Biodiversity footprint data of 175 crops and pasture at country level

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Abstract

The destruction of natural habitat for cropland and pastures represents a major threat to global biodiversity. Despite widespread societal concern about biodiversity loss associated with food production, consumers access to quantitative estimates of the impact of crop production on the world's species has been very limited compared to assessments of other environmental variables such as greenhouse gas emissions or water use. Here, we present a consistent dataset of the biodiversity footprints of pastures and 175 individual crops at country level. The data were generated by combining maps of the global distribution of agricultural areas in the year 2000 with spatially explicit estimates of the biodiversity loss associated with the conversion of natural habitat to farmland. Estimates were derived for three common alternative measures of biodiversity – species richness, threatened species richness, and range rarity – of the world's mammals, birds, and amphibians. Our dataset provides important quantitative information for food consumers and policy makers, allowing them to take evidence-based decisions to reduce the biodiversity footprint of global food production.

Keywords

biodiversity impact; agriculture; land use; species richness; threatened species; range rarity

Specifications Table

Subject	Nature and Landscape Conservation
Specific subject area	Biodiversity impacts of global food production
Type of data	Table
How data were acquired	The data were generated by overlaying species distribution maps of mammals, birds, and amphibians, with global maps of agricultural areas and yields
Data format	Analysed
Parameters for data collection	Not applicable
Description of data collection	The data were generated based on existing species distribution and agricultural datasets
Data source location	Primary data sources: - Species-specific range distribution and habitat data of birds (BirdLife International and Handbook of the Birds of the World, 2016), and mammal and amphibians (IUCN and NatureServe, 2016), available from:

	http://datazone.birdlife.org/species/requestdis and https://www.iucnredlist.org - Global croplands and pastures (Ramankutty et al., 2008), and crop-specific harvested areas (Monfreda et al., 2008), both available from: http://www.earthstat.org
Data accessibility	With the article
Related Article	Beyer and Manica (2020), Nature Communications 11, 5633

Value of the Data

- Despite widespread consumer concern about the biodiversity footprint of global food production, consistent estimates of the impacts of different crops on the world's species are not available. Our dataset fills this gap by providing country-level impact estimates based on three common biodiversity measures.
- Our data provide important quantitative evidence to inform the decision-making of conservationists, policy makers, and food consumers, aiming to reduce global food-related biodiversity impacts.
- Our estimates can be combined with crop-specific nutrient level data to rank crops and producing countries according to how efficiently they provide nutrients relative to the biodiversity footprint. This can facilitate the development of biodiversity-related food labelling systems, enabling consumers to reduce personal impacts and encourage shifts towards sustainable food production.
- Our data also open the space for in-depth analyses of the heterogeneity in the local biodiversity footprint of specific crops within and across producing countries. A better understanding of these patterns will help inform where the future expansion of growing areas of specific crops should be prioritised in order to minimise biodiversity impacts.

Data description

Our dataset (Table 1) contains the distributions of local biodiversity footprints across pastures and harvested areas of 175 crops in the year 2000, based on three different biodiversity measures – species richness, threatened species richness, and range rarity –, at the global (cf. Fig. 1) and national level. Distributions are characterised in terms of 5–95% distributional percentiles. In particular, for any given country and crop, the median (50% percentile) value of these distribution provides an estimate of the average number of species, average number of threatened species, and the average range rarity, that has been lost, compared to the scenario of natural habitat, on the growing areas of the crop of interest in the country of interest.
Analogous data is provided for the distributions of the ratio of local biodiversity footprints to local crop yields. These data are relevant, in particular, when linked to crop-specific nutritional data: multiplying them with by amount of a given nutrient in one unit of crop produce makes it possible to rank different crops according to how efficiently they provide the given nutrient relative to their biodiversity footprint.
In addition to the distributional data, our dataset contains spatially aggregated measures of the total biodiversity footprint of each crop in each country. These data make it possible, for

example, to compare the contribution of specific crops or countries to the global biodiversity footprint of agriculture (cf. Fig. 2).
The dataset is available in Netcdf format as Supplementary File 1. An R script illustrating how the data can be read and analysed is available as Supplementary File 2.

Dimension name	Length	Values
Crops	176 (175 crops and pasture)	Abaca, Agave, …, Yautia, Pasture
Country	166 (165 countries and world)	Afghanistan, Albania, …, Zimbabwe, World
Biodiversity measure	3	Species richness, Threatened species richness, Range rarity
Percentile	19	5%, 10%, …, 95%
Variable name	**Dimensions**	
Distribution of the local biodiversity footprint across agricultural areas, $b_{c,i}^{m}(p)$	176 × 200 × 3 × 19 (Crops and pasture × Countries × Biodiversity measures × Percentiles)	
Distribution of the local biodiversity footprint per unit of local crop yield across agricultural areas, $\hat{b}_{c,i}^{m}(p)$	175 × 200 × 3 × 19 (Crops × Countries × Biodiversity measures × Percentiles)	
Biodiversity footprint aggregated across agricultural areas, $B_{c,i}^{m}$	176 × 200 × 3 (Crops and pasture × Countries × Biodiversity measures)	

Table 1. Data provided in Supplementary File 1. Variable names ($b_{c,i}^{m}(p)$, $\hat{b}_{c,i}^{m}(p)$, $B_{c,i}^{m}$) are the ones used in the method description.

Experimental Design, Materials and Methods

Local biodiversity footprints of crops and pasture

We used the method previously described in detail by Jetz et al. (2007) and (Beyer and Manica, 2020) to estimate the geographical distribution of all known mammals, birds and amphibians under four different land cover types: natural vegetation, arable land, plantation, and pasture. In the following, we briefly summarise the approach. We used species-specific extents of occurrence of mammals, birds and amphibians (BirdLife International and Handbook of the Birds of the World, 2016; IUCN and NatureServe, 2016)), which we rasterised from their original spatial polygon format to a 5-arc-minute grid (~10 km at the equator). These data represent spatial envelopes of species' maximum geographic ranges that do not account for the distribution of natural or artificial land cover within these areas. Extents of occurrence were refined by incorporating species-specific habitat preferences (BirdLife International and Handbook of the Birds of the World, 2016; IUCN and NatureServe, 2016), which include one or more biome categories in which each species is known to occur. In each grid cell contained within a given species' extent of occurrence, the species was estimated as being present under natural vegetation if its list of habitat categories contained the local potential natural vegetation type, for which we used a 5-arc-minute global map (Ramankutty and Foley, 1999). In the same way, a species was estimated as being able to persist in a grid cell under arable land, plantation or pasture land cover, if its list of habitat categories included the relevant one of these three IUCN categories of artificial land cover.

For each of these three artificial land cover categories and for natural vegetation, we derived maps of species richness, threatened species richness, and range rarity, as follows. Local species richness in a given grid cell is given by the number of species estimated as being present in the grid cell under the relevant land cover type. Threatened species richness was obtained in the same way, but included only species whose Red List status is vulnerable, endangered, or critically endangered (BirdLife International and Handbook of the Birds of the World, 2016; IUCN and NatureServe, 2016). Range rarity in a grid cell was calculated as the sum of the inverse natural range sizes of all species present in the cell under the relevant land cover. Thus, for this measure, species with a narrow geographic ranges are weighted more heavily than geographically widespread species (Guerin and Lowe, 2015). The derived biodiversity maps, for each biodiversity measure and assumed land cover type, are shown in Fig. S1–3.

Lastly, for a given biodiversity measure m (representing species richness, range rarity, or threatened species richness) and a grid cell x, the local biodiversity footprint $\beta_c^m(x)$ associated with a crop c was defined as the difference between the local potential natural biodiversity and the biodiversity for the land cover type corresponding to the crop (either 'arable land' or 'plantation' as defined by IUCN (2014)). Analogously, the local biodiversity footprint $\beta_{\text{Pasture}}^m(x)$ associated with pasture was defined as the difference between local potential natural biodiversity and biodiversity under pasture.

Crop- and pasture-specific distributions of biodiversity footprints at country level

Based on the derived biodiversity footprint maps, we first determined the distribution of biodiversity footprints across the harvested areas of each crop c. We denote by $H_c(x)$ the harvested area (in ha) in the year 2000 of a crop c in a 5-arc-minute grid cell x, available for 175 crops (Monfreda et al., 2008). These maps of harvested areas represent the latest consistent global dataset containing all crops included in our dataset. More recent maps, based on different methods of spatial allocation of cropland, are available only for a much smaller number of crops (e.g. for the year 2010 (You et al., 2014)); for consistency, we did not include these here, but used the 2000 data throughout our approach. We characterised the distribution of the biodiversity footprints across global harvested areas of crop c in terms of the 5%, 10%, ..., 95% percentiles of the set of local biodiversity footprints, $\{\beta_c^m(x)\}_x$, where each element $\beta_c^m(x)$ was weighted by the appropriate local harvested area $H_c(x)$. We used the *wprctile* function in Matlab (MATLAB Central File Exchange, 2020) to compute the percentiles for each crop, denoted $b_{c,\text{World}}^m(p)$ for a percentile p. For example, for $m = \text{species richness}$, $b_{c,\text{World}}^m(50\%)$, i.e. the weighted median biodiversity footprints across the harvested areas of crop c, represents the number of species that are absent in a typical location where crop c is grown, compared to the scenario of potential natural vegetation. Fig. 1 visualises the derived $b_{c,\text{World}}^m(p)$ using boxplots for the 30 crops with the highest median biodiversity footprint across global harvested areas.

Crop-specific percentiles of biodiversity footprints across the harvested areas of a crop c in a specific country i, denoted $b_{c,\text{i}}^m(p)$, were computed in the same way, but weights corresponding to grid cells located outside the country's borders (NaturalEarth, 2018) were set to zero.

Percentiles of biodiversity footprints across global pastures, denoted $b^m_{\text{Pasture,World}}(p)$, were computed analogouly, based on the set of local biodiversity footprints of pasture $\{\beta^m_{\text{Pasture}}(x)\}_x$ and weights given by the set of local pasture areas (in ha), denoted $\{A_{\text{pasture}}(x)\}_x$, for the year 2000 (Ramankutty et al., 2008). Percentiles of biodiversity footprints across pastures in a given country i, denoted $b^m_{\text{Pasture},i}(p)$, were again computed by setting non-relevant weights to zero.

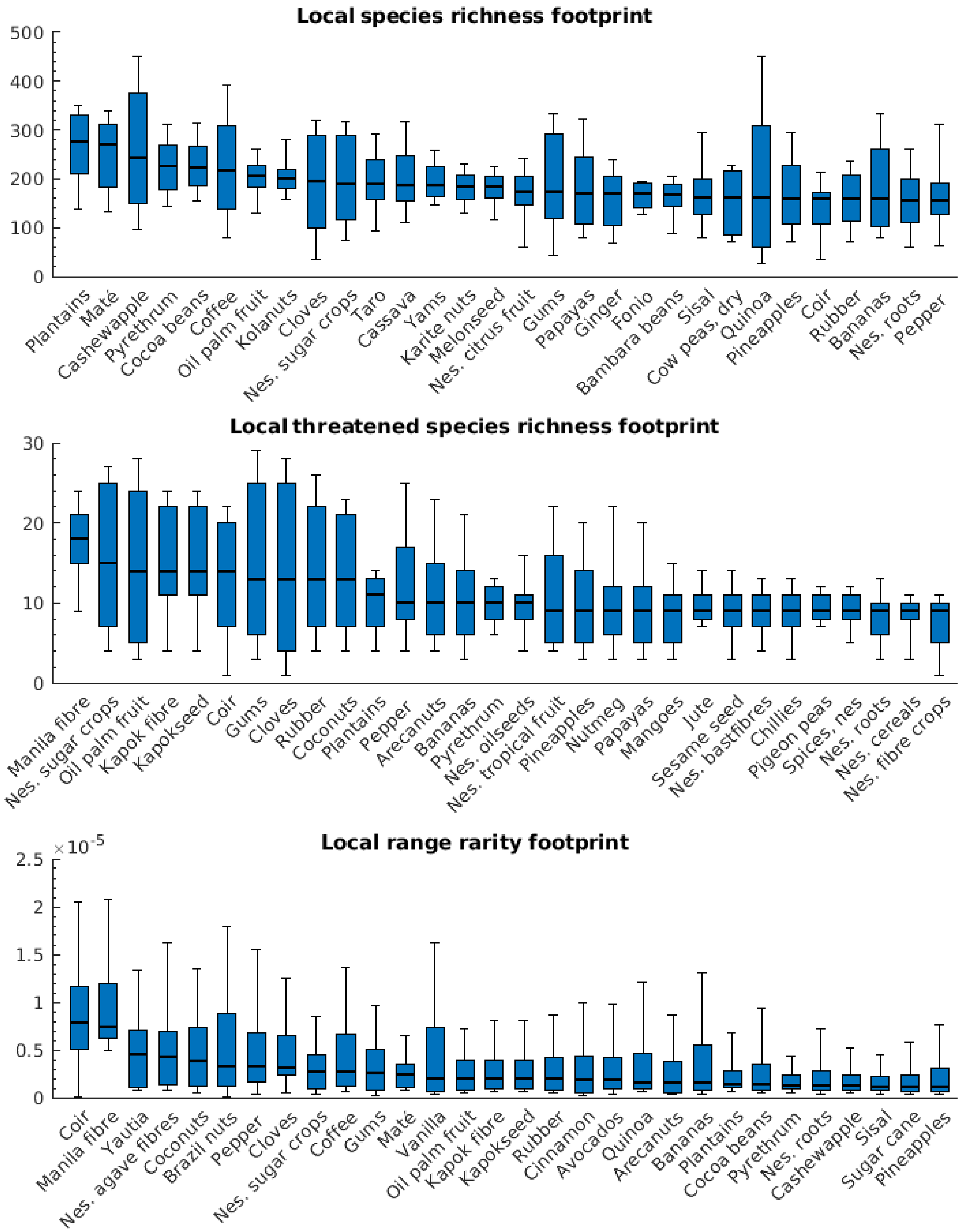

Fig. 1. Distributions of local biodiversity footprints across global harvested areas of the 30 crops with the highest median value. (Nes. = not elsewhere specified, i.e. referring to minor crop varieties.)

Crop-specific distributions of biodiversity footprints per unit yield at country level

In addition to estimating the distributions of local biodiversity footprints on agricultural areas, we used crop-specific global maps of fresh-weight yields (in Mg ha^{-1} year^{-1}) for the year 2000 (Monfreda et al., 2008) to estimate 5%, 10%, ..., 95% percentiles of the crop- and country-specific biodiversity footprints per unit of crop yield across croplands, denoted $\hat{b}^m_{c,\mathrm{World}}(p)$. For a given crop c, these were computed as the percentiles of the set $\left\{\frac{\beta^m_c(x)}{Y_c(x).}\right\}_x$ of local ratios of biodiversity footprint divided by local crop yields, $Y_c(x)$, of the crop c, weighted by the set of local harvested areas $\{H_c(x)\}_x$. Country-specific percentiles, $\hat{b}^m_{c,\mathrm{i}}(p)$, were derived analogously. These data are relevant, in particular, when estimating how efficiently a crop c provides a certain nutrient relative to its biodiversity footprint. For example, multiplying $\hat{b}^m_{c,i}(50\%)$ by the amount of a certain nutrient in one unit of produce of crop c provides an estimate of the average biodiversity footprint associated with the production of one unit of the given nutrient from crop c grown in country i.

Crop-specific total biodiversity footprints at country level

Thus far, we considered the distributions of (absolute or yield-relative) local biodiversity footprints across agricultural areas. In addition, we derived spatially aggregted estimates of the biodiversity footprint of crops and pastures at country level by integrating local footprints over the relevant areas. For pasture, we used the physical area (in ha) covered by pasture in a grid cell x in the year 2000 (Ramankutty et al., 2008), $A_{\mathrm{Pasture}}(x)$, to define the spatially-aggregted global biodiversity footprint of pasture as

$$B^m_{\mathrm{Pasture,World}} = \sum_x A_{\mathrm{Pasture}}(x) \cdot \beta^m_{\mathrm{Pasture}}(x)$$

In the case of crops, we used the physical area (in ha) covered by cropland in a grid cell x in the year 2000 (Ramankutty et al., 2008), $A_{\mathrm{Cropland}}(x)$, and the harvested area (in ha) in the year 2000 of a crop c in a grid cell x (Monfreda et al., 2008), $H_c(x)$. Generally, $A_{\mathrm{Cropland}}(x)$ is not the same as $\sum_c H_c(x)$, the sum of all local harvested areas. This is because $H_c(x)$ does not represent physical area, but harvested area, which increases if the crop is harvested multiple times per year (Monfreda et al., 2008). This can be accounted for by calculating the spatially-aggregted global biodiversity footprint of a crop c as

$$B^m_{c,\mathrm{World}} = \sum_x A_{\mathrm{Cropland}}(x) \cdot \frac{H_c(x)}{\sum_\gamma H_\gamma(x)} \cdot \beta^m_c(x).$$

Fig. 2A–C display aggregated footprints for pasture and the nine highest-impact crops.

Analogous data at country level, denoted $B^{m}_{\text{Pasture},i}$ and $B^{m}_{c,i}$ for a country i, were computed in the same way but the relevant sums did not include areas outside country i. The total spatially-aggregted biodiversity footprint of pasture and all crops, $B^{m}_{\text{Pasture},i} + \sum_c B^{m}_{c,i}$, is visualised in Fig. 2D–F for the ten countries for which this value is highest.

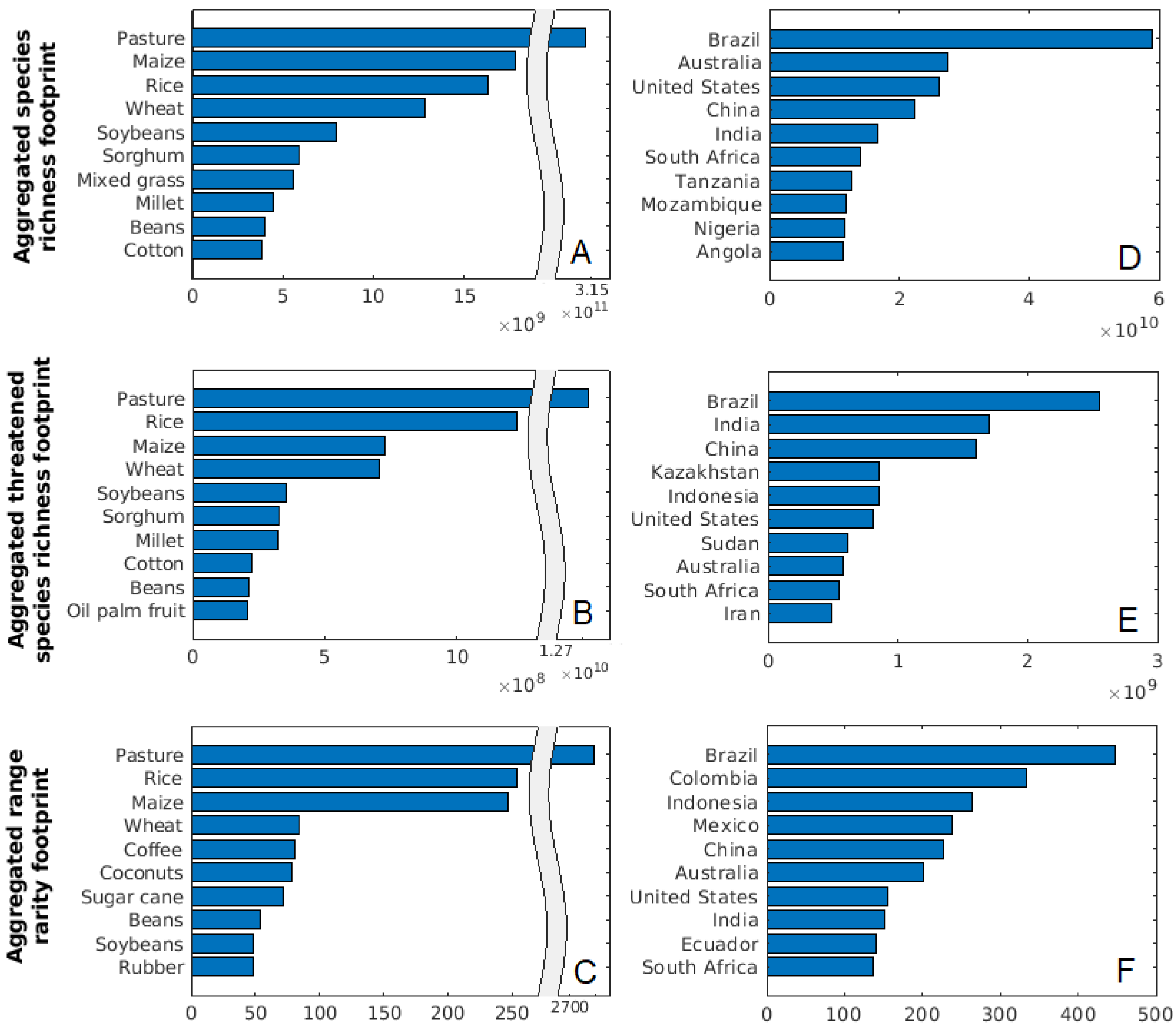

Fig. 2. Spatially-aggregated biodiversity footprints. A–C: Global footprints of pasture and the ten highest impact crops. D–F: Combined footprints of pasture and all crops in the ten highest impact countries.

Acknowledgments

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Supplementary Material

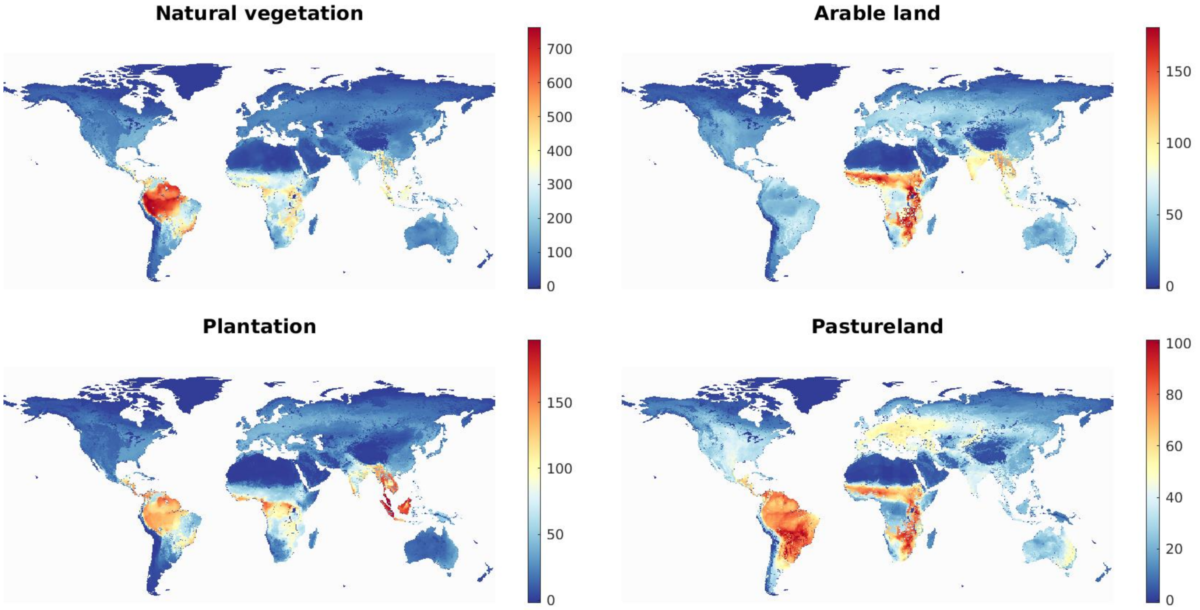

Fig. S1. Global maps of species richness under different land cover types.

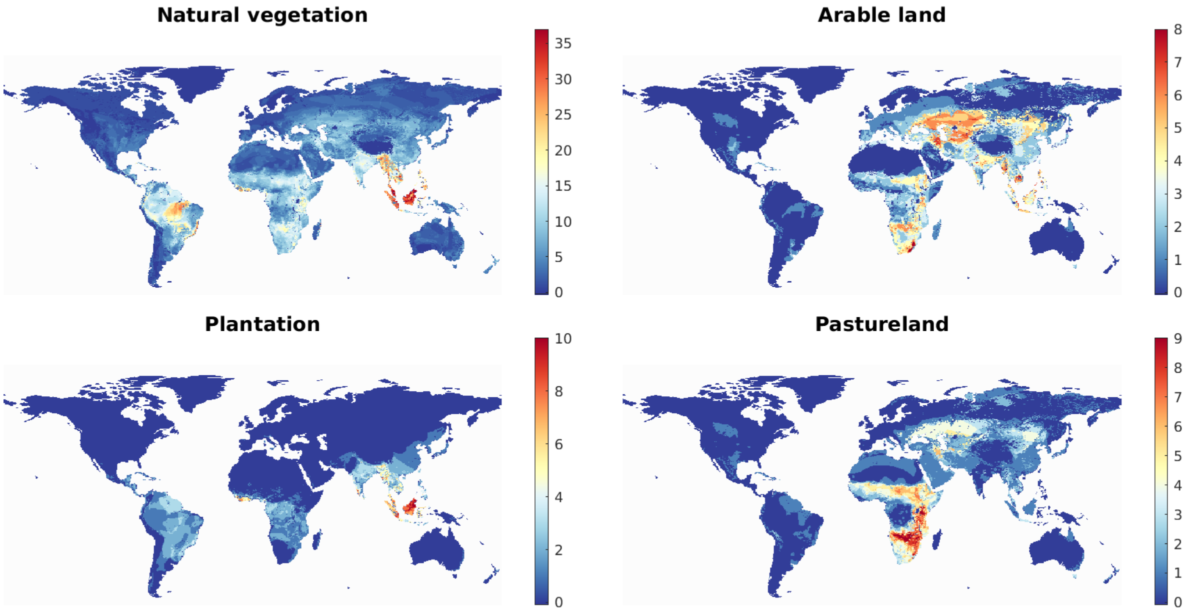

Fig. S2. Global maps of threatend species richness under different land cover types.

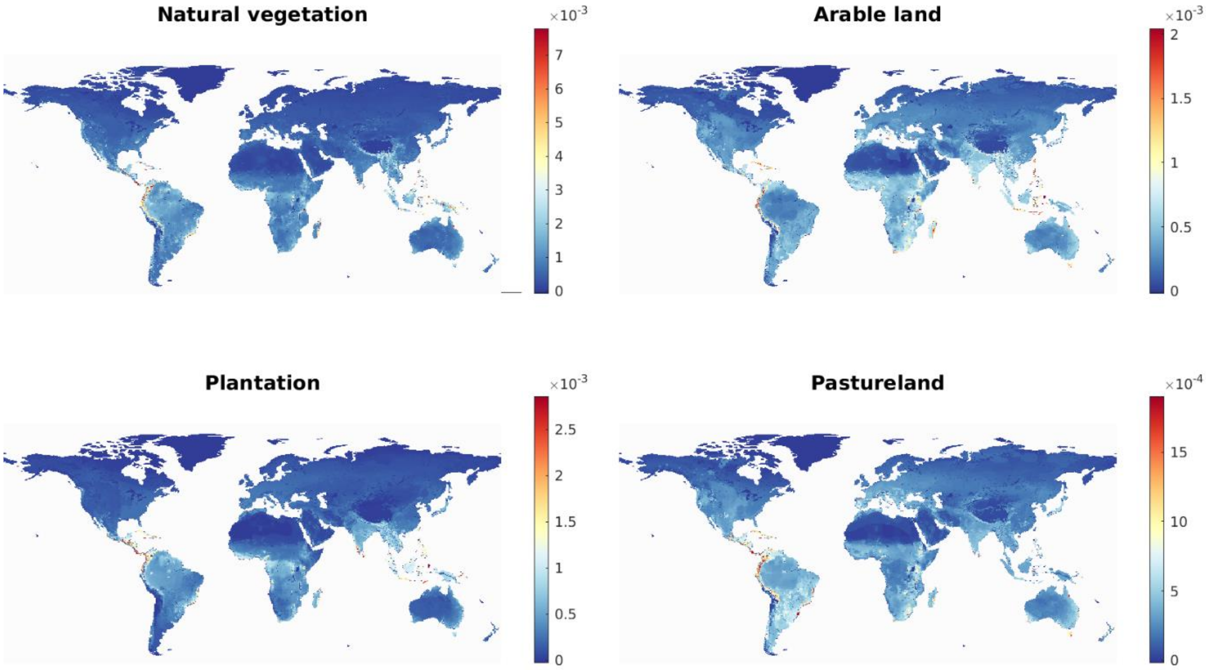

Fig. S3. Global maps of range rarity (square-rooted) under different land cover types.

Supplementary File 1. Crop- and country-specific distributions of local biodiversity footprints across agricultural areas, distributions of local biodiversity footprints per unit crop yield across agricultural areas, and spatially aggregated biodiversity footprints.

Supplementary File 2. R script demonstrating how Supplementary File 1 can be read and analysed.