Supplementary material 1

to

Patterns in modern and Holocene pollen accumulation rates across Europe; A Database of modern values as a resource for vegetation reconstructions

Biogeosciences

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Tables:

Table S1: Excluded trap samples and trap sites for all analysis

Site	year	due to:
CZE/HSS/SA10	1997	*Picea, Abies*
GEOR/EK/T4	1999	*Fagus*
GRE/TIM3	2010	*Abies*
CH/WVDK/A0	whole site	Cyperaceae (1997)
PL/AN/W2	2000	*Carpinus, Fraxinus*
RUS/PL3	2011	*Alnus*
RUS/PL4	whole site	*Alnus* (2011), *Picea* (2012)
RUS/PL5	2016	*Betula*
RUS/PL6	whole site	*Betula* (2016)
RUS/ZV3	2016	*Betula*
RUS/ZV3	2012	*Tilia*
S/TG/AS	whole site	sediment trap
S/TG/HS1	whole site	sediment trap
S/TG/HS2	whole site	sediment trap
S/TG/KS1	whole site	sediment trap
S/TG/KS2	whole site	sediment trap
S/TG/RS	whole site	sediment trap
S/TG/STS	whole site	sediment trap
S/TG/STT	whole site	2003 unreliable
S/TG/SVS	whole site	sediment trap
S/TG/TS	whole site	sediment trap
UK/HP/CC7	whole site	*Quercus, Corylus*

Table S2: Andersen's correction factors

taxa	correction factor
Abies	1
Alnus	0.25
Betula	0.25
Carpinus	0.33
Corylus	0.25
Cyperaceae	1
Fagus	1
Fraxinus	2
Pinus	0.25
Poaceae	1
Quercus	0.25
Tilia	2
Ulmus	0.5

Table S3: List of taxa and sites, where second highest class of fossil PAR was used for the link with modern analogues

taxa	fossil sites
Abies	Malá niva
Alnus	Arkutino 2, Bachalpsee
Betula	Abborrtjärnen, Akuvaara, Prášilské
Carpinus	Shabla, Suminko
Corylus	Malá niva, Rõuge Tõugjärv, Shabla, Suminko
Fagus	Malá niva, Ribno
Fraxinus	Bachalpsee, Shabla, Voulkaria
Juniperus	Abborrtjärnen, Toskaljavri
Picea	Abborrtjärnen, Malá niva
Pinus	Bachalpsee, Malá niva, Prášilské, Tsuolbmajavri
Poaceae	Arkutino 2, Bachalpsee, Malá niva, Prášilské, Rõuge Tõugjärv
Quercus	Sägistalsee, Shabla
Tilia	Rõuge Tõugjärv
tree PAR	Prášilské, Rõuge Tõugjärv, Sägistalsee

Table S4: Adjusted R^2 between logarithm of total PAR (or alternatively logarithm of adjusted total PAR) and selected environmental variables.

	PAR	adjusted PAR
Latitude	0.11	0.38
MAT	0.21	0.35
Forest biomass 10 km	0.72	0.81
latitude+MAT+Forest biomass 10 km	0.76	0.81
latitude+MAT+Forest biomass 10 km+elevation	0.73	0.82

Figures and text

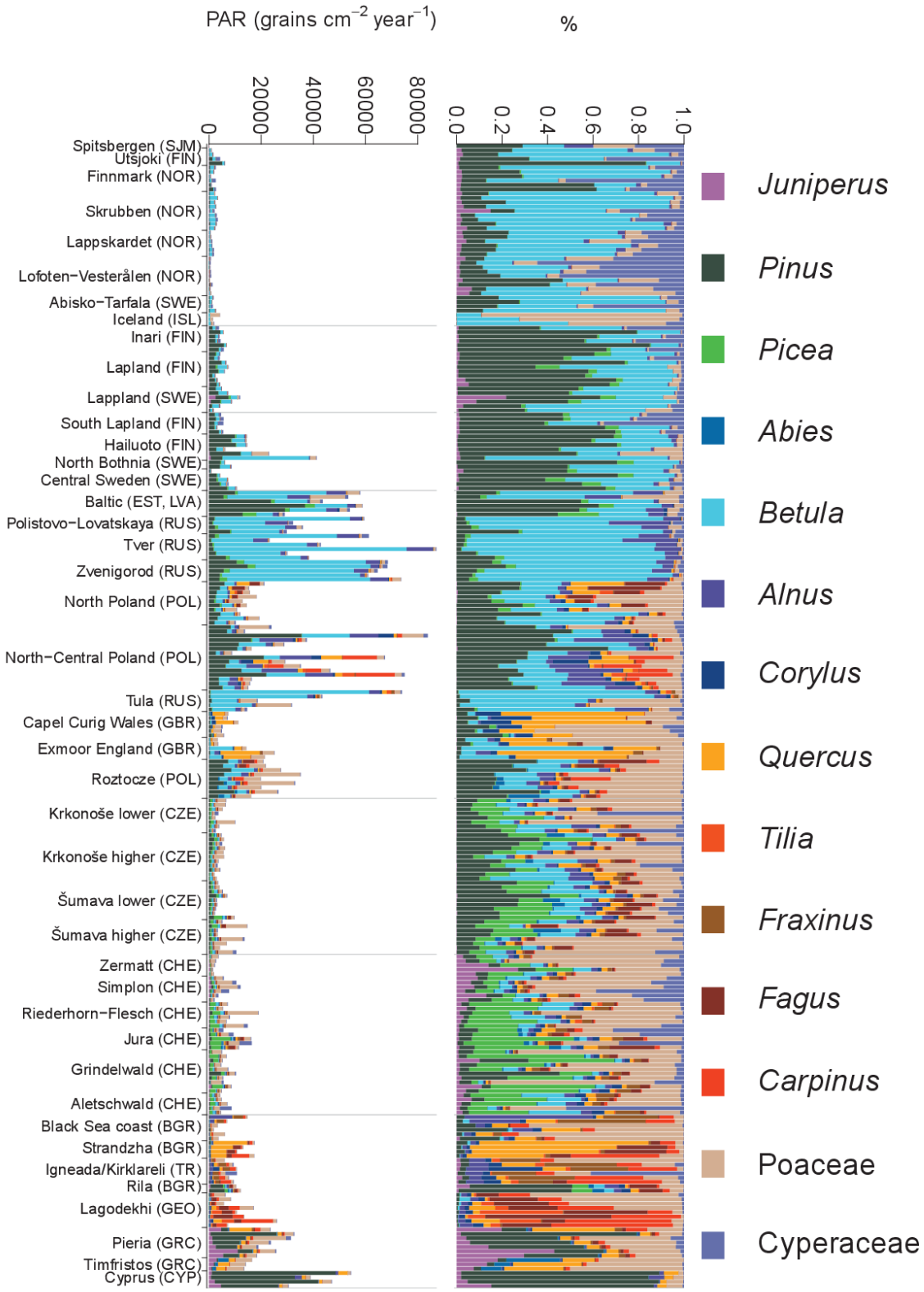


Fig. S1: Absolute and relative average composition in individual traps arranged from north (top) to south (bottom).

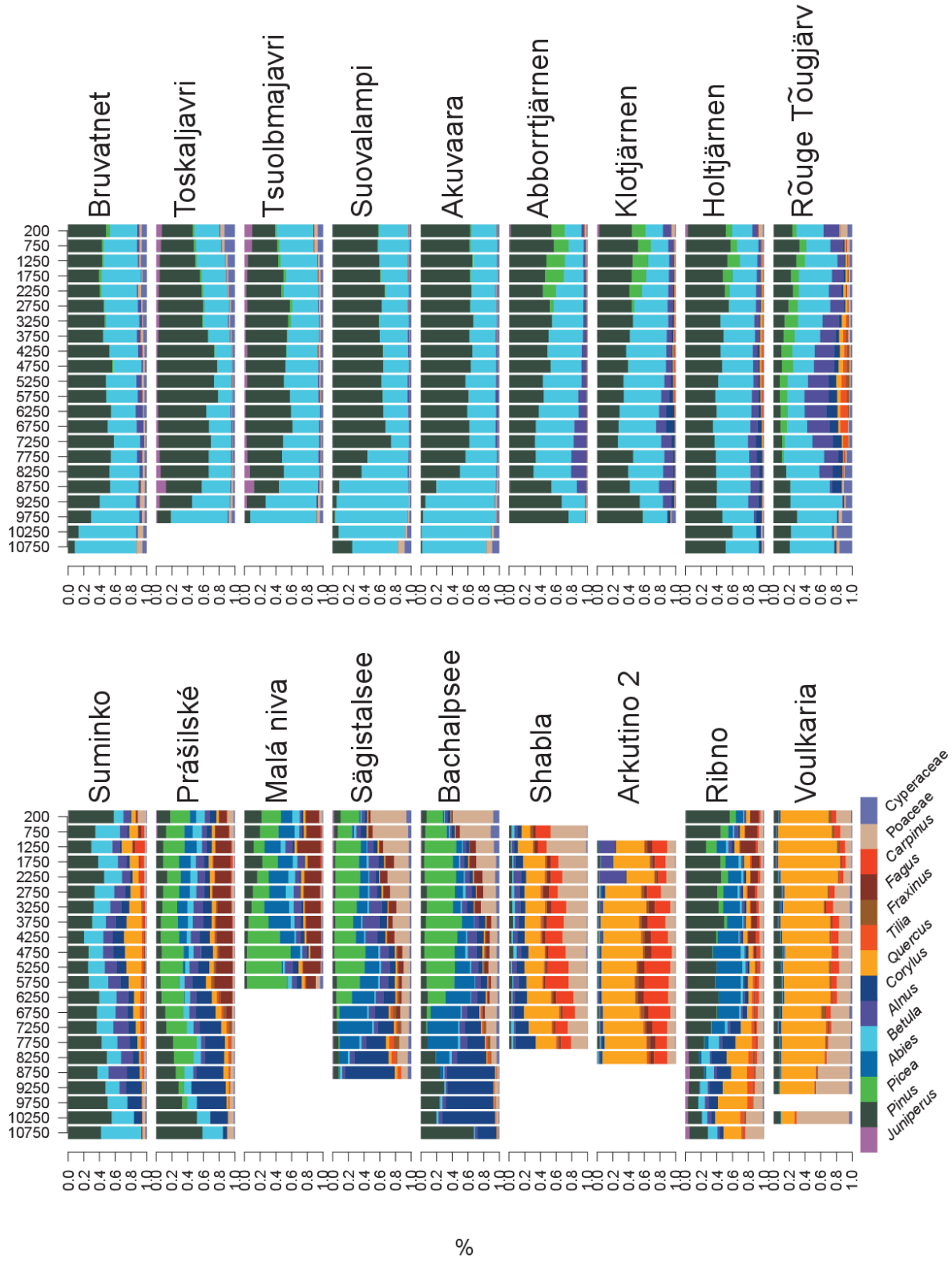


Fig. S2: Relative pollen composition of fossil sites.

Taxa specific linkage of the highest average PAR at fossil sits with individual trap values

Alnus

Since *Alnus viridis* was well distinguished in the Alps, *A. glutinosa* and *A. incana* are the only species considered contributing to the pollen type in north and central Europe. Particularly high fossil PARs of *Alnus* represent mainly *Alnus glutinosa* as this tree is frequently found on waterlogged soils near lakes and wetlands. The highest modern values between 2200-13500 grains cm^{-2} y^{-1} are present in pollen traps from North-central Poland, Baltic´s, European Russia as well as from the Black sea coast and Cyprus. Except for the traps on the island of Hailuoto, pollen traps north of 60-degree latitude collected 2-360 grains cm^{-2} y^{-1}, even if most of these pollen traps are still within the distribution of *Alnus glutinosa* or *A.incana*. Similarly, low values are collected by pollen traps at high elevations in the Alps, which collect pollen originating from lowland populations of *Alnus glutinosa*. Thus, if PARs above 1000 grains cm^{-2} y^{-1} are encountered they may be interpreted as *Alnus glutinosa* dominated wetlands near a fossil site. Like other thermophilus trees the distribution of *Alnus glutinosa* also shifted southwards in Scandinavia during the Late Holocene. This is documented by the linkage between fossil values from central Sweden and modern PARs from Poland.

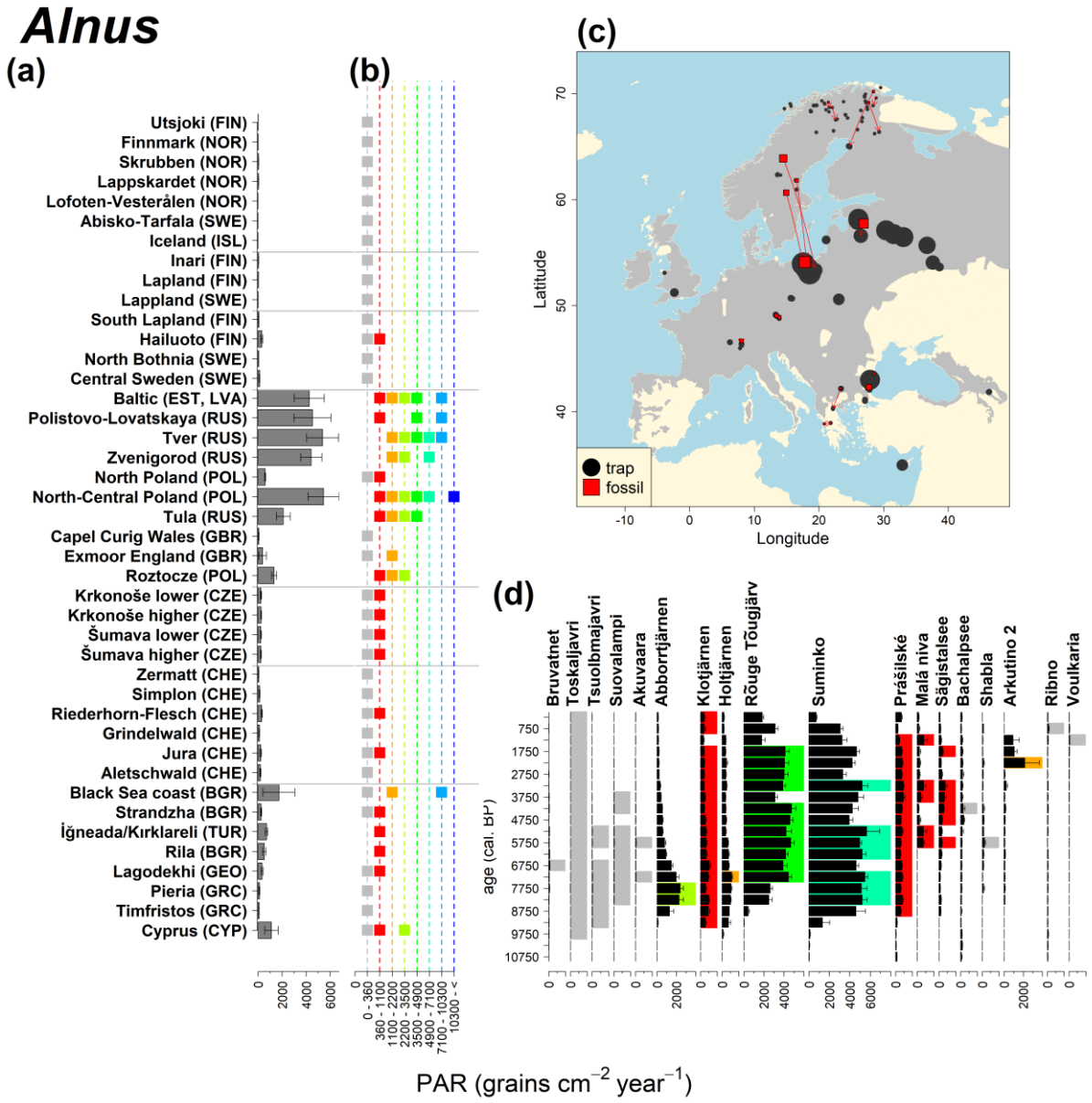


Fig. S3: Mean modern PARs averaged for each trap area. b) Range of mean individual trap values classified by one-dimensional clustering. Crossed squares indicate that pollen of the taxon was not found in any trap from the area. c) Map of Europe with the distribution of the species (Caudullo et al., 2018; Kempeneers et al., 2012; San-Miguel-Ayanz et al., 2016) falling within the pollen taxa, size of symbols shows classes of PAR in recent and the highest PAR per each fossil record. Arrows show the closest trap with the same class of PAR. d) Fossil PAR values with the highest PAR class per each record highlighted by the corresponding colour for the class (see b) Note the scale of the x-axis corresponds to the x-axis scale of graph a).

Carpinus

Highest recent PARs for *Carpinus* of 540-15000 grains cm^{-2} y^{-1} are found in pollen traps from three very distant areas: Poland, south-east Europe and Georgia. The signal in Poland is produced solely by *Carpinus betulus* while *C. orientalis* and *Ostrya* occur in the latter two areas. High fossil PARs of 540-1700 grains cm^{-2} y^{-1} occur in sites near the Black Sea coast and find matches with modern trap values from that area even though the fossil abundances decline towards the present. PARs 1700-2900 grains cm^{-2} y^{-1} are estimated for Suminko in northern Poland and here modern situations in the same region also result in similar values of *Carpinus* pollen deposition. Individual *Carpinus* pollen grains were encountered in pollen traps more than 200 km from the distribution while the values in several traps within or near the distribution of parent tree species often stayed below 160 grains cm^{-2} y^{-1}.

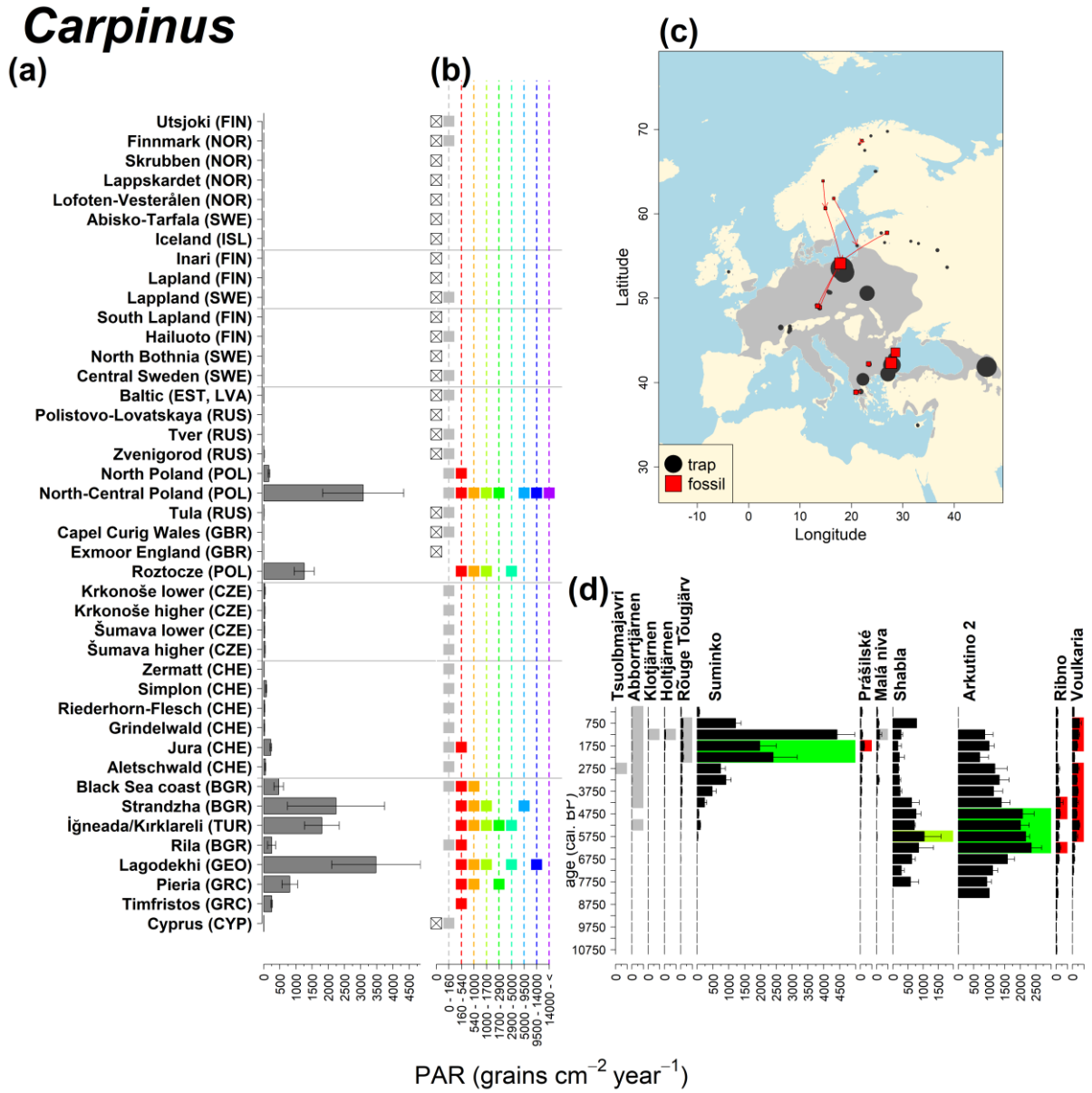


Fig. S3: continued

Cyperaceae

Modern PARs do not show a strong spatial pattern and values ranging between 470-4700 grains cm^{-2} y^{-1} occur in all regions from northern Scandinavia to Turkey, likely reflecting the local vegetation at the vicinity of the pollen trap. Fossil values are generally much lower than the high modern values, which may be partly explained by individual plants growing over the pollen trap with the pollen dropping directly into the pollen trap. Such local situations would influence individual traps within an area explaining the high range of values per trapping area. The high Early Holocene values at Rõuge Tõugjärv around 1500 grains cm^{-2} y^{-1} stand out and are in the range of generally high modern trap values. Perhaps these high fossil values document the fluvial input of *Cyperaceae* pollen from adjacent wetlands.

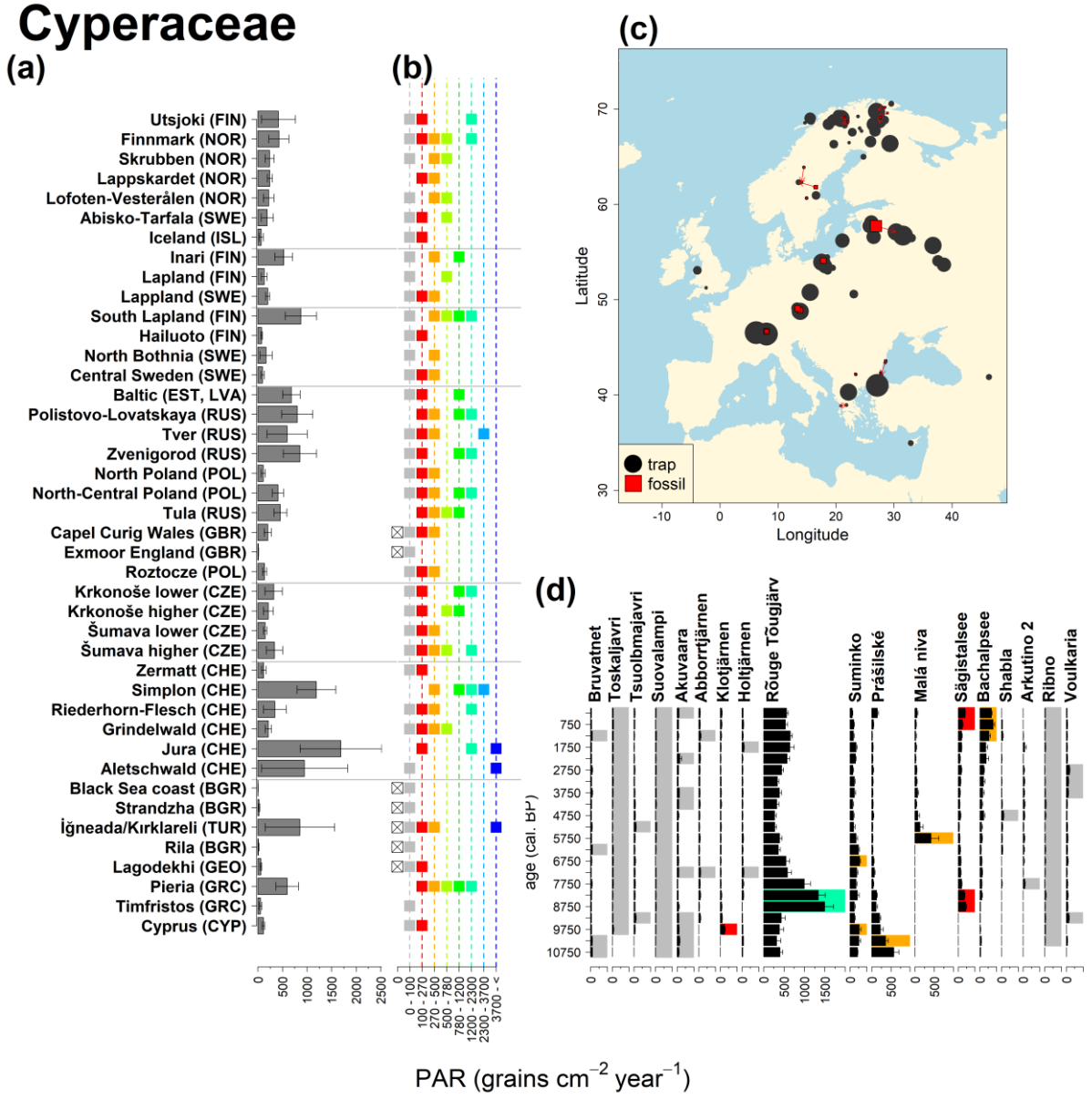


Fig. S3: continued

Fraxinus

Highest PARs of *Fraxinus* 1800-3500 grains cm^{-2} y^{-1} were monitored in stands of *F. angustifolia* near the Black Sea coast and in European Turkey. Both areas also host the rest of the European *Fraxinus* species (*F. excelsior, F. pallisea* and *F. ornus)*. Maximal PAR of solely *F. excelsior* 850-1800 grains cm^{-2} y^{-1} are found in pollen traps from southern England and Tula (Russia). Fossil PARs from Prášilské (Šumava), Suminko (north Poland), Rõuge Tõugjärv (Estonia) show maxima with up to 290-1800 grains cm^{-2} y^{-1} during the Middle Holocene, which correspond to the average deposition in pollen traps from the Jura and Tula region in Russia. Modern PARs in Šumava and Estonia are lower than fossil values consistent with the interpretation that this warmth demining tree has shifted its distribution limit south and downslope. PARs above 100 grains cm^{-2} y^{-1} occur at most traps within the distribution of the genus, while traps outside the range collect individual grains of *Fraxinus* pollen.

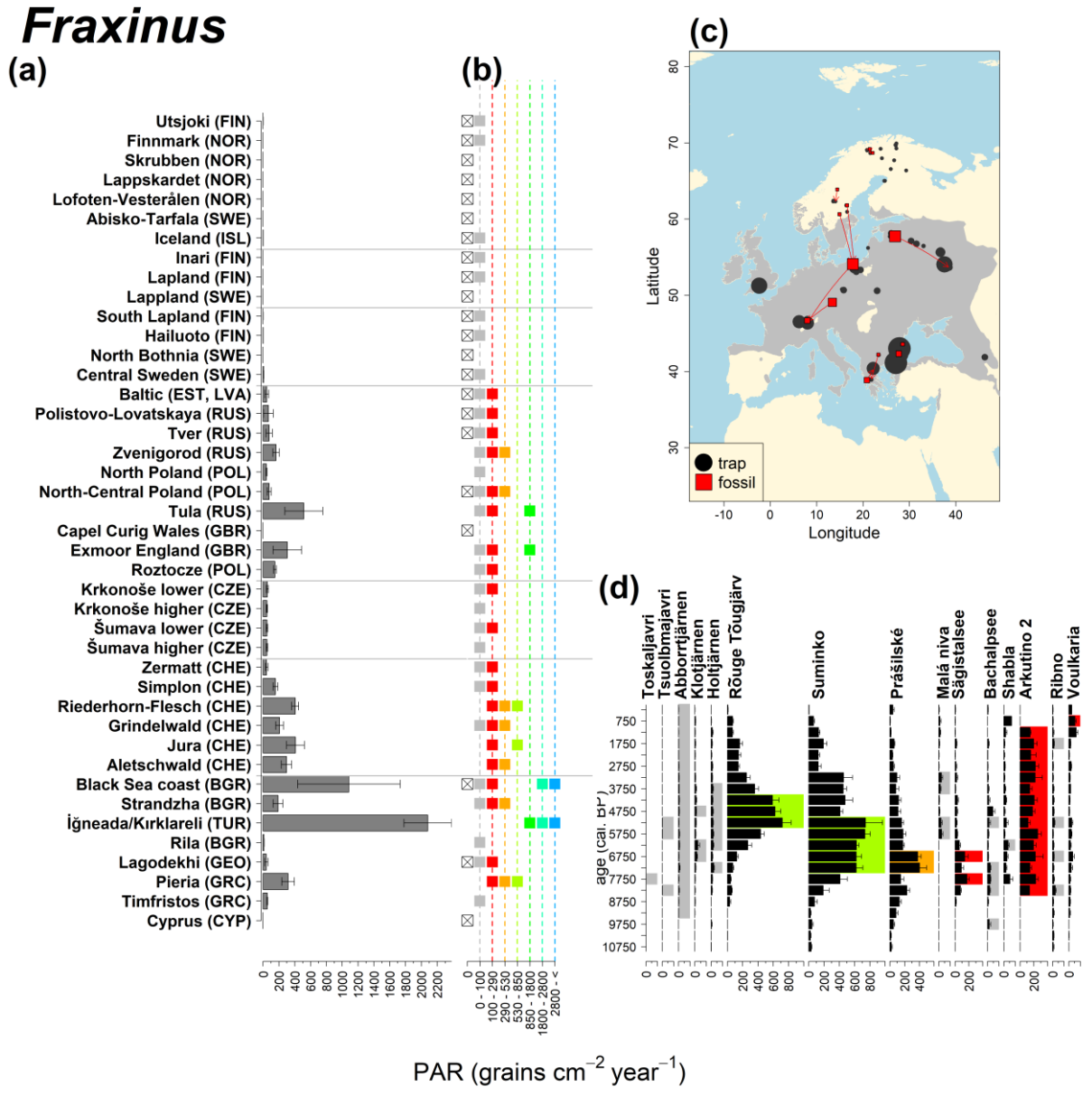


Fig. S3: continued

Juniperus

Highest modern PARs above 870 grains cm^{-2} y^{-1} come from treeline situations in Lapland, the Alps and on mountains in Greece and Cyprus. While *Juniperus communis* is the only species in the genus in northern Europe the genus has more species occurring in southern Europe and also pollen of *Cupressus sempervirens* or other ornamental Cupressaceae may be included. Fossil values from the sites selected here range below 370 grains cm^{-2} y^{-1} and date to the early Holocene and the last centuries. Late Glacial pollen records from central and western Europe often show distinct peaks in *Juniperus* pollen either at the time of forest establishment during the Bølling-Allerød and/or during the climate-induced opening of the forest in the Younger Dryas. These peaks may reach values of 4000 to 10,000 grains cm^{-2} y^{-1} (e.g. Soppensee, Lotter 1999) and thus even the closest situations at the treeline do not hold as dense a population of *Juniperus* as must have been present at Late Glacial situations.

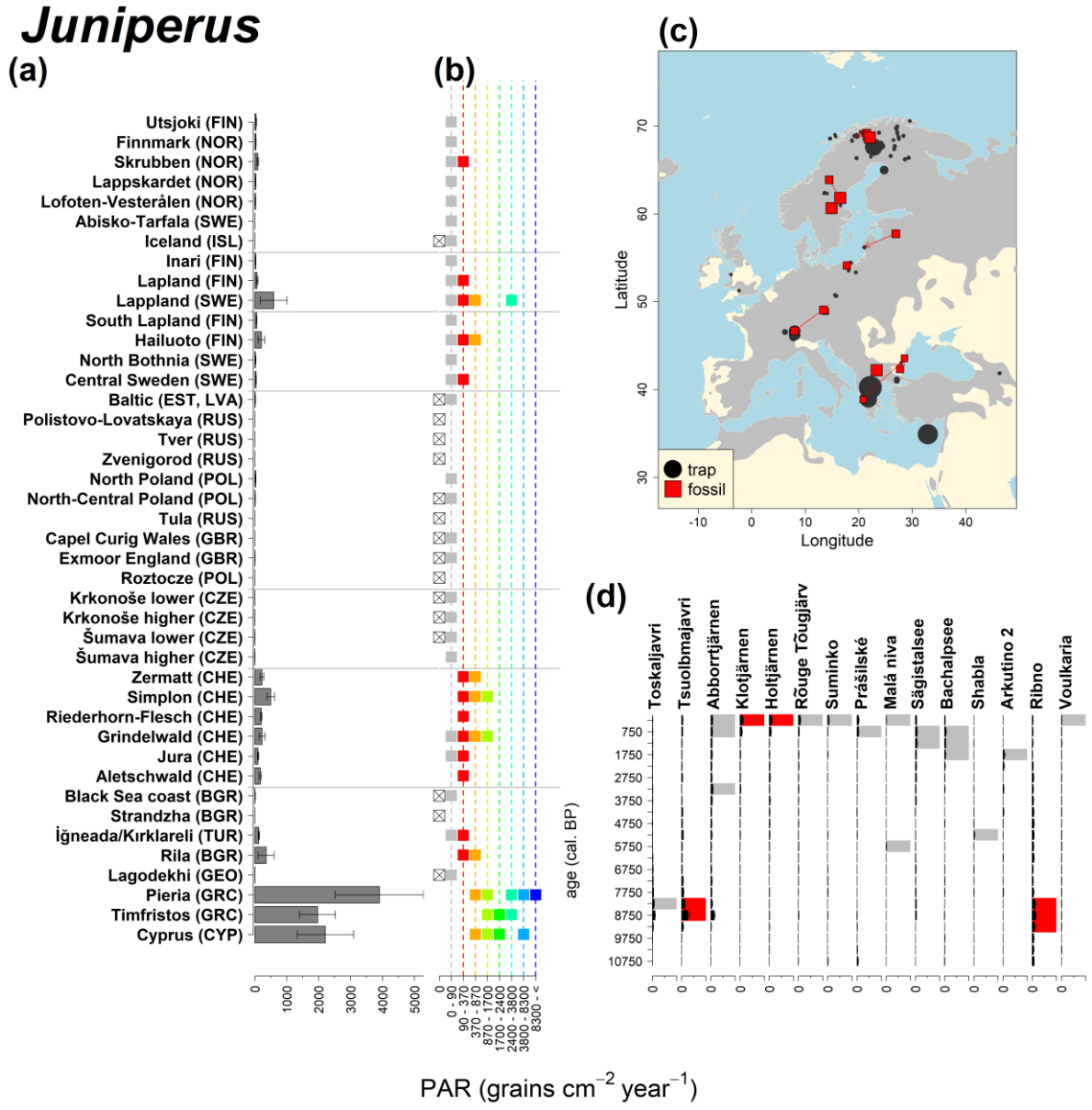


Fig. S3: continued

Poaceae

As for Cyperaceae, more Poaceae pollen is deposited in the pollen traps compared to fossil PAR estimates. Pollen traps near the Black Sea coast in northern Bulgaria are placed in situations where tree cover may be naturally low due to shallow soils on limestone. Traps from this area reach average values of up to 5300 grains cm^{-2} y^{-1} and may give some guidance on the pollen deposition in low productivity grasslands. Fossil estimates from the two Alpine lakes are interesting as Poaceae PAR increase to values around 1500 grains cm^{-2} y^{-1} as the treeline recedes to below the sites. The higher values in the pollen traps from this region, as well as elsewhere, are likely due to the local growth of grasses beside the trap, possibly overgrowing it. Poaceae PARs at Rõuge Tõugjärv increase with the deforestation of the area while at Suminko values are generally high during the Holocene also the PAR for other taxa is generally high at the two sites suggesting that these are caused by lake internal processes values. Middle Holocene values between 500 and 1000 grains cm^{-2} y^{-1} at Shabla are consistent with the above interpretation that the vegetation near the Black Sea coast of northern Bulgaria was partly open.

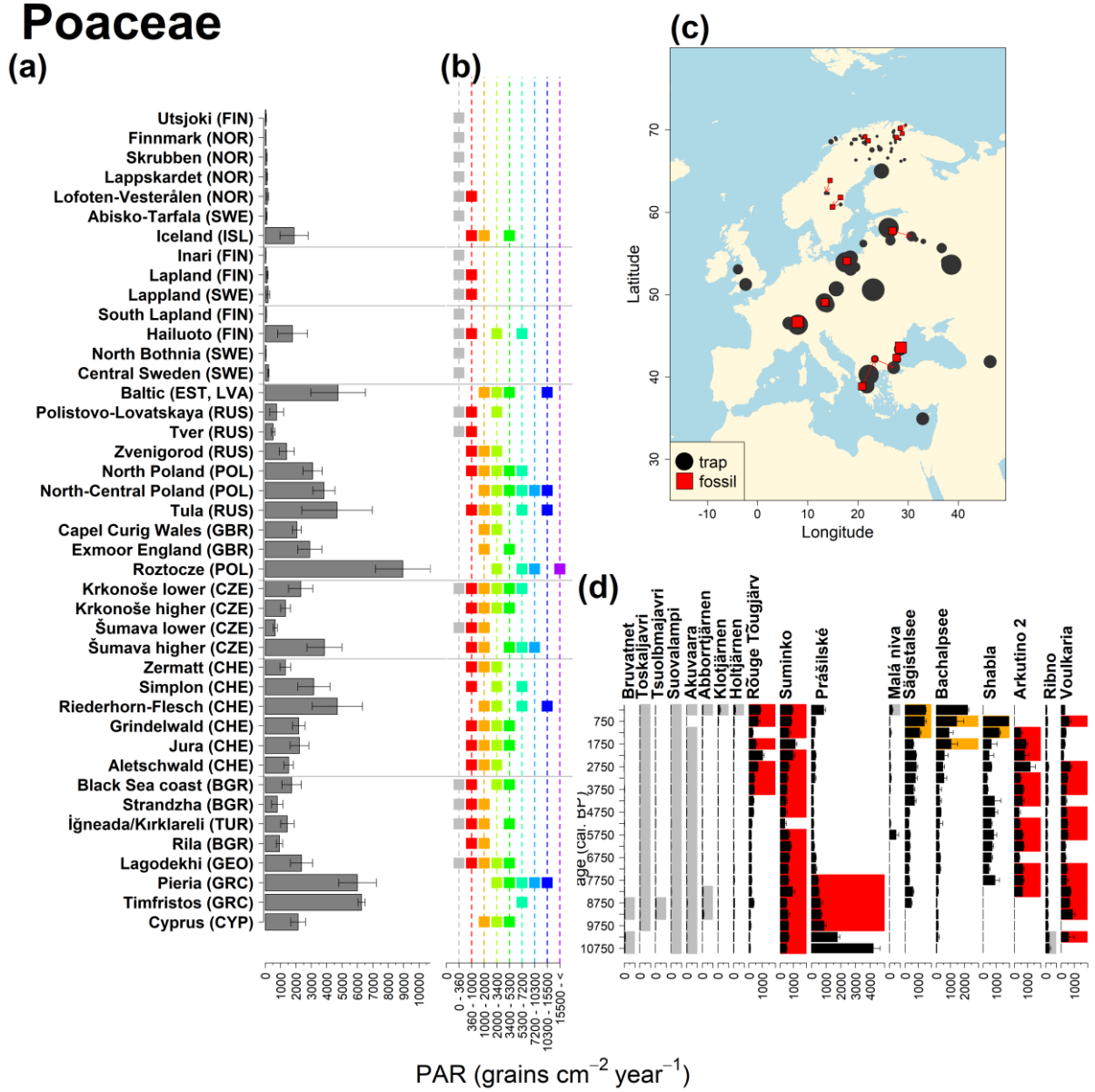
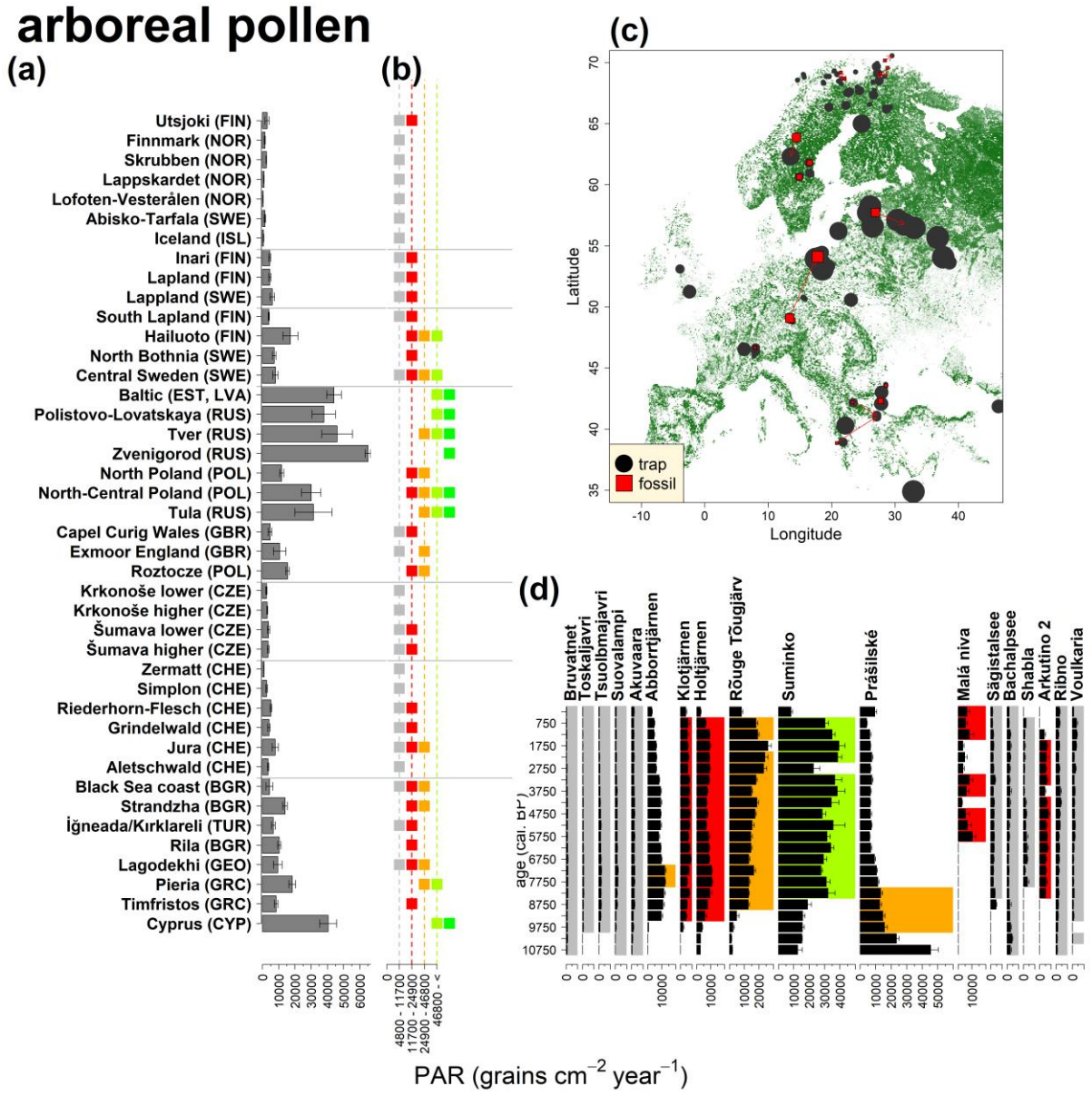


Fig. S3: continued

Trees

Here the minimum rather than the maximum values may be of particular interest as PARs were utilized in early applications to distinguish between generally open and forested landscapes (Davis and Deevey, 1964). Trap areas with the lowest mean arboreal pollen influx below 1000 grains cm^{-2} y^{-1} are Iceland, Lofoten-Vesterålen and Zermatt in the Alps. As discussed within the main manuscript highest tree PARs are found in traps from Poland, the Baltic and Russia with values between 46400-86200 grains cm^{-2} y^{-1}. Such high PARs are not estimated in any of the fossil sites selected here and may be partly due to traps placed under the canopy of trees as well as the recent carbon dioxide fertilization. The highest fossil values are estimated from the sediments of Suminko. PARs for several individual taxa from this site are the highest in comparison with the other selected fossil sites raising suspicion that lake internal processes such as the focussing of sediments in this steep sided basin may be responsible for the high values rather than the exceptional high abundance and pollen production of trees near the site. Also PARs from Rouge Tougjärv may be biased as the small lake has a big incoming stream bringing waterborne pollen to the lake. It is interesting to note that PARs in sites near the latitudinal treeline are like those from the altitudinal treeline in the Alps. The comparably low tree PARs from sites near the Black and Ionian Sea coast may be explained by the



fact that trees are not growing on water and thus a large proportion of the potential pollen source area is not producing any pollen. **Fig. S3:** continued

References

Caudullo, G., Welk, E. and San-Miguel-Ayanz, J.: Chorological maps and data for the main European woody species, figshare, doi:10.6084/m9.figshare.c.2918528.v2, 2018.

Davis, M. B. and Deevey, E. S.: Pollen Accumulation Rates: Estimates from Late-Glacial Sediment of Rogers Lake, Science, 145(3638), 1293–1295, doi:10.1126/science.145.3638.1293, 1964.

Kempeneers, P., Sedano, F., Seebach, L. M., Strobl, P. and San-Miguel-Ayanz, J.: Data Fusion of Different Spatial Resolution Remote Sensing Images Applied to Forest-Type Mapping, IEEE Trans. Geosci. Remote Sens., 49(12), 4977–4986, doi:10.1109/TGRS.2011.2158548, 2012.

San-Miguel-Ayanz, J., Rigo, D. de, Caudullo, G., Durrant, T. H. and Mauri, A.: European atlas of forest tree species, 2016th ed., Publication Office of the European Union, Luxembourg. [online] Available from: 10.2788/4251, 2016.