Title: Projected climatic changes lead to biome changes in areas of previously constant biome

Supplementary Information

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Table S1: Linear quantile regressions of species richness against biome constancy

tau	Mammals		Birds		Reptiles		Amphibians	
	slope	*p(F)*	slope	*p(F)*	slope	*p(F)*	slope	*p(F)*
0·1	-0·056	–	-0·321	–	–	–	–	–
0·2	-0·097	–	-0·560	–	0·036	–	-0·011	–
0·3	-0·076	<0·0001	-0·396	<0·0001	0·056	<0·0001	-0·010	0·0997
0·4	-0·036	<0·0001	-0·116	<0·0001	0·077	<0·0001	0·010	<0·0001
0·5	0·042	<0·0001	0·167	<0·0001	0·106	<0·0001	0·044	<0·0001
0·6	0·175	<0·0001	0·675	<0·0001	0·127	<0·0001	0·104	<0·0001
0·7	0·427	<0·0001	1·178	<0·0001	0·143	<0·0001	0·175	<0·0001
0·8	0·738	<0·0001	1·681	<0·0001	0·144	<0·0001	0·271	<0·0001
0·9	0·942	<0·0001	2·511	<0·0001	0·166	<0·0001	0·470	<0·0001

Values given for each taxonomic group are the slopes of the fitted linear regression models for each quantile, 0·1 – 0·9, and the probabilities that the slopes for quantiles 0·3 – 0·9 do not differ from the slope of the model for quantile 0·2. The probabilities were obtained using the 'anova.rq' function in the R package 'quantreg' which derives a *p* value from a modified *F* statistic. In all but one of the cases examined, that for the Amphibians, probability values indicate that it is likely that the slopes of the models for *tau* = 0·3 differ from those of the models for *tau* = 0·2. For all higher values of *tau* the models for all taxonomic groups have slopes that likely differ from that of the model for *tau* = 0·2. No model was fitted at *tau* = 0·1 for amphibians or reptiles, because in each case species number was zero for all grid cells in that quantile.

Table S2: Grid cells today supporting vertebrate species numbers in the top 10%

	Mammals	**Birds**	**Reptiles**	**Amphibians**
Mean species richness [a]	143·24	414·48	39·49	56·43
Mean past constancy (%) [a]	70·97	68·81	63·71	69·22
Mean species richness of previously constant grid cells [b]	146·61	445·06	51·07	72·09
Previously constant cells committed to eventual biome change (%) [b]				
2050 – RCP 4.5	20·10	27·04	19·25	27·37
RCP 8.5	33·28	44·13	29·58	44·50
2100 – RCP 4.5	33·27	44·29	29·70	44·33
RCP 8.5	46·82	60·05	46·80	59·56

[a] Based on the 6217 (i.e. the top 10%) most species-rich grid cells out of the total of 62165 grid cells with ice-free land at present, and for which a present biome hence was inferred.

[b] Based on 1270 / 1110 / 847 / 1109 (Mammals / Birds / Reptiles / Amphibians)) of the 6217 most species-rich grid cells for which the same biome was inferred for the present and all 88 past time slices examined.

Note that the particular grid cells in the top 10% differs amongst the four vertebrate groups, being based, in each case, on the number of species of that group occurring in each grid cell, and so, hence, does the number of those cells with constant biome.

Appendix S1: Assessing the magnitude of projected biome changes

Following Allen *et al*. (2020), the magnitude of projected biome change in a grid cell was calculated as the sum of any change in major climatic zone and any change in vegetation structure between the biome simulated for the present and that projected for the future. Each biome was assigned to one, or exceptionally two, of five major global climatic zone(s), namely: Arctic; Boreal; Temperate; Warm temperate / Sub-tropical; and Tropical. Vegetation structure similarly was assigned to one, or exceptionally two, of the following seven categories: Unvegetated; Desert; Grassland; Shrubland; Savanna / Parkland; Woodland; and Forest. Biome assignments to climatic zones and structural types are shown in Table S3 (see Table S4 for key to biome acronyms used in Table S3).

Table S3: Biome assignments to climatic zones and structural types

Biome	Climatic zone	Structural type	Biome	Climatic zone	Structural type
Des	Arctic **or** Sub-tropical	Desert	TePk	Temperate	Savanna / Parkland
Se-des	Warm temperate / Sub-tropical	Grassland **and** Shrubland	St	Temperate	Grassland
TrG	Tropical	Grassland	BPk	Boreal	Savanna / Parkland
Sav	Tropical	Savanna / Parkland	BENF	Boreal	Forest
TrRF	Tropical	Forest	BSNF	Boreal	Forest
TrEF	Tropical	Forest	BSBF	Boreal	Forest
TeSh	Warm temperate / Sub-tropical	Shrubland	BWo	Boreal	Woodland
WteWo	Warm temperate / Sub-tropical	Woodland	ShT	Arctic	Shrubland
TeBEF	Temperate **and** Warm temperate / Sub-tropical	Forest	Tun	Arctic	Grassland
TeSF	Temperate	Forest	UNC	—	—
TeNEF	Temperate	Forest	NoVeg	any	Unvegetated
TeMxF	Temperate	Forest			

Table S4: Key to biome acronyms

Acronym	Biome
Des	Desert
Se-des	Semi-desert
TrG	Tropical Grassland
Sav	Savanna
TrRF	Tropical Raingreen Forest
TrEF	Tropical Evergreen Forest
TeSh	Temperate Shrubland
WteWo	Warm Temperate Woodland
TeBEF	Temperate Broad-leaved Evergreen Forest
TeSF	Temperate Summergreen Forest
TeNEF	Temperate Needle-leaved Evergreen Forest
TeMxF	Temperate Mixed Forest
TePk	Temperate Parkland
St	Steppe
BPk	Boreal Parkland
BENF	Boreal Evergreen Needle-leaved Forest
BSNF	Boreal Summergreen Needle-leaved Forest
BSBF	Boreal Summergreen Broad-leaved Forest
BWo	Boreal Woodland
ShT	Shrub Tundra
Tun	Tundra
UNC	Unclassified
NoVeg	grid cell without ice-free land

Tables S5 and S6 show the contribution to the overall magnitude of biome change for changes in climatic zone and in vegetation structure, respectively. Where no change in biome was projected, a biome change magnitude of -9 was assigned. Grid cells for which either the present or projected future biome was unclassified were assigned a change magnitude of 20. In all other cases the contributions for climatic zone and vegetation structure were summed to obtain the magnitude of biome change. It is important to note that a biome change magnitude of zero does not reflect a lack of biome change, but rather that the present and projected future biomes belonged to the same climatic zone and had the same vegetation structural type.

Table S5: Contribution to magnitude of biome change for climatic zone changes

Present biome / Projected future biome	Arctic	Boreal	Temperate	Warm temperate / Sub-tropical	Tropical
Arctic	0	1	2	3	4
Boreal	1	0	1	2	3
Temperate	2	1	0	1	2
Warm temperate / Sub-tropical	3	2	1	0	1
Tropical	4	3	2	1	0

Table S6: Contribution to magnitude of biome change for vegetation structural type changes

Present biome / Projected future biome	Unvegetated	Desert	Grassland	Shrubland	Savanna / Parkland	Woodland	Forest
Unvegetated	0	1	2	3	4	5	6
Desert	1	0	1	2	3	4	5
Grassland	2	1	0	1	2	3	4
Shrubland	3	2	1	0	1	2	3
Savanna / Parkland	4	3	2	1	0	1	2
Woodland	5	4	3	2	1	0	1
Forest	6	5	4	3	2	1	0

When mapping magnitudes of projected biome changes, grid cells with a change magnitude of -9, indicating no projected biome change, were unshaded, thus allowing the cream shading used for continental areas to show through, whilst those with a magnitude of 20, indicating that either the present or projected future biome was unclassified, were shaded red. All other change magnitudes were assigned shades of green, with darker shades indicating greater difference scores. A legend to the colour scale used is given on Figure 4.

Supplementary Figures

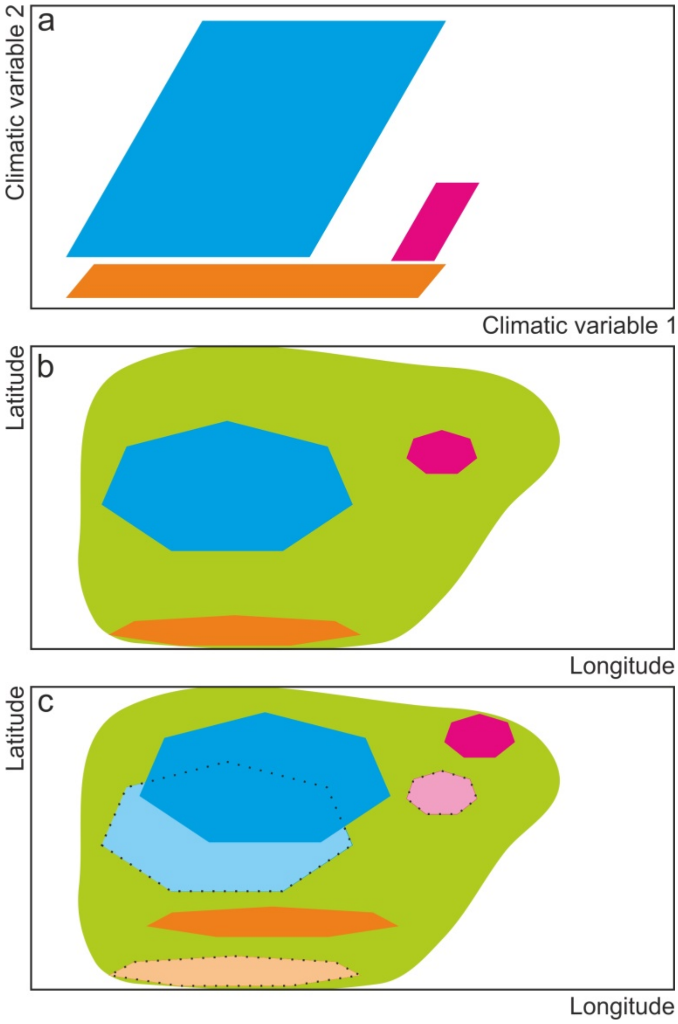

Figure S1: Biome shifts in relation to climatic change

a The extents of three hypothetical biomes, shown as the cyan, orange and magenta trapezoids, in the space of two climatic variables. In this example the cyan biome has a much greater extent with respect to both climatic variables than does the magenta biome, whereas the orange biome has a similar extent for climatic variable 1 to that of the cyan biome, but a much smaller extent for climatic variable 2. **b** The present geographic locations and extents of the three biomes within a continental region, represented by the green-shaded area, as determined by the present climate of the region. **c** The projected future locations of the three biomes after a 'uniform' climatic change throughout the region; their present locations are shown by the 'faded' shading and dotted outlines. Whereas there is a large overlap between the projected future and present locations of the cyan biome, the same magnitude of climatic change results in no overlaps for either the magenta or orange biomes.

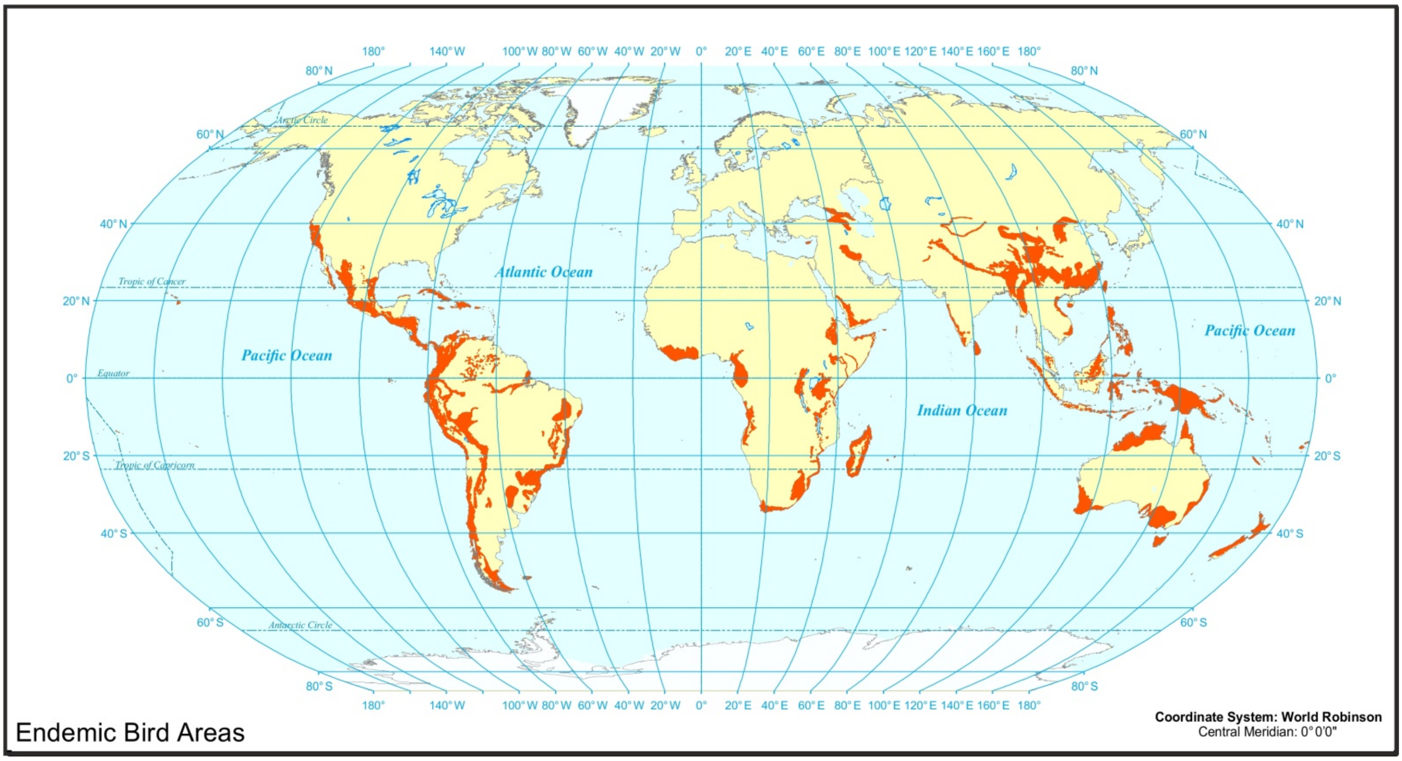

Figure S2: Endemic Bird Areas

Global extent of Endemic Bird Areas identified by BirdLife International (Stattersfield *et al.*, 1998). (Map data for Endemic Bird Areas provided by Stuart Butchart and Mark Balman, of BirdLife International, Cambridge.)

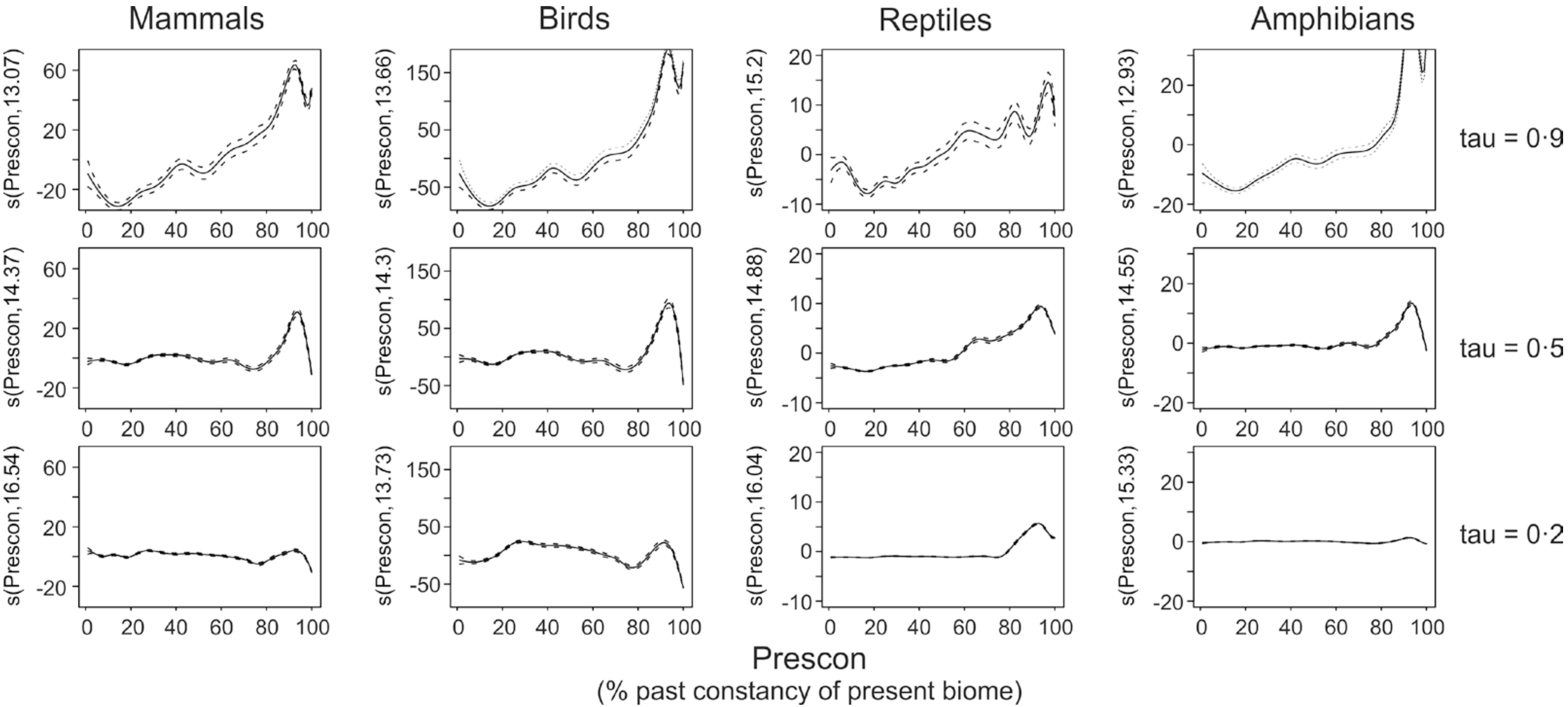

Figure S3: Quantile generalised additive models of species richness in relation to past constancy of the present biome

The relationship between total species richness (s) and constancy of the present-day biome (Prescon) since 140 ka for four taxonomic groups of terrestrial vertebrates. Lines show fitted quantile generalised additive models for *tau* = 0·9 (i.e. the 90th percentile, top), 0·5 (i.e. the median, centre) and 0·2 (i.e. the 20th percentile, bottom) quantiles. Y-axis labels show the smoothing terms and the estimated degrees of freedom of the fitted models.

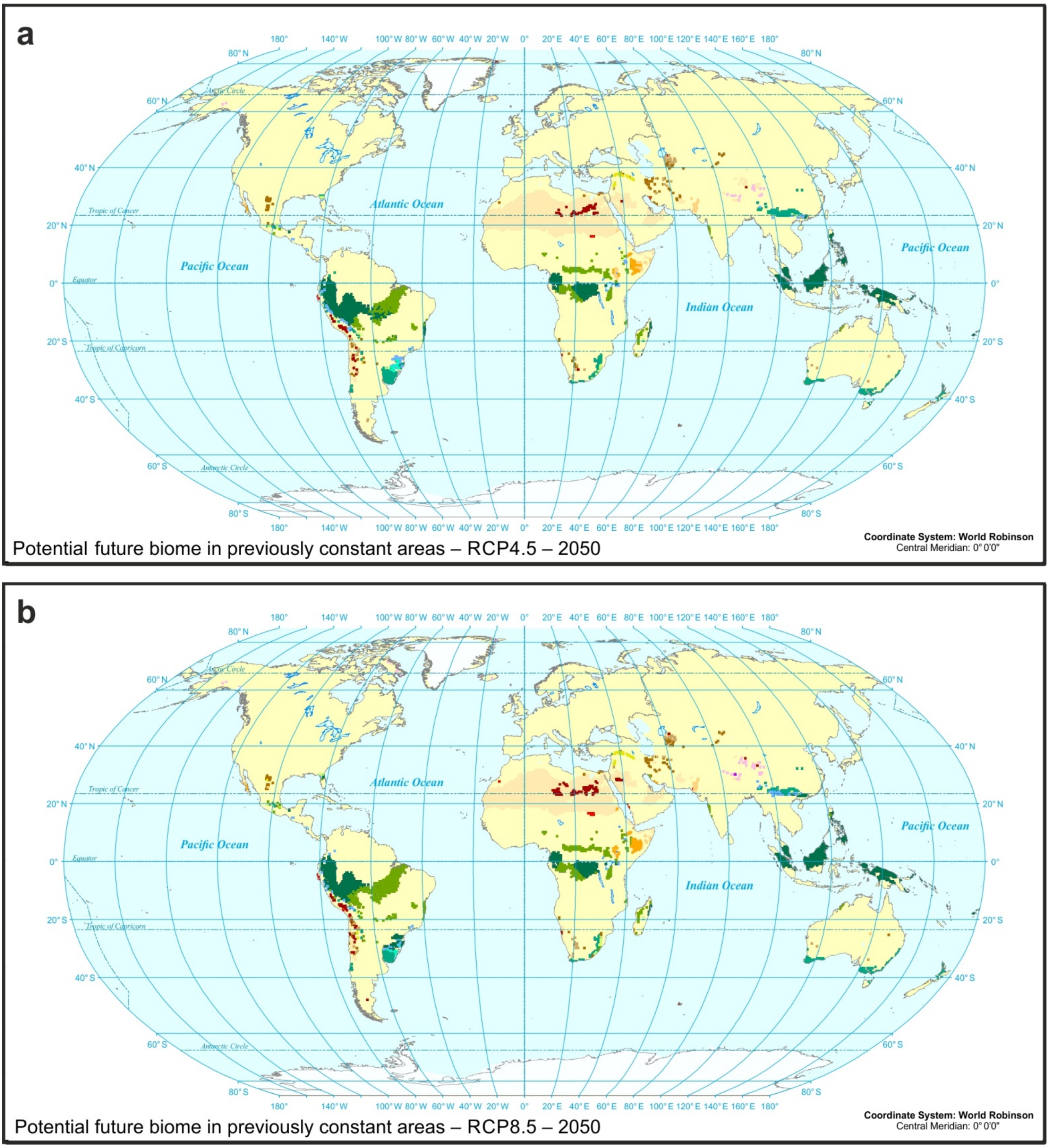

Figure S4: Committed eventual future biomes in areas of past biome constancy

Committed eventual future biomes in areas of biome constancy 140 ka to present. **a**. under the climate simulated for 2050 for RCP 4.5 and **b**. for RCP 8.5. (See Figure 2 for legend).

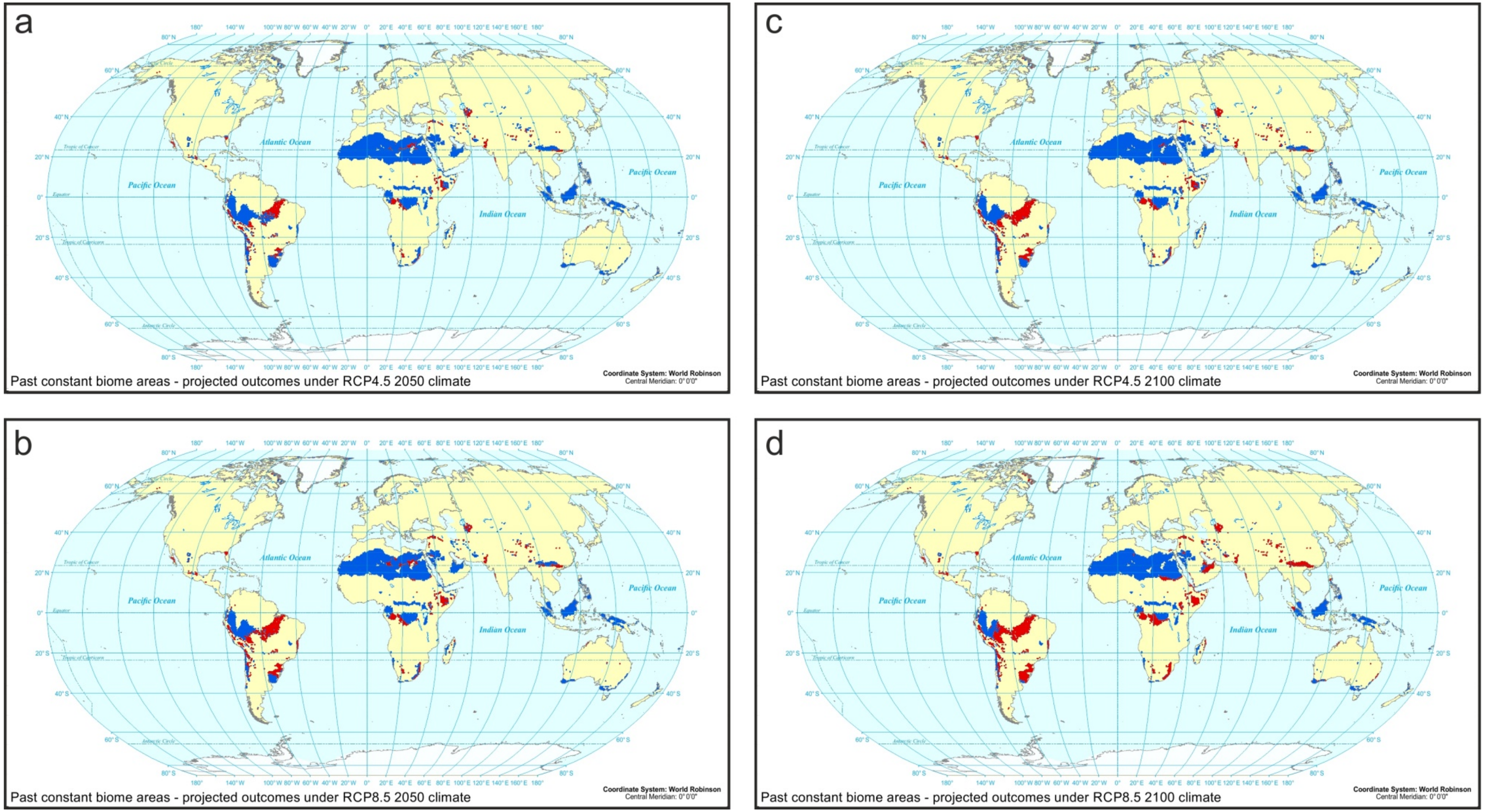

Figure S5: Commitment to eventual future biome change in areas of past biome constancy

Areas of past biome constancy with a commitment to eventual future biome change are shown in red, whilst areas of past and projected future continued biome constancy are shown in blue: **a**. under the climate simulated for 2050 for RCP 4.5; **b**. under the climate simulated for 2050 for RCP 8.5; **c**. under the climate simulated for 2100 for RCP 4.5; and **d**. under the climate simulated for 2100 for RCP 8.5.

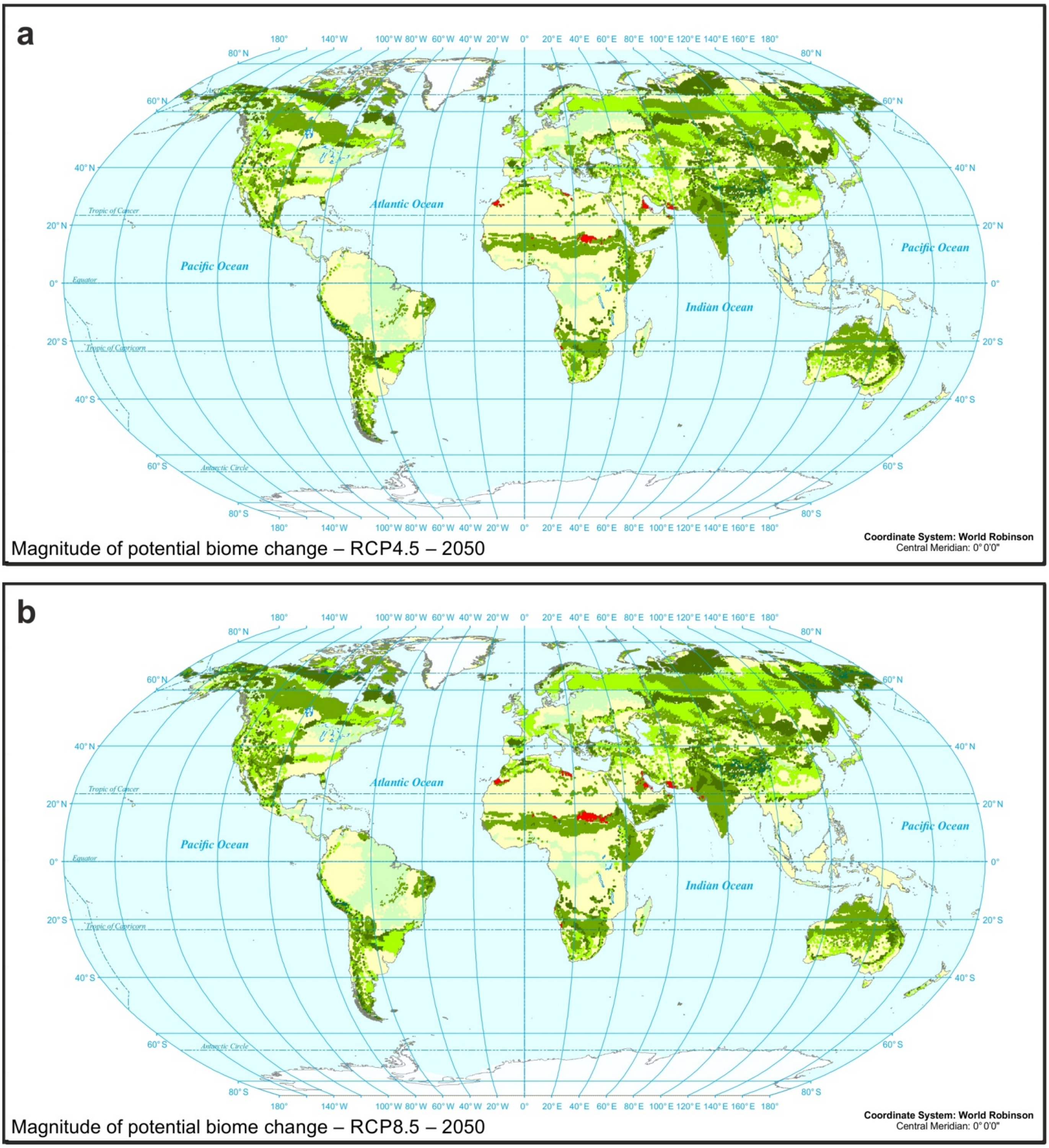

Figure S6: Magnitude of committed eventual future biome changes

Global extent of committed eventual biome changes, and their magnitude, for the climates simulated for 2050 under RCP 4.5 (**a**) and RCP 8.5 (**b**). (See Figure 4 for legend).

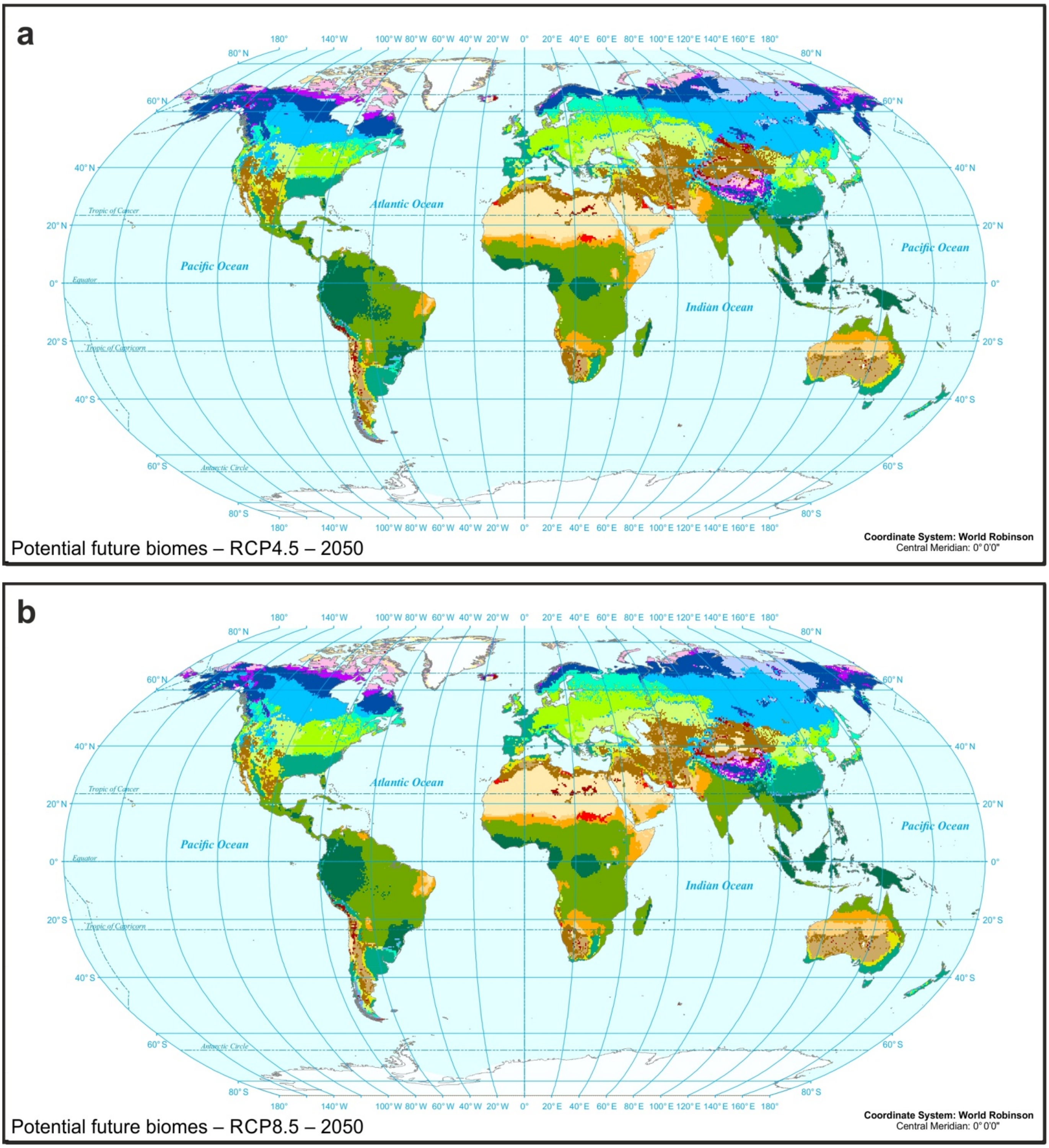

Figure S7: Potential future biomes – 2050 climates

Potential future biomes. **a**. under the climate simulated for 2050 for RCP 4.5 and **b**. for RCP 8.5. (See Figure 2 for legend).

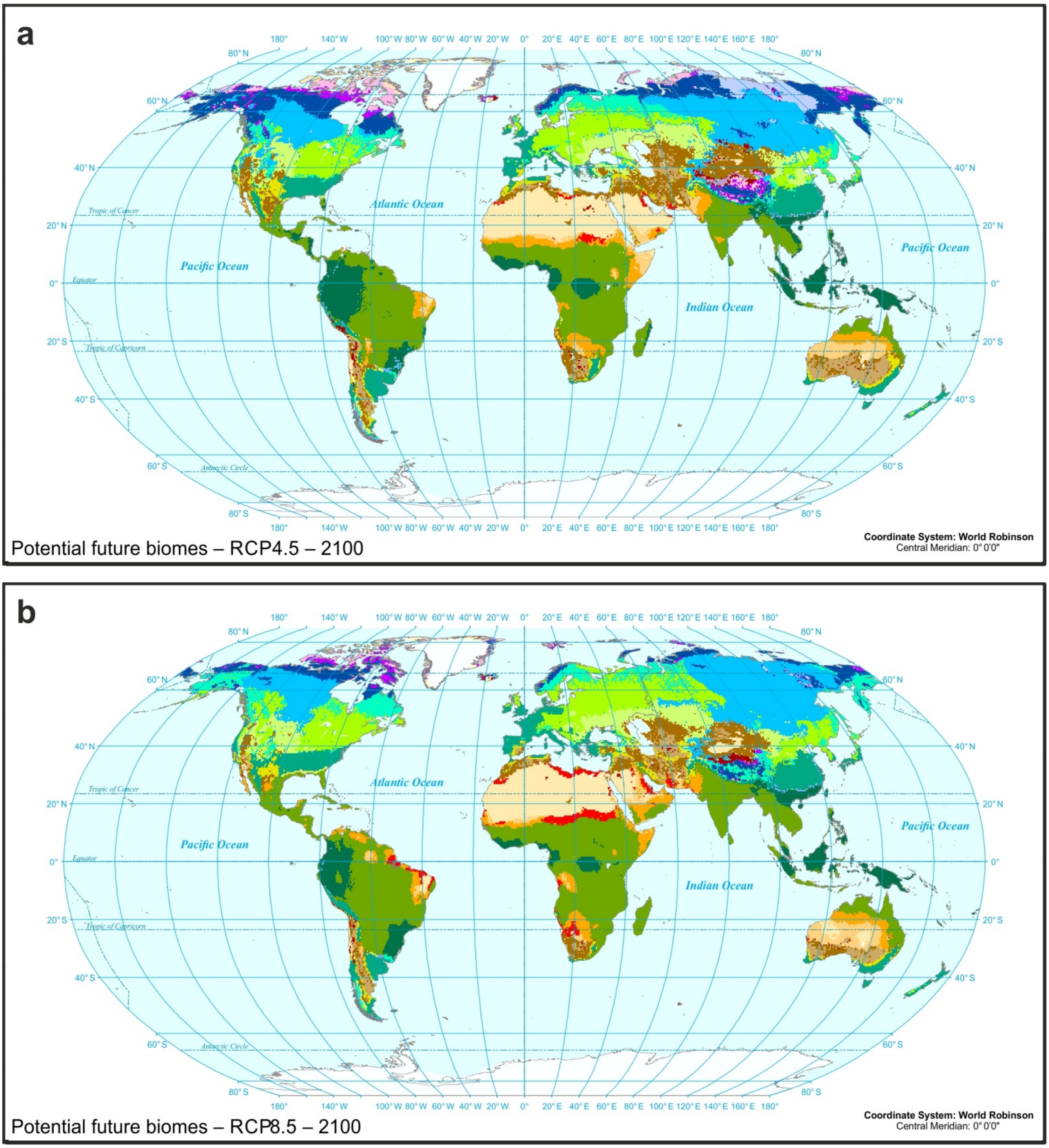

Figure S8: Potential future biomes – 2100 climates

Potential future biomes. **a**. under the climate simulated for 2100 for RCP 4.5 and **b**. for RCP 8.5. (See Figure 2 for legend).

References

Allen, J.R.M., Forrest, M., Hickler, T., Singarayer, J.S., Valdes, P.J. & Huntley, B. (2020) Global vegetation patterns of the past 140,000 years. *Journal of Biogeography*, **47**, 2073-2090.

Stattersfield, A.J., Crosby, M.J., Long, A.J. & Wege, D.C. (1998) *Endemic bird areas of the world: Priorities for biodiversity conservation*. BirdLife International, Cambridge.