Supplementary Materials for

Global trends and scenarios for terrestrial biodiversity and ecosystem services from 1900-2050

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Materials and Methods

This study was conducted under the auspices of the Expert Group on Scenarios and Models of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The detailed protocol of this biodiversity and ecosystem services scenario inter-model comparision (BES SIM)was published in (*58*). Below we summarize the main methodological aspects.

Scenarios

All models used the same set of scenarios: SSP1xRCP2.6 ("global sustainability") with low land-use pressure and low level of climate change (*59*), SSP3xRCP6.0 ("regional rivalry") with high land-use pressure and intermediate level of climate change (*60*), and SSP5xRCP8.5 ("fossil-fueled development") with intermediate land-use pressure and high level of climate change (*61*) – to assess a broad range of plausible futures (Table S1). We used land-use projections for these scenarios ignoring the impacts of climate change, although the deployment of land-based climate mitigation strategies is considered in connection to each of the SSP-RCP combinations. Land-use projections for SSP3xRCP6.0 were not available, so we chose the closest land-use projections available, SSP3xRCP7.0.

Land use data

All models used the Land Use Harmonization (*62–65*) version 2 dataset (LUH2, see (*56*)for data). LUH2 provides global gridded land-use datasets at 0.25° resolution with annual time-steps comprising estimates of historical land-use change (850-2015) and future projections (2015-2100) under the assumptions of each Shared Socio-economic Pathway (SSP) (*66*). The 12 land use categories (Table S3) include the separation of primary and secondary natural vegetation into forest and non-forest sub-types, pasture into managed pasture and rangeland, and cropland into multiple crop functional types (C3 annual, C3 perennial, C4 annual, C4 perennial, and C3 nitrogen-fixing crops). The LUH2 dataset also computes all transitions between these 12 land use types, resulting in over 100 possible transitions per grid cell per year (e.g., crop rotations, shifting cultivation, agricultural changes, wood harvest) as well as various agricultural management layers (e.g., irrigation, synthetic nitrogen fertilizer, biofuel crops). Due to specific model parameterizations, each biodiversity and ecosystem service model used its own aggregation of the land use categories (Table S4).

Climate data

Models used historical climate data and future projections associated with each SSPxRCP combination (*17*) from CMIP5 / ISIMIP2a (*67*) or its downscaled version from the WorldClim (*68*), or the projections from MAGICC 6.0 (*69*, *70*) (Table S4). Most models used the IPSL-CM5A-LR (*71*) projections which are mid-range across the 5 GCMs in ISIMIP2a (*72*) – that includes 12 climate variables at 0.5° resolution on daily time steps from the pre-industrial period 1951 to 2099 (*67*). The WorldClim downscaled dataset has 19 bioclimatic variables monthly from 1960 to 1990 and multi-year averages for specific points in time (e.g., 2050, 2070) up to 2070 at 1km resolution. MAGICC 6.0 climate data (*69*, *70*) in the IMAGE model framework (*73*) was used for the GLOBIO model.

Additional sources of data

Some models used additional information besides land-use data and climate data, including population density, road density, soil data, agricultural yields, topography, nitrogen deposition and others (Table S4). In addition, several of the models used data from LUH2 besides the 12 land-use categories, such as wood harvest, biofuel fraction, and crop irrigated fraction Table S4).

Biodiversity models

All models have been published in peer-reviewed journals (see Table S2 with key references provided for each model), although in some cases modifications have been made to the original model (see (*58*) for details about modifications). In total, 8 spatially-explicit models were used, these include three species distributions models - AIM-biodiversity, InSiGHTS, MOL; and five community models (cSAR-iDiv, cSAR-IIASA-ETH, BILBI, PREDICTS, GLOBIO. Three of these models, BILBI, PREDICTS and cSAR-iDiv share coefficients for the impacts of land-use on biodiversity estimated from the PREDICTS database (*74*). The biodiversity models have different methodological approaches, taxonomic groups, spatial resolution and output metrics (Table S2), but they were harmonized as described below.

Ecosystem services models

For ecosystem functioning and services, five spatially-explicit models were used (see Table S2 with key references provided for each model). They include three process-based DGVM models – LPJ-GUESS, LPJ, and CABLE-POP – and two ecosystem services models – InVEST and GLOBIO-ES. These rely on different modelling approaches to estimate a wide range of biophysical outputs, which were harmonized as described in the next sections.

Land-use change only versus land-use combined with climate change simulations

We ran two types of simulations: simulating land-use changes but a constant climate (LU) and simulating both land-use and climate changes (LUCC). For biodiversity models we ran LU simulations for historical trends (1900-2015) and future scenarios (2015-2020). We also ran future scenarios with LUCC simulations for models that assess the impacts of both drivers (Table 2). For the latter models we assumed the current climate (2015) to be defined by the average climate of a multi-decadal period before 2015 (e.g. 1986-2005 for Insights, 1960-1990 for BILBI), both in the LU and LUCC simulations. For ecosystem services models we only used LUCC simulations, with both historical (1900-2015) and future (2015-2050) land-use change and climate data.

Scales of analysis (local, regional and global), harmonization of metrics, and time scales

Model outputs were produced at three spatial scales: one-degree grid cells (α metrics), at the regional level (regional γ metrics) for the 17 IPBES sub-regions (*75*), and at the global level (global γ metrics). The IPBES sub-regions are: Caribbean, Central Africa, Central and Western Europe, Central Asia, East Africa, Eastern Europe, Mesoamerica, North Africa, North America, North East-Asia, Oceania, South America, South Asia, South-East Asia, Southern Africa, West Africa and Western Asia. A shapefile with these sub-regions is available in (*55*).

The methodology adopted by each modelling team to aggregate from the original resolution of the model to one-degree cells was the arithmetic average of the values in the original resolution.

The model outputs addressed very different facets of biodiversity (e.g., species ranges, local species richness, global species extinctions, abundance-based intactness, and compositional similarity), as well as different facets of ecosystem services (e.g., pollination, carbon sequestration, soil erosion, wood production, nutrient export, coastal vulnerability), often with little overlap between different models. In addition, even for the same facet of biodiversity or ecosystem service, different models outputted different metrics. In order to ensure comparability, output metrics for each model were converted to proportional changes relative to the beginning time of the analysis (e.g., $\Delta y = \frac{y_{t1} - y_{t0}}{y_{t0}}$), where y_t is the value of the metric at time t, and t_0 and t_1 are respectively the beginning and the end of the time period. In addition, models that simulated a continuous time series of climate change impacts calculate y_t as 20-year averages around the midpoint t in order to account for inter-annual variability.

Most analysis were carried out either for historical changes from 1900 to 2015 or for future changes from 2015 to 2050. In order to compare the longer historical period (1900-2015) with the shorter scenarios period (2015-2050) we report % changes per decade. These are obtained as $[(\Delta y + 1)\text{^}(1/\Delta \text{t})\text{-}1]*100$ where Δt is the time period measured in decades. In selected figures we provide additional time steps: in Fig S1(a) we provide land-use change values at decadal intervals; in Fig S2(a) we provide mean temperature values in yearly steps and 20-year averages centered in 1910, 1935, 1960, 1990, 2015 and 2050.

Biodiversity metrics

Outputs of each biodiversity model were assigned to one or more of the following harmonized biodiversity metrics (Table S2): species richness (S), mean species habitat extent ($\dot{H}$), and species-abundance based biodiversity intactness (I) (*76*). The habitat extent metric for each species is typically calculated by species distribution models, as a intersection of the species climate-based range and habitat suitability (*77*, *78*). To provide an integrated metric across species, we calculate averages across species. Species-abundance biodiversity intactness is reported by community models and is a metric of impact of humans on biodiversity (*79*). It can be defined as the average abundance of species in site, relative to abundance in an undisturbed habitat (*74*, *80*).

While all metrics were reported as proportional changes relative to the beginning of a time period, intactness was also reported as an absolute score (relative to a pristine baseline). For mapping purposes, local changes in proportional species richness were converted in normalized changes in absolute species richness (ΔSS), by multiplying by the number of species in each cell and then dividing by the number of species in the richest cell. When relative changes in species richness (ΔS) are compared with absolute changes (ΔSS) (Figure S14), it is apparent that the latter are larger in tropical regions and continents (except Australia), as temperate areas and islands often have lower species richness. Global spatial averages of the local metrics were calculated across all terrestrial one-degree cells and are denoted with an overbar (e.g. $\overline{\Delta S_\alpha}$) to distinguish it from averages of a metric across species ($\dot{H}$).

All five community-based models (i.e. cSAR-iDiv, cSAR-IIASA, BILBI, PREDICTS, GLOBIO) are based on empirical responses of community composition (as measured by species richness or another indicator such as mean species abundance) to each land-use type, relative to native habitat, often measured at the site level at very small scales (e.g. 1 ha). To scale up these community composition responses to the grid-cell level (our α scale), cSAR-iDiv and cSAR-IIASA use a species-area relationship approach, while PREDICTS uses a linear scaling, based on the relative fraction of the grid-cell covered by each habitat type (*81*). Everything else being equal, the species-area relationship approach tends to project smaller relative changes than the linear method for this kind of upscaling (*81*), but the habitat affinities and the number of species groups used also have an influence, and they all differ between the three models (see Table S2). BILBI, cSAR-iDiv and cSAR IIASA also scale up site-level responses to whole sub-continental regions and the globe (γ regional and γ global). For species distribution models (INSIGHTS, AIM, and MOL) the intersections of the species range with the habitat suitability and climate envelopes, is integrated across species for each spatial level of analysis, and no scaling relationships are needed. However, this kind of stacking of species distribution models ignore species interactions and may underestimate species declines at the grid-cell level, as the species only disappear when either no suitable habitat or suitable climate is available anywhere in a grid cell.

In the end, the harmonized metrics analyzed were:

- $\Delta S_\alpha(x,y) = \frac{S_\alpha(x,y,t1) - S_\alpha(x,y,t0)}{S_\alpha(x,y,t0)}$, where $S_\alpha(x,y,t)$ is the number of species at cell (x,y) at time t;
- $\Delta SS_\alpha(x,y) = \Delta S_\alpha(x,y) \times \frac{S(x,y)}{Mean_{\{x,y\}}[S(x,y)]}$, where $S(x,y)$ is the number of species at cell (x,y) calculated from current species distribution maps, and the mean value is calculated across all cells;
- $\Delta S_\gamma(region) = \frac{S_\gamma(region,t1) - S_\gamma(region,t0)}{S_\gamma(region,t0)}$, where $S_\gamma(region,t)$ is the number of species in an IPBES sub-region or in the globe at time t;
- $\Delta \dot{H}_\gamma = \frac{1}{S\gamma}\sum_{i=1}^{S\gamma} \frac{H_\gamma(i,t1,i) - H_\gamma(i,t0)}{H_\gamma(i,t0)}$, where $H_\gamma(i,t)$ is the global habitat extent of species i at time t
- $I_\alpha(x,y,t)$, which is the species-abundance based intactness value for cell (x,y) at time t relative to a pristine baseline, with 100% corresponding to a pristine habitat and 0% to a completely degraded habitat.

In addition, global spatial averages for α metrics were calculated using area-weights as follows:

- $\overline{\Delta S_\alpha} = \sum_{x,y} \Delta S_\alpha(x,y)\ w_{x,y}$
- $\overline{I_\alpha} = \sum_{x,y} I_\alpha(x,y)\ w_{x,y}$

where $w_{x,y}$ is the area of each one-degree cell divided by the global land surface area. Finally, metrics were reported as % changes standardised by the number of years between the beginning (t_0) and end (t_1) of the considered time period.

The harmonized biodiversity metrics need to be interpreted with care as the original model outputs mapped to the same harmonized metric can differ in some technical details. For instance, the GLOBIO model (*11*) outputs a metric called "Mean Species Abundance" (MSA) that is obtained *"by dividing the abundance of each species found in relation to a given pressure level by its abundance found in an undisturbed situation within the same study, truncating the values at 1, and then calculating the arithmetic mean over all species present in the reference situation"*; likewise the PREDICTS model (*82*) outputs a metric called "Abundance-based Biodiversity Intactness Index" (BIIAb) that represents *"the average abundance of originally present species across a broad range of species, relative to abundance in an undisturbed habitat"*. While both metrics have been harmonized as representing species-abundance based intactness (*I*), they are calculated differently in the models (i.e. the former is the average of abundance ratios while the latter is the ratio of the sums). Similarly, models based on the countryside species-area relationship (*83*) produced similar metrics (relative change in species richness) but were calibrated for different taxonomic groups, and with different numbers of habitat affinity groups (Table S2). Finally, BILBI takes into account shared species between regions (e.g. between one degree cells) whereas the other community models implicitly assume independence between cells.

Ecosystem services metrics

A similar effort was made to assign the metrics outputted by the ecosystem function and services models to a set of harmonized metrics (Table S2). We used the typology of the IPBES Nature's Contributions to People (NCPs) (*16*) to classify material and regulating services. For each of the following ecosystem services we assigned one biophysical metric from one or more models, sometimes changing the sign of the reported metric for consistency: bioenergy production; food and feed production; timber production; ecosystem carbon; crop pest control (more is better control); coastal resilience (more is greater resilience); pollination; soil protection; nitrogen retention (more is higher water quality).

The dynamic global vegetation models (DGVMs) tend to output similar metrics and have similar assumptions (*84*), but the two ecosystem service models (GLOBIO and InVEST) tended to output different metrics for the same service. DGVMs have been used in the climate change modeling community for decades so they benefit from a long history of multi-model inter-comparison (*85*). Therefore, while for certain metrics, such as ecosystem carbon pool, the metrics are calculated in a similar way and use equivalent biophysical units (e.g. Kg C), for other metrics, e.g. pollination, direct comparison of absolute values was not feasible. For instance, GLOBIO-ES (*86*) defines their metric of pollination services as the fraction of cropland potentially pollinated, relative to all available cropland, but InVEST (*87*) defines it as the proportion of agricultural lands whose pollination needs are met by sufficient amounts of natural habitat within the flight range of pollinators. As for biodiversity metrics, this issue was addressed by using proportional changes of each metric in each model at each scale of analysis.

At the grid-cell level (α), proportional changes for ecosystem services were calculated as:

- $\Delta ES_{\alpha}(x,y)=\frac{S_{\alpha}(x,y,t1)-S_{\alpha}(x,y,t0)}{S_{\alpha}(x,y,t0)}$, where $ES_{\alpha}(x,y,t)$ is the total service (e.g. Ecosystem Carbon) at cell (x,y) at time t;

At the regional (γregion) or global (γglobal) proportional changes for ecosystem services were calculated as

- $\Delta ES_{\gamma}(region)=\frac{ES_{\gamma}(region,t1)-ES_{\gamma}(region,t0)}{ES\gamma(region,t0)}$, where $ES_{\gamma}(region,t)$ is the level of the service estimated for the whole region or for the globe at time t.

It is important to note that, in contrast with biodiversity metrics, there is a simple way of scaling α estimates to regional or global γ estimates for most ecosystem services: the relative change at the γ level can be calculated by first summing for a region the area-weighted absolute values of the ecosystem service in each cell $ES_{\alpha}(x,y,t)$ at each time step, and then calculating the relative change of those summed values. In addition, these sums can even be interpreted in many cases at the value of the ecosystem level at the regional or global level $ES_{\gamma}(region,t)$.

Comparison of biodiversity, regulating and material ecosystems services

To understand how biodiversity and ecosystem services varied concurrently in each IPBES sub-region (Figure 4) we mapped regional changes in biodiversity and in aggregated regulating and material ecosystem services, from 2015 to 2050 for all three scenarios. First, we normalized changes in regional species richness (ΔS_{γ}) and ecosystem service metrics for all scenarios and regions, by dividing the proportional changes for each sub-region and scenario and model metric by the maximum value of that metric for all subregions in all scenarios. In this way, we obtained a normalized ΔY with values between -1 and +1 for biodiversity or ecosystem service metric in each region and scenario. Next, we clustered all normalized model values into biodiversity metrics, material ecosystem services and regulating ecosystem services.

Intermodel means

For each metric for which comparable projections from multiple models exist, we calculated the means and standard error of the means, reporting as mean ± SEM. Therefore, all models were treated equally in the analysis. For some models reporting metrics for more than one taxonomic group or sub-group (AIM, cSAR-IIASA, cSAR-iDiv), we report the average value across taxa weighted by the species richness of the taxonomic group.

Maps

All maps in the figures are in equirectangular projections (i.e. geographic coordinates).

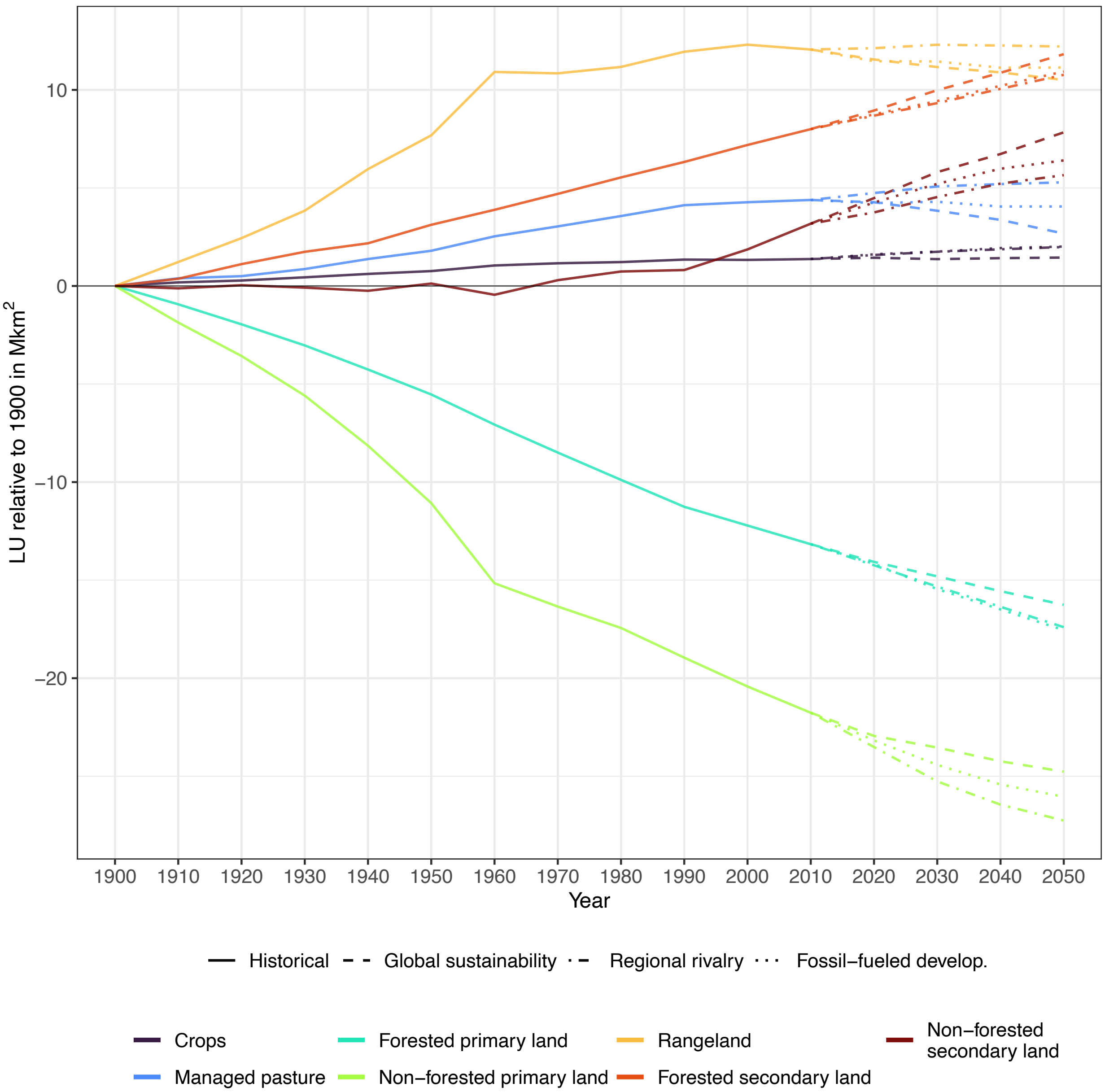

Fig. S1. Global historical trends (1900-2015) in land-use and projected trends for each scenario (2015-2050). Lines correspond to absolute area changes relative to the year 1900. The original area covered by each land-use in 1900 was: forested primary land (36.0 Mkm^2), non-forested primary land (50.7 Mkm^2), forested secondary land (6.3 Mkm^2), non-forest secondary land (11.8 Mkm^2), managed pasture (3.5 Mkm^2), rangeland (12.9 Mkm^2), cropland (9.5 Mkm^2).

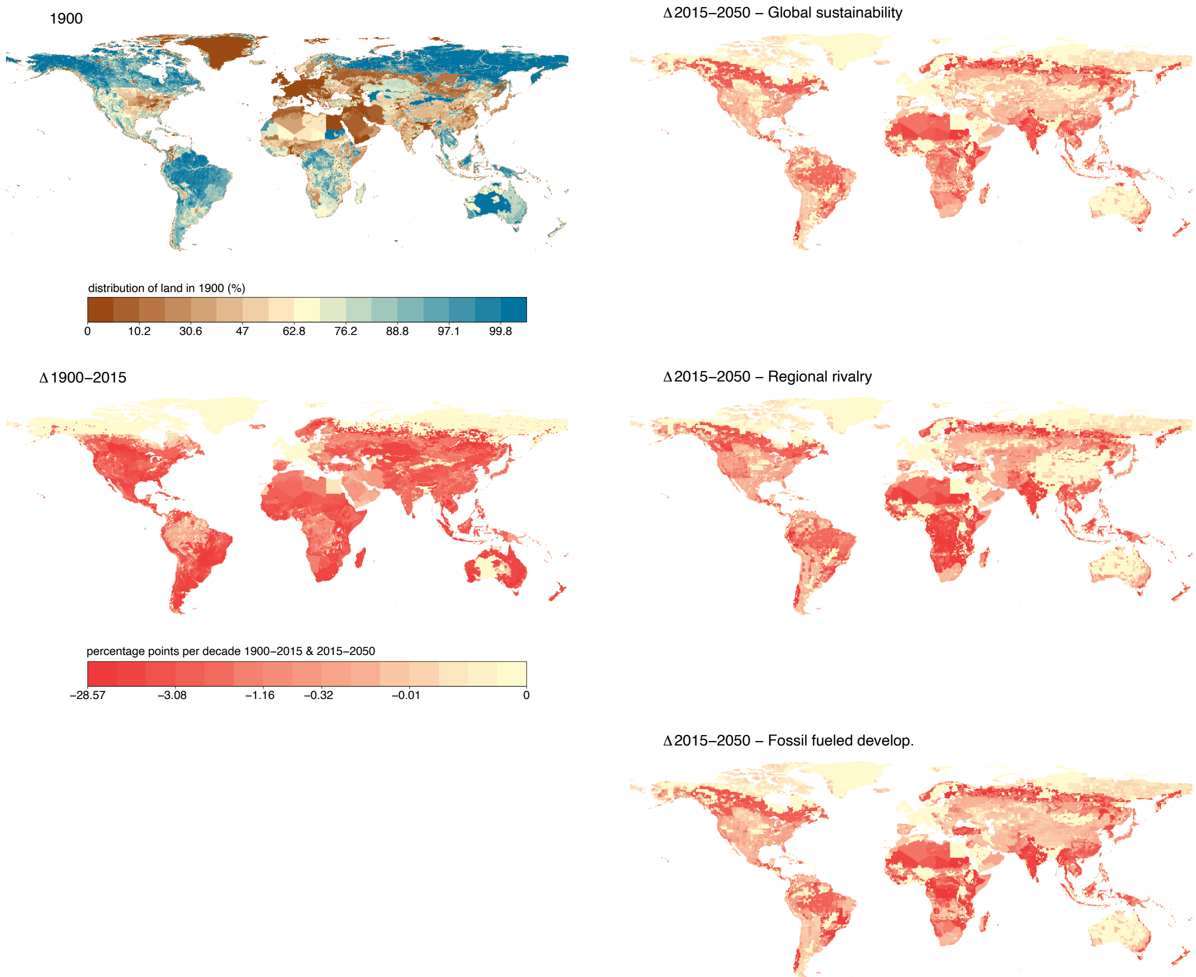

Fig. S2 Distribution of primary land (forest & non-forest) in 1900, historical changes (1900-2015) and future changes (2015-2050) in each scenario. Please note that changes are reported in absolute percentage points per decade (i.e., $(y_{t1}-y_{t0})/(t_1-t_0)\times 10$ where y_t is the percentage of the area in a cell covered by a land use type at year *t*). Color scales are based on quantile intervals considering all land cluster types for i) 1900 and ii) the past (Δ1900-2015) and future (Δ2015-2050) combined.

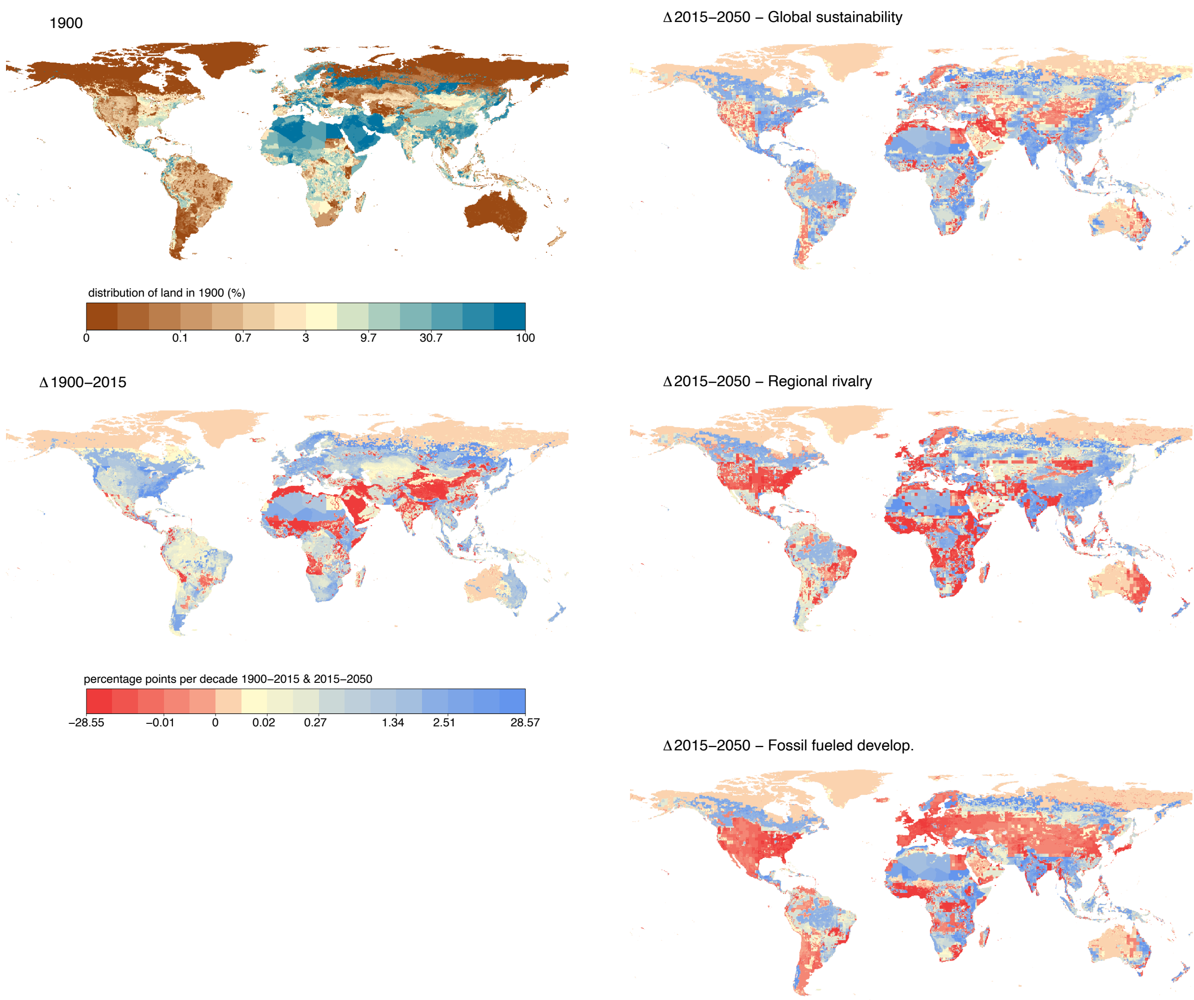

Fig. S3 Distribution of secondary land (forest & non-forest) in 1900, historical changes (1900-2015) and future changes (2015-2050) in each scenario. Please note that changes are reported in absolute percentage points. Color scales are based on quantile intervals considering all land cluster types for i) 1900 and ii) the past (Δ1900-2015) and future (Δ2015-2050) combined.

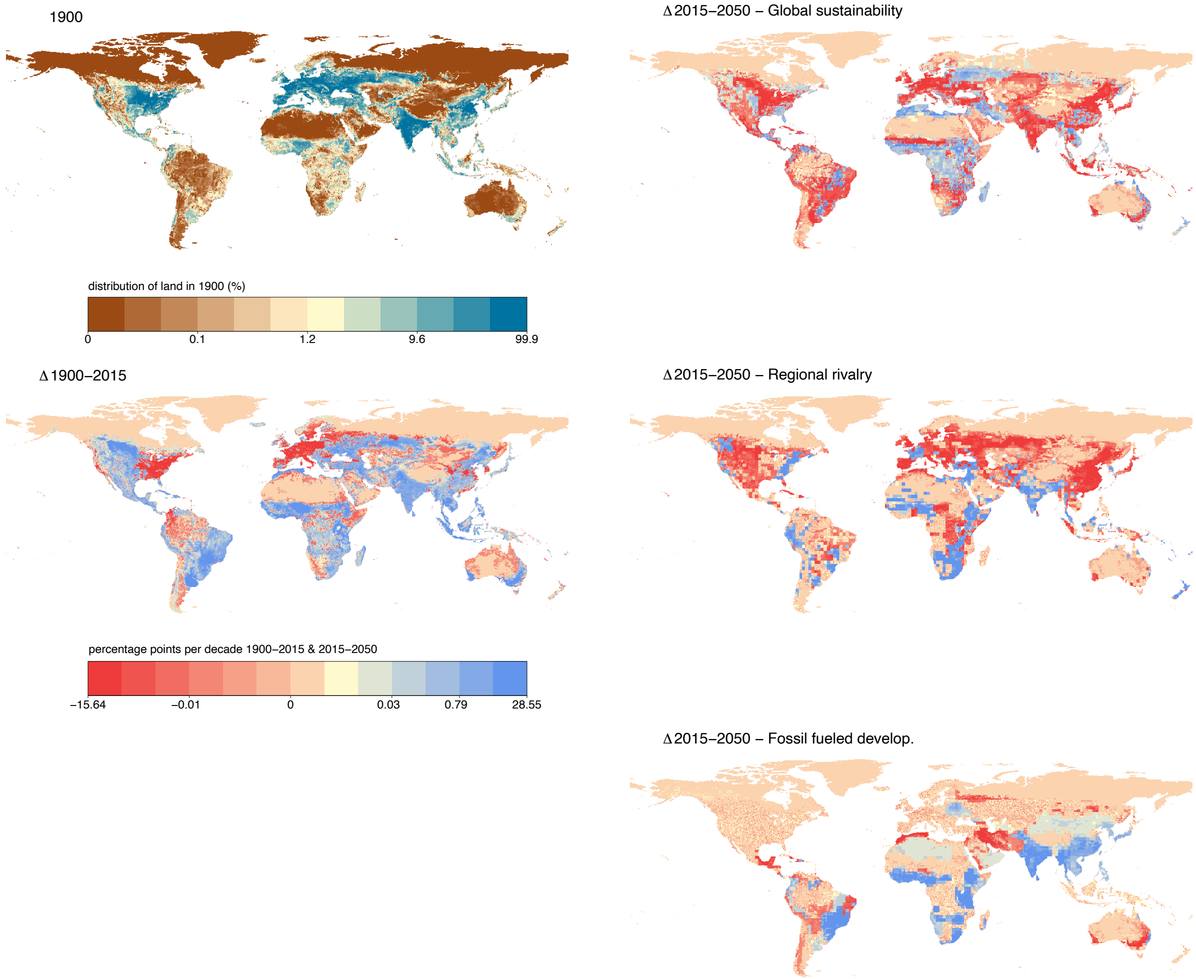

Fig. S4 Distribution of cropland (C3 & C4) in 1900, historical changes (1900-2015) and future changes (2015-2050) in each scenario. Please note that changes are reported in absolute percentage points. Color scales are based on quantile intervals considering all land cluster types for i) 1900 and ii) the past (Δ1900-2015) and future (Δ2015-2050) combined.

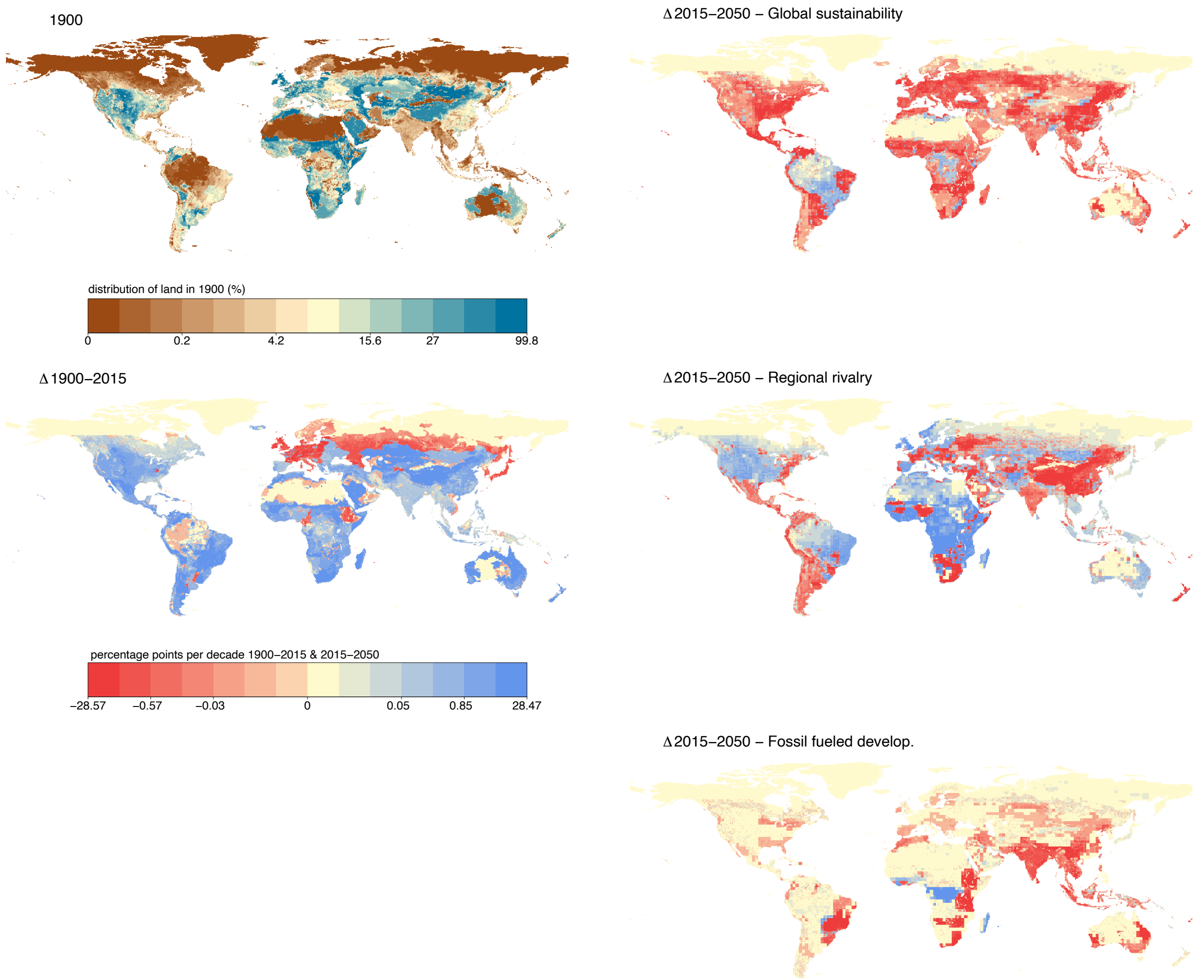

Fig. S5 Distribution of pasture and rangeland in 1900, historical changes (1900-2015) and future changes (2015-2050) in each scenario. Please note that changes are reported in absolute percentage points. Color scales are based on quantile intervals considering all land cluster types for i) 1900 and ii) the past (Δ1900-2015) and future (Δ2015-2050) combined.

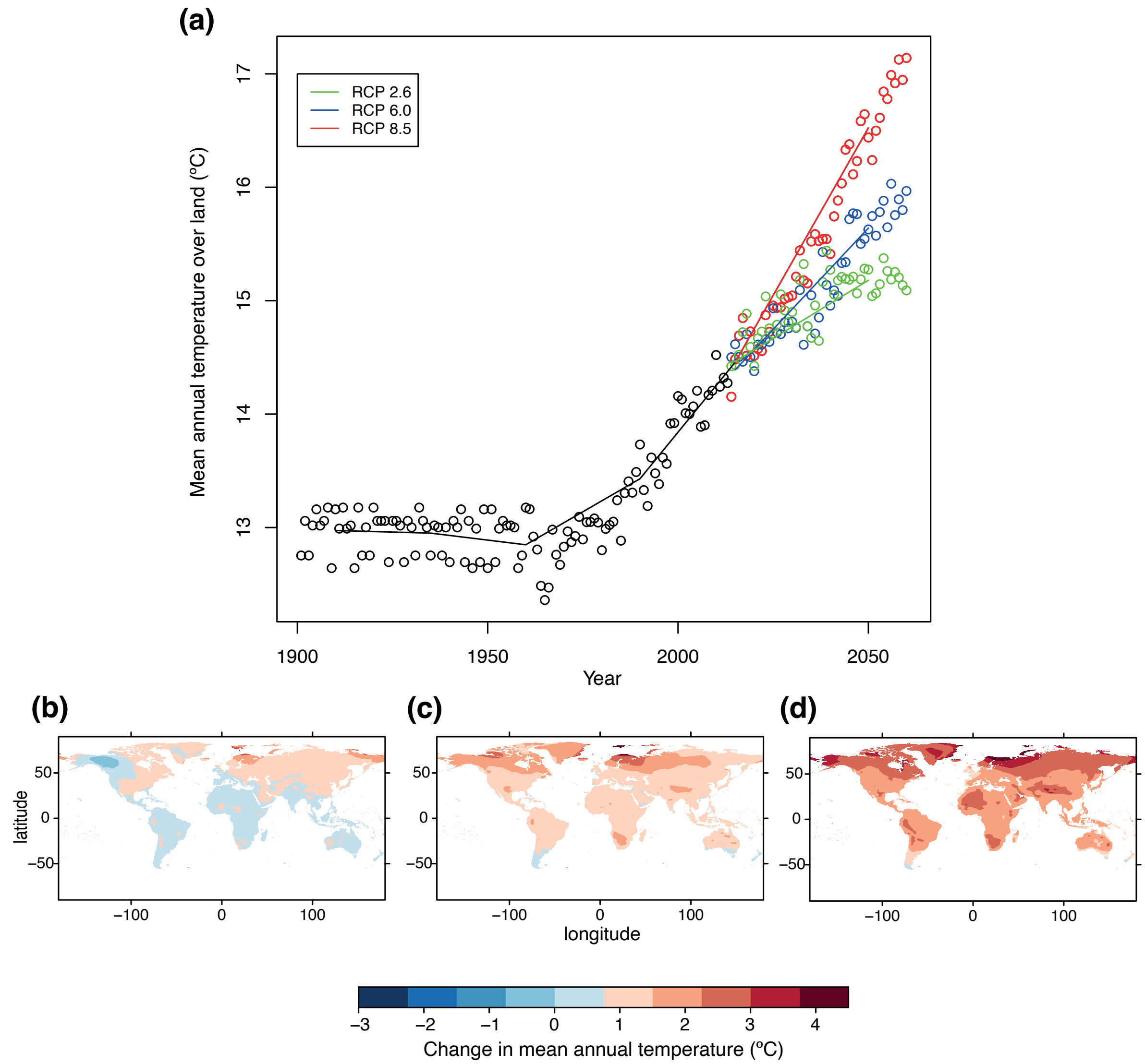

Fig. S6. **(a)** Global historical trends (1990-2015) in mean annual temperature and for each scenario (2015-2050). Spatial distribution of absolute changes in mean annual temperature in each scenario (2015-2050): **(b)** global sustainability - RCP2.6, **(c)** regional rivalry - RCP6.0, **(d)** fossil-fueled development - RCP8.5.

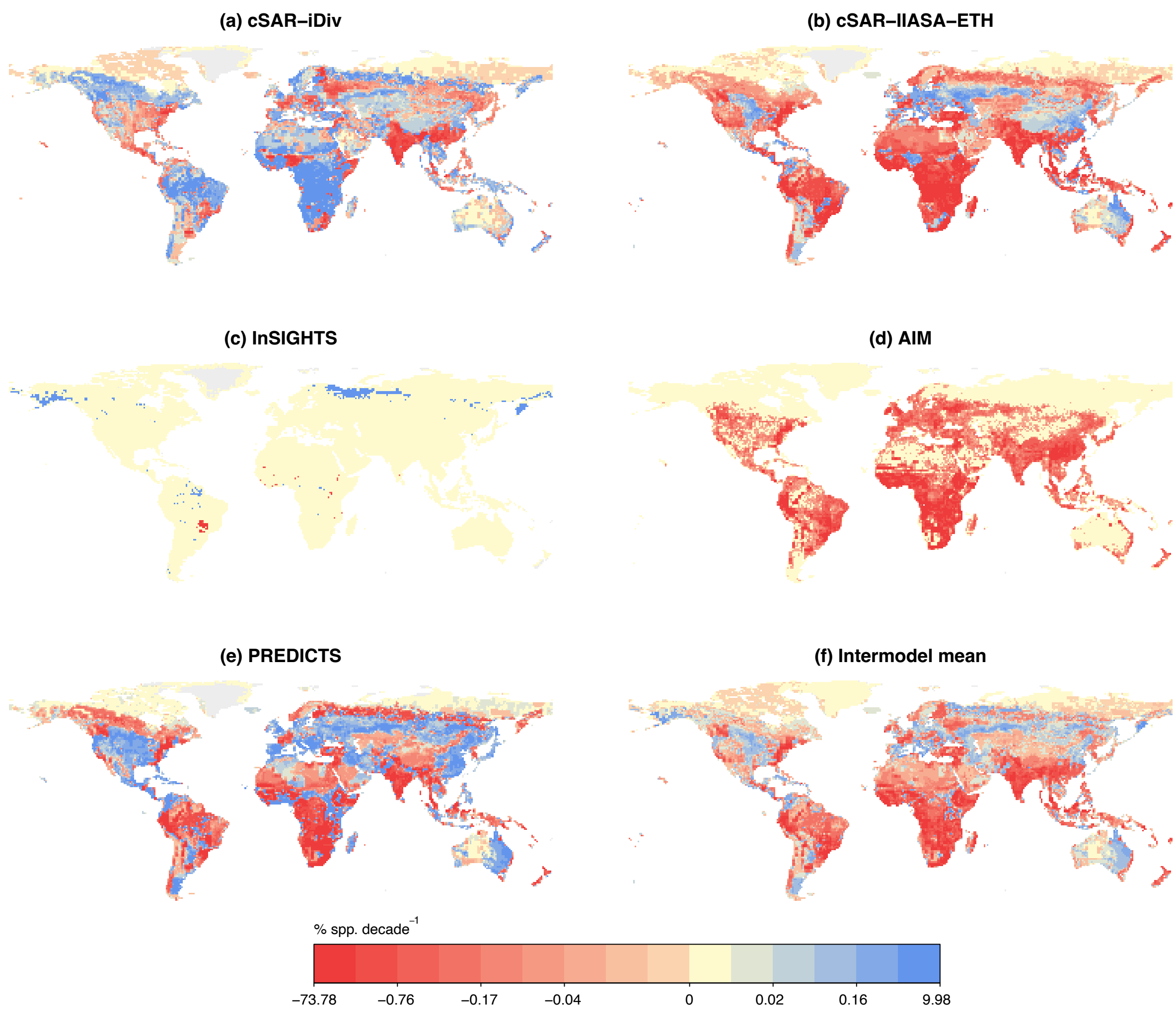

Fig. S7. Spatial agreement between biodiversity models. Projection of normalized changes in local species richness per year (ΔSS_{α}) during 2015-2050 caused by land-use change alone for the regional rivalry scenario: **(a)** cSAR-iDiv model; **(b)** cSAR-IIASA-ETH model; **(c)** InSIGHTS model; **(d)** AIM-B model; **(e)** PREDICTS model; **(f)** inter-model mean. A value of 1% decade^{-1} corresponds to a decline in the number of local species equal to 1% species of the mean number of species across cells. Color scale is based on quantile intervals when considering all maps features.

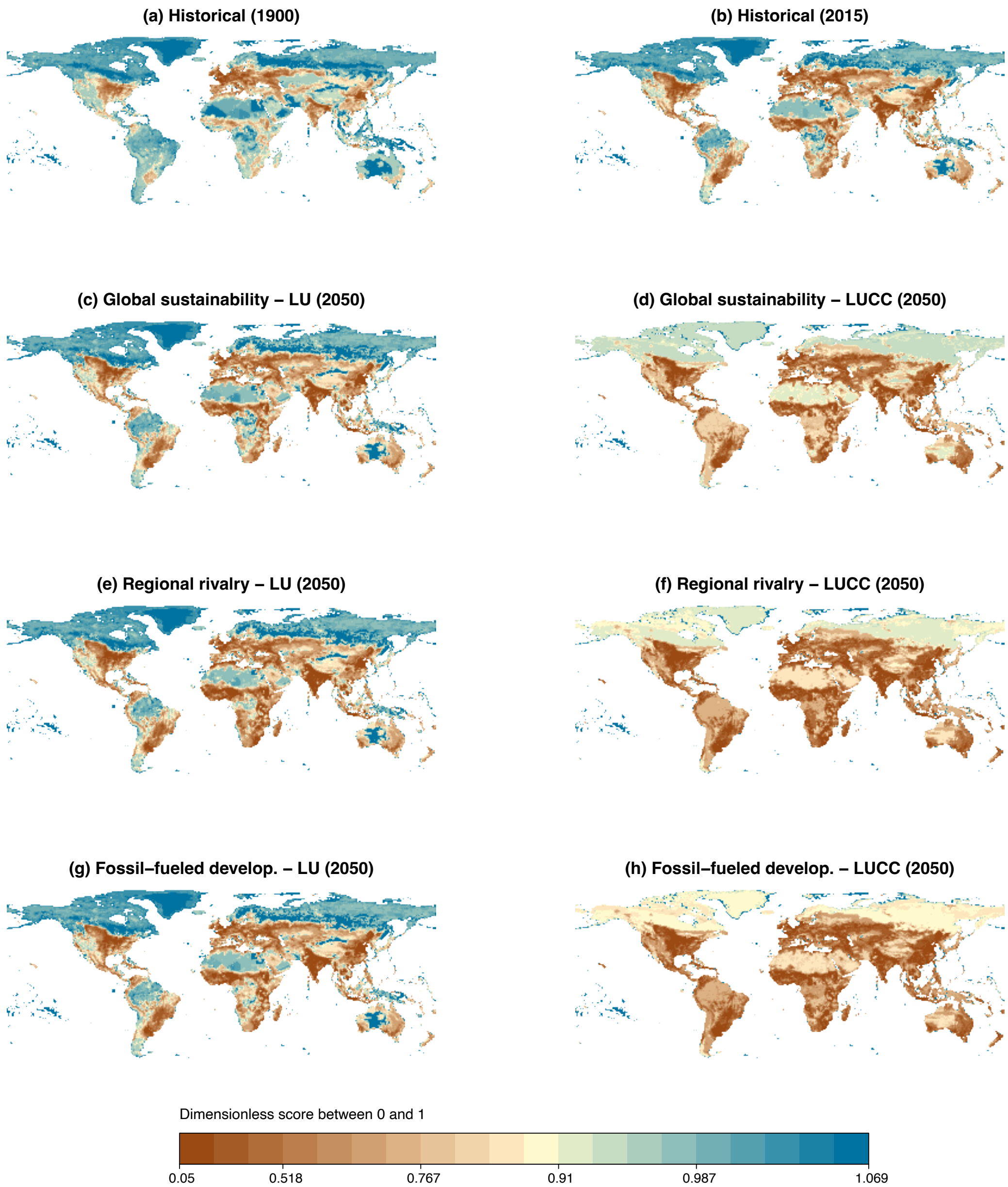

Fig. S8. Spatial distribution of intactness (*I*): **(a)** year 1900; **(b)** 2015; **(c-h)** 2050 based on land-use change alone **(c,e,g)** and on the combined impacts of land-use change and climate **(d, f, h)**. Values correspond to the inter-model mean between PREDICTS and GLOBIO, except for **(d,f,h)** which are based only on GLOBIO. Values are scores relative to a pristine baseline (a score of 1 corresponds to pristine, while a score of 0 corresponds to fully degraded). Color scale is based on quantile intervals when considering all maps features.

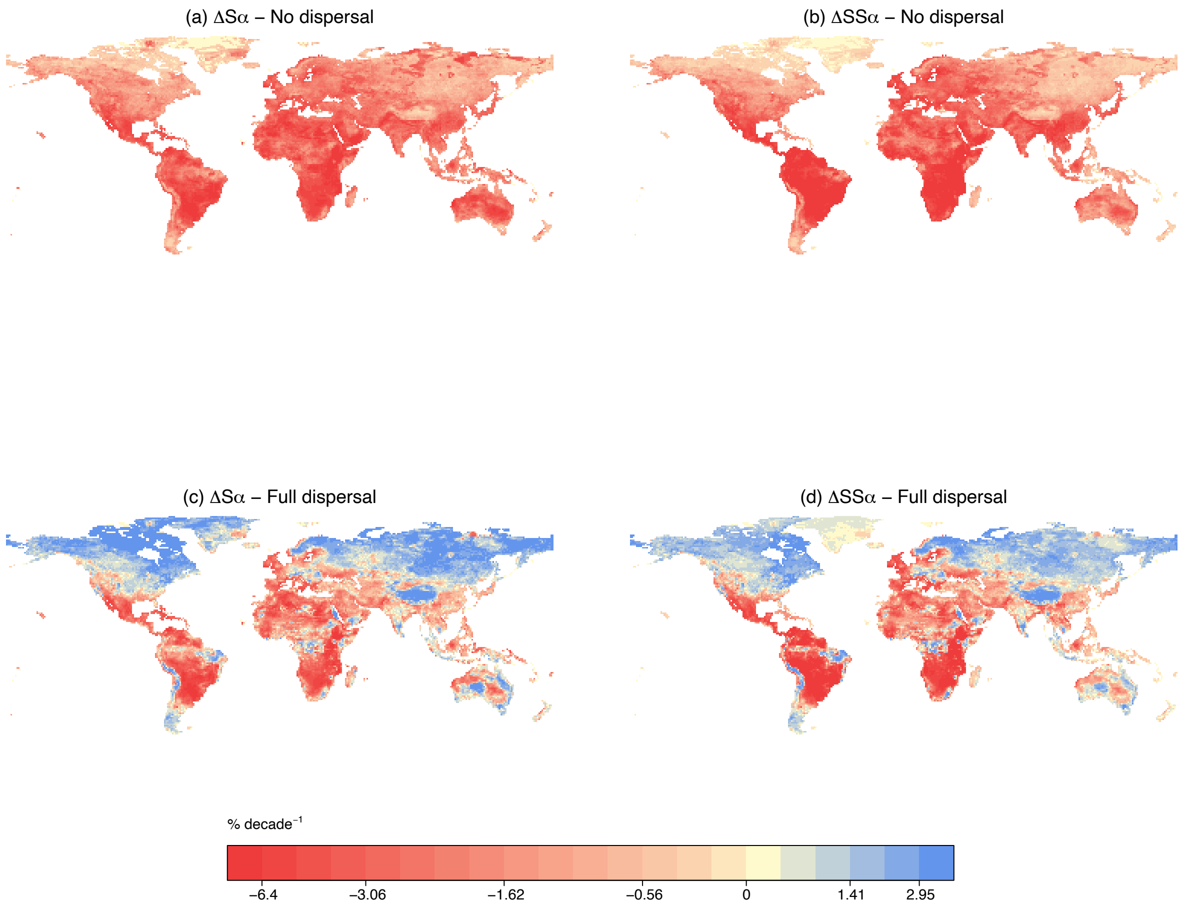

Fig. S9. Biodiversity metrics of the AIM model for the fossil fueled development scenario for 2015-2050: assuming species cannot disperse (a) and (b); assuming species can disperse without any limits (c) and (d). **(a) and (c)** proportional changes in local species richness (ΔS_α); **(b) and (d)** normalized changes in local species richness per year (ΔSS_α). Color scale is based on quantile intervals when considering all maps features.

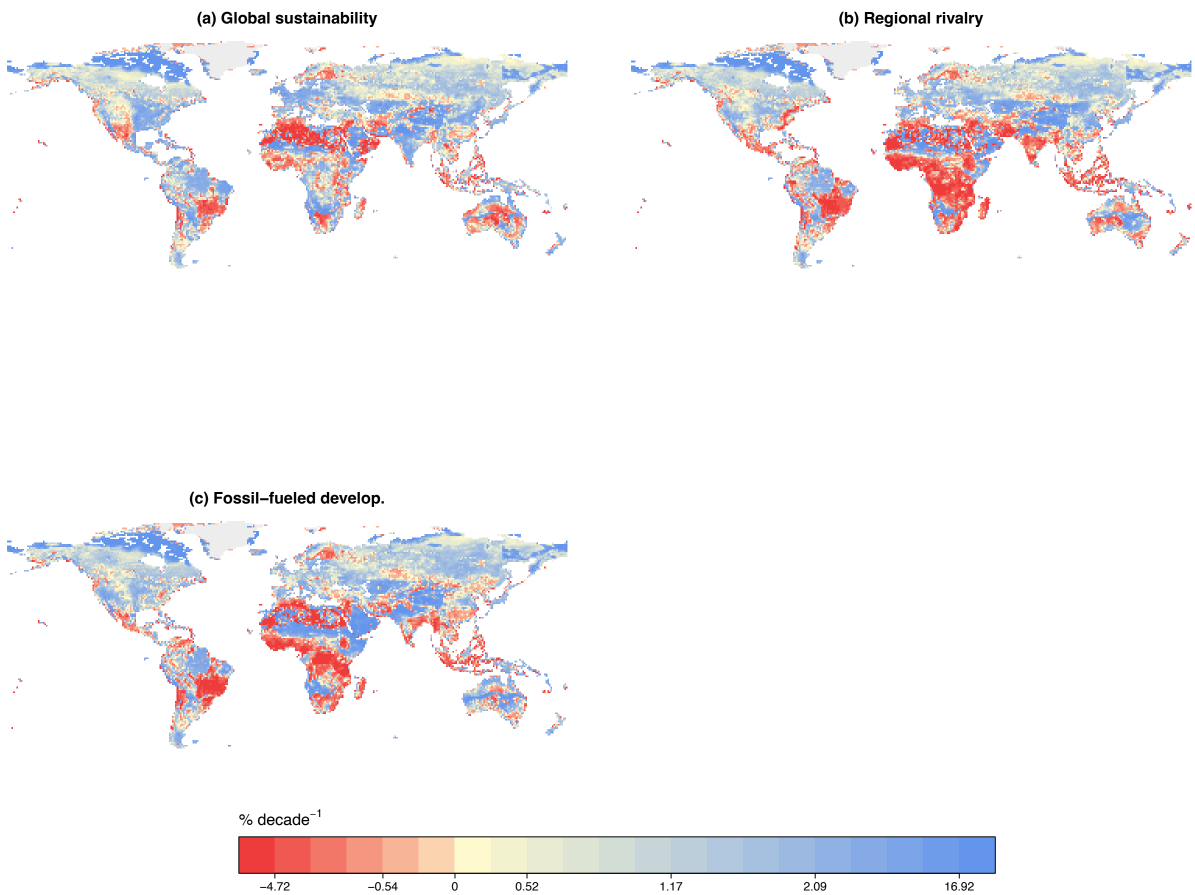

Fig. S10. Ecosystem carbon pools across scenarios. Inter-model mean of proportional changes for 2015-2050 (N=4, CABLE-POP, LPJ, LPJ-GUESS, GLOBIO-ES): (a) global sustainability, (b) regional rivalry, (c) fossil-fueled development. Color scale is based on quantile intervals when considering all maps features.

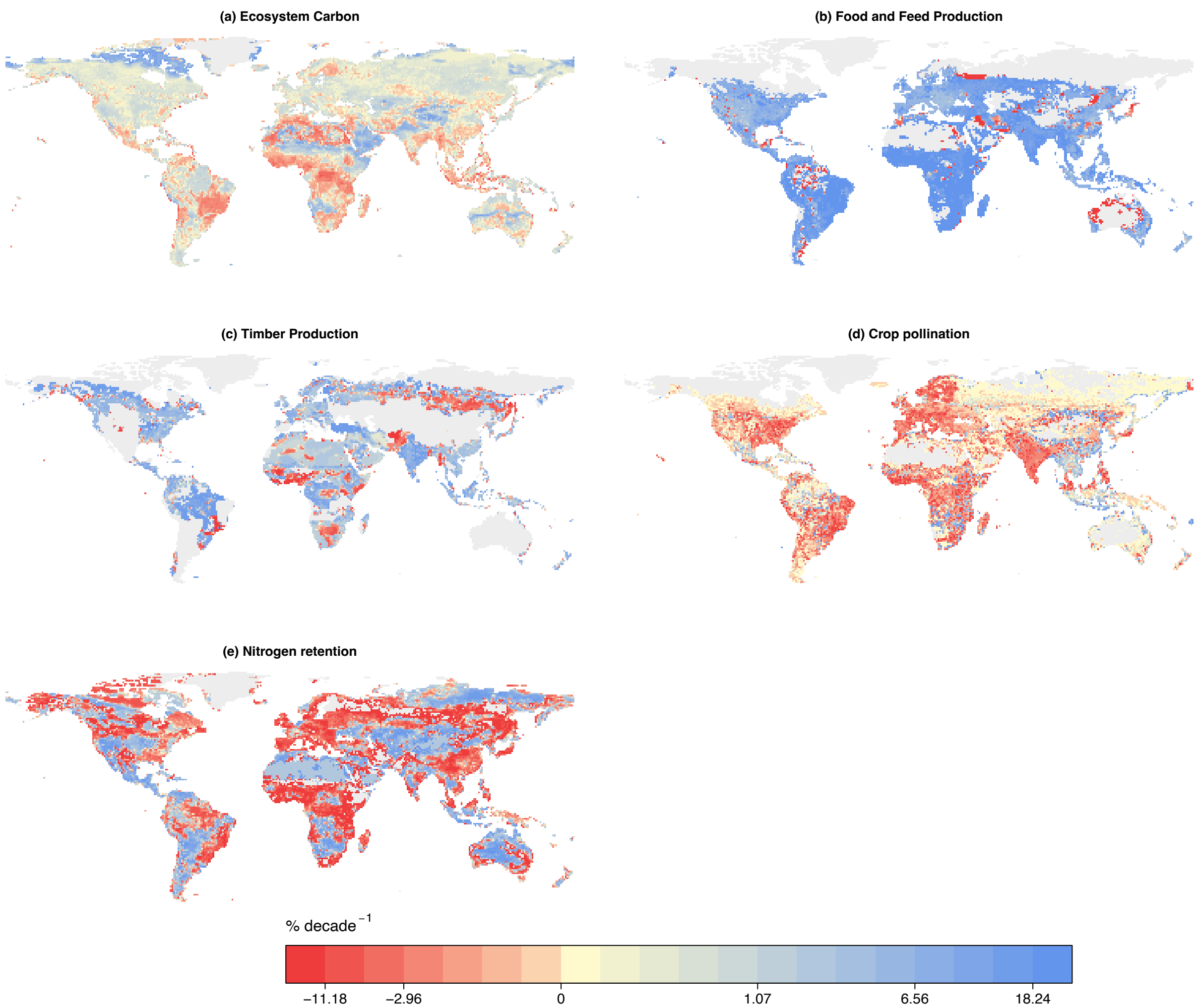

Fig. S11. Spatial distribution of ecosystem service changes. Inter-model mean projection of proportional changes (2015-2050) in the fossil fueled development scenario for: (a) Ecosystem carbon (N=4), (b) Food and feed production (N=2), (c) Timber production (N=3), (d) Crop pollination (N=2) and (e) Nitrogen retention (N=2). Colour scale is based on quantile intervals when considering all maps features.

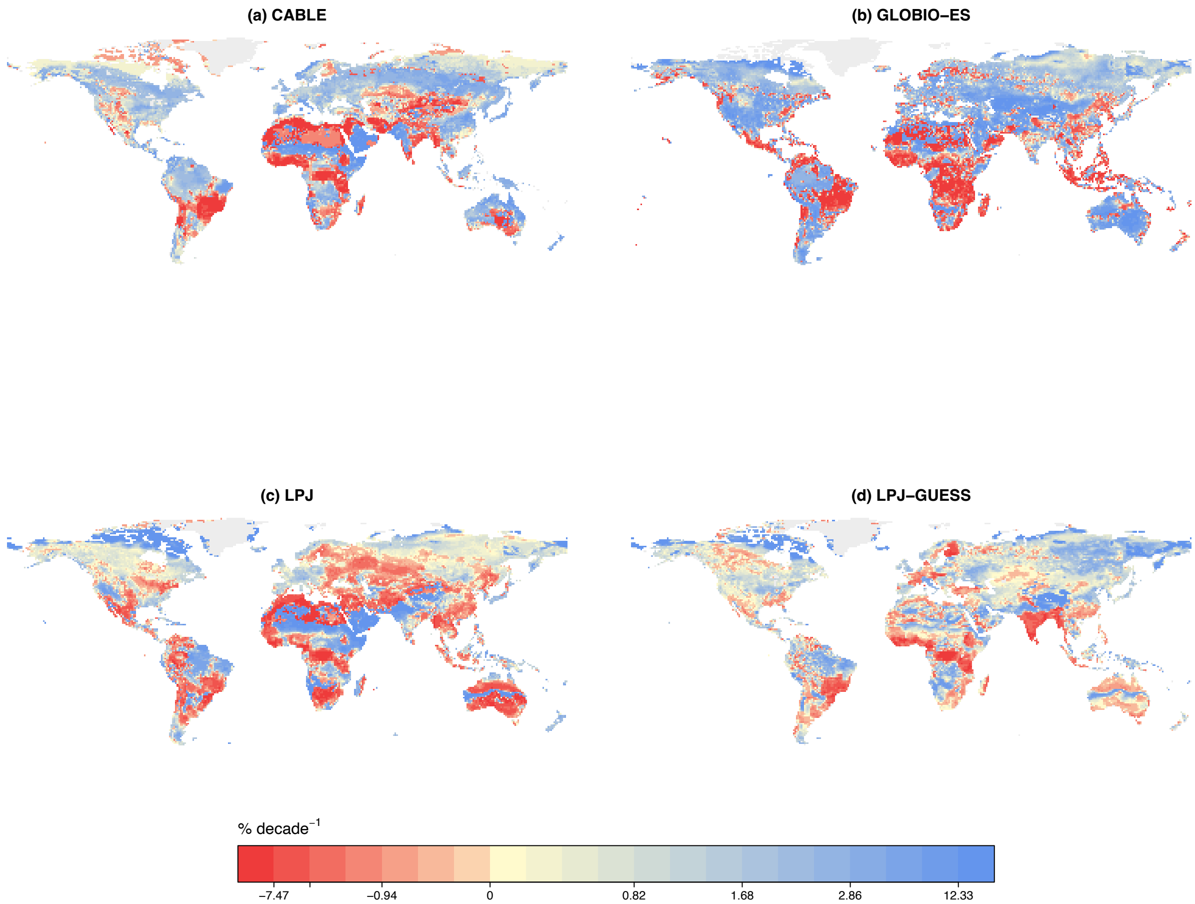

Fig. S12 Spatial agreement across models in ecosystem carbon for the fossil fuel development scenario for 2015-2050: **(a)** CABLE-POP, **(b)** GLOBIO-ES, **(c)** LPJ and **(d)** LPJ-GUESS. Color scale is based on quantile intervals when considering all maps features.

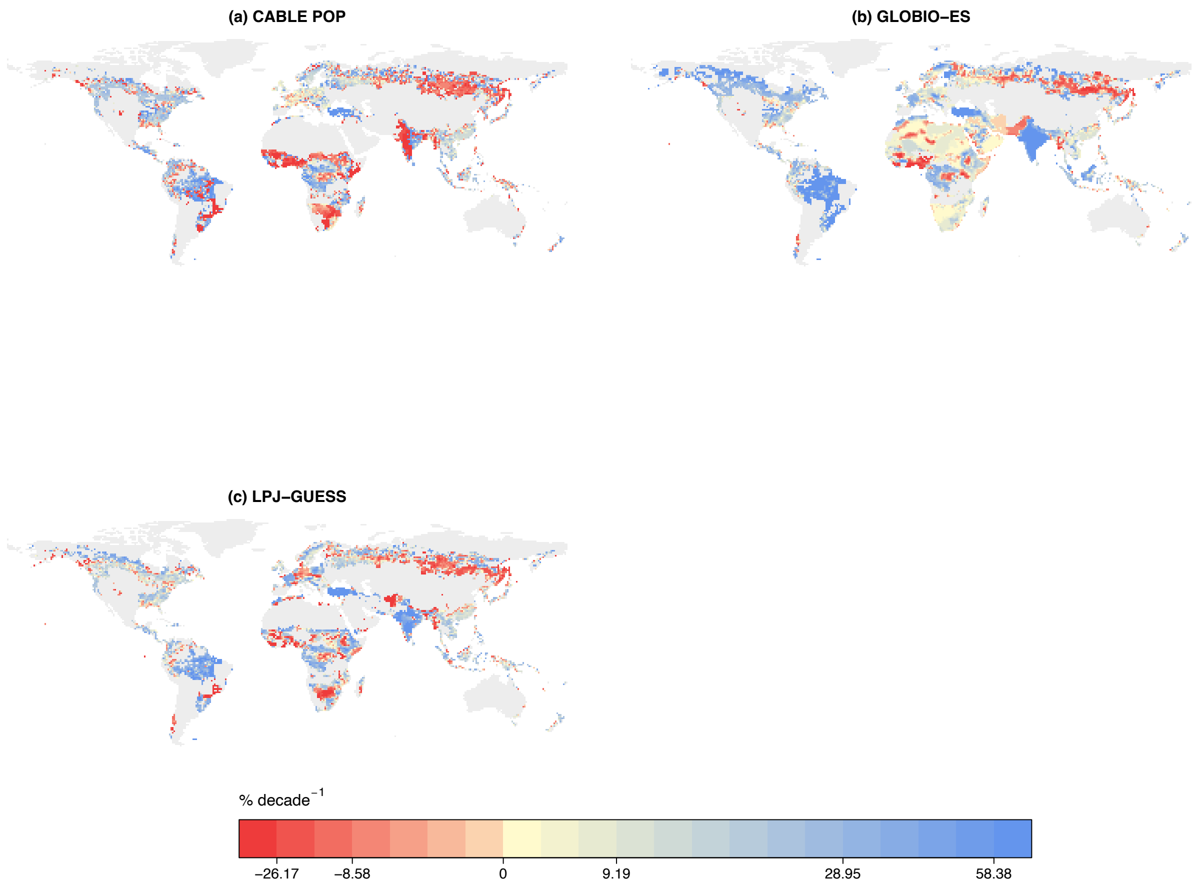

Fig. S13. Spatial agreement across models in projected timber production for the fossil fueled development scenario for 2015-2050: **(a)** CABLE, **(b)** GLOBIO-ES and **(c)** LPJ-GUESS. Color scale is based on quantile intervals when considering all maps features.

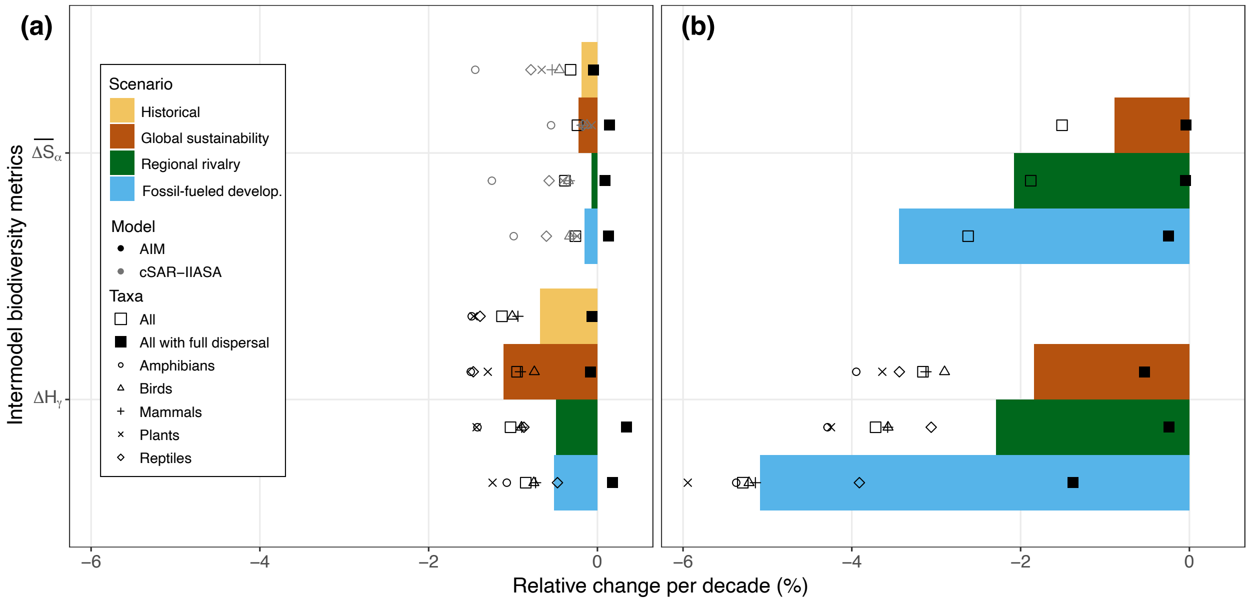

Fig. S14 Historical trends in biodiversity since 1900 and future projections for each scenario to 2050. Change in different dimensions of biodiversity for the historical period (1900-2015) and for each future scenario (2015-2050) with values for each taxon displayed for two models and for the AIM model, with no dispersal versus full dispersal: **(a)** from land-use alone; **(b)** from land-use change and climate change combined. Metrics correspond to proportional changes in: global species richness (ΔS_γ), local species richness averaged across space ($\overline{\Delta S_\alpha}$), mean species global habitat extent ($\Delta \dot{H}_\gamma$), and local intactness averaged across space ($\overline{\Delta I_\alpha}$). Colored bars are means across models.

Table S1. Characteristics of SSP and RCP scenarios (based on (*18*))

	SSP1xRCP2.6 Global sustainability	SSP3xRCP6.0 Regional Rivalry	SSP5xRCP8.5 Fossil-fueled Development
Land-use projections			
Population growth	Relatively low (8.5 billion in 2050)	Low to high (10 billion in 2050)	Relatively low (8.5 billion in 2050)
Economic growth	High to medium (284,565 GDP/PPP billion US$2005/yr in 2050)	Slow (177,284 GDP/PPP billion US$2005/yr in 2050)	High (360,926 GDP/PPP billion US$2005/yr in 2050)
Urbanization	High (92% in 2050)	Low (60% in 2050)	High (92% in 2050)
Equity and social cohesion	High	Low	High
International trade and globalization	Moderate	Strongly constrained	High
Policy focus	Sustainable development	Security	Development, free market, human capital
Institution effectiveness	Effective	Weak	Increasingly effective
Technology development	Rapid	Slow	Rapid
Land-use regulation	Strong	Limited	Medium
Agricultural productivity	High	Low	High
Consumption & diet	Low growth, low-meat	Resource-intensive	Material-intensive, meat-rich diet
Mitigation policies in land use	Full	Absent	Absent
Bioenergy	High	Low	Lowest
Climate projections			
Carbon intensity	Low	High	High
Energy intensity	Low	Intermediate	High
Radiative forcing	Peak at 3W/m^2 before 2100 and declines	Stabilizes to 6W/m^2 in 2100	Rising to 8.5 W/m^2 in 2100
Concentration (p.p.m)	Peak at 490 CO_2 equiv. before 2100 then declines	850 CO_2 equiv. (at stabilization after 2100)	>1,370 CO_2 equiv. in 2100
Methane emissions	Reduced	Stable	Rapid increase

Table S2. Model description, taxonomic scope, metrics, scenarios and output maps. (S) species richness, ($\dot{H}$) mean species habitat extent, *(I)* and species-abundance based biodiversity intactness. Metrics were calculated at the one or more of the following spatial levels: grid cell (α), regional (regional γ), global level (global γ). The grid cell values were also reported as global averages. For BILBI and MOL only the tabular outputs of the models were used, therefore there are no links to output maps.

Model	Description	Taxonomic scope	Metrics	Scenarios	Output maps
AIM-biodiversity (Asia-Pacific Integrated Model – biodiversity) (*88*)	A species distribution model that estimates biodiversity loss based projected shift of species range under the conditions of land-use and climate change. Species range shifts were projected under two commonly used dispersal assumptions: 'no' migration, which did not allow for species colonization and 'full' migration, which allowed for species colonization. The "no-migration" estimates were used, unless stipulated otherwise.	Amphibians, birds, mammals, plants, reptiles	$S\alpha$ $S\gamma$ $H\gamma$	Historical Land use Land use and climate	(*51*)
InSiGHTS (*77*, *89*, *90*)	A high-resolution, cell-wise, species-specific hierarchical species distribution model that estimate the extent of suitable habitat (ESH) for mammals accounting for land and climate suitability. The model did not consider species colonization in this exercise from climate-change, but allowed colonization from land-use change within the climate space of the species.	Mammals	$S\alpha$ $S\gamma$ $H\gamma$	Historical Land use Land use and climate	(*45*)
MOL (Map of Life) (*78*, *91*)	An expert map-based species distribution model that projects potential losses in species occurrences and geographic range sizes given changes in suitable conditions of climate and land cover change. The model considered range loss within the currently known distribution, and not the species colonization in this exercise.	Amphibians, birds, mammals	$H\gamma$	Land use and climate	-

Model	Description	Taxonomic scope	Metrics	Scenarios	Output maps
cSAR - iDiv (*92*)	A countryside species-area relationship model that estimates the number of species persisting in a human-modified landscape, accounting for the habitat preferences of different species groups.	Birds (forest and non-forest)	$S\alpha$ $S\gamma$	Historical Land use	(*50*)
cSAR-IIASA-ETH (*93*, *94*)	A countryside species area relationship model that estimates the impact of time series of spatially explicit land-use and land-cover changes on community-level measures of terrestrial biodiversity.	Amphibians, birds, mammals, plants, reptiles	$S\alpha$	Historical Land use	(*49*)
BILBI (Biogeographic modelling Infrastructure for Large-scale Biodiversity Indicators) (*95*, *96*)	A modelling framework that couples application of the species-area relationship with correlative generalized dissimilarity modeling (GDM)-based modelling of continuous patterns of spatial and temporal turnover in the species composition of communities (applied in this study to vascular plant species globally).	Vascular plants	$S\gamma$	Historical Land use Land use and climate	-
PREDICTS (Projecting Responses of Ecological Diversity In Changing Terrestrial Systems) (*74*, *97*, *98*)	The hierarchical mixed-effects model that estimates how four measures of site-level terrestrial biodiversity – overall abundance, within-sample species richness, abundance-based compositional similarity and richness-based compositional similarity – respond to land use and related pressures.	Invertebrates, plants, vertebrates	$S\alpha$ $I\alpha$	Historical Land use	(*48*)
GLOBIO (GLObal BIOdiversity model for policy support) (*11*, *80*)	A modelling framework that quantifies the impacts of multiple anthropogenic pressures on biodiversity intactness, quantified as the mean species abundance (MSA) metric.	Vascular plants and warm-blooded vertebrates	$I\alpha$	Historical Land use Land use and climate	(*54*)

Model	Description	Taxonomic scope	Metrics	Scenarios	Output maps
LPJ-GUESS (Lund-Potsdam-Jena General Ecosystem Simulator) (*99–101*)	A big leaf model that simulates the coupled dynamics of biogeography, biogeochemistry and hydrology under varying climate, atmospheric CO_2 concentrations, and land-use land cover change practices to represent demography of grasses and trees in a scale from individuals to landscapes.	Not applicable	Bioenergy production Food and feed production Ecosystem carbon Nitrogen retention Timber production	Historical Land use and climate	(*53*)
LPJ (Lund-Potsdam-Jena) (*102–104*)	A big leaf model that simulates the coupled dynamics of biogeography, biogeochemistry and hydrology under varying climate, atmospheric CO_2 concentrations, and land-use land cover change practices to represent demography of grasses and trees in a scale from individuals to landscapes.	Not applicable	Ecosystem carbon	Historical Land use and climate	(*52*)
CABLE-POP (Community Atmosphere Biosphere Land Exchange) (*105*)	A "demography enabled" global terrestrial biosphere model that computes vegetation and soil state and function dynamically in space and time in response to climate change, land-use change, CO_2 concentrations and N-input.	Not applicable	Ecosystem carbon Timber production Food and feed production	Historical Land use and climate	(*47*)

Model	Description	Taxonomic scope	Metrics	Scenarios	Output maps
GLOBIO-ES (*86*, *106*)	The model simulates the influence of various anthropogenic drivers on ecosystem functions and services.	Not applicable	Food and feed production Timber production Crop pest control Nitrogen retention Pollination Ecosystem carbon	Land use and climate	(*44*)
InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) (*87*, *107–110*)	A suite of geographic information system (GIS) based spatially-explicit models used to map and value the ecosystem goods and services in biophysical or economic terms.	Not applicable	Coastal resilience Pollination Nitrogen retention	Historical Land use and climate	(*46*)

Table S3. Description of land use categories in LUH2 (based on (*62*, *97*, *111*))

forested primary land (primf)	natural vegetation that has never been impacted by human activities (agriculture or wood harvesting) and that is potentially forest; there is no transition to primary land from any other land cover categories
non-forested primary land (primn)	natural vegetation that has never been impacted by human activities (agriculture or wood harvesting) and is non-forest based on the LUH2 potential forest land layer; there is no transition to primary land from any other land cover categories
potentially forested secondary land (secdf)	natural vegetation that is recovering from previous human disturbance (either wood harvesting or agricultural abandonment) and is potentially forest; secondary land can never return to primary land
potentially non-forested secondary land (secdn)	natural vegetation that is recovering from previous human disturbance (either wood harvesting or agricultural abandonment) and is potentially non-forest; secondary land can never return to primary land
managed pasture (pastr)	land where livestock is known to be grazed regularly or permanently with some level of management activities, with low aridity and high population density
rangeland (range)	land where livestock is known to be grazed regularly or permanently, with high aridity and low population density; not managed except by grazing (i.e., no external inputs of pesticides or fertilizers, or fire/mowing)
urban land (urban)	areas with human habitation and/or buildings where primary vegetation has been removed
C3 annual crops (c3ann)	land where native vegetation has been removed and replaced with C3 annual crops; includes biofuel crops
C3 perennial crops (c3per)	land where native vegetation has been removed and replaced with C3 perennial crops; includes biofuel crops
C4 annual crops (c4ann)	land where native vegetation has been removed and replaced with C4 annual crops; includes biofuel crops
C4 perennial crops (c4per)	land where native vegetation has been removed and replaced with C4 perennial crops; includes biofuel crops
C3 nitrogen-fixing crops (c3nfx)	land where native vegetation has been removed and replaced with C3 nitrogen fixing crops; includes biofuel crops

Table S4. Recategorization of land-use categories by each model, climate data used and additional sources of data in the model. Modified from (*58*).

Model	**Land-use data – recategorization of LUH2 land-use classes in the model**	**Climate-data – data sources and variables used**	**Other data**
AIM- biodiversity	Cropland (c3ann, c4ann, c3per, c4per, c3nfx) Pasture (pastr) Built-up area (urban) Forest (primf, secdf) Other natural land (primn, secdn, range)	ISIMIP2a IPSL - monthly mean maximum temperature, monthly mean minimum temperature, monthly precipitation	Species occurrence records (GBIF)
InSiGHTS	Cropland (c3ann, c3per, c3nfx, c4ann, c4per) Forest (primf, secdf) Non-forest (primn, secdn, range) Pasture (pastr) Urban (urban)	Worldclim v1 - annual mean temperature, diurnal range (mean of monthly), isothermality, temperature seasonality, max temperature of warmest month, minimum temperature of coldest month, temperature annual range, mean temperature of wettest, driest, warmest quarter, and coldest quarters, annual precipitation, precipitation of wettest and driest months, seasonality, wettest, driest, warmest, and coldest quarters	Global mammal habitat suitability models (*89*) Mammal range maps (IUCN)
MOL	Forest (primf, secdf) Grassland/shrubland/wetland (secdf, secdn) Rangeland (pastr, range) Urban (urban) Crops (c3ann, c3per, c3nfx, c4ann, c4per)	Worldclim v2 (present), v1.4 (future) - annual mean temperature, temperature seasonality, annual precipitation, precipitation seasonality, precipitation of driest quarter	Expert maps (IUCN) Species land cover preferences drawn from the literature
cSAR-iDiv	Primary vegetation (primf, primn Secondary vegetation (secdf, secdn) Pasture (pastr, range) Urban (urban) Cropland (c3ann, c4ann, c3nfx) Permanent cropland (c3per, c4per)		Bird species occurrence data (Birdlife International) Coefficients for affinities (PREDICTS)
cSAR- IIASA-ETH	Urban (urban) Annual cropland (c3ann, c3nfx, c4ann) Perennial cropland (c3per, c4per) Pasture (pastr, range) Extensive forest (secdf, secdn) Pristine (primf, primn)		cSAR model parameters (*93*, *94*)

BILBI	Primary vegetation (primf, primn) Mature secondary vegetation (secdf, secdn) *if older than 50yrs* Intermediate secondary vegetation (secdf, secdn) *if 10-50 years old* Young secondary vegetation (secdf, secdn) *if younger than 10yrs* Rangelands (range) Managed pasture (pastr) Urban (urban) Perennial croplands (c3per, c4per) Nitrogen-fixing croplands (c3nfx) Annual croplands (c3ann, c4ann)	Worldclim v1.4 – BIO6 and BIO12 Climate variables derived by integrating Worldclim monthly temperature and precipitation estimates with radiative adjustment for terrain, and with soil water-holding capacity (Ferrier et al., 2013): max temperature of warmest month, max diurnal temperature range, actual evaporation, potential evaporation, min monthly water deficit, max monthly water deficit	Plant species occurrence records (GBIF) Soil attributes: pH, Clay %, Silt %, Bulk Density, Depth (*112*) Terrain attributes: Ruggedness Index (G. Arnatulli, Yale University), Topographic Wetness Index (WorldGrids) MODIS Vegetation Continuous Fields (NASA) Global Human Settlement Population Grid Coefficients: impact of land use on local native-species richness (PREDICTS)
PREDICTS	Primary vegetation (primf, primn) Secondary vegetation (secdf, secdn - split into three age bands: Mature, Intermediate and Young) Managed pasture (pastr) Rangeland (range) Urban (urban) Annual (c3ann, c4ann) Nitrogen-fixing (c3nfx) Perennial (c3per, c4per)	IMAGE model (MAGICC 6.0) - global mean temperature increase (^{o}C)	PREDICTS database (*113*) Human population density (GRUMP v1., HYDE (historical) and the corresponding SSPs as developed by (*114*) (future projection)). Agricultural suitability (*115*)
GLOBIO - Terrestrial	GLOBIO downscaled LUH2 data (see (*58*) for more details)		Nitrogen deposition (IMAGE model) Roads (GRIP dataset, (*116*)) Settlements in tropical regions (Humanitarian Data Exchange, Open Street Map)
LPJ-GUESS	Primary natural vegetation (primf, primn) Secondary natural vegetation (secdf, secdn) Pasture (pastr, range) C3 crops (c3ann, c3per, c3nfx) C4 crops (c4ann, c4per) Urban (modelled as natural vegetation)	ISIMIP2a IPSL - monthly min/max T, precipitation, shortwave radiation; atmospheric CO2, N-input, fractional land cover (crop irrigated yes/no, pasture, managed forest, natural)	Crop irrigated and biofuel fraction (LUH2 dataset) Wood harvest estimate (LUH2 dataset) Nitrogen deposition (*117*)
LPJ	Primary natural vegetation (primf, primn) Secondary natural vegetation (secdf, secdn) Pasture (pastr, range, c3ann, c3per, c3nfx, c4ann, c4per) Urban (modelled as natural vegetation)	ISIMIP2a IPSL - monthly T, precipitation, shortwave radiation or cloudiness; atmospheric CO2, fractional land cover (pasture, managed forest, natural)	
CABLE	Primary natural vegetation (primf, primn) Secondary natural vegetation (secdf, secdn)	ISIMIP2a IPSL - daily min/max T, precipitation, shortwave radiation, longwave radiation, humidity, windspeed, atmospheric	Wood harvest estimate (LUH2 dataset) Nitrogen deposition (*117*)

	Grass (pastr, range) Crops (c3ann, c3per, c3nfx, c4ann, c4per, c4nfx)	CO_2, N-deposition, land-use transitions (crop, pasture, secondary forest, natural)	
GLOBIO- ES	Primary forest (primf) Primary other vegetation (primn) Secondary forest (secdf) Pastures (pastr) Rangelands (range) Cropland (c3ann, c4ann, c3nfx) Perennials (c3per, c4per) Secondary non-forest (secdn) Urban (urban)	IMAGE model (MAGICC 6.0) - aggregated monthly precipitation, monthly wet day frequency	Population size, GDP per capita, soil data, altitude range, slope (IMAGE model) Population density in river floodplains Water demand for electricity, industry and households (*118*)
InVEST	GLOBIO downscaled LUH2 data (see (*58*) for more details)	*Nutrient delivery* Worldclim v1.4 - precipitation *Coastal Vulnerability* CMIP5 AOGCMs - sea level rise	*Nutrient delivery* Digital elevation model (ASTER) Biophysical table (InVEST database) Rural population scenarios (*114*) Population raster (GPWv4, 2018) *Coastal Vulnerability* Natural Habitat polygons for mangrove, corals, and eel grass (WCMC) Continental Shelf polygon (COMARGE, Census of Marine Life) Digital elevation model (ASTER) Wind and wave exposure (WAVEWATCH III) Population raster (GPWv4 - 2018) *Pollination* Yield raster for 115 crops (*119*) Nutrient content of 115 crops (USDA 2011) Pollination dependence of 115 crops (*120*) Dietary requirements (*121*) Demographic population data (GPWv4 Age Dataset – 2018)