This file includes:

Tables S1-S2

Figures S1–S9

References in the supplementary materials

Table S1 List of the covariates used in the RF-temporal models.

Variable	Type	Source and Reference
123 pollen taxes	Pollen	Modern pollen dataset for Asia https://data.tpdc.ac.cn
Elevation Slope Aspect Eastness Northness Roughness TRI (Terrain Ruggedness Index) TPI (Topographic Position Index)	Topographic	WorldClim version 2. http://www.worldclim.com/version2

Table S2 List of the 63 covariates used in the RF-spatial models.

Variable	Type	Data resolution	Source and Reference
Annual mean temperature	Bioclimatic	~0.5°	CHELSA-TraCE21k www.chelsa-climate.org
Temperature annual range	Bioclimatic	~0.5°	
Temperature seasonality	Bioclimatic	~0.5°	
Isothermality	Bioclimatic	~0.5°	
Maximum temperature of warmest month	Bioclimatic	~0.5°	
Mean diurnal range	Bioclimatic	~0.5°	
Mean temperature of coldest quarter	Bioclimatic	~0.5°	
Mean temperature of driest quarter	Bioclimatic	~0.5°	
Mean temperature of warmest quarter	Bioclimatic	~0.5°	
Mean temperature of wettest quarter	Bioclimatic	~0.5°	
Minimum temperature of coldest month	Bioclimatic	~0.5°	
Precipitation seasonality	Bioclimatic	~0.5°	
Annual precipitation	Bioclimatic	~0.5°	
Precipitation of coldest quarter	Bioclimatic	~0.5°	
Precipitation of driest month	Bioclimatic	~0.5°	
Precipitation of driest quarter	Bioclimatic	~0.5°	
Precipitation of warmest quarter	Bioclimatic	~0.5°	
Precipitation of wettest month	Bioclimatic	~0.5°	
Precipitation of wettest quarter	Bioclimatic	~0.5°	
Monthly maximum precipitation	Climatic	~0.5°	CHELSA-TraCE21k www.chelsa-climate.org
Monthly minimum temperature	Climatic	~0.5°	
Monthly precipitation	Climatic	~0.5°	
Elevation	Topographic	~0.5°	WorldClim version 2. http://www.worldclim.com/version2
Slope	Topographic	~0.5°	
Aspect	Topographic	~0.5°	
Eastness	Topographic	~0.5°	
Northness	Topographic	~0.5°	
Roughness	Topographic	~0.5°	
TRI (Terrain Ruggedness Index)	Topographic	~0.5°	
TPI (Topographic Position Index)	Topographic	~0.5°	

Figure S1. Spatial distribution of modern and fossil pollen records.

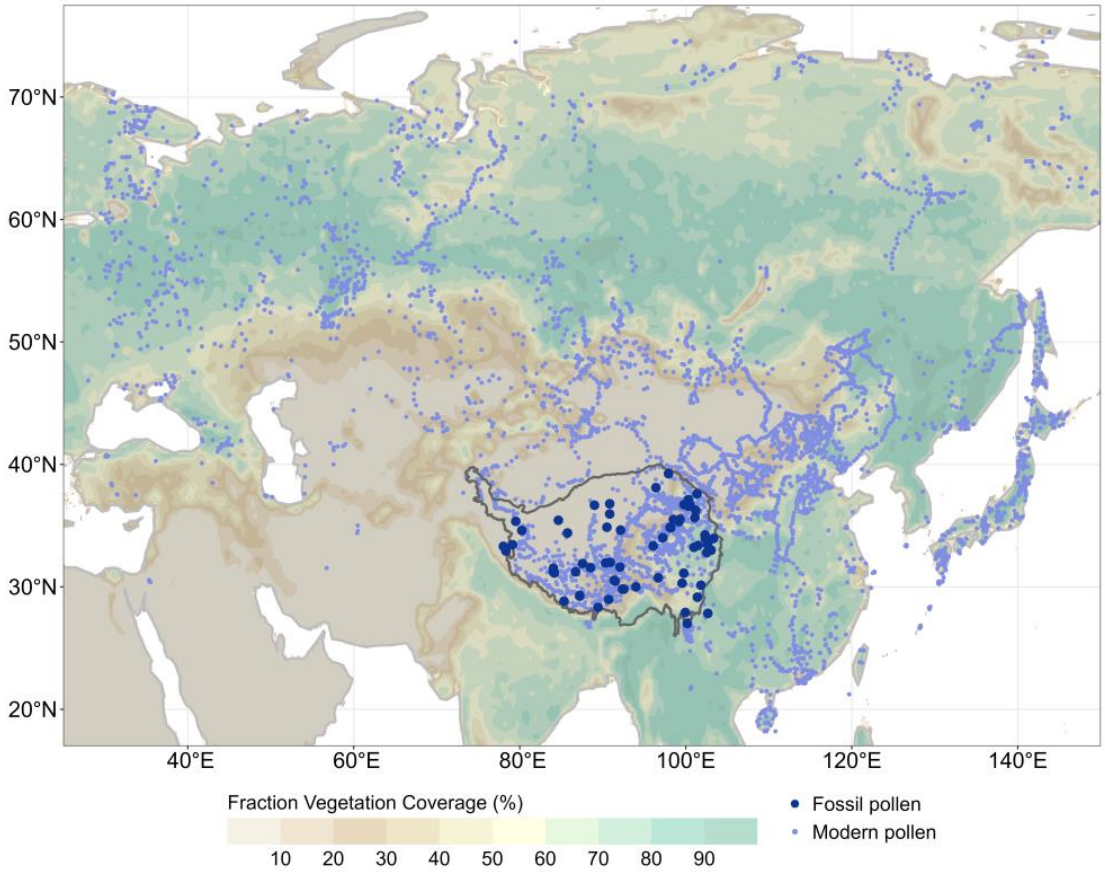


Figure S2. Performance comparison between five machine learning methods and the Modern Analogy Technique. The methods selected for this study are highlighted in blue text.

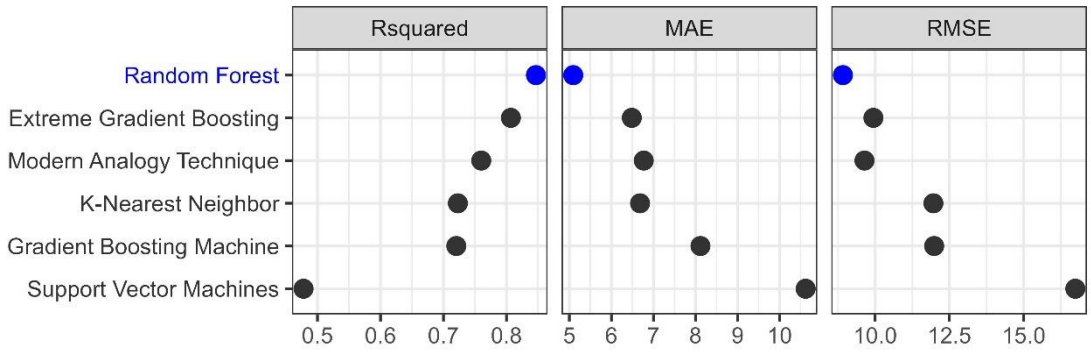


Figure S3. Vegetation, woody, and herbaceous cover for eight selected time windows from the last deglaciation to the present.

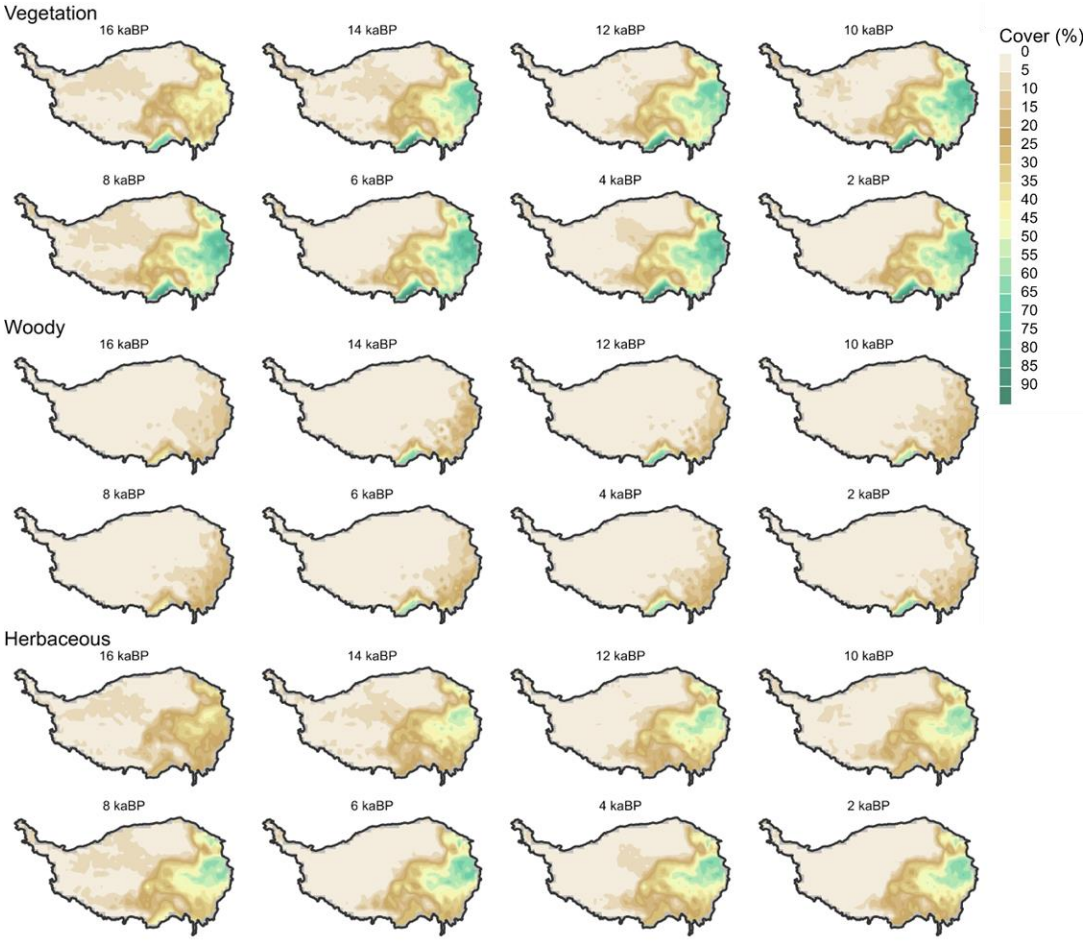


Figure S4. Spatial distribution of the differences of vegetation cover between the model simulations and reconstructed dataset for the mid-Holocene (6 Ka BP). The values below each panel indicate the mean difference between the model simulations and reconstruction.

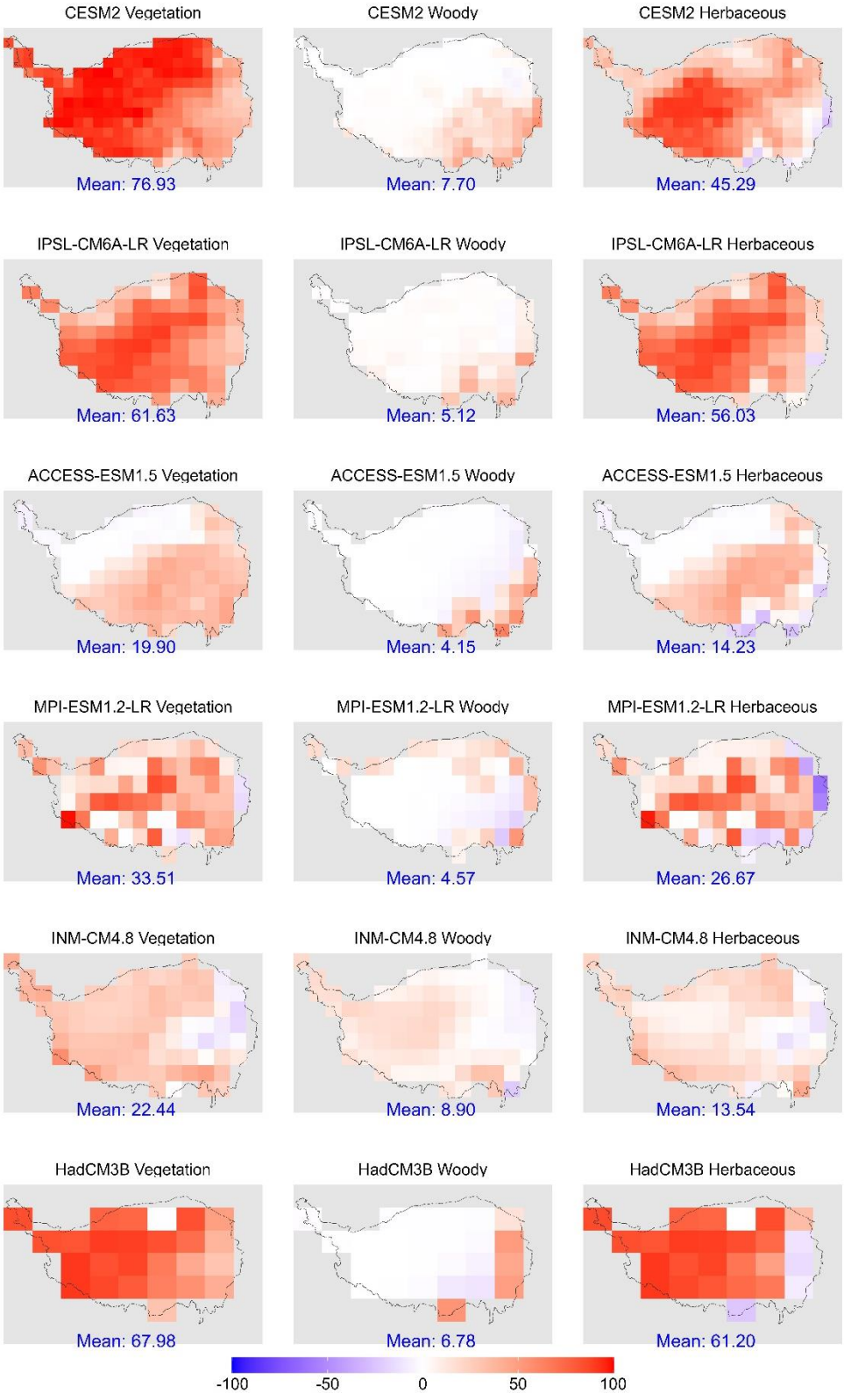


Figure S5. Temperature anomaly of the Tibetan Plateau's growing season (June–October) from the deglaciation period (16 ka BP) to the present, compared to the reference period (1900–1990).

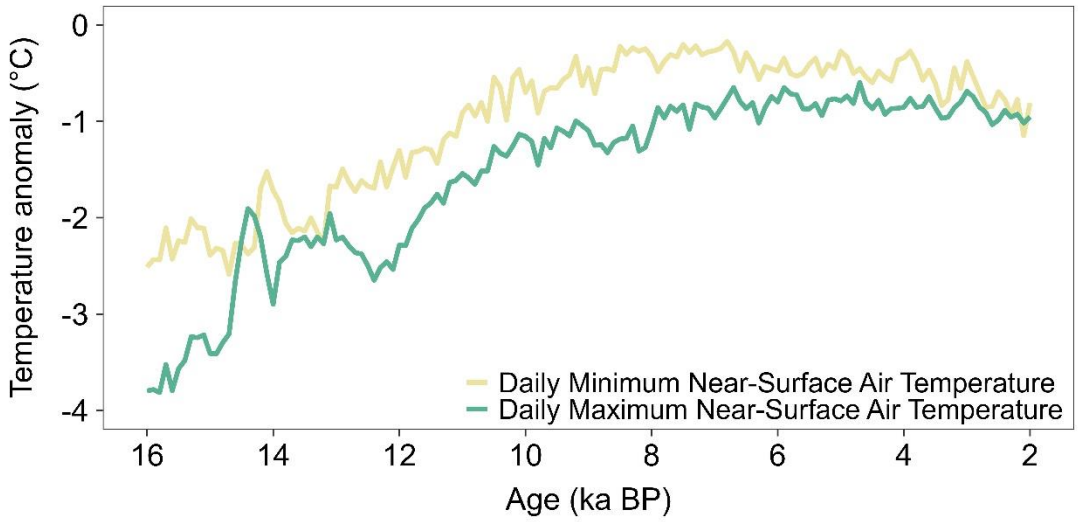


Figure S6. Climatic envelope overlap between modern and fossil records, mapped in climate space using TraCE-21ka climate information and the direct methodological approach ('ecospat' package in R; (Di Cola et al., 2017)). a. Asia modern vs. TP fossil pollen records climatic envelopes. b. Tibetan plateau modern vs. Tibetan plateau fossil pollen records climatic envelopes. Green areas represent climatic spaces where only fossil records occurred; red areas represent climatic spaces where only modern records; and blue/purple areas represent climatic spaces where modern and fossil records overlapped in their climatic distribution. The solid green outline indicates the extent of the fossil records' climatic space across the entire study period. The solid red outline indicates the extent of the modern records' climatic space. Darker areas represent higher densities of overlap. In the upper left corner, the overlap index displays the degree of overlap between the two climate spaces, with higher values indicating a greater extent of overlap (referencing the niche stability index for two species; (Guisan et al., 2014)).

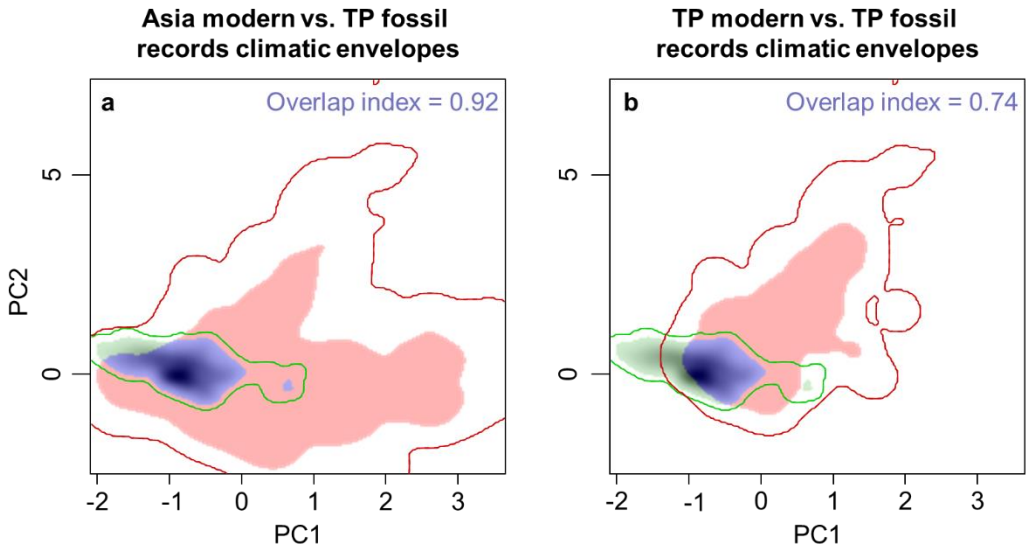


Figure S7. Prediction accuracy of the Random Forest model under different combinations of predictor variables, using 10-fold cross-validation.

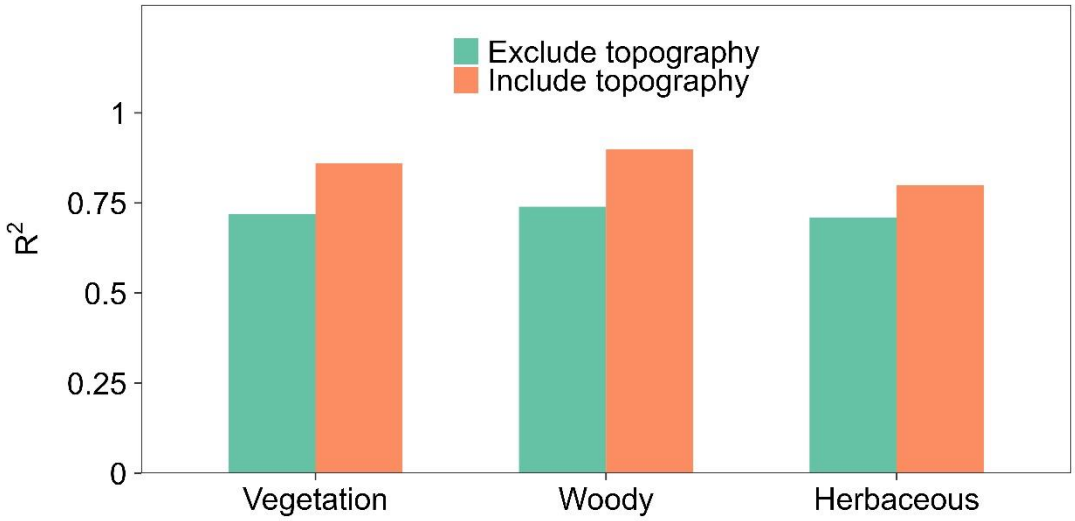


Figure S8. Changes in the number of fossil pollen records from 16 ka to the present at different temporal resolutions.

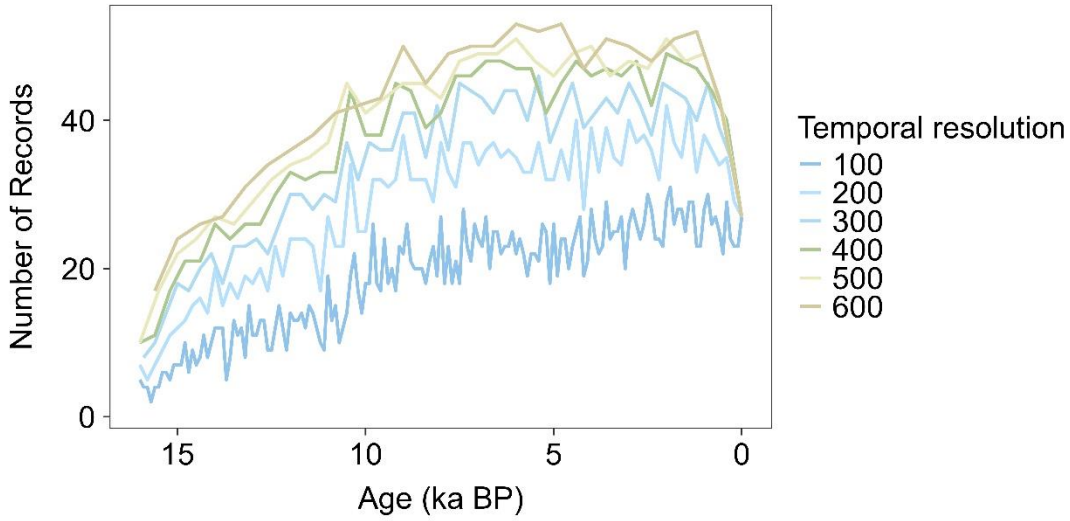
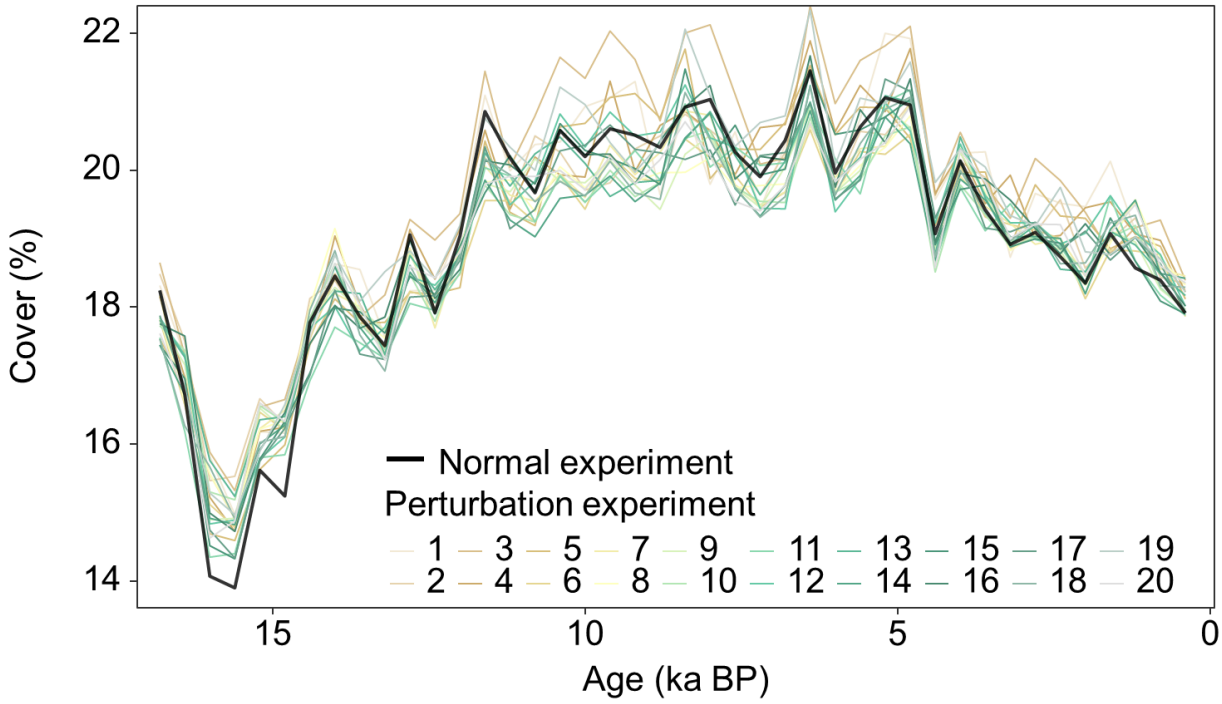


Figure S9. The comparison between the perturbation experiment and the normal experiment. In the perturbation experiment, the temporal sequence of input data used for RF-spatial is randomly scrambled.



References

Di Cola, V., Broennimann, O., Petitpierre, B., Breiner, F. T., D'Amen, M., Randin, C., Engler, R., Pottier, J., Pio, D., Dubuis, A., Pellissier, L., Mateo, R. G., Hordijk, W., Salamin, N., and Guisan, A.: ecospat: an R package to support spatial analyses and modeling of species niches and distributions, Ecography, 40, 774–787, https://doi.org/10.1111/ecog.02671, 2017.

Guisan, A., Petitpierre, B., Broennimann, O., Daehler, C., and Kueffer, C.: Unifying niche shift studies: insights from biological invasions, Trends Ecol. Evol., 29, 260–269, https://doi.org/10.1016/j.tree.2014.02.009, 2014.