Supplementary material for 'Tropical and Mediterranean biodiversity is disproportionately sensitive to land-use and climate change'

Tim Newbold, Philippa Oppenheimer, Adrienne Etard, Jessica J. Williams

Supplementary Figures and Tables

Extended Data 1. Map of sites with data in the PREDICTS database used for analysing land-use responses. Points are coloured by one of the classifications of biomes, which we used in our analyses.

Extended Data 2. Modelled differences in biodiversity among land-use types. Results are shown for three community-level measures of biodiversity: total sampled species richness, total sampled community abundance, and community-average range size. The last is a measure of the inverse of the endemicity of species within communities, and is the average of the range sizes of all sampled species in the community, weighted by sampled abundance. All values are expressed as a percentage change relative to primary vegetation as the baseline. Numbers in parentheses are the lower and upper bounds of the 95% confidence limits.

Extended Data 3. Statistics for mixed-effects models of species richness with different land-use groupings. Species richness was modelled as a function of both land use (using the different combinations as shown here) and biome (using the finest division into 11 different biomes). Shown are the model degrees of freedom (DF), difference in AIC compared with the best fitting model (ΔAIC), and the conditional and marginal R^2 values[72]. The best-fitting model is shown in italics, while the land-use combination used in the final models is shown in bold. PV = Primary Vegetation; SV = Secondary Vegetation; PF = Plantation Forest; CR = Cropland; PA = Pasture; Agric. = Cleared Agriculture (Cropland + Pasture); Harv. = Harvested agriculture (Plantation Forest + Cropland); Human = Human-dominated Land use (Plantation Forest + Cropland + Pasture).

Extended Data 4. Statistics for species richness models with different biome groupings. Species richness was modelled as a function of both land use (using the finest division into five different land-use categories) and biome (using the different combinations as shown here). Shown are the model degrees of freedom (DF), difference in AIC compared with the best fitting model (ΔAIC), and the conditional and marginal R^2 values[72]. The best-fitting model is shown in italics, while the biome combination used in the final models is shown in bold. BF = Boreal Forests/Taiga; TeCF = Temperate Conifer Forests; TeBF = Temperate Broadleaf and Mixed Forests; TrCF = Tropical and Subtropical Coniferous Forests; TrDBF = Tropical and Subtropical Dry Broadleaf Forests; TrMBF = Tropical and Subtropical Moist Broadleaf Forests; TeG = Temperate Grasslands, Savannas and Shrublands; TrG = Tropical and Subtropical Grasslands, Savannas and Shrublands; MoG = Montane Grasslands and Shrublands; MED = Mediterranean Forests, Woodlands and Scrub; DRY = Deserts and Xeric Shrublands; TeF = Temperate Forests (Coniferous and Broadleaf); TrF = Tropical Forests (Coniferous, Dry Broadleaf and Moist Broadleaf); TeMoG = Temperate and Montane Grasslands; Temp. = Temperate (Forests and Grasslands, including Montane Grasslands); Trop. = Tropical (Forests and Grasslands); NonTrop. = Non-Tropical (Boreal and Temperate Forest and Grasslands, including Montane Grasslands); For. = Forest (Boreal, Temperate and Tropical); Grass. = Grasslands (Temperate, Montane and Tropical).

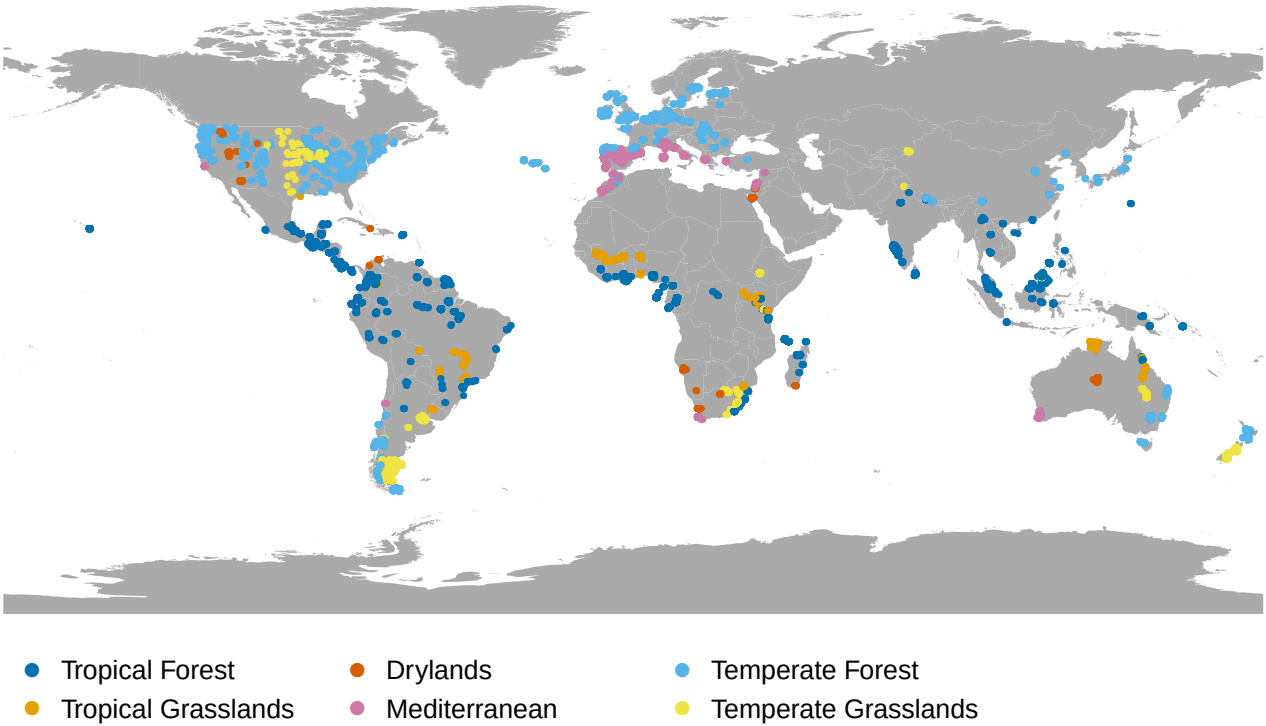
Extended Data 5. Differences in total abundance among land-use types, across different biomes. a) Tropical forest; b) Tropical grasslands; c) Drylands; d) Mediterranean; e) Temperate forest; and f) Temperate grassland. Plots show the percentage change in species richness compared to primary vegetation (PV), in secondary vegetation (SV), pasture (PAS) and areas of harvested agriculture

(woody plantations and herbaceous croplands; HARV). Error bars show 95% confidence intervals. Sample sizes at the bottom of each panel refer to the number of sites in each combination of land use and biome. The final model plotted here had an $R^2_{conditional}$ of 0.89 and an $R^2_{marginal}$ of 0.031).

Extended Data 6. Differences in community-average range size (RCAR) among land-use types, across different biomes. a) Tropical forest; b) Tropical grasslands; c) Drylands; d) Mediterranean; e) Temperate forest; and f) Temperate grassland. Plots show the percentage change in species richness compared to primary vegetation (PV), in secondary vegetation (SV), pasture (PAS) and areas of harvested agriculture (woody plantations and herbaceous croplands; HARV). Error bars show 95% confidence intervals. Sample sizes at the bottom of each panel refer to the number of sites in each combination of land use and biome. The final model plotted here had an $R^2_{conditional}$ of 0.87 and an $R^2_{marginal}$ of 0.10).

Extended Data 7. Sensitivity of biodiversity to climate change across biomes. Shown is the predicted percentage change in species richness for each °C of climate warming expected under the RCP 2.6 scenario. Results for the RCP8.5 scenario are shown in Figure 2. Biomes considered were tropical forests (Trop F), tropical grasslands (Trop G), drylands (Dry), Mediterranean (Med), temperate forest (Temp F), temperate grasslands (Temp G) and boreal forest (Bor F). Thick horizontal black lines show median values across all grid cells within the biome, boxes extend to the first and third quartiles, and whiskers to 1.5 × the inter-quartile range.

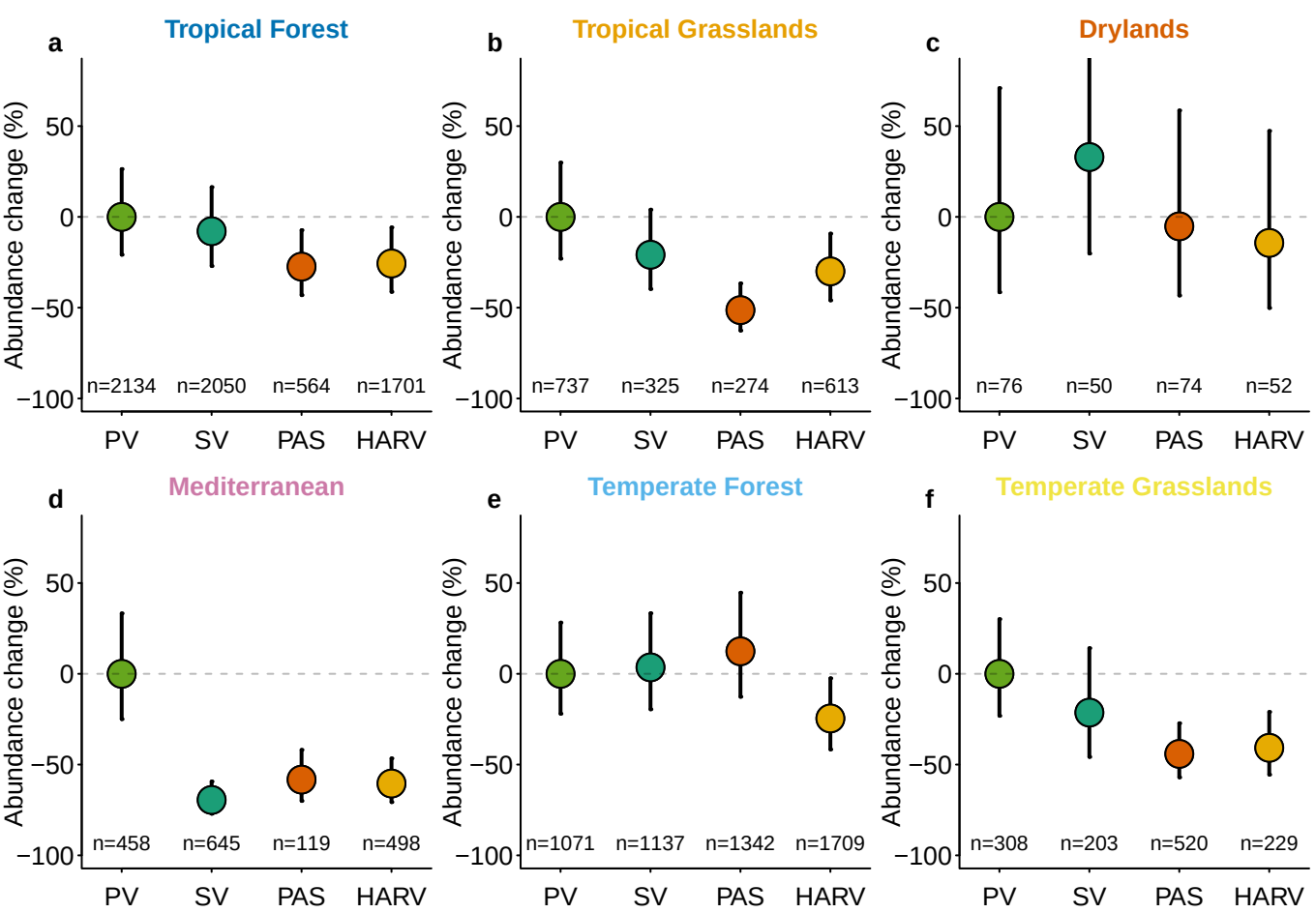
Extended Data 8. Overview of input datasets used. References correspond to the numbered references in the bibliography, unless given as DOIs.

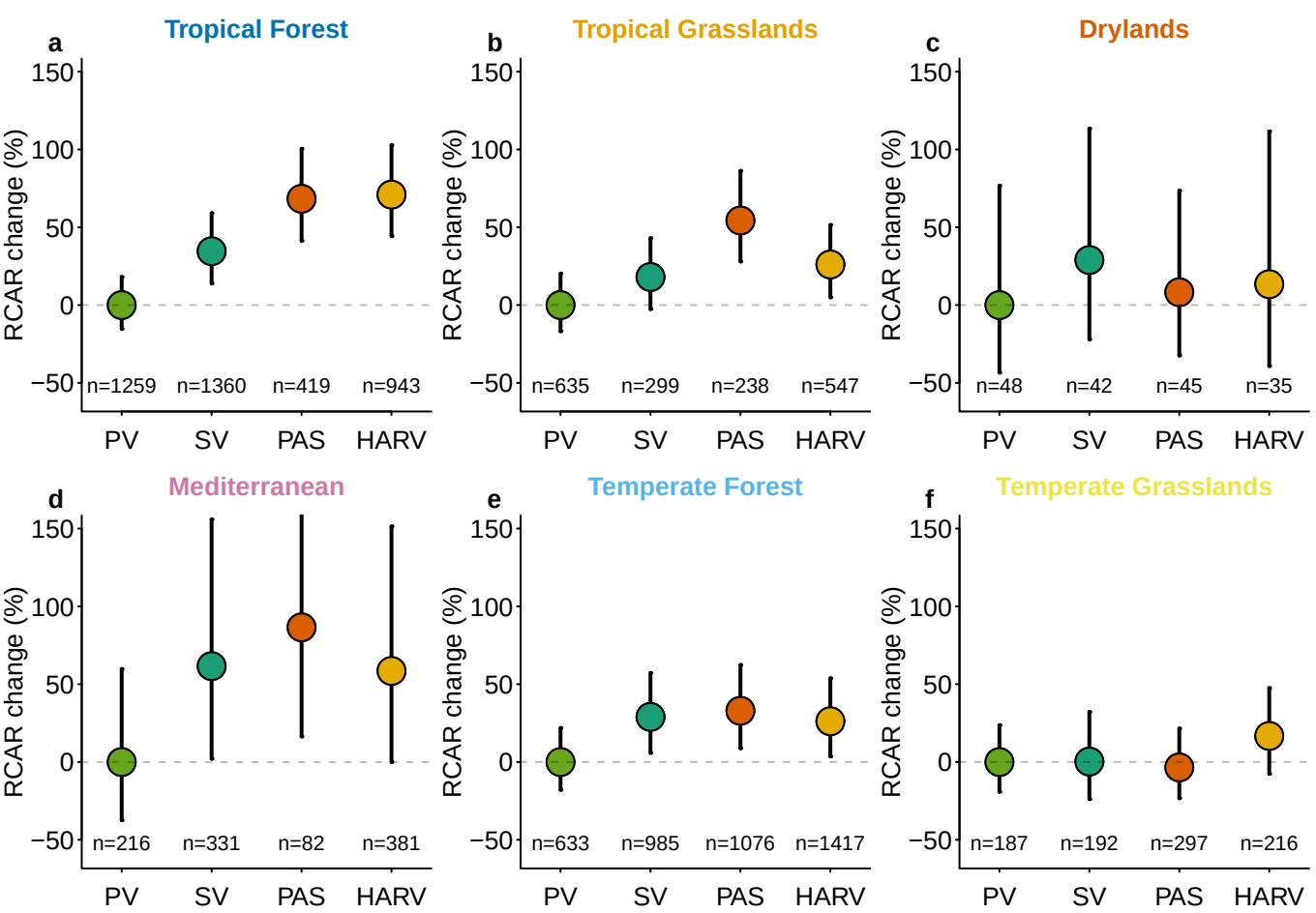

Tropical Forest
Tropical Grasslands
Drylands
Mediterranean
Temperate Forest
Temperate Grasslands

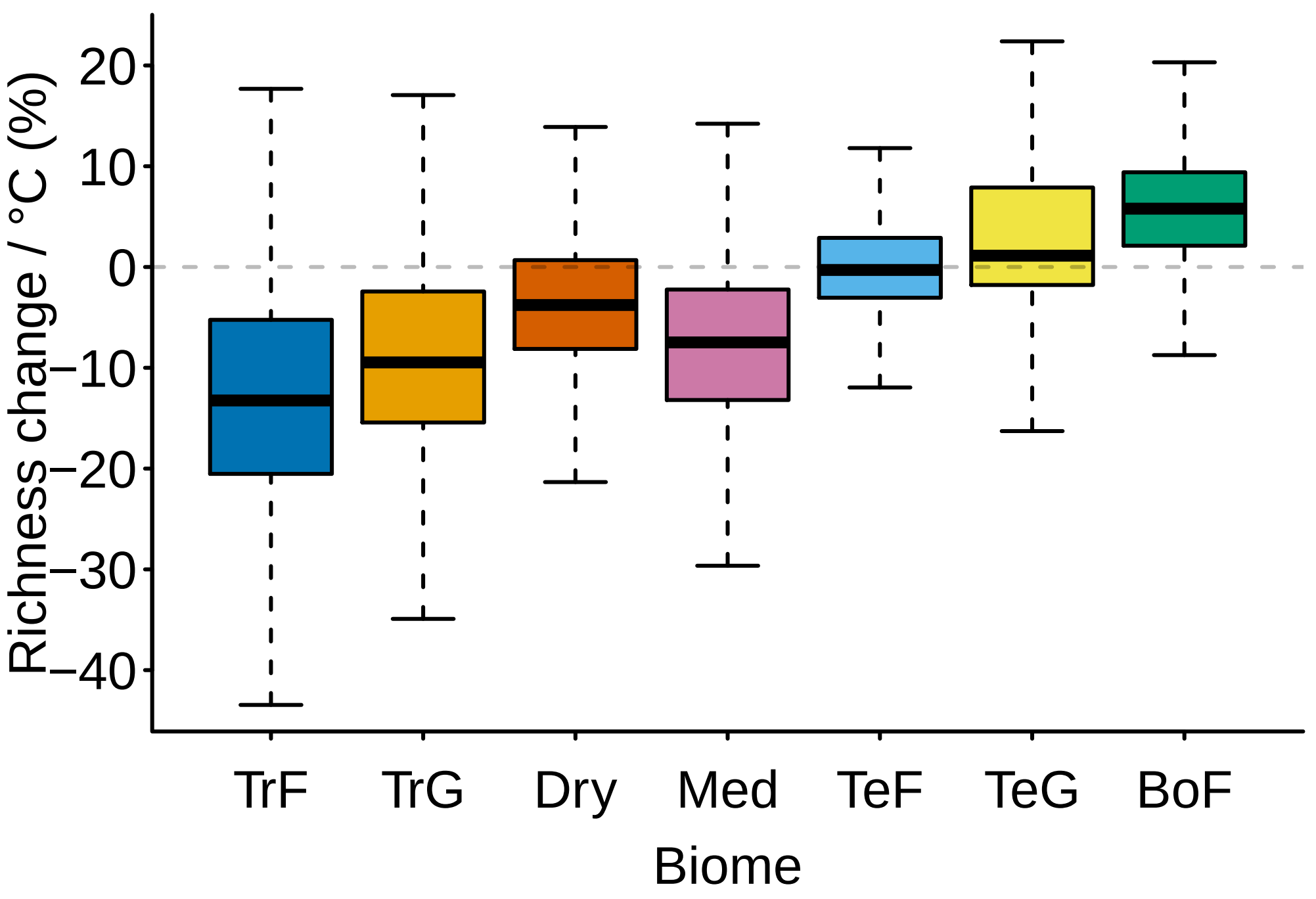
Biome	Primary vegetation	Secondary vegetation	Harvested agriculture	Livestock pasture
Species richness:				
Tropical forests	0 (-10.5 | 11.7)	-13.9 (-23.0 | -3.8)	-31.3 (-38.6 | -23.1)	-34.4 (-41.8 | -26.1)
Tropical grasslands	0 (-12.4 | 14.1)	-11.7 (-23.1 | 1.4)	-17.0 (-27.2 | -5.2)	-36.6 (-45.0 | -26.9)
Drylands	0 (-27.1 | 37.2)	13.3 (-14.2 | 49.7)	-10.4 (-35.4 | 24.3)	12.2 (-14.6 | 47.4)
Mediterranean	0 (-13.2 | 15.2)	-46.2 (-53.3 | -38.0)	-35.4 (-44.5 | -24.8)	-24.6 (-36.2 | -10.9)
Temperate forests	0 (-11.2 | 12.6)	-2.1 (-13.2 | 10.4)	-18.1 (-27.8 | -7.1)	-1.8 (-12.9 | 10.8)
Temperate grasslands	0 (-11.3 | 12.8)	4.2 (-9.4 | 19.7)	-27.2 (-35.8 | -17.4)	-16.8 (-26.2 | -6.2)
Total community abundance:				
Tropical forests	0 (-20.8 | 26.3)	-7.9 (-27.1 | 16.4)	-25.6 (-41.3 | -5.8)	-27.4 (-43.1 | -7.3)
Tropical grasslands	0 (-23.0 | 29.9)	-20.8 (-39.7 | 4.0)	-30.0 (-46.0 | -9.2)	-51.3 (-62.6 | -36.6)
Drylands	0 (-41.5 | 70.9)	33.0 (-20.2 | 121.5)	-14.3 (-50.2 | 47.3)	-5.2 (-43.3 | 58.6)
Mediterranean	0 (-25.0 | 33.3)	-69.5 (-77.1 | -59.3)	-60.4 (-70.7 | -46.6)	-58.3 (-70.0 | -41.9)
Temperate forests	0 (-22.0 | 28.2)	3.6 (-19.5 | 33.4)	-24.6 (-41.7 | -2.5)	12.4 (-12.6 | 44.7)
Temperate grasslands	0 (-23.1 | 30.1)	-21.3 (-45.8 | 14.1)	-40.7 (-55.5 | -21.0)	-44.1 (-57.0 | -27.3)
Community-average range size				
Tropical forests	0 (-15.3 | 18.0)	34.6 (14.0 | 59.1)	71.0 (44.3 | 102.7)	68.3 (41.4 | 100.4)
Tropical grasslands	0 (-16.8 | 20.2)	18.0 (-2.6 | 43.0)	26.1 (5.0 | 51.5)	54.4 (28.0 | 86.2)
Drylands	0 (-43.4 | 76.7)	29.0 (-22.0 | 113.4)	13.4 (-39.2 | 111.6)	8.3 (-32.4 | 73.5)
Mediterranean	0 (-37.4 | 59.8)	61.6 (2.1 | 155.9)	58.6 (0 | 151.4)	86.5 (16.4 | 198.9)
Temperate forests	0 (-17.9 | 21.8)	29.0 (5.9 | 57.2)	26.2 (3.6 | 53.8)	32.9 (8.8 | 62.4)
Temperate grasslands	0 (-19.1 | 23.7)	0.3 (-23.9 | 32.2)	16.8 (-7.6 | 47.5)	-3.4 (-23.3 | 21.5)

Land-use classification	DF	ΔAIC	Conditional R^2	Marginal R^2
Null model (Biome only)	13	1202	0.60	0.013
PV, SV, PF, CR, PA	*57*	*0*	*0.61*	*0.024*
PV, SV, PF, Agric. (CR+PA)	46	50	0.61	0.023
PV, SV, Harv. (PF+CR), PA	**46**	**31**	**0.61**	**0.024**
PV, SV, Human (PF+CR+PA)	35	108	0.61	0.023
Natural (PV+SV), PF, CR, PA	46	348	0.60	0.018
Natural, PF, Agric.	35	409	0.60	0.018
Natural, Harv., PA	35	370	0.61	0.018
Natural, Human	24	460	0.60	0.017

Biome classification	DF	ΔAIC	R^2 conditional	R^2 marginal
Null model (Land-use only)	7	758	0.60	0.005
BF, TeCF, TeBF, TrCF, TrDBF, TrMBF, TeG, TrG, MoG, MED, DRY	*57*	*0*	*0.61*	*0.024*
BF, TeF (TeCF+TeBF), TrF (TrCF+TrDBF+TrMBF), TrG, TeMoG (TeG, MoG), MED, DRY	**37**	**251**	**0.61**	**0.025**
BF, Temp. (TeCF+TeBF+TeG+MoG), Trop. (TrCF+TrDBF+TrMBF+TrG), MED, DRY	27	327	0.60	0.018
For. (BF+TeCF+TeBF+TrCF+TrDBF+TrMBF), Grass. (TeG+MoG+TrG), MED, DRY	22	431	0.60	0.018
NonTrop. (BF+TeCF+TeBF+TeG+MoG+MED +DRY), Trop. (TrCF+TrDBF+TrMBF+TrG)	12	614	0.60	0.006


a
Tropical Forest
b
Tropical Grasslands
c
Drylands
d
Mediterranean
e
Temperate Forest
f
Temperate Grasslands
Abundance change (%)
50
0
−50
−100
n=2134
n=2050
n=564
n=1701
n=737
n=325
n=274
n=613
n=76
n=50
n=74
n=52
n=458
n=645
n=119
n=498
n=1071
n=1137
n=1342
n=1709
n=308
n=203
n=520
n=229
PV
SV
PAS
HARV


a
Tropical Forest
RCAR change (%)
150
100
50
0
−50
n=1259
n=1360
n=419
n=943
PV
SV
PAS
HARV
b
Tropical Grasslands
n=635
n=299
n=238
n=547
c
Drylands
n=48
n=42
n=45
n=35
d
Mediterranean
n=216
n=331
n=82
n=381
e
Temperate Forest
n=633
n=985
n=1076
n=1417
f
Temperate Grasslands
n=187
n=192
n=297
n=216


Richness change / °C (%)
20
10
0
−10
−20
−30
−40
TrF
TrG
Dry
Med
TeF
TeG
BoF
Biome

Dataset	Source references	Spatial resolution	Timespan	Analyses in which used
Global map of ecoregions	62	Spatial polygons	Not explicitly specified (approximately present day)	All
PREDICTS database	40,56,63	Sites typically span an area less than 1 square km[1]	Field sampling between 1984 and 2013 (95% since 2000)	Effects of land use on biodiversity
Estimates of community-average range size at PREDICTS sites	18, DOI: 10.6084/m9.figshare.7262732.v1	As for PREDICTS database	As for PREDICTS database	Effects of land use on biodiversity
IUCN/Birdlife extent-of-occurrence maps for vertebrates	54,55	Polygons, rasterised at 10-km resolution	Not explicitly specified (approximately present day)	Species distribution models of climate responses (see below), estimating species climatic niche limits to explain sensitivity to land-use and climate change
Species distribution models as a function of climate	9	As for extent-of-occurrence maps	Fitted against climate data for 1960-1990	Estimating effect of climate on distributions and projecting future responses to climate change
Climate seasonality	69	10 arc-minutes	1960-1990	Explaining sensitivity to land-use and climate change
Climate monthly extremes	69	5 arc-minutes, resampled to 10-km equal-area resolution to match species' distribution data (see above)	1960-1990	Estimating species climatic niche limits to explain sensitivity to land-use and climate change
HYDE model estimates of historical land use	45	0.5 degrees	1500-2005	Explaining sensitivity to land-use change