrial biodiversity is decreasing rapidly[1,2] as a result of human pressures, largely through habitat loss and degradation due to the conversion of natural habitats to land for agriculture and forestry[5]. Conservation efforts have not halted these trends[6] and the demand for land for the production of food, feed and energy is increasing[7,8], putting at risk the myriad of ecosystem services upon which people depend[9–11].

Ambitious targets for biodiversity have been proposed, such as halting and even reversing the currently declining global trends in biodiversity[3,12] and conserving half of the Earth[13]. However, evidence is lacking with regards to whether such biodiversity targets can be achieved, given that they may conflict with food provision[4] and other land uses. As a step towards developing a strategy for biodiversity that is consistent with the Sustainable Development Goals, we used a multi-model ensemble approach[14,15] to assess whether and how future biodiversity trends from habitat loss and degradation can be reversed, while still feeding the growing human population.

We designed seven scenarios to explore pathways that would enable the reversal of the decreases in biodiversity (Table 1 and Methods) based on the Shared Socioeconomic Pathway (SSP) scenario framework[16]. The 'Middle of the Road' SSP 2 defined our baseline (BASE) scenario for future drivers of habitat loss. In six additional scenarios, we considered different combinations of supply-side, demand-side and conservation efforts to reverse the biodiversity trends; these were based on the 'green growth' SSP 1 scenario, augmented by ambitious conservation assumptions (Extended Data Fig. 1) and culminated in the integrated action portfolio (IAP) scenario, which includes all efforts to reverse the biodiversity trends.

Because of the uncertainties that are inherent to the estimation of how drivers will change and how these changes will affect biodiversity, we used an ensemble approach to model biodiversity trends for each scenario. First, we used the land-use components of four integrated assessment models (IAMs) to generate four spatially and temporally resolved projections of habitat loss and degradation for each scenario (Methods). These IAM outputs were then evaluated using eight biodiversity models (BDMs) to project nine biodiversity indicators (BDIs, each defined as one biodiversity metric estimated by one BDM) (Table 2) that described trends in five aspects of biodiversity: the extent of suitable habitat, the wildlife population density, the intactness of the local species composition, and the regional and global extinction of species. The BASE and IAP scenarios were projected for an ensemble of 34 combinations of IAMs and BDIs; the other five scenarios were evaluated for a subset of seven BDIs for each IAM (an ensemble of

Table 1 | The seven scenarios describing the efforts to reverse declining biodiversity trends

Scenarios	Additional efforts to reverse trends in biodiversity					
	Supply side		Demand side		Increased conservation	
	Sustainably increased crop yields	Increased trade of agricultural goods	Reduced waste of agricultural goods from field to fork	Diet shift to a lower share of animal calories	Increased extent and management of protected areas	Increased restoration and landscape-level conservation planning
Baseline scenario						
BASE scenario	–	–	–	–	–	–
Single-action scenarios						
SS scenario	x	x	–	–	–	–
DS scenario	–	–	x	x	–	–
C scenario	–	–	–	–	x	x
Combined-action scenarios						
C + SS scenario	x	x	–	–	x	x
C + DS scenario	–	–	x	x	x	x
IAP scenario	x	x	x	x	x	x

In addition to the BASE scenario, we considered three scenarios that each comprised a single type of action aimed to reverse biodiversity trends due to future habitat loss (indicated by an 'x') and three scenarios in which actions were combined.

28 combinations) (Methods). To obtain more-robust insights, we performed bootstrap resampling[17] of the ensembles (10,000 samples with replacement) (Methods). We used state-of-the-art models of terrestrial biodiversity for global scale and broad taxonomic coverage; however, more-sophisticated modelling approaches—which are currently difficult to apply to such scales—could provide more-accurate estimates at smaller scales[18]. We estimate how future biodiversity will be affected by future trends in the largest threat to biodiversity at present (that is, habitat destruction and degradation); however, more-accurate projections of future biodiversity trends should account for additional threats to biodiversity, such as climate change or biological invasions.

Reversing biodiversity trends by 2050

Without further efforts to counteract habitat loss and degradation, we projected that global biodiversity will continue to decline (BASE scenario) (Fig. 1). Rates of loss over time for all nine BDIs in 2010–2050 were close to or greater than those estimated for 1970–2010 (Extended Data Table 1). For various biodiversity aspects, on average across IAM and BDI combinations, peak losses during the 2010–2100 period were: 13% (range, 1–26%) for the extent of suitable habitat, 54% (range, 45–63%) for the wildlife population density, 5% (range, 2–9%) for the local compositional intactness, 4% (range, 1–12%) for the global extinction of species and 4% (range, 2–8%) for the regional extinction of species (Extended Data Table 1). Percentage losses were greatest in biodiversity-rich regions (sub-Saharan Africa, South Asia, Southeast Asia, the Caribbean and Latin America) (Extended Data Fig. 2). The projected future trends in the loss and degradation of habitats and associated drivers[8,16], biodiversity loss[7,8] and variation in loss across biodiversity aspects[7,19,20] are consistent with those reported in other studies[1] (Extended Data Figs. 2–5 and Supplementary Discussion 1).

By contrast, ambitious integrated efforts could minimize further declines and reverse biodiversity trends driven by habitat loss (IAP scenario) (Fig. 1). In the IAP scenario, biodiversity loss was halted by 2050 and was followed by recovery for all IAM and BDI combinations except for one (IMAGE IAM combined with GLOBIO's estimate of the mean species abundance index (MSA) metric). This reflects the reductions in the loss and degradation of habitats and associated drivers, and the restoration of degraded habitats in this scenario (Extended Data Figs. 3–5 and Supplementary Discussion 1). Although global biodiversity losses are unlikely to be halted by 2020[6], rapidly stopping the global biodiversity declines that are caused by habitat loss is a milestone on the path to more-ambitious targets.

There are considerable uncertainties in both future land use and the effect on biodiversity, which reflect gaps in our knowledge[15]. To maximize the robustness of conclusions in the face of these uncertainties, we used a strategy with three main elements. First, as recommended by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[15], we conducted a multi-model assessment, building on the strengths and mitigating the weaknesses of several individual IAMs and BDMs to characterize uncertainties, understand their sources and identify results that are robust to these uncertainties. Analysing a single BDI across multiple IAMs (Fig. 1) or comparing two BDIs that provide information on the same biodiversity aspect (for example, MSA and the biodiversity intactness index (BII) in Fig. 1c) highlights the uncertainties that stem from individual model features such as the initial condition, internal dynamics and implementation of the different scenarios. These analyses show, for example, that differences between IAMs in the size of the initial area of grassland that is suitable for restoration and in the intensity of restoration efforts produces large uncertainties in biodiversity trends in all of scenarios that included increased conservation efforts (that is, the increased conservation effort (C) scenario, scenarios comprising increased conservation efforts combined with either supply-side (C + SS) or demand-side (C + DS) efforts and the IAP scenario) (Extended Data Figs. 3–6 and Supplementary Discussion 2). Similarly, differences between BDMs in the timing of the recovery of the biodiversity under the restoration of degraded land introduces further uncertainties, as do differences in taxonomic coverage and the source of the input data between BDMs that model the same BDI (Supplementary Discussion 2).

Second, rather than focussing on the absolute values of BDIs, we focus on the direction and inflexion of the relative change in BDIs over time and their response to differences in land-use change outcomes across scenarios. This emphasizes aspects of biodiversity outcomes that are more-directly comparable across multiple models and means that comparisons are less affected by model-specific differences and biases. We also used the most-recent versions of BDMs that are regularly improved—for example, the PREDICTS implementation of BII that is used here[21] better captures compositional turnover caused by land-use change than did an earlier implementation[22]. All BDMs remain affected by uncertainty in the initial land-use distribution, especially the spatial distribution of current forest and grassland management, which varies across IAMs and causes estimates of all BDIs for the year 2010 to differ

Table 2 | Key features of the nine estimated BDIs

Biodiversity metric	Biodiversity model(s)	Definition of the biodiversity metric	Biodiversity aspect
ESH	AIM-B and INSIGHTS	- Measures the extent of suitable habitat relative to 2010, geometrically averaged across species. - Ranges from 0 (no suitable habitat left for any species) to 1 (mean extent equal to that of 2010) or larger that 1 (mean extent larger than that of 2010).	Extent of suitable habitat
LPI	LPI-M	- Measures the population size relative to 2010, geometrically averaged across species. - Ranges from 0 (zero population for all species) to 1 (mean population size equal to that of 2010) or larger than 1 (mean population size larger than that of 2010).	Wildlife population density
MSA	GLOBIO	- Measures the compositional intactness of local communities (arithmetic mean of the relative abundance of species—truncated to 1—across all species that were originally present in comparison to an undisturbed state) relative to 2010. - Ranges from 0 (population of zero for all original species) to 1 (intactness equivalent to that of 2010) or larger than 1 (intactness closer to an undisturbed state than in 2010).	Intactness of the local species composition
BII	PREDICTS	- Measures the compositional intactness of local communities (arithmetic mean of the relative abundance of species across all species that were originally present in comparison to an undisturbed state, truncated to 1) relative to 2010. - Ranges from 0 (population of zero for all original species) to 1 (intactness equivalent to that of 2010) to larger than 1 (composition closer to an undisturbed state than in 2010).	Intactness of the local species composition
FRRS	cSAR_CB17	- Measures the proportion of species not already extinct or committed to extinction in a region (but not necessarily in other regions) relative to 2010. - Ranges from 0 (all species of a region extinct or committed to extinction) to 1 (as many species of a region are extinct or committed to extinction as in 2010) or larger (fewer species of a region are extinct or committed to extinction than in 2010).	Regional extinctions
FGRS	BILBI, cSAR_CB17 and cSAR_US16	- Measures the proportion of species not already extinct or committed to extinction across all terrestrial areas, relative to 2010. - Ranges from 0 (all species extinct or committed to extinction at a global scale) to 1 (as many species are extinct or committed to extinction at a global scale as in 2010) or larger (fewer species are extinct or committed to extinction at a global scale than in 2010).	Global extinctions

Using eight global BDMs (Methods), we estimated the relative change from 2010 (which was set to 1) in the nine different BDIs that each combine a BDM with a biodiversity metric. Biodiversity metrics and BDIs can be grouped into five broader biodiversity aspects. ESH, extent of suitable habitat; LPI, living planet index; FRRS, fraction of regionally remaining species; FGRS, fraction of globally remaining species.

considerably among IAMs. Because these initial differences between IAMs persist across time horizons and scenarios, the direction and amplitude of projected relative changes in indicator values are more informative than their absolute values across the ensemble.

Third, we used bootstrap resampling with replacement to obtain confidence intervals for ensemble statistics and limit the influence of any particular model on the key results (Methods). However, our approach does not cover part of the overall uncertainty, which stems from either individual models (for example, related to the uncertainty in input parameters) or limitations common to most models implemented in this study, such as the rudimentary representation of relationships between biodiversity and land-use intensity (see Methods and Supplementary Discussion 2 for more information on the evaluation of individual BDMs).

Contribution of different interventions

To understand the contribution of different strategies, we analysed the projected BDI trends for all seven scenarios (Table 1) for an ensemble of 28 BDI and IAM combinations, as shown in Fig. 2a for GLOBIO's MSA BDI and Extended Data Fig. 6 for other BDIs. We focused on ensemble statistics for three outcomes (Fig. 2b and Extended Data Table 2): the date of peak loss—that is, the date at which the BDI value reached its minimum over the 2010–2100 period; the share of future peak loss that could be avoided compared with the BASE scenario; and the speed of recovery after the peak loss—that is, the recovery rate after peak loss, relative to the rate of decline over the historical period (Methods).

Our analysis shows that a bold conservation plan is important to halt biodiversity declines and to place ecosystems on a recovery path[3]. Increased conservation efforts (C scenario) was the only single-action scenario that led, on average across the ensemble, to both a peak in future biodiversity losses before the last quarter of the twenty-first century (mean and 95% confidence interval of the average date of peak loss before or during 2075) and large reductions in future losses (mean and 95% confidence interval of the average reductions of at least 50%). On average across the ensemble, the speed of biodiversity recovery after peak loss was slow in the supply-side (SS) and demand-side (DS) scenarios, but much faster when also combined with increased conservation and restoration (that is, the C, C + SS, C + DS and IAP scenarios), consistent with a larger amount of reclaimed managed land (Extended Data Fig. 4). Our IAP scenario involved the restauration of 4.3–14.6 million km^2 of land by 2050, which requires the Bonn Challenge target (3.5 million km^2 by 2030) to be followed by higher targets for 2050.

However, efforts to increase both the management and the extent of protected areas—to 40% of the terrestrial area, based on wilderness areas and key biodiversity areas—and to increase landscape-level conservation planning efforts in all terrestrial areas (C scenario) (Methods) were insufficient, on average, to avoid more than 50% of the losses projected in the BASE scenario in many biodiversity-rich regions (Extended Data Fig. 7). Furthermore, the slight decrease in the global crop price index that is, on average, projected across IAMs in the BASE scenario was reversed in the C scenario (Extended Data Fig. 8). Without transformation of the food system, more-ambitious conservation efforts would be in conflict with the future provision of food, given the projected technological developments in agricultural productivity across models (Supplementary Discussion 3).

By contrast, a deeper transformation of the food system, which relies on feasible supply-side and demand-side efforts as well as increased conservation efforts (the IAP scenario) (Supplementary Discussion 3), would greatly facilitate the reversal of biodiversity trends, reduce the trade-offs that emerge from siloed policies and offer broader benefits. On average across the ensemble, at least 67% of future peak losses were avoided for 96% (95% confidence interval, 89–100%) of IAM and BDI combinations in the IAP scenario, in contrast to 43% (95% confidence interval, 25–61%) in the C scenario (Extended Data Table 2). Similarly, across the ensemble, biodiversity trends were reversed by 2050 for 96% (95% confidence interval, 89–100%) of IAM and BDI combinations in the IAP scenario compared with 61% (95% confidence interval, 43–79%) in

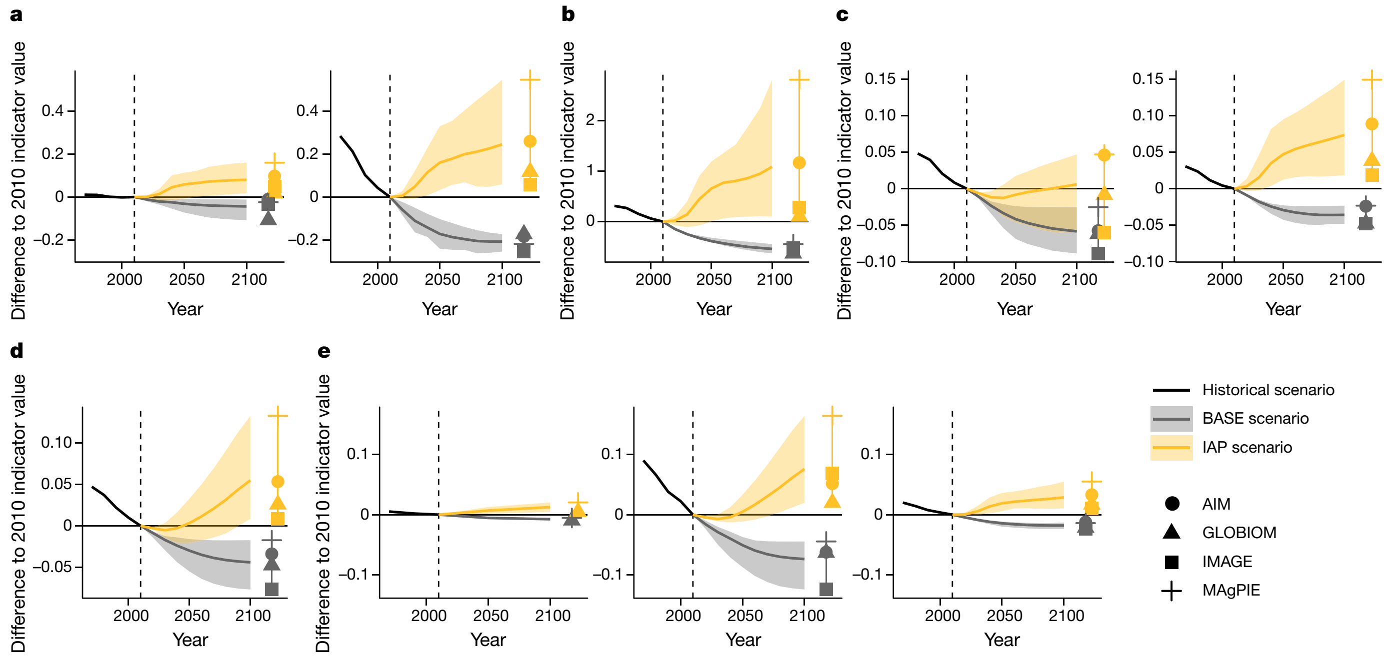

Fig. 1 | Estimated recent and future global biodiversity trends resulting from land-use change, with and without coordinated efforts to reverse trends. **a**–**e**, The trends for the five aspects of biodiversity that result from changes in nine BDIs (Table 2). BDI values are shown as differences from the 2010 value (which was set to 1); a value of −0.01 means a 1% loss in the respective BDI. **a**, The extent of suitable habitat (measured using the extent of suitable habitat metric; estimates from AIM-B (left) or INSIGHTS (right) BDMs are shown). **b**, The wildlife population density (measured using the LPI metric; estimate from the LPI-M BDM is shown). **c**, The local compositional intactness (measured using the MSA metric (estimate from the GLOBIO BDM) (left) or BII metric (estimate from the PREDICTS BDM) (right)). **d**, The regional number of species not already extinct or committed to extinction (measured using the fraction of regionally remaining species metric; estimate from the cSAR_CB17 BDM is shown). **e**, The global number of species not already extinct or committed to extinction (measured using the fraction of globally remaining species metric, estimates from the BILBI (left), cSAR_CB17 (middle) and cSAR_US16 (right) BDMs are shown). BDI values are projected in response to land-use change derived from one source over the historical period (1970–2010, black line (IMAGE/HYDE 3.1)) and from four IAMs (AIM, GLOBIOM, IMAGE and MAgPIE; lines display the mean of all models; shading shows the range of all models) for the BASE scenario (grey) and IAP scenario (yellow) (Table 1) over the future period (2010–2100). 2010 is indicated with a vertical dashed line. 2100 values for individual IAMs are shown as different symbols.

the C scenario. Integrated efforts thus alleviate pressures on habitats (Extended Data Fig. 5) and reverse biodiversity trends from habitat loss decades earlier than strategies that allow habitat losses followed by restoration (Extended Data Fig. 7). Integrated efforts could also mitigate the trade-offs between regions and exploit complementarities between interventions. For example, increased agricultural intensification and trade may limit agricultural land expansion at the global scale, but induce expansion at a regional scale unless complemented with conservation efforts[23,24]. We found spatially contrasted—and sometimes regionally negative—effects of various interventions, but the number of regions with a favourable status increased with integration efforts (Extended Data Fig. 7). Finally, integrated strategies have benefits other than just enhancing biodiversity: dietary transitions alone have considerable benefits for human health[25], and integrated strategies may also increase food availability, reverse future trends in greenhouse gas emissions from land use and limit increases in the influence of land use on the water and nutrient cycles (Extended Data Fig. 8 and Supplementary Discussion 4).

Discussion and conclusions

Our study suggests ways to resolve key trade-offs that are associated with ambitious actions for terrestrial biodiversity[4,26]. Actions in our IAP scenario address the largest threat to biodiversity—habitat loss and degradation—and are projected to reverse declines for five aspects of biodiversity. These actions may be technically possible, economically feasible and consistent with broader sustainability goals, but designing and implementing policies that enable such efforts will be challenging and will demand concerted leadership (Supplementary Discussion 3). In addition, reversing declines in other biodiversity aspects (for example, phylogenetic and functional diversity) might require different spatial allocation of conservation and restoration actions, and possibly a higher increase in the amount of area to be protected (Supplementary Discussion 5). Similarly, other threats (for example, climate change or biological invasions) currently affect two to three times fewer species than land-use change at the global scale[5], but can be more important locally, can have synergistic effects with land-use change and will increase in global importance in the future. Therefore, a full reversal of biodiversity declines will require additional interventions, such as ambitious climate change mitigation that exploits synergies with biodiversity rather than leading to the further erosion of biodiversity. Nevertheless, even if the actions explored in this study are insufficient, they will remain essential for the reversal of terrestrial biodiversity trends.

The need for transformative change and responses that simultaneously address a nexus of sustainability goals was recently documented by the IPBES[1,2]. Our study complements that assessment by shedding light on the nature, ambition and complementarity of actions that are required to reverse the decline of global biodiversity trends from habitat loss, with direct implications for the international biodiversity strategy after 2020. Reversing biodiversity trends—an interpretation of the 2050 Vision of the Convention on Biological Diversity—requires the urgent adoption of a conservation plan that retains the remaining biodiversity and restores degraded areas. Our scenarios feature an expansion to up to 40% of terrestrial areas with effective management for biodiversity, restoration efforts beyond the targets of the Bonn Challenge and a generalization of land-use planning and landscape approaches. Such a bold

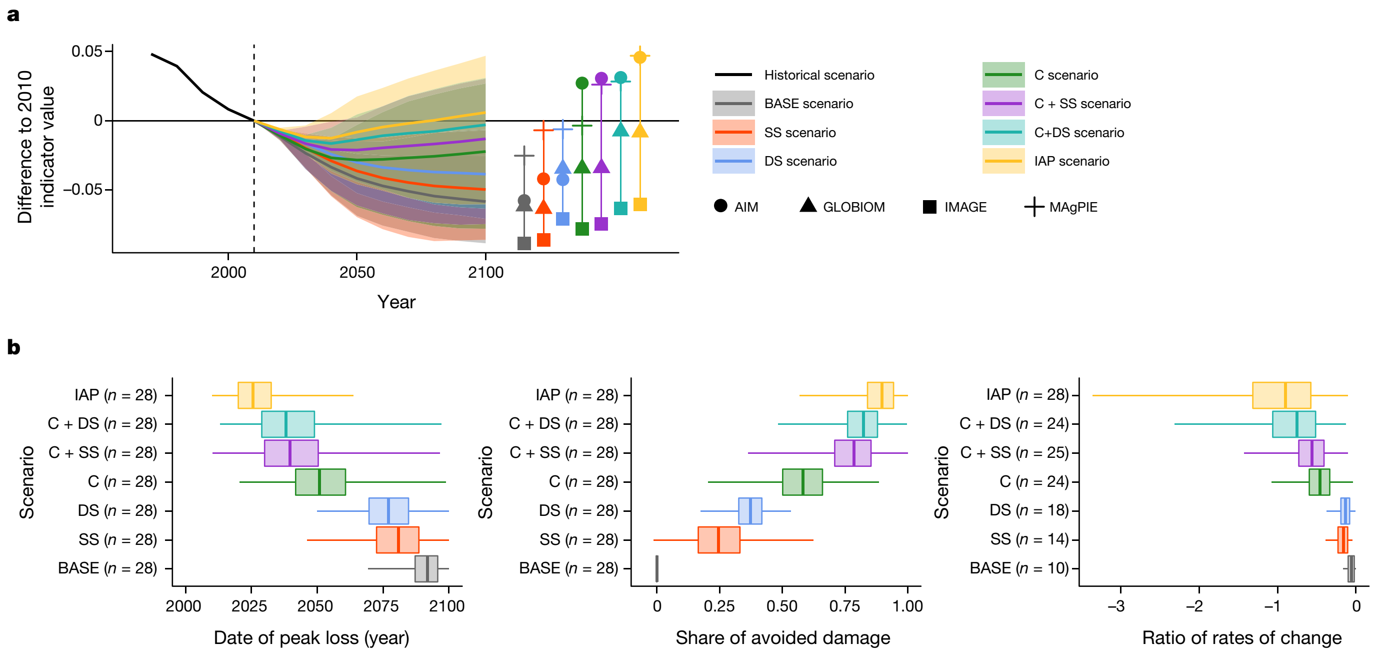

Fig. 2 | Contributions of various efforts to reverse land-use change-induced biodiversity trends. Future actions towards reversing biodiversity trends vary across the seven scenarios (BASE, SS, DS, C, C + SS, C + DS and IAP). **a**, The line for each future scenario represents the mean across four IAMs and the shading represents the range across four IAMs of future changes (compared with 2010) for one illustrative biodiversity metric (MSA) estimated by one biodiversity model (GLOBIO). For the historical period, the black line represents the changes projected in the same biodiversity metric for the single land-use dataset considered over this period. Symbols show the estimated changes by 2100 for individual IAMs. **b**, Estimates of the distribution across combinations of BDIs and IAMs, for each scenario. Left, the date of the twenty-first century minimum date of peak loss. Middle, the proportion of peak biodiversity losses that could be avoided compared with the BASE scenario. Right, the speed of recovery after the minimum has been reached. Data were normalized by the historical speed of change, so that a value of −1 means recovery at the speed at which biodiversity losses took place in 1970–2010; values lower than −1 indicate a recovery faster than the 1970–2010 loss. Values are estimated from 10,000 bootstrap samples from the original combination of BDIs and IAMs. In each box plot, the vertical bar indicates the mean estimate (across bootstrap samples) of the mean value (across BDI and IAM combinations), the box indicates the 95% confidence interval of the mean value and the horizontal lines indicate the mean estimates (across bootstrap samples) of the 2.5th and 97.5th percentiles (across BDI and IAM combinations). The estimates are based on bootstrap samples with $n = 28$ (7 BDIs × 4 IAMs), except in the right panel, for which $n \leq 28$, as the speed of recovery after peak loss is not defined if the peak loss is not reached before 2100.

conservation plan will conflict with other societal demands from land, unless transformations for sustainable food production and consumption are simultaneously considered. For a successful biodiversity strategy after 2020, ambitious conservation must be combined with action on drivers of biodiversity loss, especially in the land-use sectors. Without an integrated approach that exploits synergies with the Sustainable Development Goals, future habitat losses will at best take decades to restore, and further irreversible biodiversity losses are likely to occur.

Models and scenarios can help to further outline integrated strategies that build on contributions from nature to achieve sustainable development. This will, however, necessitate further research and the development of appropriate practices at the science–policy interface. Future assessments should seek to better represent land-management practices as well as additional pressures on land and biodiversity, such as the influence and mitigation of climate change, overexploitation, pollution and biological invasions. The upscaling of new modelling approaches could facilitate such improvements, although such modelling efforts currently face data and technical challenges[18]. In addition to innovative model development and multi-model assessments, efforts are needed to evaluate and report on the uncertainty and performance of individual models. Such efforts, however, remain constrained by the complexity of natural and human systems and data limitations. For example, the models used in this analysis lack validation, not least because a thorough validation would face data and conceptual limitations[27]. In such a context, both improved modelling practices (for example, open source and FAIR principles[28], and community-wide modelling standards[29]) and participatory approaches to validation could have a key role in enhancing the usefulness of models and scenarios[30].

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41586-020-2705-y.

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Methods

Data reporting

No statistical methods were used to predetermine sample size. The experiments were not randomized and the investigators were not blinded to allocation during experiments and outcome assessment.

Qualitative and quantitative elements of the scenarios

The SSP scenario framework[31] provides qualitative narratives and model-based quantifications of the future evolution of human demographics, economic development and lifestyles, policies and institutions, technology and the use of natural resources. Our baseline assumption (the BASE scenario) for the future evolution of drivers of habitat loss and degradation followed the 'Middle Of the Road' SSP 2 scenario[32], which extends historical trends in population, dietary preferences, trade and agricultural productivity. SSP 2 describes a world in which the human population peaks at 9.4 billion by 2070 and economic growth is moderate and uneven, while globalization continues with slow socioeconomic convergence between countries.

In six additional scenarios (Table 1), we assumed that additional actions are implemented in either single-action or combined-action bundles with an intensity that increases gradually from 2020 to 2050. The three bundles that we considered included: increased conservation efforts (C)—specifically, increases in the extent and management of protected areas, restoration and landscape-level conservation planning; supply-side efforts (SS), namely, further increases in agricultural land productivity and trade of agricultural goods; and demand-side efforts (DS), namely, waste reduction in the food system and a shift in human diets towards a halving of the consumption of animal products in regions in which it is currently high. The additional scenarios correspond to each bundle separately (single-action scenarios: C, SS and DS) and to combined-action scenarios, in which actions are paired (C + SS and C + DS) or combined as the integrated action portfolio of all three bundles (IAP scenario). The scenarios correspond to the following scenarios described in a methodological report[33]: BASE, RCPref_SSP2_NOBIOD; SS, RCPref_SSP1pTECHTADE_NOBIOD; DS, RCPref_SSP1pDEM_NOBIOD; C, RCPref_SSP2_BIOD; C + SS, RCPref_SSP1pTECHTADE_BIOD; C + DS, RCPref_SSP1pDEM_BIOD; IAP, RCPref_SSP1p_BIOD.

The supply-side and demand-side efforts are based on assumptions from the green growth SSP 1 scenario[16,34], or are more ambitious. For the supply-side measures, we followed the SSP 1 assumptions strictly, with faster closing of yield gaps leading to higher convergence towards the level of high-yielding countries, and trade in agricultural goods developing more easily in a more-globalized economy with reduced trade barriers. Our assumed demand-side efforts are more ambitious than SSP 1 and involve a progressive transition from 2020 onwards, reaching by 2050: (1) a substitution of 50% of animal calories in human diets with plant-derived calories, except in regions in which the share of animal products in diets is already estimated to be low (the Middle East, sub-Saharan Africa, India, Southeast Asia and other Pacific Islands) and (2) a 50% reduction in total waste throughout the food supply chain, compared with the BASE scenario. See Supplementary Discussion 3 for a discussion of the feasibility of these options.

We generated new qualitative and quantitative elements that reflect increased conservation efforts that were more ambitious than the SSPs. Qualitatively, they relied on two assumptions. First, protection efforts are increased at once in 2020 in their extent to all land areas (hereafter referred to as 'expanded protected area') that are either currently under protection or identified as conservation priority areas through agreed international processes or based on wilderness assessments. Land management efforts also mean that land-use change leading to further habitat degradation is not allowed within the expanded protected areas from 2020 onwards. Second, we assume that ambitious efforts—starting low in 2020 and progressively increasing over time—to both restore degraded land and make landscape-level conservation planning a more central feature in land-use decisions, with the aim to reclaim space for biodiversity outside of expanded protected areas, while considering spatial gradients in biodiversity and seeking synergies with agriculture and forestry production.

To provide quantifications for the increased conservation efforts narrative, we compiled spatially explicit datasets (Extended Data Fig. 1) that were used as inputs by the IAMs, as follows:

For the first assumption (increased protection efforts), we generated 30-arcmin resolution rasters of (1) the extent of expanded protected areas and (2) land-use change restrictions within these protected areas. We estimated a plausible realization of expanded protected areas by overlaying the World Database of Protected Areas[35] (that is, currently protected areas), the World Database on Key Biodiversity Areas[36] (that is, agreed priorities for conservation) and the wilderness areas in 2009[37] (that is, proposed priorities based on wilderness assessment) at 5-arcmin resolution before aggregating the result to 30-arcmin resolution to provide, on a 30-arcmin raster, the proportion of land within expanded protected areas (Extended Data Fig. 1a). To estimate land-use change restrictions within expanded protected areas, we allowed a given land-use transition only if the implied biodiversity impact was estimated to be positive by the effects of land use on the BII[20,38] modelled using the PREDICTS database[39] (Extended Data Fig. 1c). The BII estimates are global, but vary depending on spatially explicit features for the level of land-use aggregation considered in IAMs (whether the background potential ecosystem is forested or not and whether the managed grassland is pasture or rangeland), so we used the 2010 land-use distribution from the LUH2 dataset[40] to estimate spatially explicit land-use change restrictions. These layers were used as input in the modelling of future land-use change, to constrain possible land-use changes in related scenarios.

For the second assumption (increased restoration and landscape-level conservation planning efforts), we generated—at a 30-arcmin resolution—a set of coefficients that enabled the estimation of a relative biodiversity stock BV(p) score for any land-use configuration in any pixel p. To calculate the score (equation (1)), we associated a pixel-specific regional relative range rarity-weighted species richness score RRRWSR(p) (Extended Data Fig. 1b) with land-use class (l)- and pixel (p)-specific modelled effects of land use on the intactness of ecological assemblages[20] BII(l, p) (Extended Data Fig. 1c) and the modelled proportion of pixel terrestrial area occupied by each land use in each pixel AS(l, p). The RRRWSR(p) score was estimated from range maps of comprehensively assessed groups (amphibians, chameleons, conifers, freshwater crabs and crayfish, magnolias and mammals) from the IUCN Red List[41] and birds from the Handbook of the Birds[42] and gave an indication of the relative contribution of each pixel to the representation of the biodiversity of the region. This spatially explicit information was used as an input for modelling future land-use change to quantify spatial and land-use-specific priorities for biodiversity outside protected areas (including restoring degraded land).

$$\mathrm{BV}(p) = \sum_{l=1}^{N} [\mathrm{BII}(l,p) \times \mathrm{RRRWSR}(l,p) \times \mathrm{AS}(l,p)] \quad (1)$$

Projections of recent past and future habitat loss and degradation

To project future habitat loss and degradation, we used the land-use component of four IAMs to generate spatially and temporally explicit projections of land-use change for each scenario. IAMs are simplified representations of the various sectors and regions of the global economy. Their land-use components can be used to provide quantified estimates of future land-use patterns for given assumptions about their drivers, enabling the projection of biodiversity metrics into the future[43]. The IAM land-use components included AIM (from AIM/CGE)[44,45], GLOBIOM (from MESSAGE-GLOBIOM)[46], IMAGE (from IMAGE/MAGNET)[47,48] and MAgPIE (from REMIND-MAgPIE)[49]—see section 5.1 of the methodological report[33] for details. All have global coverage (excluding Antarctica), and model demand, production and trade at a scale of 10–37 world regions. Land-use changes are modelled at the pixel scale in all IAMs except for AIM, for which regional model outputs are downscaled. For the GLOBIOM model, high-resolution land-use change model outputs were refined by downscaling from the regional to the pixel scale.

Scenario implementation was done according to previous work[16], with the exception of assumptions on increased conservation efforts (see section 5.2 of the methodological report[33] for details). For all IAMs, the increased protection efforts were implemented within the economic optimization problem as spatially explicit land-use change restrictions within the expanded protected areas from 2020 onwards. The expanded protected areas reached 40% of the terrestrial area (compared with 15.5% assumed for 2010), and more than 87% of additionally protected areas were solely identified as wilderness areas. The increased restoration and landscape-level conservation planning efforts were implemented in the economic optimization problem as spatially explicit priorities for land-use change from 2020 onwards. A relative preference for biodiversity conservation over production objectives, increasing over time, was implemented through a tax on changes in the biodiversity stock or increased scarcity of land available for production.

For each scenario, the IAMs projected the proportion of land occupied by each of 12 different land-use classes (built-up area, cropland other than short-rotation bioenergy plantations, cropland dedicated to short-rotation bioenergy plantations, managed grassland, managed forest, unmanaged forest, other natural vegetation, restoration land, abandoned cropland previously dedicated to crops other than short-rotation bioenergy plantations, abandoned cropland previously dedicated to short-rotation bioenergy plantations, abandoned managed grassland and abandoned managed forest) in pixels over the terrestrial area (excluding Antarctica) of a 30-arcmin raster, in 10-year time steps from 2010 to 2100. Abandoned land was treated differently according to the scenarios. In scenarios with increased conservation efforts (C, C + SS, C + DS and IAP), it was systematically considered to be restored and entered the 'restoration land' land-use class. In other scenarios, it was placed in one of the four abandoned land-use classes for 30 years, after which it was moved to the 'restoration land' land-use class, unless it had been reconverted into productive land.

This led to the generation of 3,360 individual raster layers that depicted, at the global scale and 30-arcmin resolution, the proportion of pixel area occupied by each land-use class (12 in total) at each time horizon (10 in total), as estimated by each IAM (4 in total) for each scenario (7 in total). As the spatial and thematic coverage of the four IAMs differed slightly, further harmonization was conducted, leading to the identification of 111 terrestrial ecoregions that were excluded from the analysis due to inconsistent coverage across IAMs. For analysis, the land-use projections were also aggregated at the scale of IPBES sub-regions[50]. More details on the outputs, including a definition of land-use classes and the specifications of each IAM, can be found in the methodological report[33].

To estimate the biodiversity impacts of recent past trends in habitat losses and degradation, we used the spatially explicit reconstructions of the IMAGE model, estimated from the HYDE 3.1 database[51] for the period from 1970 to 2010, for the same land-use classes and with the same spatial and temporal resolution as used for future projections.

Projections of recent past and future biodiversity trends

We estimated the effects of the projected future changes in land use on nine BDIs, providing information on six biodiversity metrics (Table 2) indicative of five aspects of biodiversity: the extent of suitable habitat (ESH metric), the wildlife population density (LPI metric), the compositional intactness of local communities (MSA and BII metrics), the regional extinction of species (FRRS metric) and the global extinction of species (FGRS metric). Each BDI is defined as a combination of one of six biodiversity metrics and of one of eight BDMs that we used: AIM-B[52], INSIGHTS[53,54], LPI-M[19,55], BILBI[56–58], cSAR_CB17[59], cSAR_US16[60,61], GLOBIO[62] and PREDICTS[63–65]. These models were selected for their ability to project biodiversity metrics regionally and globally under various scenarios of spatially explicit future changes in land use. Their projections considered only the effect of future changes in land use, and did not account for future changes in other threats to biodiversity (for example, climate change, biological invasions or hunting).

Estimating future trends in biodiversity for all seven scenarios, ten time horizons and four IAMs was not possible for all BDMs. We therefore adopted a tiered approach (see section 6 of the methodological report[33]): for the two extreme scenarios (BASE and IAP), trends were estimated for all IAMs and time horizons for all BDIs except FGRS using the BILBI BDM, for which trends were estimated for only two IAMs (GLOBIOM and MAgPIE) and three time horizons (2010, 2050 and 2100). For the other five scenarios (C, SS, DS, C + SS, C + DS), trends were estimated for all IAMs and time horizons for seven BDIs (MSA metric using the GLOBIO BDM, BII metric using the PREDICTS BDM, ESH metric using the INSIGHTS BDM, LPI metric using the LPI-M BDM, FRRS metric using the cSAR_CB17, FGRS metric using the cSAR_CB17 and cSAR_US16 BDMs). Values of each indicator are reported at the global level and for the 17 IPBES sub-regions[50] for all BDIs except for the FGRS metric using the cSAR_US16 BDM (which is reported only at the global level).

The BDMs differ in key features that affect the projected trends (see section 6 of the methodological report[33]). For example, the two models that project changes in the extent of suitable habitat rely on the same type of model (habitat suitability models) but have different taxonomic coverage (mammals for INSIGHTS compared with vascular plants, amphibians, reptiles, birds and mammals for AIM-B), different species-level distribution modelling principles (expert-driven for INSIGHTS compared with a species distribution model for AIM) and different granularity in their representation of land use and land cover (12 classes for INSIGHTS compared with 5 classes for AIM-B). Although all BDMs implicitly account for the current intensity of cropland, only one (GLOBIO) accounts for the effect on biodiversity of future changes in cropland intensity. Similarly, temporal lags in the response of biodiversity to restoration of managed land differed across models, often leading to different biodiversity recovery rates within restored land (Supplementary Discussion 2). As described in section 6.5 of the methodological report[33], the individual BDMs have been subject to various forms of model evaluation.

Further calculations on projected biodiversity trends

To facilitate the comparison with the literature and the comparison of baseline trends between time periods and BDIs, we estimated the linear rate of change per decade in the indicator value for all BDI and IAM combinations for two time periods (1970–2010, 2010–2050), as the percentage change per decade (Extended Data Table 1). The linear rate of change per decade for each period and the combination of BDI and IAM was derived by dividing the total change projected over the period by the number of decades.

We also estimated the date D_{PeakLoss} and value V_{PeakLoss} of the peak loss over the 2010–2100 period for each BDI, IAM and scenario combination for which all time steps were available. The date of peak loss is defined as the date at which the minimum indicator value estimated over the 2010–2100 period is reached, and the value of peak loss is defined as the corresponding absolute BDI value difference from the 2010 level (which was set to 1). For the 28 concerned combinations of BDI and IAM, we then defined the share of future losses that could be avoided in each scenario S (compared with the BASE scenario) as $[1 - V_{\mathrm{PeakLoss}}(S)/V_{\mathrm{PeakLoss}}(\mathrm{BASE})]$. For scenario, IAM and BDI combinations for which the date of the peak loss was earlier than 2100, we defined the period between the date of peak loss and 2100 as the recovery period, and estimated the relative speed of BDI recovery as the average linear rate of change over the recovery period, relative to the average rate of decline in the historical period (1970–2010). The date of peak loss, share of avoided losses and relative speed of recovery were also estimated at the scale of IPBES subregions, for the 24 BDI and IAM combinations for which data were available at such a scale.

To estimate more robust estimates of the summary statistics (mean, median, standard deviation, 2.5th and 97.5th quantiles) across the ensemble of IAM and BDM combinations (28 at the global scale and 24 at the regional scale) for the above-mentioned values (date of peak loss, share of future losses that could be avoided and speed of recovery) in each scenario, we performed bootstrap resampling with replacement for 10,000 samples. This allowed us to estimate a mean, a standard deviation and a confidence interval (defined as the range between the 2.5th and 97.5th percentiles) for each ensemble statistic (mean, median, standard deviation, 2.5th and 97.5th percentiles) at global and regional scales (Extended Data Table 2). No weighting of individual IAM and BDI combinations was applied. Analysis was done with version 3.6.1 of the R software[66].

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this paper.

Data availability

The World Database of Protected Areas[35] can be accessed at https://www.protectedplanet.net/, IUCN species range maps[41] are available at https://www.iucnredlist.org/resources/spatial-data-download, access to the World Database of Key Biodiversity Areas[36] can be requested at http://www.keybiodiversityareas.org/site/requestgis, wilderness areas are available from a previous study[37], LUH2 datasets can be accessed at https://luh.umd.edu/data.shtml, the HYDE 3.1 database[51] can be accessed at https://themasites.pbl.nl/tridion/en/themasites/hyde/download/index-2.html. The 30-arcmin resolution raster layers (extent of expanded protected areas, land-use change rules in expanded protected areas, coefficients allowing the estimation of the pixel-specific and land-use change transition-specific biodiversity impact of land-use change) used by the IAMs to model increased conservation efforts cannot be made freely available due to the terms of use of their source, but will be made available upon reasonable request to the corresponding authors. The 30-arcmin resolution raster layers, which provide the proportion of grid cell area occupied by each of the twelve land-use classes, four IAMs, seven scenarios and ten time horizons, are publicly available from a data repository under a CC-BY-NC license (http://dare.iiasa.ac.at/57/)[33], together with the IAM outputs that underpin the global scale results of Extended Data Figs. 3, 8 (for all time horizons), the global and IPBES subregion-specific results of Extended Data Figs. 4, 5, and the BDM outputs that underpin the global and IPBES subregion-specific results shown in Figs. 1, 2, Extended Data Figs. 2, 6, 7 and Extended Data Tables 1, 2 (for all available time horizons, BDIs, IAMs and scenarios).

Code availability

The code and data used to generate the BDM outputs are publicly available from a data repository under a CC-BY-NC license (http://dare.iiasa.ac.at/57/)[33] for all BDMs. The code and data used to analyse IAM and BDM outputs and generate figures are publicly available from a data repository under a CC-BY-NC license (http://dare.iiasa.ac.at/57/)[33].

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Author contributions D.L. and M.O. led the study. D.L. coordinated the modelling, performed the analysis, coordinated the writing of the preliminary draft and performed the writing of later drafts. D.L., M.B., S.H.M.B., A.C., A.D.P., F.A.J.D., M.D.M., J.C.D., M.D., R.F., M. Harfoot, T. Hasegawa, S.H., J.P.H., S.L.L.H., F.H., N.J., T. Krisztin, G.M.M., H.O., A. Popp, A. Purvis, A.M.S., A.T., H.V., H.v.M., W.J.v.Z. and P.V. were involved in the core modelling and writing. R. Alkemade, R. Almond, G.B., N.D.B., S.E.C., F.D.F., S. Ferrier, S. Fritz, S. Fujimori, M.G., T. Harwood, P.H., M. Herrero, A.J.H., M.J., T. Kram, H.L.-C., T.M., C.M., D.N., T.N., G.S.-T., E.S., B.B.N.S., D.P.v.V., C.W., J.E.M.W., W.W. and L.Y. contributed through several iterations to the study design, result analysis and article writing.

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Additional information

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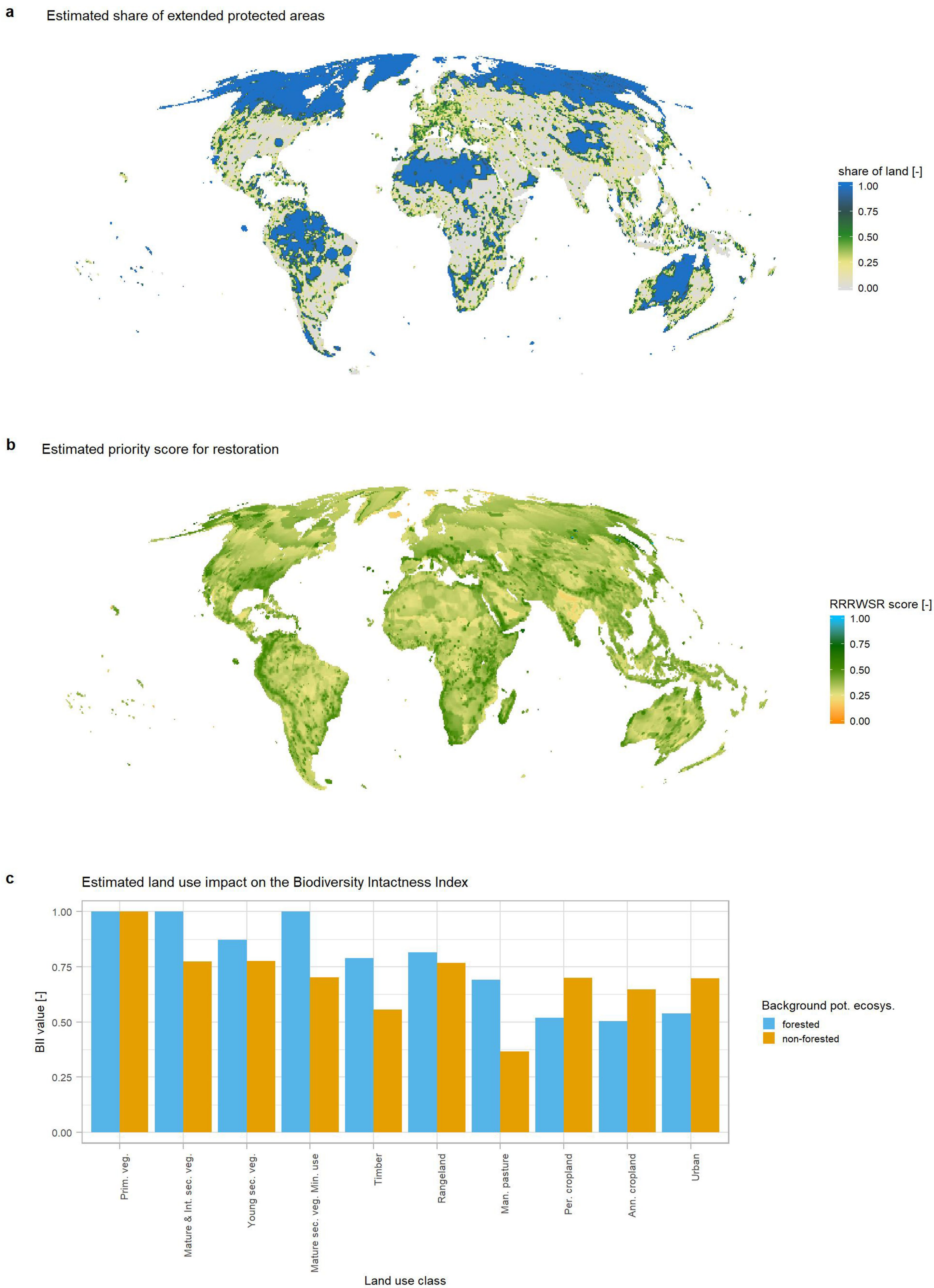
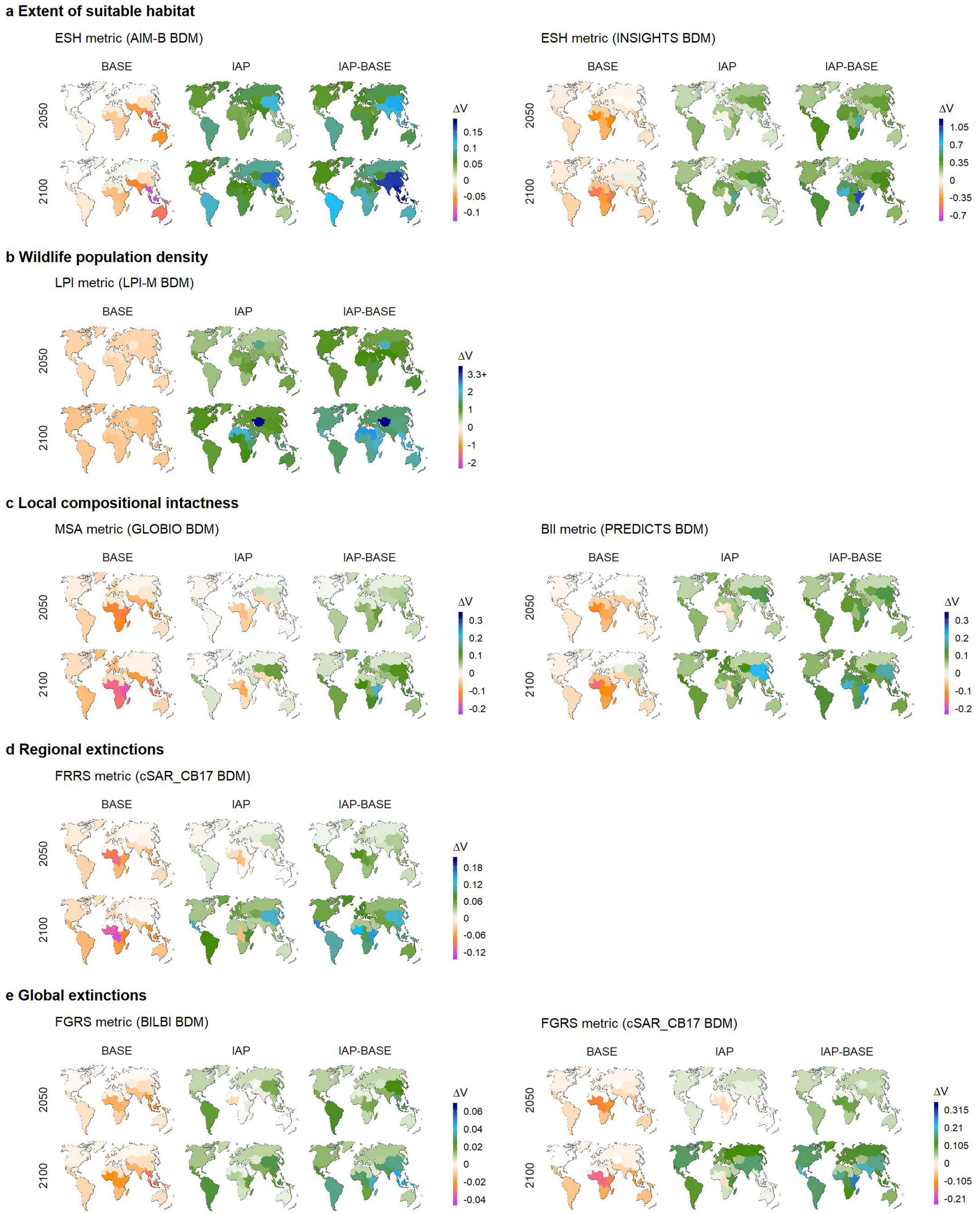
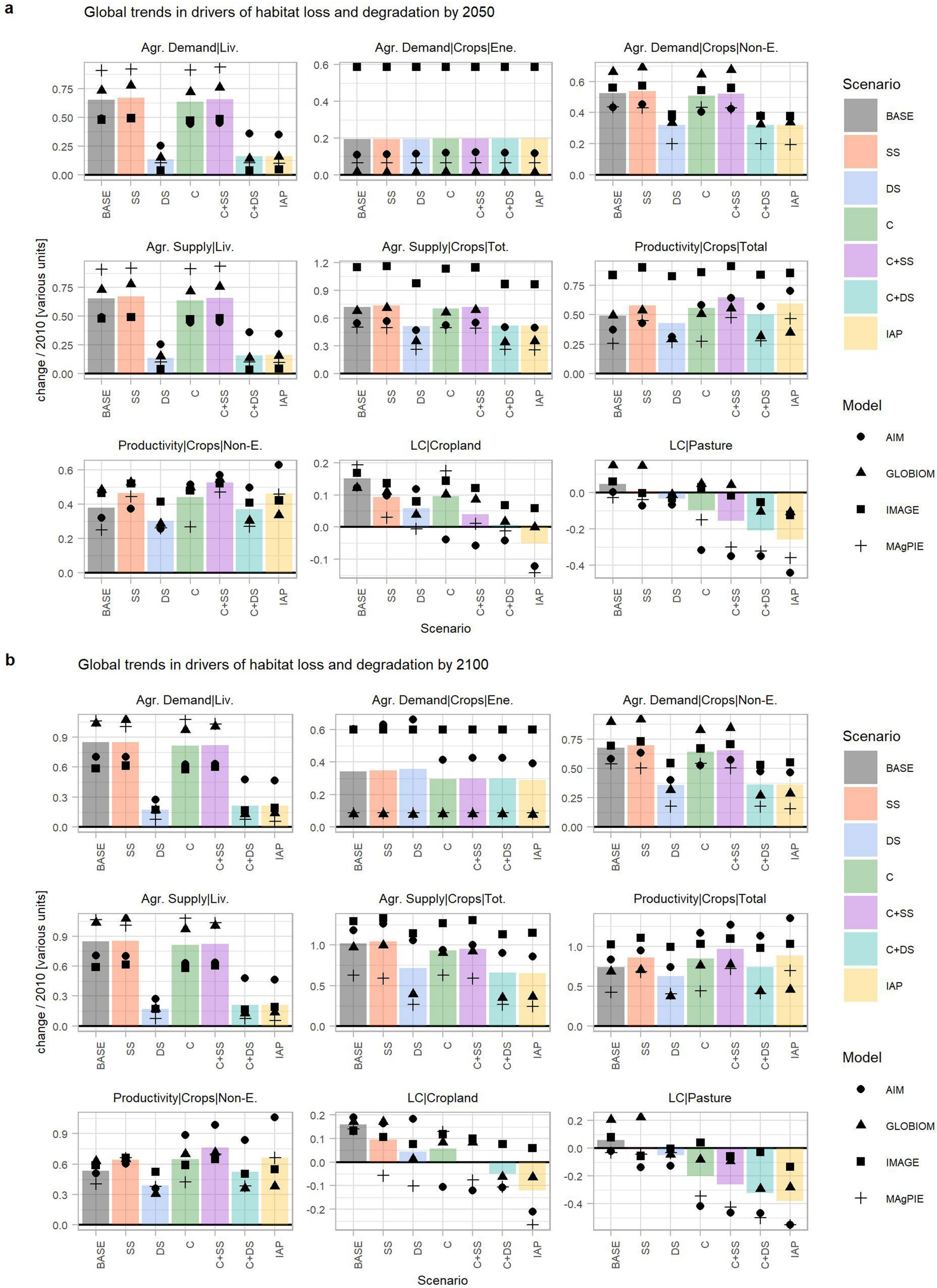


Extended Data Fig. 1 | See next page for caption.

Extended Data Fig. 1 | Datasets used to provide spatially explicit input for modelling increased conservation efforts into the land-use models. **a**–**c**, The proportion of land under the assumed expanded protected areas at 30-arcmin resolution (**a**; based on all areas from the World Database on Protected areas[35], areas from Key Biodiversity Areas[36] and wilderness areas[37]) and the value of the assumed spatial priority score for restoration at 30-arcmin resolution (**b**; relative range rarity-weighted species richness score RRRWSR, based on species range maps from the ICUN Red List[41] and the Handbook of the Birds of the World[42]), as well as the impact of various land uses on the BII[38] of various land-use classes (**c**; estimated from assemblage data for 21,702 distinct sites worldwide from the PREDICTS database[20], 11,534 from naturally forested biomes and 10,168 from naturally non-forest biomes). Datasets from **a** and **c** were used to implement spatially explicit restrictions to land-use change within land-use models (from 2020 onwards), and datasets from **b** and **c** were used to implement spatially explicit priorities for restoration and landscape-level conservation planning (from 2020 onwards) in scenarios for which increased conservation efforts were assumed (Methods).

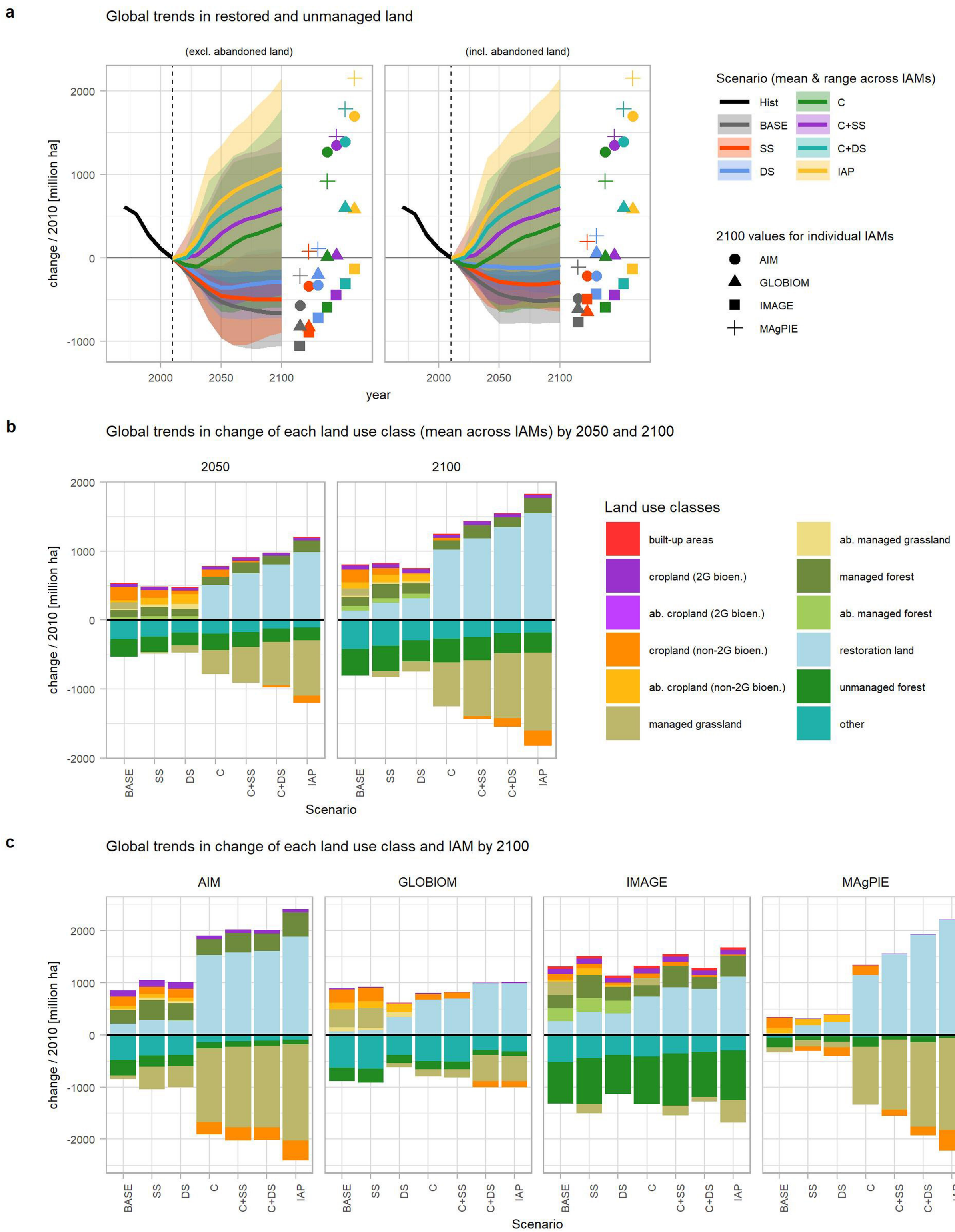


Extended Data Fig. 2 | Spatial patterns in projected changes in the value of biodiversity indicators for BASE and IAP scenarios (and the difference between the IAP and BASE scenarios) for the 17 IPBES subregions by 2050 and 2100 (compared to 2010 value). **a**–**e**, The projected changes (mean across IAMs) for each of the eight combinations of BDIs and BDMs (Table 2) for which values at the scale of the IPBES subregions were available, grouped according to the five aspects of biodiversity. **a**, Extent of suitable habitat. **b**, Wildlife population density. **c**, Local composition intactness. **d**, Regional extinctions. **e**, Global extinctions. The FGRS indicator was estimated by the cSAR_US16 model only at the global scale.

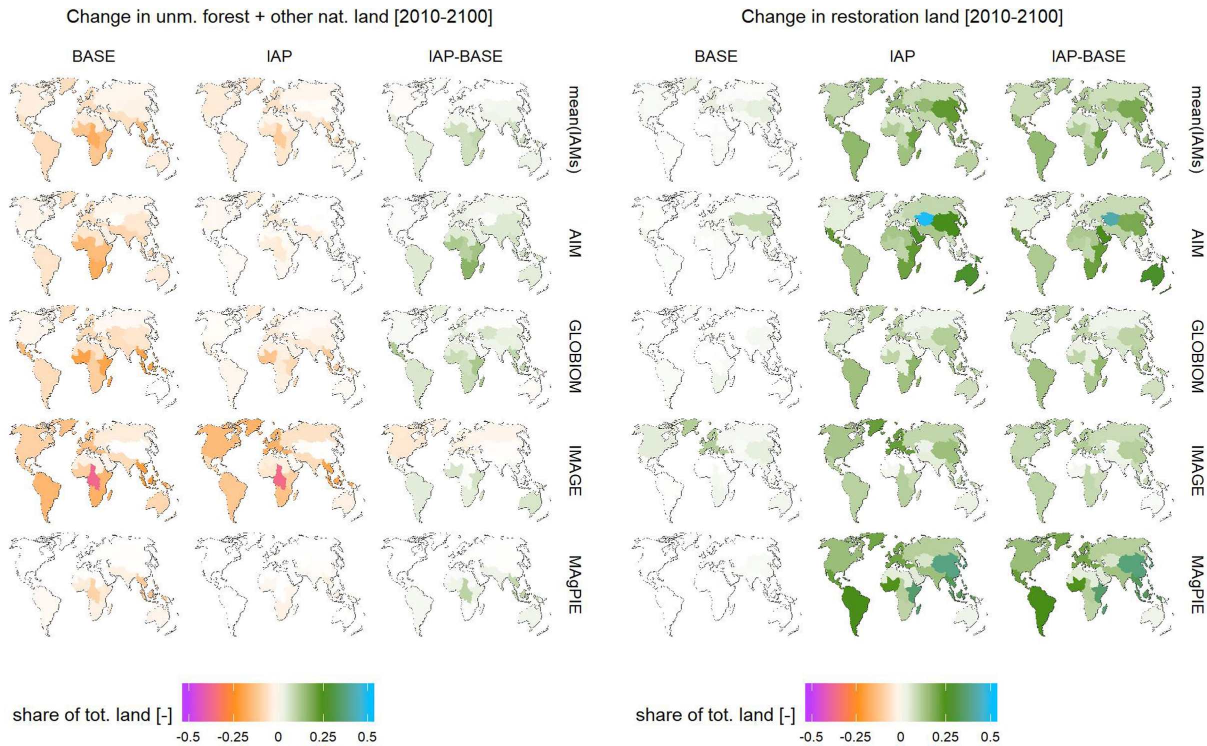


Extended Data Fig. 3 | See next page for caption.

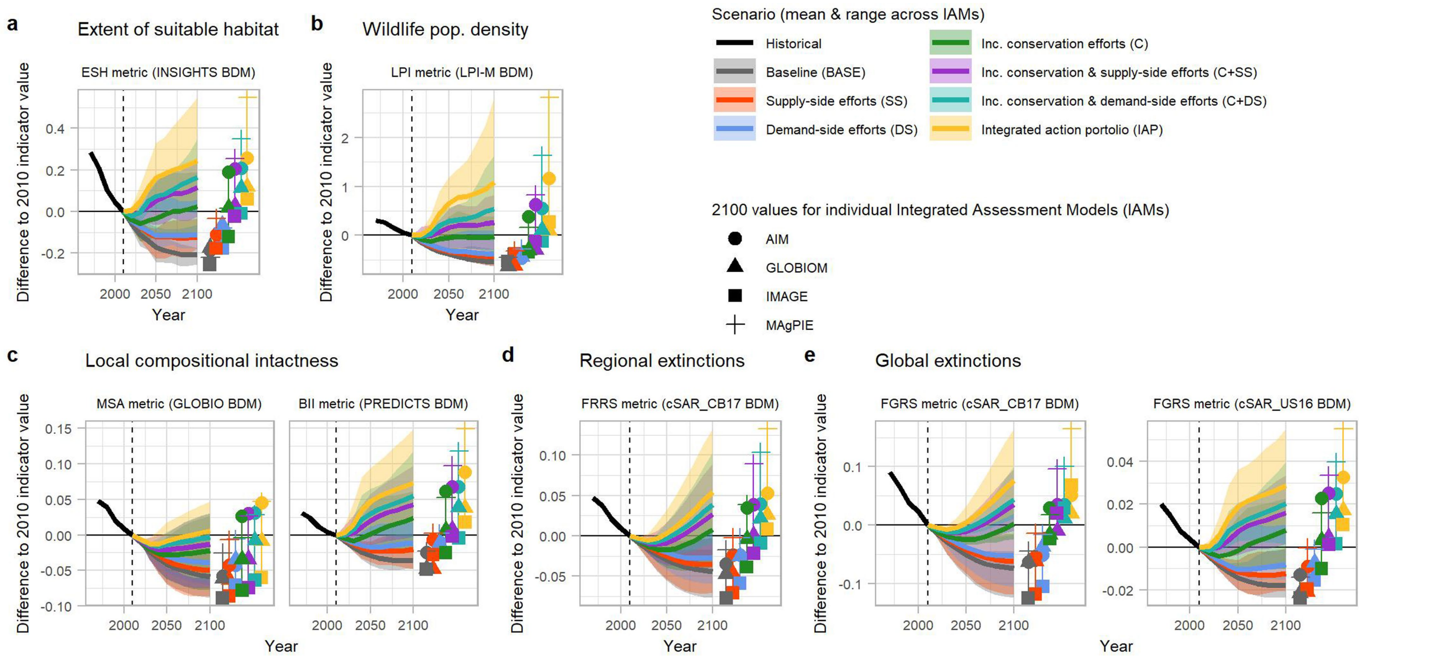
Extended Data Fig. 3 | Projected future global trends in drivers of habitat loss and degradation. a, **b**, For each scenario (colours, mean across all four IAMs), the relative change from 2010 to 2050 (**a**) and 2100 (**b**) in nine variables are shown. The symbols indicate the IAM-specific values. The variables displayed from the top left to bottom right are: agricultural demand for livestock products (Agr. Demand|Liv.), agricultural demand for short-rotation bioenergy crops (Agr. Demand|Crops|Ene.), agricultural demand for crops other than short-rotation bioenergy crops (Agr. Demand|Crops|Non-E.), agricultural supply of livestock products (Agr. Supply|Liv.), agricultural supply of all crop products (Agr. Supply|Crops|Tot.), average yield of crops other than short-rotation bioenergy crops (in metric tonnes dry matter per hectare, Productivity|Crops|Non-E.), and the land dedicated to cropland (LC|Cropland) and pasture (LC|Pasture). Values displayed for each variable are change relative to the value of the same variable simulated for 2010, except for two variables (Agr. Demand|Crops|Ene. and Agr. Demand|Crops|Non-E.), for which the change in each of the variables is normalized to the sum of values simulated in 2010 for the two variables (that is, normalization to the total demand for crops).



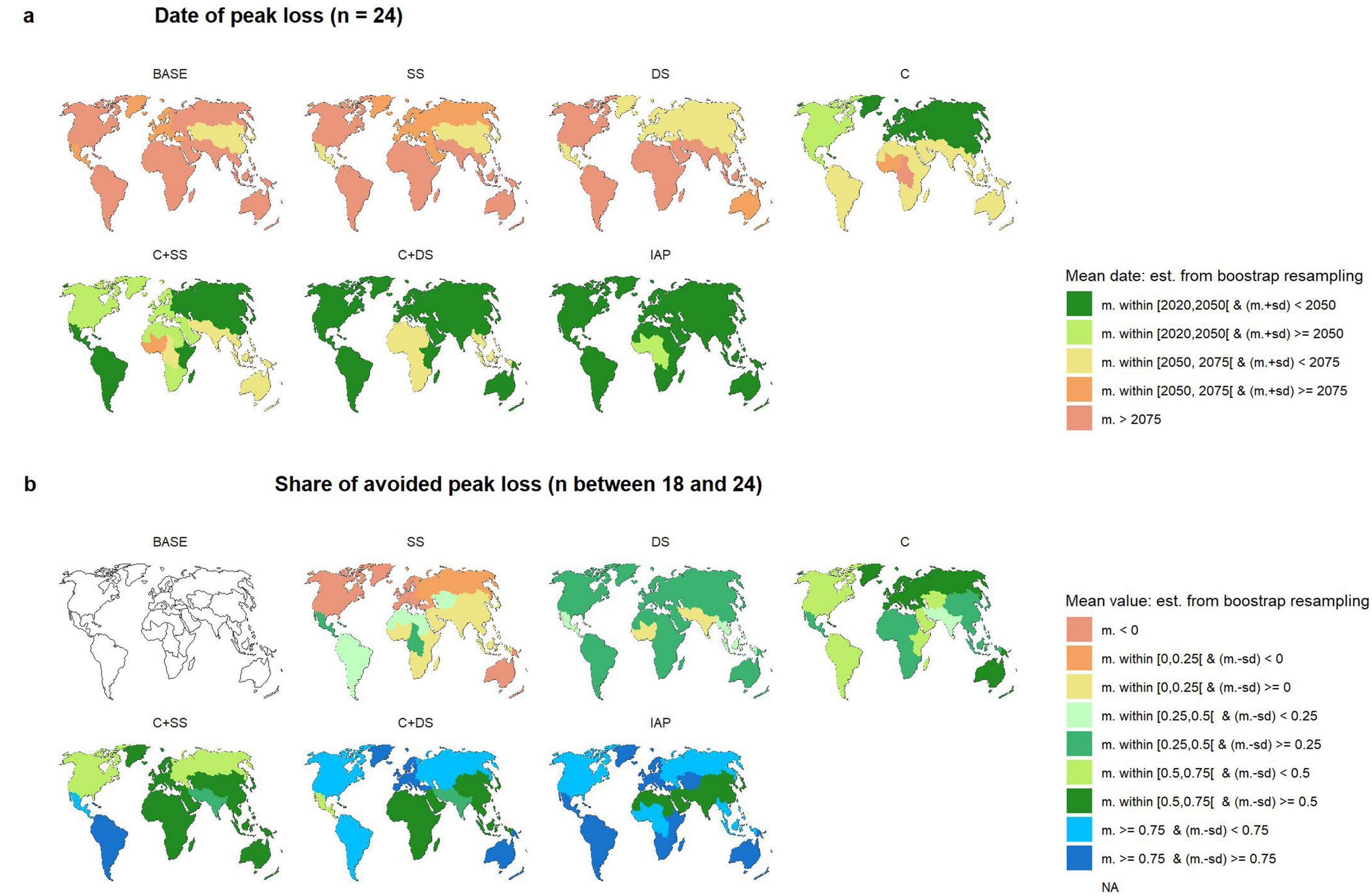
Extended Data Fig. 4 | Projected global trends in land-use change across all scenarios. a, Global trends in the sum of restored land, unmanaged forest and other natural land classes compared to 2010 (with and without excluding the land abandoned and not yet in restoration—different only for scenarios without increased conservation efforts; Methods). Thick lines show the average values across all four IAMs; shading shows the range across IAMs. **b**, **c**, Global changes projected in the area of each of the 12 land-use classes (compared to 2010) for the seven scenarios averaged across the four IAMs by 2050 and 2100 (**b**), and for each individual IAM by 2100 (**c**).



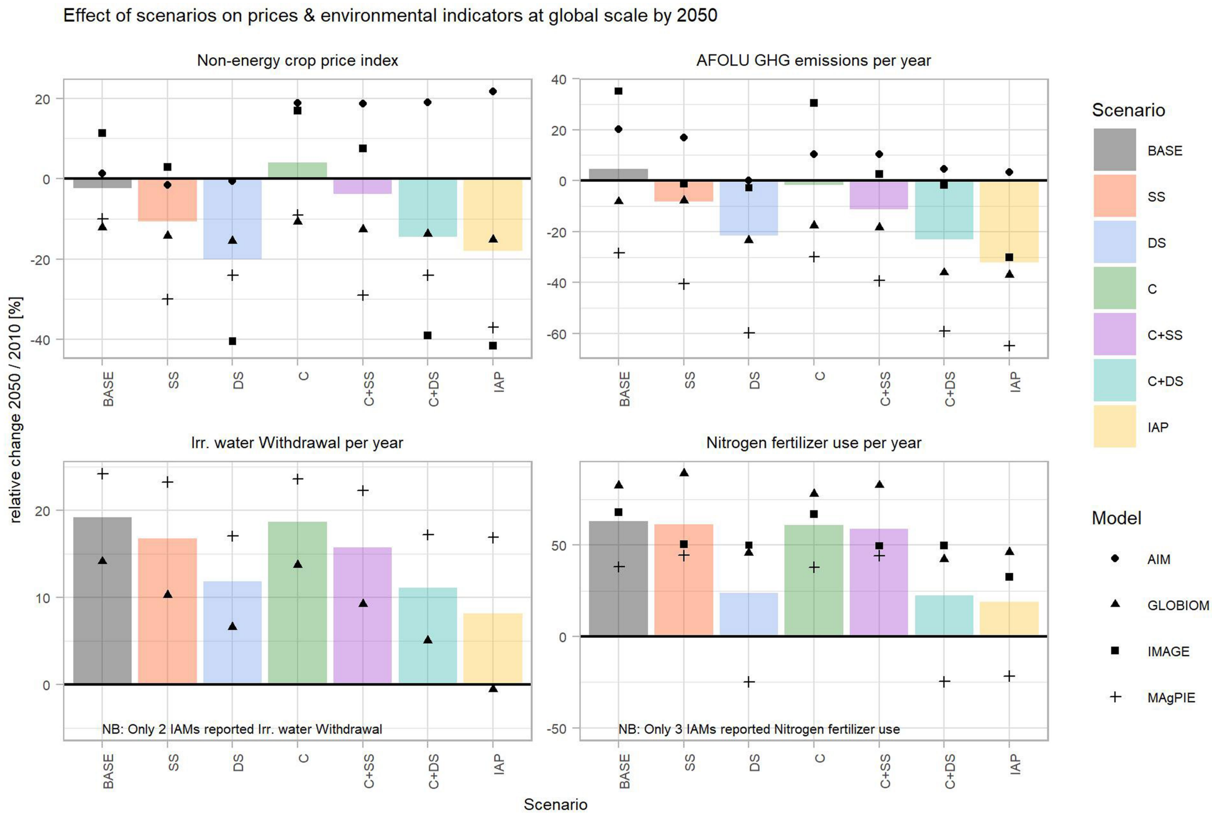
Extended Data Fig. 5 | Spatial patterns of projected habitat loss and restoration by 2100. Data are shown for the BASE and IAP scenarios and the difference (IAP − BASE), and are shown as the mean across IAMs (top) and separately for each of the four IAMs (AIM, GLOBIOM, IMAGE, MAgPIE).



Extended Data Fig. 6 | Estimated recent and future global biodiversity trends that resulted from land-use change for all seven scenarios. a–**e**, The trends—for the five different biodiversity aspects—that result from changes in seven biodiversity indicators (see Table 2 for definitions). Indicator values are shown as differences from the 2010 value (which was set to 1); a value of −0.01 means a loss of 1% in: the extent of suitable habitat (**a**), the wildlife population density (**b**), the local compositional intactness (**c**), the regional number of species not already extinct or committed to extinction (**d**) or the global number of species not already extinct or committed to extinction (**e**). Indicator values are projected in response to land-use change derived from one source over the historical period (1970–2010, black line; 2010 is indicated with a vertical dashed line) and from four different IIAMs (AIM, GLOBIOM, IMAGE and MAgPIE; thick lines show the mean across models and shading shows the range across models) for each of the seven future scenarios (Table 1).



Extended Data Fig. 7 | Spatial patterns of the date of peak loss in the twenty-first century and the share of avoided future peak loss. a, **b**, Across the 17 IPBES subregions, individual maps show, for each region and for each of the seven scenarios, the mean value of the date of peak loss in the twenty-first century (**a**) and the share of avoided future peak loss (**b**). Means were estimated from 10,000 bootstrapped samples of the simulated IAM and BDI combinations (**a**, $n = 24$; **b**, $n = 18$–24, as regions and combinations for which the baseline peak loss was less than 0.1% were excluded). Colour codes are based on the mean (m.) and standard deviation (sd) estimates (across the 10,000 samples for each region and scenario) of the sample mean value.



Extended Data Fig. 8 | Global relative changes in the price index of non-energy crops, total greenhouse gas emissions from agriculture, forestry and other land uses, total irrigation water withdrawal and nitrogen fertilizer use between 2010 and 2050. Top left, global changes in the price index of non-energy crops. Top right, global changes in total greenhouse gas emissions from agriculture, forestry and other land uses. AFOLU, agriculture, forestry and other land uses. Bottom left, global changes in total irrigation water withdrawal. Irrigation water withdrawal was reported by only two IAMs (MAgPIE and GLOBIOM); values were not reported for the other two IAMs. Bottom right, global changes in nitrogen fertilizer use. Nitrogen fertilizer use was reported by only three IAMs (MAgPIE, GLOBIOM and IMAGE); values were not reported for AIM. Data are shown for the seven scenarios and four IAMs. Averages across IAMs are shown as bars, individual IAMs are shown as symbols.

Extended Data Table 1 | Prolongation of historical biodiversity trends in the BASE scenario

Biodiversity indicator	Mean linear rate of change 1970-2010 [%/decade]	Mean linear rate of change 2010-2050 (BASE scenario) [%/decade] mean (range) across IAMs	Peak loss 2010-2100 (BASE scenario) [%] mean (range) across IAMs	Biodiversity aspect	Mean linear rate of change rate 1970-2010 [%/decade] mean (range) across BDIs	Mean linear rate of change rate 2010-2050 (BASE scenario) [%/decade] mean (range) across BDIs & IAMs	Peak loss 2010-2100 (BASE scenario) [%] mean (range) across BDIs & IAMs
ESH metric (AIM-B BDM)	-0.26	-0.79 (-1.81; -0.21)	-4.61 (-10.76; -1.18)	Extent of suitable habitat	-2.90 (-5.54; -0.26)	-2.55 (-6.03; -0.21)	-12.91 (-26.29; -1.18)
ESH metric (INSIGHTS BDM)	-5.54	-4.30 (-6.03; -2.57)	-21.20 (-26.29; -17.30)				
LPI metric (LPI-M BDM)	-5.94	-9.68 (-10.25; -7.98)	-54.16 (-62.97; -44.59)	Wildlife population density	-5.94 (-)	-9.68 (-10.25; -7.98)	-54.16 (-62.97; -44.59)
MSA metric (GLOBIO BDM)	-1.15	-1.04 (-1.72; -0.60)	-5.84 (-8.85; -2.52)	Local compositional intactness	-0.94 (-1.15; -0.74)	-0.89 (-1.72; -0.57)	-4.77 (-8.85; -2.38)
BII metric (PREDICTS BDM)	-0.74	-0.73 (-1.06; -0.57)	-3.71 (-4.95; -2.38)				
FRRS metric (cSAR_CB17 BDM)	-1.12	-0.75 (-1.37; --0.40)	-4.4 (-7.66; -1.75)	Regional extinctions	-1.12 (-)	-0.75 (-1.37; -0.40)	-4.40 (-7.66; -1.75)
FGRS metric (BILBI BDM)	-0.13	-0.14 (-0.14; -0.13)	-0.75 (-0.95; -0.54)	Global extinctions	-0.90 (-2.07; -0.13)	-0.68 (-2.18; -0.13)	-3.84 (-12.44; -0.54)
FGRS metric (cSAR_CB17 BDM)	-2.07	-1.27 (-2.18; -0.93)	-7.38 (-12.44; -4.46)				
FGRS metric (cSAR_US16 BDM)	-0.49	-0.36 (-0.50; -0.28)	-1.83 (-2.37; -1.40)				

Summary metrics (mean linear rate of indicator change in the periods 1970–2010 and 2010–2050, peak loss—that is, the minimum value of indicator change—over 2010–2100) for each biodiversity indicator (1970–2010 linear change rate, mean and range across IAMs for 2010–2050 linear change rate and peak loss in the BASE scenario) and biodiversity aspect (mean across BDIs for 1970–2010 linear change rate, mean and range across IAMs and BDIs for 2010–2050 linear change rate and 2010–2100 minimum change in the BASE scenario).

Extended Data Table 2 | Key statistics for the date of peak loss, share of avoided loss and relative recovery speed

			mean				median			
			simulated	est. from bootstrap resampling			simulated	est. from bootstrap resampling		
metric	scenario	N		mean	q025	q975		mean	q025	q975
Date of peak loss	BASE	28	2091.8	2091.8	2087.1	2095.7	2100.0	2098.7	2080.0	2100.0
	SS	28	2080.7	2080.7	2072.5	2088.6	2095.0	2090.1	2065.0	2100.0
	DS	28	2077.1	2077.1	2069.6	2084.6	2075.0	2078.4	2060.0	2100.0
	C	28	2050.7	2050.8	2041.8	2060.7	2040.0	2044.2	2030.0	2060.0
	C+SS	28	2039.6	2039.6	2030.0	2050.4	2035.0	2034.0	2020.0	2045.0
	C+DS	28	2038.2	2038.1	2028.9	2048.9	2030.0	2029.6	2020.0	2035.0
	IAP	28	2025.7	2025.7	2020.0	2032.5	2020.0	2021.2	2020.0	2030.0
Share of avoided future peak loss	BASE	28	0	0	0	0	0	0	0	0
	SS	28	0.25	0.25	0.17	0.33	0.20	0.20	0.06	0.30
	DS	28	0.37	0.37	0.33	0.42	0.39	0.38	0.31	0.46
	C	28	0.58	0.58	0.50	0.66	0.60	0.60	0.47	0.73
	C+SS	28	0.79	0.79	0.71	0.85	0.81	0.81	0.74	0.88
	C+DS	28	0.82	0.82	0.76	0.88	0.85	0.86	0.77	0.93
	IAP	28	0.90	0.90	0.84	0.94	0.95	0.94	0.88	1.00
Relative recovery speed	BASE	10	-0.06	-0.06	-0.10	-0.02	-0.03	-0.04	-0.10	-0.01
	SS	14	-0.16	-0.16	-0.23	-0.11	-0.11	-0.13	-0.21	-0.08
	DS	18	-0.13	-0.13	-0.19	-0.08	-0.12	-0.11	-0.14	-0.05
	C	24	-0.46	-0.46	-0.60	-0.34	-0.44	-0.41	-0.62	-0.24
	C+SS	25	-0.56	-0.56	-0.73	-0.41	-0.46	-0.45	-0.62	-0.31
	C+DS	24	-0.76	-0.75	-1.06	-0.52	-0.52	-0.55	-0.81	-0.40
	IAP	28	-0.89	-0.90	-1.32	-0.58	-0.56	-0.58	-0.73	-0.47
share of BDI x IAM combinations with (date of peak loss ≤ 2050)	BASE	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SS	28	0.21	0.21	0.07	0.39	0.00	0.00	0.00	0.00
	DS	28	0.25	0.25	0.11	0.43	0.00	0.00	0.00	0.00
	C	28	0.61	0.61	0.43	0.79	1.00	0.87	0.00	1.00
	C+SS	28	0.82	0.82	0.68	0.96	1.00	1.00	1.00	1.00
	C+DS	28	0.86	0.86	0.71	0.96	1.00	1.00	1.00	1.00
	IAP	28	0.96	0.96	0.89	1.00	1.00	1.00	1.00	1.00
share of BDI x IAM combinations with (share of avoided future losses ≥	BASE	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SS	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	DS	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C	28	0.43	0.43	0.25	0.61	0.00	0.23	0.00	1.00
	C+SS	28	0.82	0.82	0.68	0.96	1.00	1.00	1.00	1.00
	C+DS	28	0.82	0.82	0.68	0.96	1.00	1.00	1.00	1.00
	IAP	28	0.96	0.96	0.89	1.00	1.00	1.00	1.00	1.00

			2.5th quantile				97.5th quantile			
			simulated	est. from bootstrap resampling			simulated	est. from bootstrap resampling		
metric	scenario	N		mean	q025	q975		mean	q025	q975
Date of peak loss	BASE	28	2066.8	2069.2	2060.0	2080.0	2100.0	2100.0	2100.0	2100.0
	SS	28	2046.8	2046.2	2040.0	2050.0	2100.0	2100.0	2100.0	2100.0
	DS	28	2050.0	2050.0	2050.0	2050.0	2100.0	2100.0	2100.0	2100.0
	C	28	2020.0	2020.6	2020.0	2026.8	2100.0	2098.8	2086.5	2100.0
	C+SS	28	2010.0	2010.2	2010.0	2016.8	2100.0	2096.6	2066.3	2100.0
	C+DS	28	2010.0	2013.0	2010.0	2020.0	2100.0	2097.1	2066.3	2100.0
	IAP	28	2010.0	2010.0	2010.0	2010.0	2063.0	2063.7	2040.0	2090.0
Share of avoided future peak loss	BASE	28	0	0	0	0	0	0	0	0
	SS	28	-0.02	-0.01	-0.03	0.02	0.64	0.62	0.58	0.65
	DS	28	0.17	0.17	0.15	0.22	0.54	0.54	0.51	0.54
	C	28	0.19	0.20	0.12	0.35	0.89	0.88	0.81	0.90
	C+SS	28	0.35	0.36	0.15	0.60	1.00	1.00	0.99	1.00
	C+DS	28	0.49	0.48	0.28	0.67	1.00	1.00	0.98	1.00
	IAP	28	0.58	0.57	0.32	0.79	1.00	1.00	1.00	1.00
Relative recovery speed	BASE	10	-0.19	-0.16	-0.21	-0.08	0.00	0.00	-0.01	0.00
	SS	14	-0.44	-0.39	-0.49	-0.22	-0.04	-0.05	-0.07	-0.04
	DS	18	-0.41	-0.37	-0.42	-0.21	0.00	-0.01	-0.03	0.00
	C	24	-1.13	-1.08	-1.18	-0.79	-0.03	-0.04	-0.12	-0.02
	C+SS	25	-1.50	-1.43	-1.56	-1.02	-0.09	-0.10	-0.19	-0.04
	C+DS	24	-2.48	-2.31	-3.44	-1.16	-0.11	-0.13	-0.28	-0.05
	IAP	28	-3.36	-3.36	-5.26	-1.38	-0.08	-0.10	-0.27	0.00
share of BDI x IAM combinations with (date of peak loss ≤ 2050)	BASE	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SS	28	0.00	0.00	0.00	0.00	1.00	0.99	1.00	1.00
	DS	28	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
	C	28	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
	C+SS	28	0.00	0.02	0.00	0.68	1.00	1.00	1.00	1.00
	C+DS	28	0.00	0.06	0.00	0.68	1.00	1.00	1.00	1.00
	IAP	28	0.68	0.62	0.00	1.00	1.00	1.00	1.00	1.00
share of BDI x IAM combinations with (share of avoided future losses ≥ 67%)	BASE	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SS	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	DS	28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C	28	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
	C+SS	28	0.00	0.02	0.00	0.68	1.00	1.00	1.00	1.00
	C+DS	28	0.00	0.02	0.00	0.68	1.00	1.00	1.00	1.00
	IAP	28	0.68	0.61	0.00	1.00	1.00	1.00	1.00	1.00

Statistics support the data shown in Fig. 2. Summary statistics for the date of peak loss, the share of avoided future peak loss compared with the BASE scenario and the relative speed of recovery after peak loss, by scenario (rows). For each scenario, whether looking at the mean, median or 2.5th and 97.5th percentiles of each quantity (groups of columns), the statistics across BDI and IAM combinations (columns) are estimated from samples of size *n* (between 10 and 28) either directly from the unique sample of BDM outputs (simulated) or from the 10,000 bootstrapped samples (with replacement) for which we present estimates across samples of mean, median and percentiles (q025 and q975 for, respectively, the 2.5th and 97.5th percentiles, defining the 95% confidence intervals as [q025, q975]).

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Reporting Summary

Nature Research wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Research policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☒	☐	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☒	☐	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☒	☐	A description of all covariates tested
☒	☐	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☒	☐	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	The code and data used to generate the BDM outputs is publicly available from a data repository under a CC-BY-NC license (http://dare.iiasa.ac.at/57/) for all BDMs. The code and data used to analyze IAM and BDM outputs and generate figures is publicly available from a data repository under a CC-BY-NC license (http://dare.iiasa.ac.at/57/).
Data analysis	The code and data used to analyze land use and biodiversity models' output and generate figures relies on R sfotware version 3.6.1 and is publicly available from a data repository under a CC-BY-NC license (http://dare.iiasa.ac.at/57/)

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

TThe World Database on Protected Areas can be accessed at https://www.protectedplanet.net/, IUCN species range maps are available at https://www.iucnredlist.org/resources/spatial-data-download, access to Key Biodiversity Areas can be requested at http://www.keybiodiversityareas.org/site/requestgis, Wilderness Areas are available at https://www.nature.com/articles/sdata2017187, LUH2 datasets can be accessed at https://luh.umd.edu/data.shtml, HYDE 3.1 database can be accessed at https://themasites.pbl.nl/tridion/en/themasites/hyde/download/index-2.html. The 30-arcmin resolution raster layers (extent of expanded protected areas, land-use change rules in expanded protected areas, coefficients allowing the estimation of the pixel-specific and land-use change transition-specific biodiversity impact of land-use change) used by the IAMs to model increased conservation efforts cannot be made freely available due to the terms of use of their source, but will be made available upon direct request to the authors. The 30-arcmin resolution raster layers providing the proportion of land cover for each of the twelve land-use classes, four IAMs, seven scenarios and ten time horizons are publicly available from a data repository under a CC-BY-NC license (http://dare.iiasa.ac.at/57/), together with the IAM outputs underpinning the global scale results of Extended Data Fig. 3 and Extended Data Fig. 8 (for all time horizons), the global and IPBES subregion-specific results of Extended Data Fig. 4 and Extended Data Fig. 5, and the BDM outputs underpinning the global and IPBES subregion-specific results depicted in Fig. 1, Fig. 2, Extended Data Fig. 2, Extended Data Fig. 6, Extended Data Fig. 7, Extended Data Table 1 and Extended Data Table 2 (for all available time horizons, BDIs, IAMs and scenarios).

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	The study uses spatially -and temporally-explicit global land-use and biodiversity models and scenarios to assess whether and how negative biodiversity trends due habitat loss can be reversed during the 21st century.
Research sample	No population sample was taken. The following datasets were used as input to the land-use models (see Methods for more details): the World Database on Protected Areas (ref 35), the World Database on Key Biodiversity Areas (ref 36), Wilderness Areas (ref 37), the PREDICTS database (ref 39), the LUH2 land use dataset (ref 40), IUCN range maps (ref 41), the Handbook of the Birds (ref 42), the HYDE database (ref 51).
Sampling strategy	No new data was collected, no sample size calculation was performed.
Data collection	No new data was collected, above-mentioned datasets were collected from indicated sources.
Timing and spatial scale	No new data was collected, above-mentioned datasets were collected in 2017.
Data exclusions	For spatial dataset, all analyses were limited to land areas above of the latitude of 60°S (i.e. excluding Antarctica).
Reproducibility	The input data, code and software versions of the various model runs is stored; the model output data, code and software used for the analysis is stored.
Randomization	Not relevant.
Blinding	Not relevant.

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology and archaeology
☒	☐	Animals and other organisms
☒	☐	Human research participants
☒	☐	Clinical data
☒	☐	Dual use research of concern

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging