Supplementary information

S1 REVEALS

We provide here some additional background on the REVEALS pollen-vegetation model, but again refer readers to (Sugita, 2007; Githumbi et al., 2022) for a more detailed and theoretical description of the REVEALS model.

REVEALS estimates the relative cover of plant taxa in proportions (dimensionless) for a large area (estimated to a minimum of 100 km x 100 km in southern Sweden (Hellman et al., 2008a) based one pollen records from a large lake, or multiple proximal pollen records. While REVEALS was initially developed to infer vegetation from pollen records from large lakes (with a large catchment area), it has subsequently been used to infer vegetation from multiple pollen records from a set of nearby smaller lakes (Sugita, 2007). There have been several studies that have carried out model validation for REVEALS. These include validation for: southern Sweden for large lakes (Hellman et al., 2008a, b); multiple small sites in the same region (Trondman et al., 2016); northern America (Sugita et al., 2010); and several regions of Europe and China (Sugita, 2023, and references therein).

We note that the REVEALS model does not estimate bare ground; the estimated proportions of plant taxa sum up to 1 (or 100%). REVEALS has been used in combination with estimates of proportion of bare ground simulated by the dynamic vegetation model LPJ-GUESS where these bare ground proportions were used to adjust REVEALS estimates (Strandberg et al., 2022).

REVEALS assumes that there is no vegetation growing on the deposition basin; as such, it is not suitable for use with a single pollen record from a large bogs (Sugita, 2007). However, vegetations reconstructions from REVEALS based on multiple pollen records where only a small proportion of of records are from large bogs may be only slightly biased (Mazier et al., 2012; Trondman et al., 2016). For detailed discussion of this issue see (Li et al., 2020).

REVEALS accounts for differential dispersibility among pollen types using fall speed of pollen. Moreover, REVEALS includes two alternative deposition models: a model for bogs (Prentice, 1985), and model for lakes (Sugita, 1993). As noted in the main text, we used the Gaussian plume dispersal model to be consistent with the dispersal model used in the PAGES LandCover6k protocol. This is motivated by the fact that the PPEs were calculated using the Gaussian plume model. The use of a Lagrangian model would require PPEs calculated using that same model (Theuerkauf et al., 2012; Theuerkauf and Couwenberg, 2020).

REVEALS also estimates standard errors (SE) associated with the relative cover for each plant taxon. In 'REVEALSinR', to estimate the SEs random noise (error) is added to both the pollen data and the PPEs and REVEALS is used to infer relative vegetation cover from a large set (minimum of 1,000) of perturbed states. By default, the 10th and 90th percentile of the inferred set of vegetation cover are used to determine SEs. In the LRA.REVEALS v6.2.4 program, the SEs account for both the uncertainty in the pollen productivity estimates (PPEs) and the number of pollen grains counted in the sample. Pollen samples with more total counts are more certain than those with fewer counts.

We implemented the REVEALS model using the REVEALSinR R package (Theuerkauf et al., 2016), while the gridded REVEALS reconstructions for China (Li et al., 2023) were produced by implementing REVEALS either in the computer program LRA.REVEALS.v6.2.4.exe (Sugita, unpublished, available at the https://1drv.ms/u/s!AkY-0mVRwOaykdgmINfXVsC-4t4n5w?e=7U55hO) (China) or in the LRA R package of (Abraham et al., 2014) that implements the model in the same way as Sugita's program (Europe). The major difference between REVEALSinR and the Sugita's program is the calculation of error estimates.

Supplementary Table 2: Pollen productivity estimates and corresponding standard errors, using grass as a reference taxon, pollen fall speeds, and conversion of plant taxa names from the REVEALS pollen-vegetation model to land cover types (LCT) for the 32 considered taxa (Wieczorek and Herzschuh, 2020; Dawson et al., 2016; Trachsel et al., 2020; Niklas, 1984). Land cover names and abbreviations are evergreen trees and shrubs (ETS), summergreen trees and shrubs (STS), and open vegetation/land (OVL). Note that some taxa, such as *Quercus*, include both summergreen and evergreen species, so these continental-scale assignments of taxa to land cover types are not correct for all species and all regions. Due to indistinguishable pollen morphologies, the *Larix* pollen type (STS) includes *Pseudotsuga menziesii*, an evergreen species.

Taxon Latin	Taxon Common	PPE (unitless)	PPE SE	FS (cm/s)	LCT
Abies	fir	6.88	1.44	0.12	ETS
Acer	maple	0.23	0.04	0.056	STS
Alnus	alder	2.7	0.12	0.021	STS
Ambrosia	ambrosia	1.36	0.36	0.013	OVL
Asterx	asters	0.59	0.13	0.025	OVL
Betula	birch	6.19	0.15	0.051	STS
Brassicaceae	mustard	0.48	0.09	0.021	OVL
Carya	walnut	2.8	0.11	0.032	STS
Caryophyllaceae	pink	0.6	0.05	0.041	OVL
Castanea	chestnut	5.87	0.24	0.014	STS
Amaranthaceae	chenopods	5.24	0.5	0.011	OVL

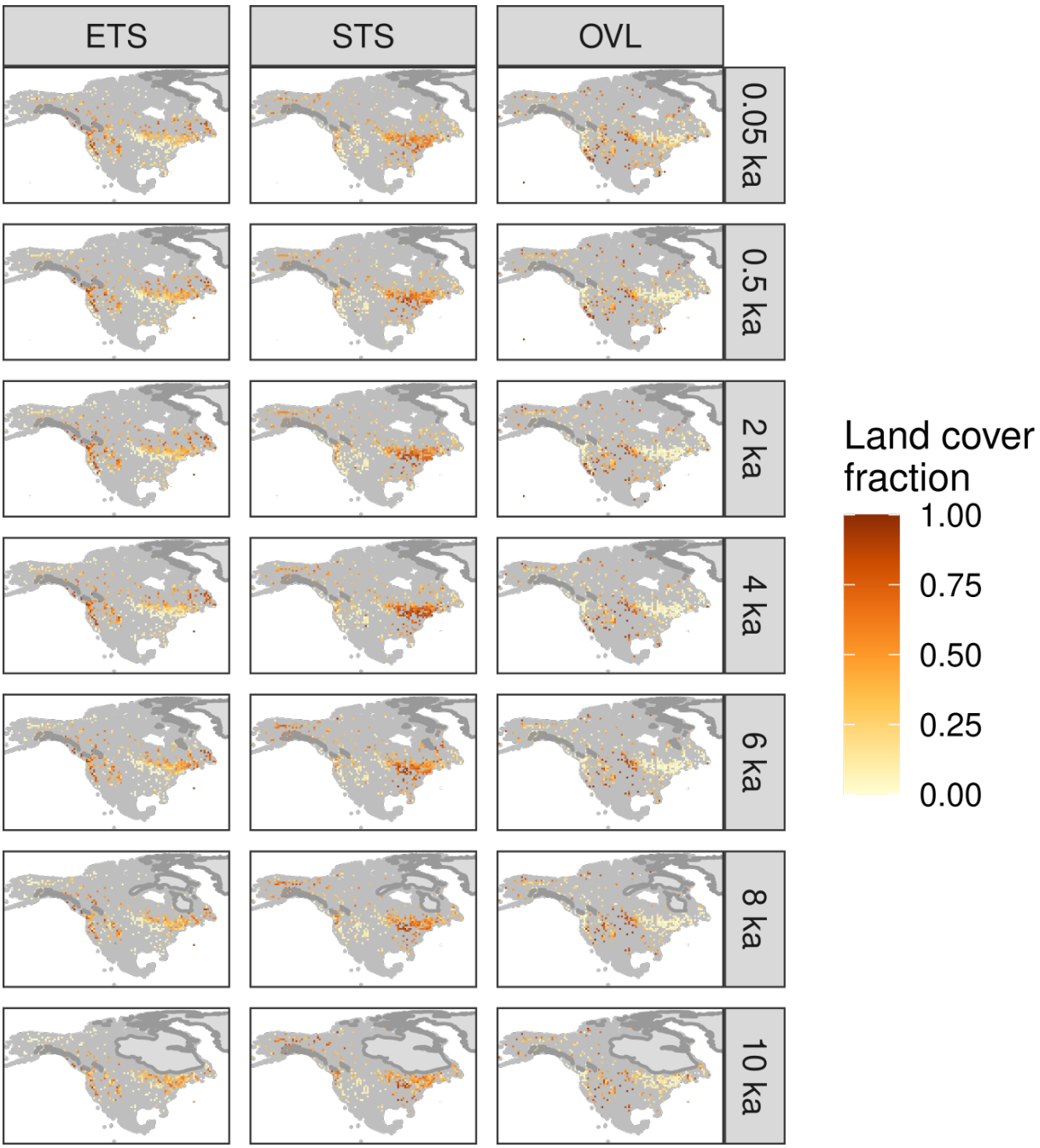
Corylus	hazel	1.58	0.06	0.019	STS
Cupressaceae	cypress	1.11	0.09	0.01	ETS
Cyperaceae	sedge	0.98	0.03	0.031	OVL
Ericaceae	heather	0.45	0.01	0.038	OVL
Fabaceae	pea	0.02	0.02	0.021	OVL
Fagus	beech	2.35	0.11	0.056	STS
Fraxinus	ash	2.42	0.19	0.02	STS
Larix	larch	1.24	0.15	0.065	STS
Ostrya.carpinus	hornbeam	3.09	0.28	0.042	STS
Picea	spruce	6.46	0.18	0.056	ETS
Pinus	pine	14.1	0.45	0.033	ETS
Plantaginx	plantain	5.96	0.31	0.019	OVL
Poaceae	grass	1	0.05	0.026	OVL
Populus	poplar	0.67	0.09	0.026	STS
Prosopis	legume	0.02	0.02	0.021	OVL
Quercus	oak	2.08	0.43	0.035	STS
Rumex	rumex	2.79	0.17	0.014	OVL

Salix	willow	0.68	0.01	0.016	STS
Tilia	basswood	0.8	0.07	0.03	STS
Tsuga	hemlock	3.4	0.13	0.08	ETS
Ulmus	elm	2.24	0.46	0.026	STS

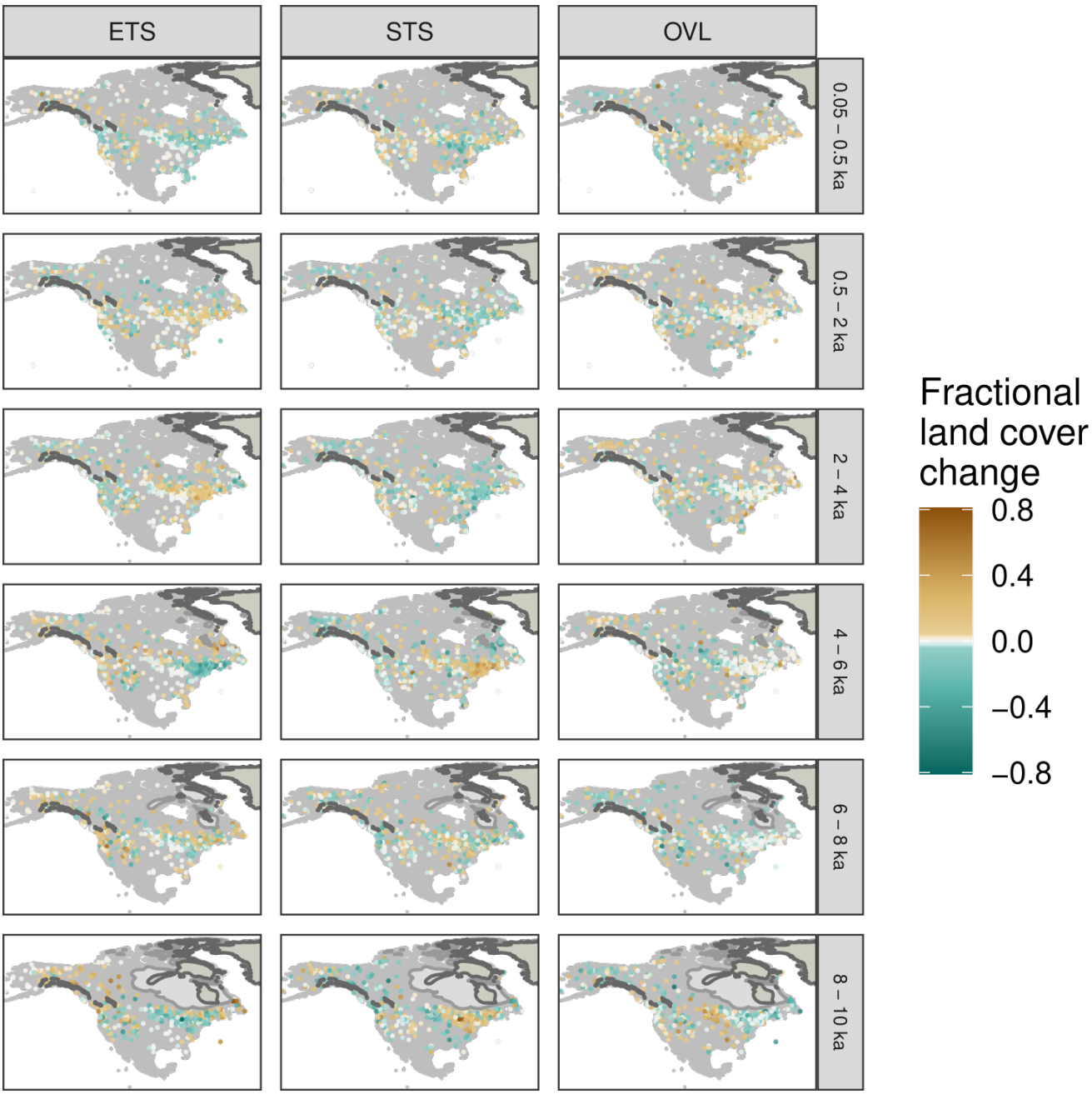
Supplementary Table 3: Time intervals specified by the PAGES LandCover6k working group protocol.

Interval Identifier (ka)	Younger Boundary (ka)	Older Boundary (ka)	Interval Width (years)
0.05	−0.074	0.1	174
0.2	0.1	0.35	250
0.5	0.35	0.7	350
1	0.7	1.2	500
1.5	1.2	1.7	500
2	1.7	2.2	500
2.5	2.2	2.7	500
3	2.7	3.2	500
3.5	3.2	3.7	500
4	3.7	4.2	500

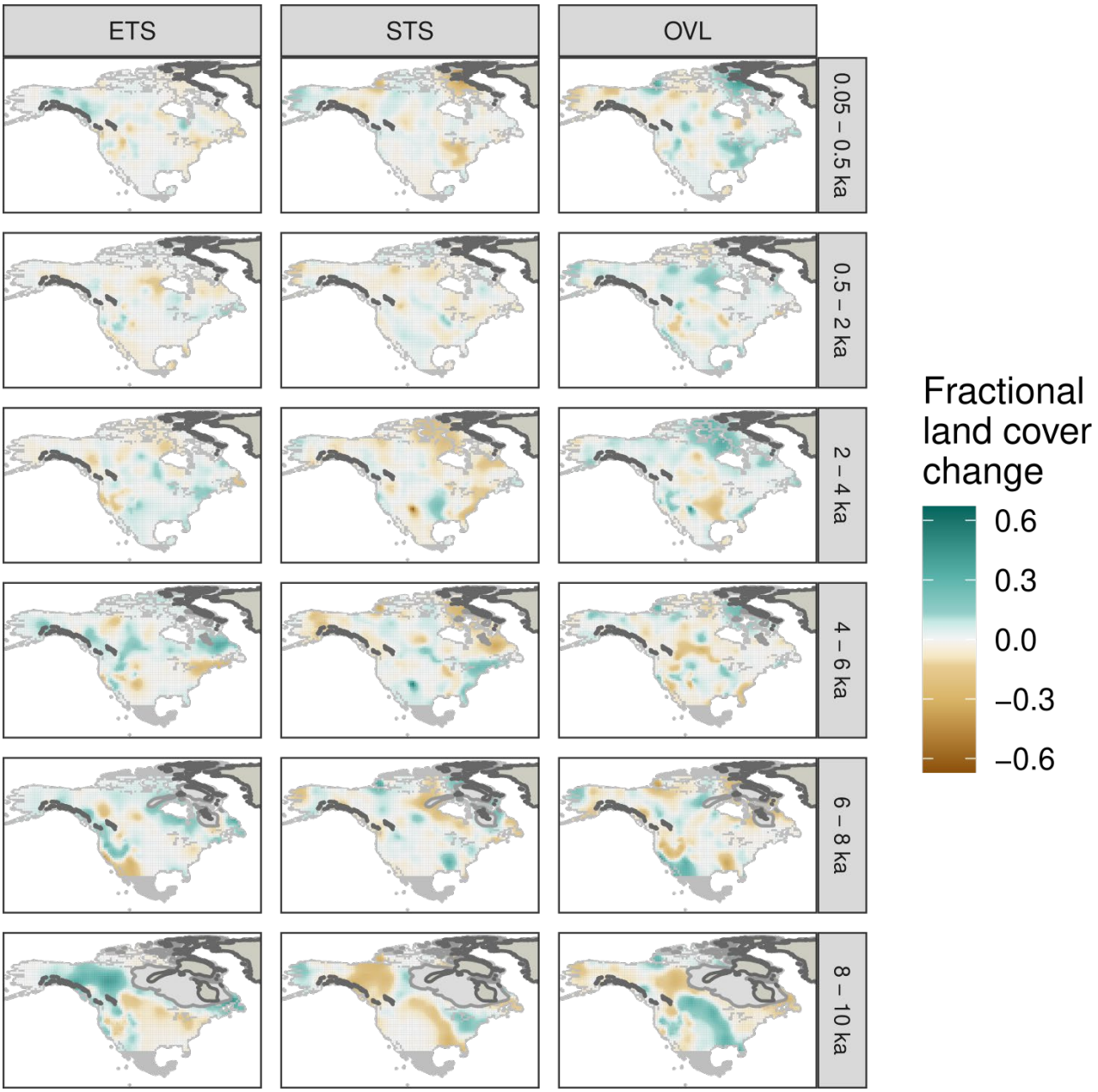
4.5	4.2	4.7	500
5	4.7	5.2	500
5.5	5.2	5.7	500
6	5.7	6.2	500
6.5	6.2	6.7	500
7	6.7	7.2	500
7.5	7.2	7.7	500
8	7.7	8.2	500
8.5	8.2	8.7	500
9	8.7	9.2	500
9.5	9.2	9.7	500
10	9.7	10.2	500
10.5	10.2	10.7	500
11	10.7	11.2	500
11.5	11.2	11.7	500



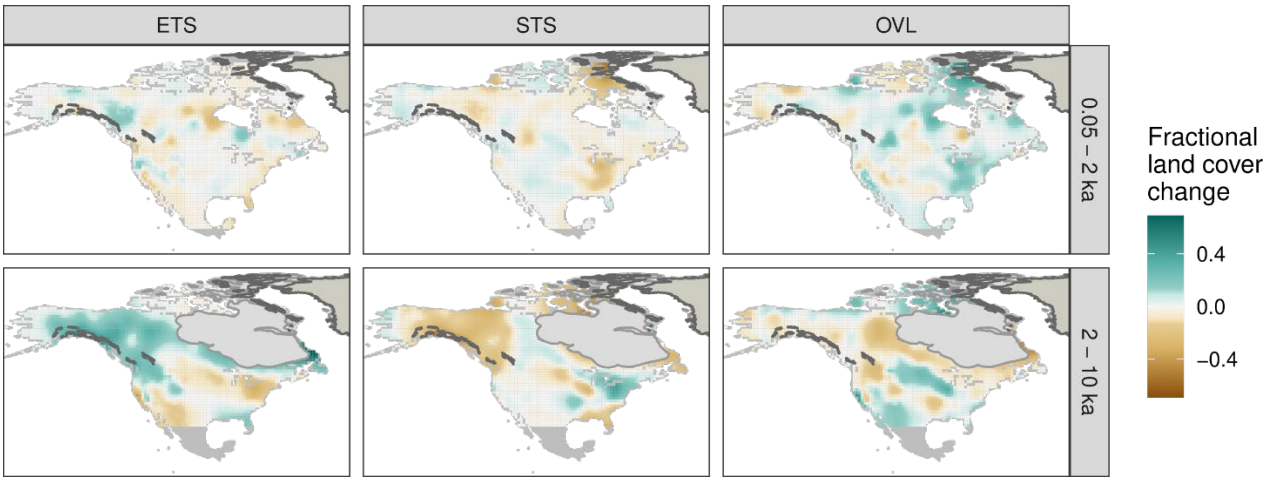
Supplementary Figure 1: Maps of land cover fraction inferred using REVEALS for summergreen trees and shrubs (STS), evergreen trees and shrubs (ETS), and open land (OVL).. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.



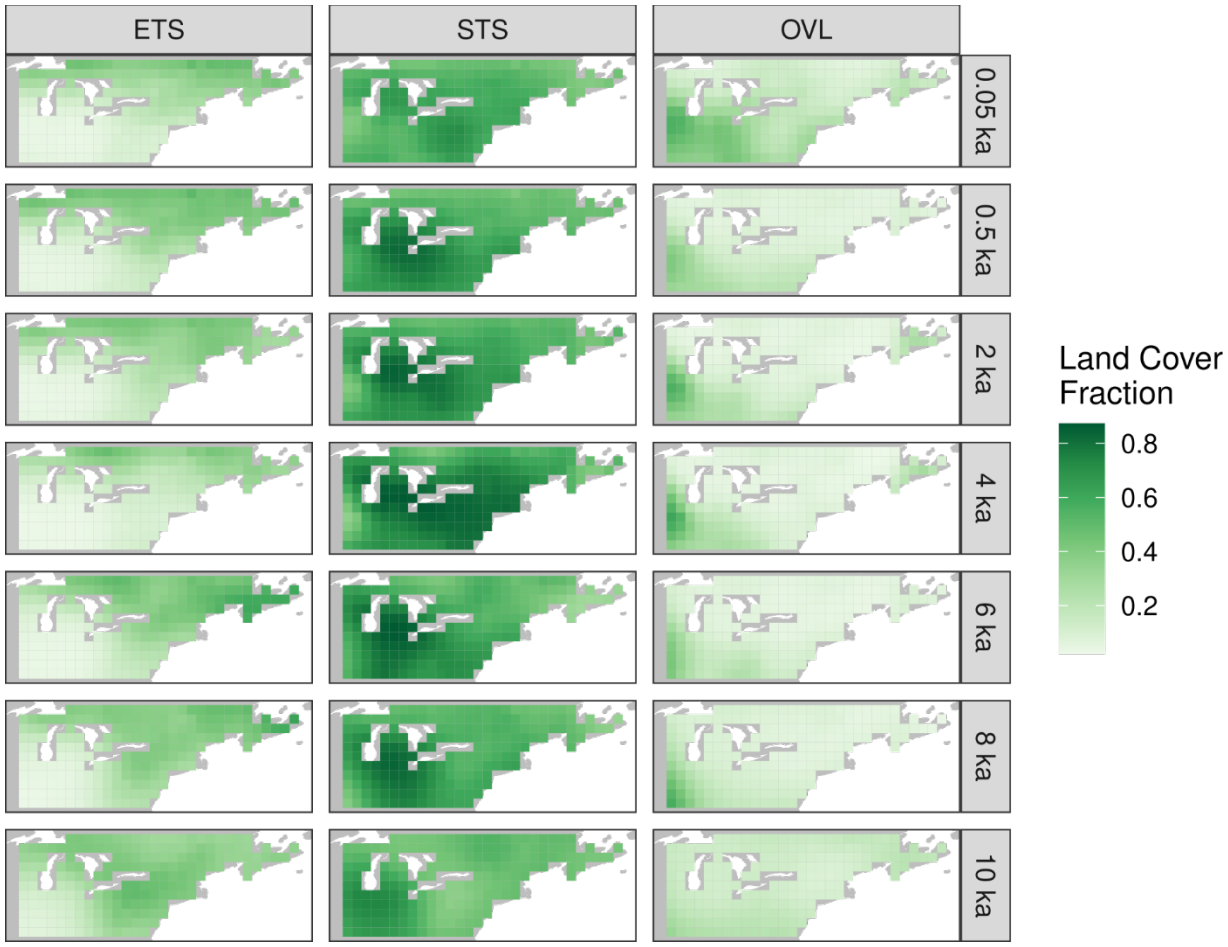
Supplementary Figure 2: Maps of the difference of land cover fraction across indicated time intervals inferred using REVEALS for summergreen trees and shrubs (STS), evergreen trees and shrubs (ETS), and open land (OVL). Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom. Ice extent shown for the older period in light grey, and the younger period in darker grey.



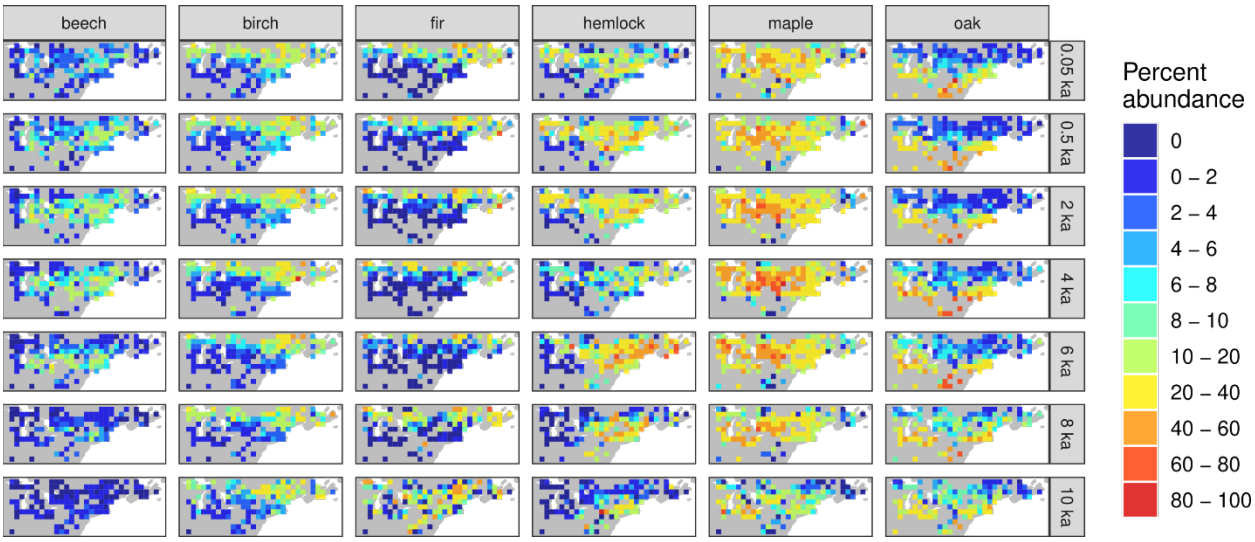
Supplementary Figure 3: Maps of the difference of REVEALS-GMRF interpolated land cover fraction across indicated time intervals for summergreen trees and shrubs (STS), evergreen trees and shrubs (ETS), and open land (OVL). Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom. Ice extent shown for the older period in light grey, and the younger period in darker grey.



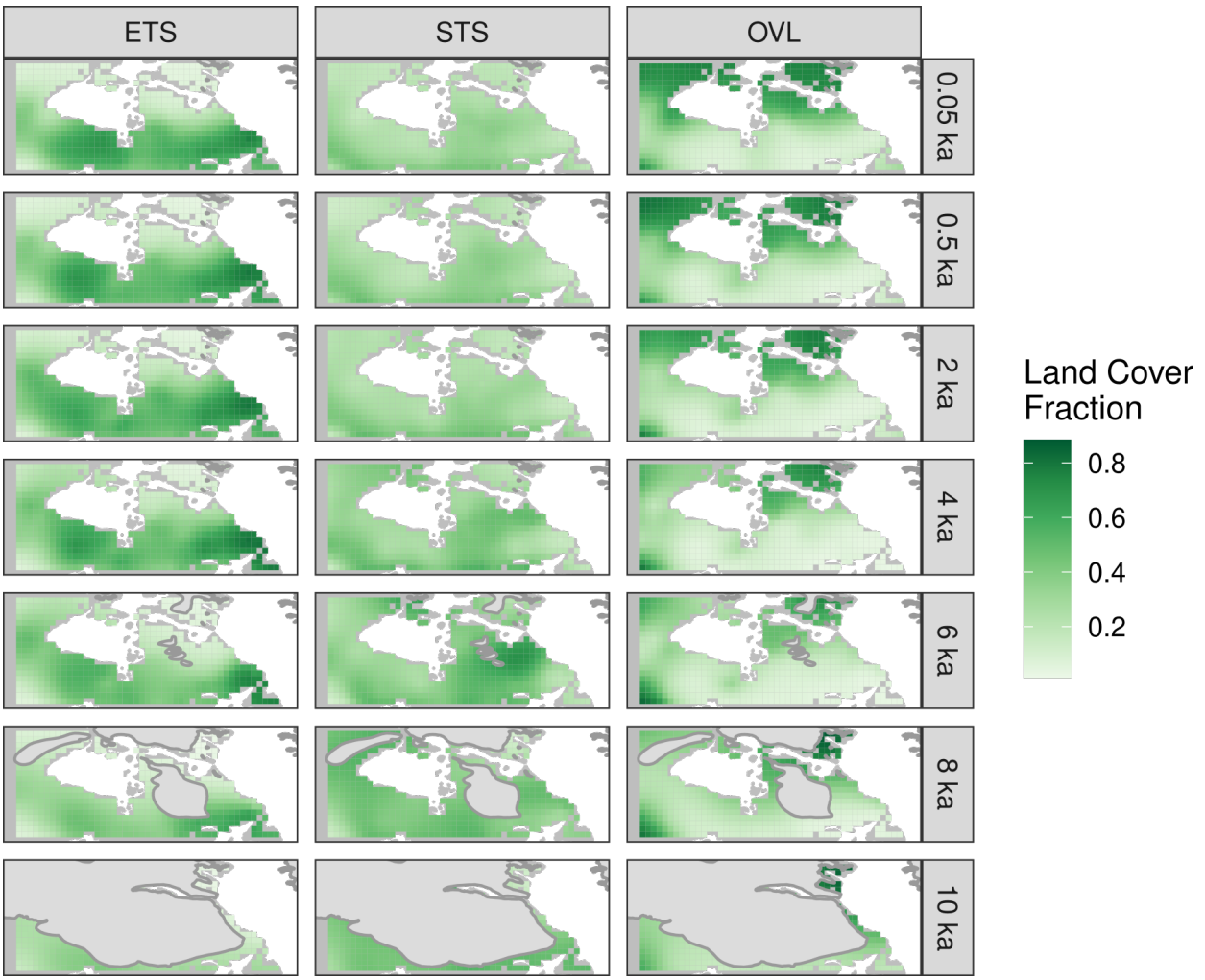
Supplementary Figure 4: Maps of the difference of REVEALS-GMRF interpolated land cover fraction across indicated time intervals for summergreen trees and shrubs (STS), evergreen trees and shrubs (ETS), and open land (OVL). Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom. Ice extent shown for the older period in light grey, and the younger period in darker grey.



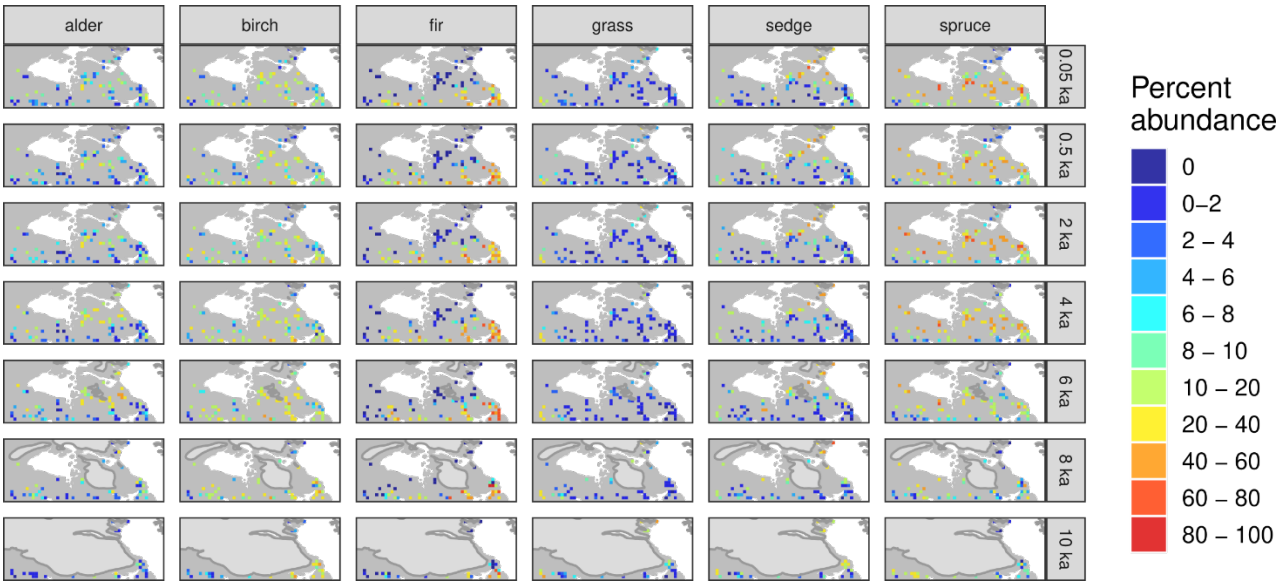
Supplementary Figure 5: Interpolated REVEALS-based estimates of fractional cover for evergreen trees and shrubs (ETS), summergreen trees and shrubs (STS), and open land (OVL) for the Northeastern US & Southeastern Canada (NEUS/SEC) case study region. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.



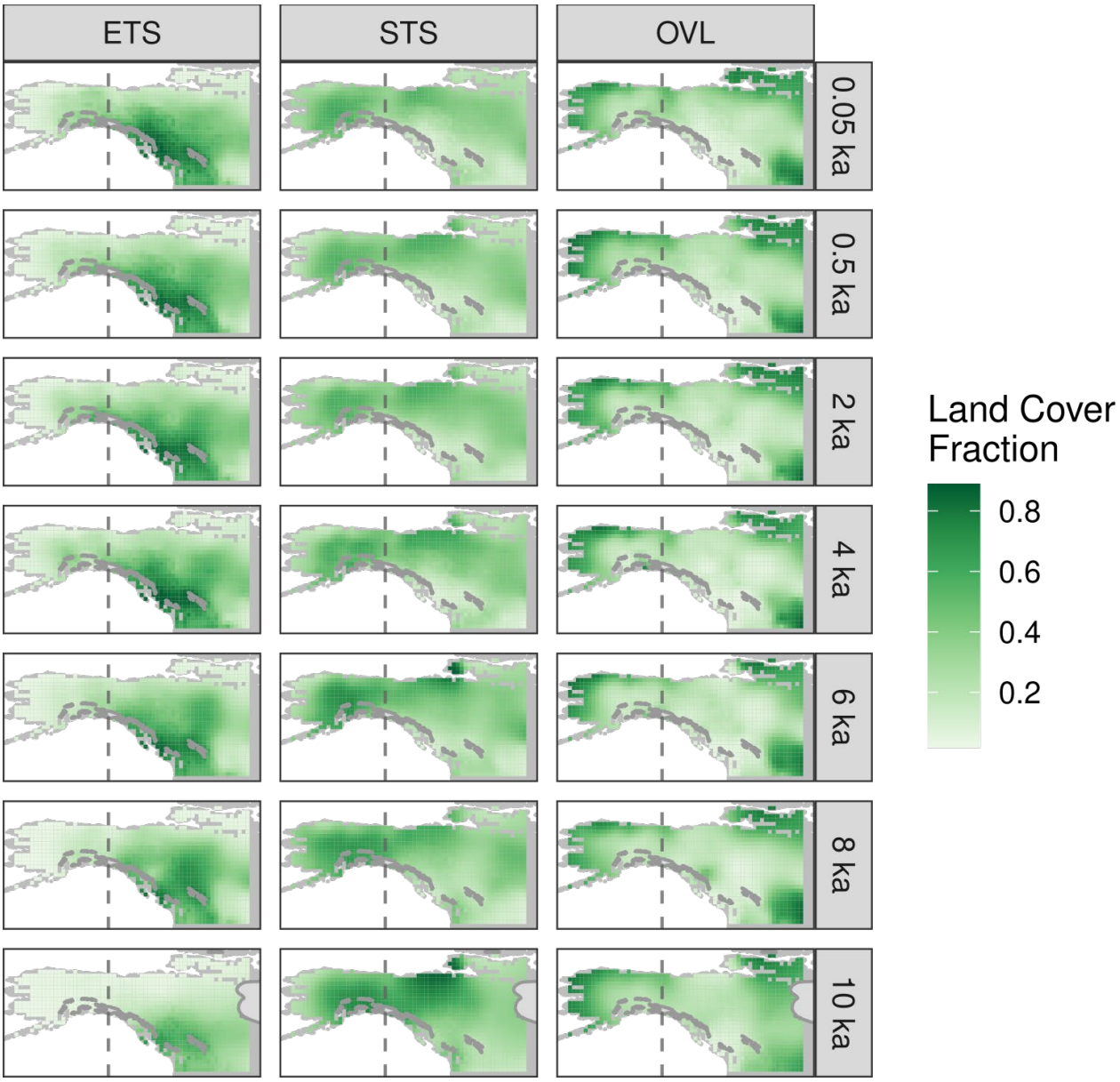
Supplementary Figure 6: Maps of taxon percent abundance inferred using REVEALS for beech, birch, fir, hemlock, maple, and oak for the Northeastern US & Southeastern Canada (NEUS/SEC) case study region. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.



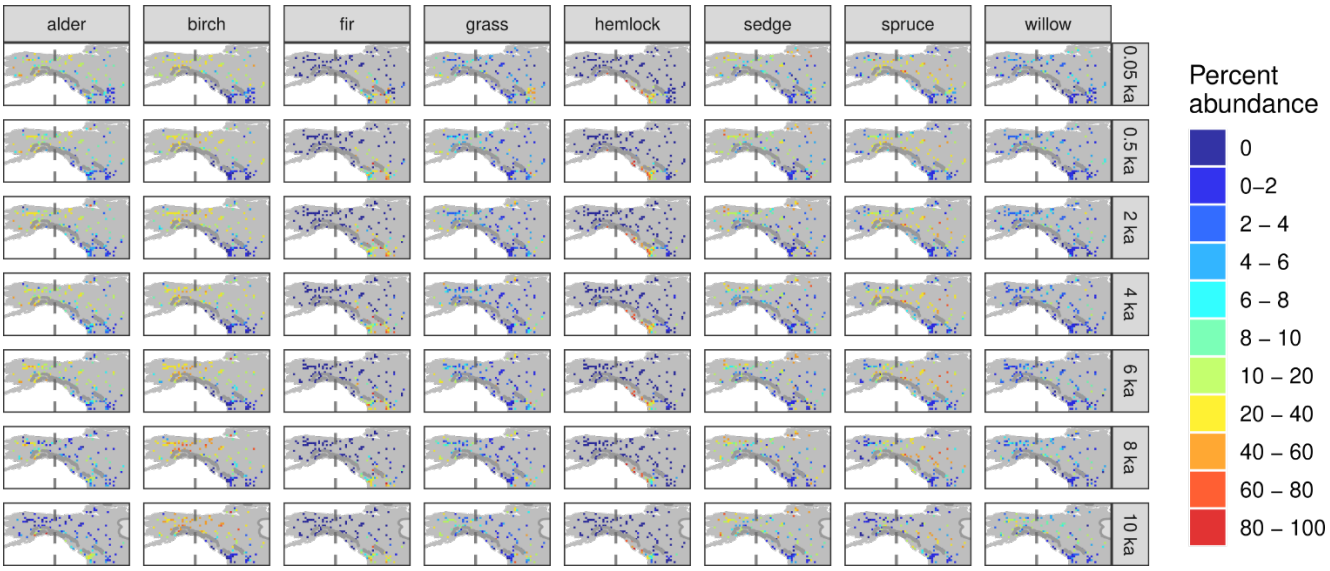
Supplementary Figure 7: Interpolated REVEALS-based estimates of fractional cover for evergreen trees and shrubs (ETS), summergreen trees and shrubs (STS), and open land (OVL) for the Eastern Canada (ECAN) case study region. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.



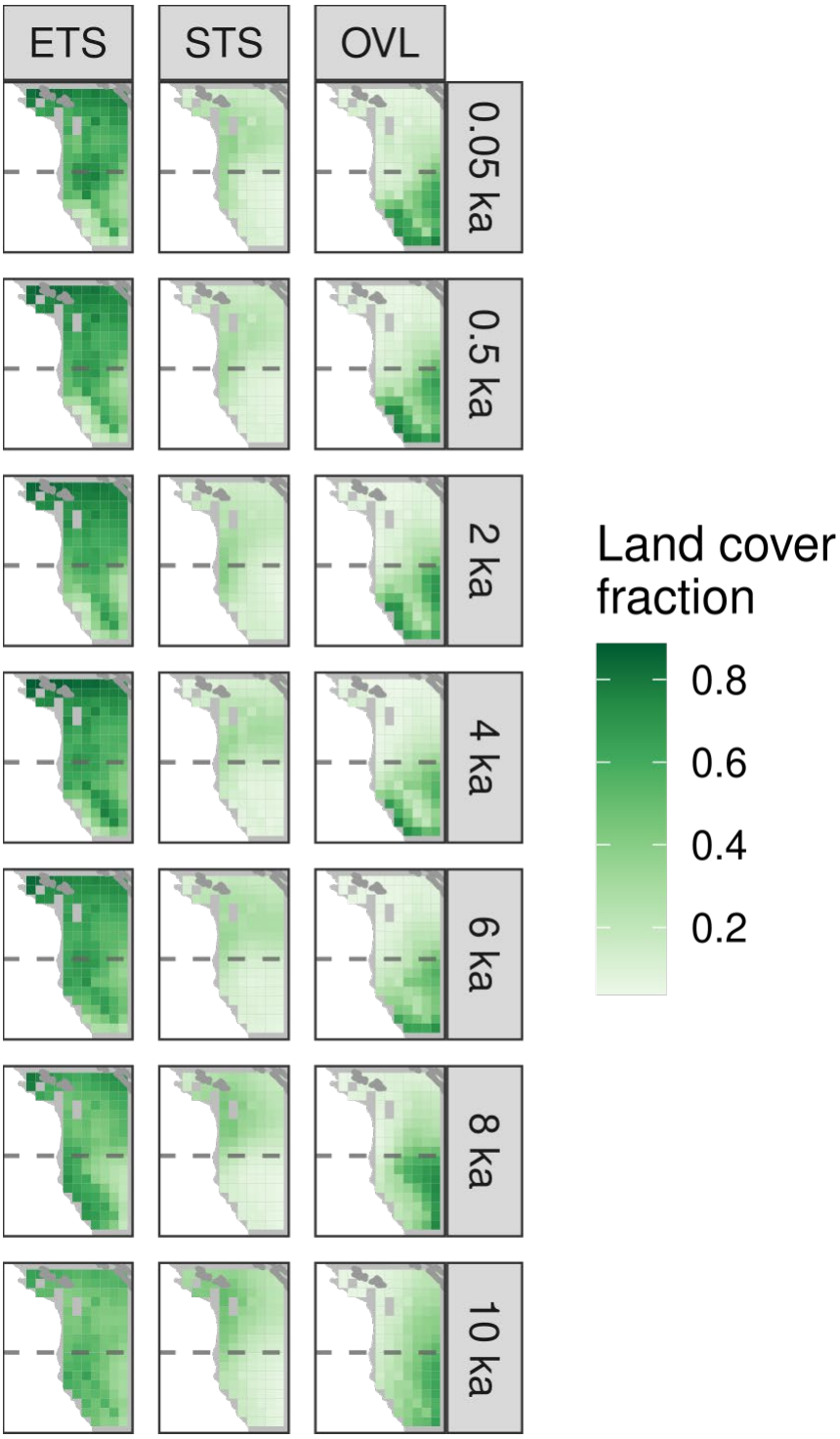
Supplementary Figure 8: Maps of taxon percent abundance inferred using REVEALS for alder, birch, fir, grass, sedge, and spruce for the Eastern Canada (ECAN) case study region. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.



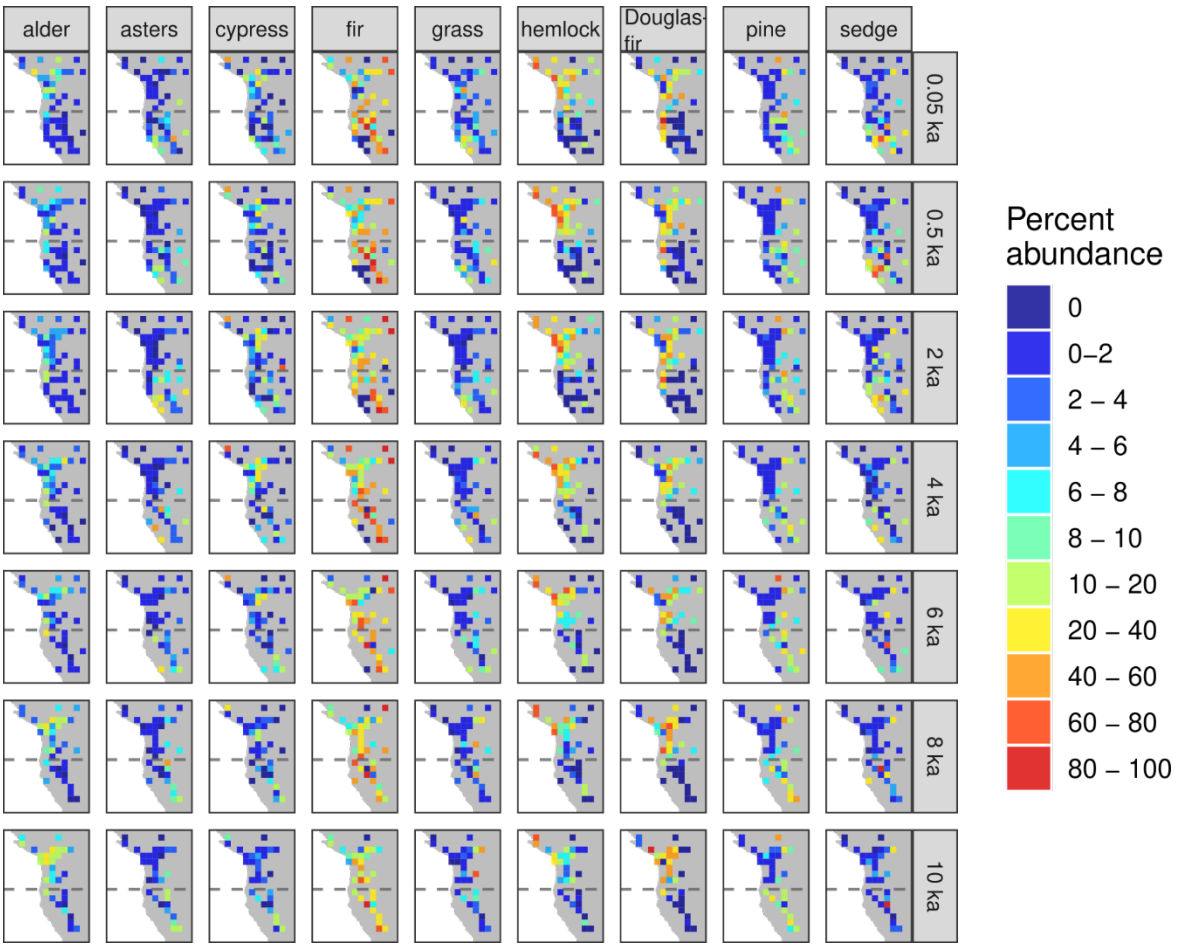
Supplementary Figure 9: Interpolated REVEALS-based estimates of fractional cover for evergreen trees and shrubs (ETS), summergreen trees and shrubs (STS), and open land (OVL) for the Western Canada and Alaska (WCAN/AK) case study region. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.



Supplementary Figure 10: Maps of taxon percent abundance inferred using REVEALS for alder, birch, fir, grass, sedge, and spruce for the Western Canada and Alaska (WCAN/AK) case study region. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.



Supplementary Figure 11: Interpolated REVEALS-based estimates of fractional cover for evergreen trees and shrubs (ETS), summergreen trees and shrubs (STS), and open land (OVL) for the Pacific Coast, Cascade, and Sierra Nevada Ranges (PCCS) case study region. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.



Supplementary Figure 12: Maps of taxon percent abundance inferred using REVEALS for alder, asters, cypress, fir, grass, hemlock, larch, pine, and sedge for the Pacific Coast, Cascade, and Sierra Nevada Ranges (PCCS) case study region. Estimates are presented on a 1°x1° grid, for selected time periods, with ages reported as ka. Map ordering follows the geological convention of oldest maps at bottom.