Review of the revised manuscript by Schild et al.

Report for the responsible Editor

By Marie-José Gaillard

Dear Editor, dear authors

I focused mainly on the authors' responses to my comments on the first submitted version of the manuscript, and on the implementation of the related revisions. I did read the entire revised manuscript but only partly commented the manuscript for revisions that still need to be done. I provide here general comments on issues that I think require revisions. The authors will have to implement the revisions consistently throughout the text, figures, tables and figure/table captions, and not only in places where I have commented in the revised manuscript. I did not check the authors' responses to the other reviewers but have seen that the authors have considered those comments in the revision.

General comments

The authors have made substantial revisions that were necessary such as deleting the southern hemisphere from the reconstruction and producing REVEALS estimates based on pollen records from several sites within areas (grid cells) of various sizes and for time windows of various lengths. This leads to more acceptable results. I appreciate the hard work made to finalize this revision, but there are still misunderstandings that needs to be clarified in the paper.

1.One of my major concerns is the calculation of REVEALS mean estimates based on the REVEALS reconstructions for several sites within grid cells and several pollen counts within time windows, i.e. the step that the authors call "aggregation" in space and time.

For the **"aggregation" in space** the authors calculate the mean of the individual site REVEALS estimates without any weighting by the K coefficient that is dependent of basin size (the larger the basin, the heavier the weighting should be for each taxon, and vice versa). Such a weighting is implemented in Sugita's REVEALS computer program but not in REVEALSinR. In Sugita's method, the REVEALS estimates from individual sites within a grid cell are weighted with the taxon-specific "pollen dispersal-deposition coefficient K" of all pollen taxa involved, se e.g. Li et al. (2017). This should be clarified under METHODS.

For the **"aggregation" in time** the authors similarly calculate the mean of the individual counted level REVEALS estimates. The reliability of REVEALS estimates depends, among other things, on the size of the pollen count. In this context, the usual size of pollen counts (often around 1000, seldom more, quite often around 500 and sometimes less) is a low pollen count. This implies that all REVEALS estimates in the Schield et al. REVEALS dataset are of relatively low reliability and calculating the mean of these REVEALS estimates does not make them more reliable. All earlier continental Holocene REVEALS reconstructions have worked with time windows of such a length that it would maximize the size of the counts without using too long time windows (generally maximum 500 years). The compromise to make depends on the aim of the study. One has then to <u>sum pollen counts within each time window and use this new pollen count for the REVEALS application to obtain the REVEALS estimates for the time window</u> (see e.g. Githumbi et al., 2022). This procedure is very different from calculating mean REVEALS estimates and is statistically the correct way to do. **I understand that it would be a huge work to redo the work in this way for this manuscript. But this should be listed as one of the many differences between this REVEALS dataset and earlier ones.** I do not know whether the error on REVEALS estimates as calculated by REVEALSinR (see my point below) is sensitive to the size of pollen counts. I guess not, but I can't find anything about this issue in the REVEALSinR original paper or elsewhere. In that case, this is also an aspect that makes REVEALS applications using REVEALSinR weaker if the size of pollen counts is not considered in the error estimate on REVEALS results.

2. Another major difference between implementation of the REVEALS model with the computer programs of Sugita and REVEALSinR of Theuerkauf et al. (2016) is **the calculation of the uncertainties (errors) on the REVEALS estimates**. The REVEALS standard error accounts for the standard errors (or deviations) of the relative pollen productivities for the individual pollen taxa and on the number of pollen counted; i.e. the size of the pollen count matters. The error calculated in REVEALSinR does not consider the RPP errors. I do not mean that the errors from the REVEALSinR program are wrong, but it is a pity not to use the errors on RPPs as this parameter is very influential on the final REVEALS estimate of plant cover. **This difference between the two applications should at least been mentioned.**

3. 80% pollen source area: this information should be presented as an alternative to estimate the size of the region that is represented by REVEALS estimates of plant cover. **Sugita (2007a) who developed the REVEALS model assumes that Zmax is the size of the region represented by REVEALS estimates (see also Li et al., 2017)**. Zmax can only be assumed (you assumed it to be 1000 km over the entire study region) and the region from which most of the pollen are coming (in your case 80%) can be estimated. See also Hellman et al., 2008b (in VHA) who assumed Zmax to be 400 km (distance from the pollen site) in S Sweden and the 90% source area (200 km) was considered to be the area from which most of the pollen came. **One should therefore state that the assumed value for Zmax influences the estimate of x% pollen source area**. Please, **also specify what dispersal model you use, the Gaussian Plume Model or the Lagrangian Stochastic Model, for estimating your 80% pollen source area, which makes also a difference** (see Theuerkauf et al., 2016).

Two additional comments, minor but still important:

4. Avoid the term reconstruction for pollen percentages or raw pollen data. These are simply data, pollen% are not a reconstruction of vegetation, they are proxy data of vegetation, while a traditional narrative interpreting the pollen percentages using various kind of information is a reconstruction, as REVEALS-based estimates of plant cover is a reconstruction of past plant cover. I advise you to revise this throughout the manuscript, text and Figures. I made comments in the manuscript about that, but not everywhere. Using "reconstruction" for pollen data is misleading, and makes the text difficult to understand in some places.

5. I would use the terms **"(total) tree pollen"** and **"(total) tree cover"** instead of "forest cover" when it refers to pollen % and REVEALS-based estimates of tree cover. It is important to be clear in terms of what you are comparing the satellite vegetation (forest cover) with. If you choose to follow my advice, revise the manuscript consequently. I made comments in the manuscript about that, but not everywhere.

In conclusion:

I miss a description of your new REVEALS dataset for the N Hemisphere in comparison to the earlier continental REVEALS dataset for Europe, China and N America. What is **different** and **what are the improvements**.

1.In terms of what is different in the methodology, **please see my major comments above, and specific comments in the revised manuscript**. Do not forget that you use different chronologies than those used in earlier reconstructions. They might not be so different, but we do not know. **The best solution is to describe all the differences in methodology already in the METHODS section, in the part describing REVEALSinR and in the part describing how you "aggregate" site-specific and level (time)-specific REVEALS estimates to mean REVEALS estimates (level-specific meaning using single analysed levels/samples to run REVEALS.**

2. In my view, the improvements in your REVEALS dataset are:

-You have included in your synthesis the pollen records from the northern hemisphere between Europe and China, those sites that were included in Cao et al (2019) REVEALS reconstruction, and applied REVEALS on them in accordance with the methodology you use for the rest of the Northern Hemisphere.

-Further, it would be informative to know how many pollen records you use overall and in specific continents (Europe, China, N America) for which earlier REVEALS reconstructions exist. For Europe, compare with Serge et al. (2023). In terms of RPP, you should also mention if you use more RPP values than in earlier studies and also clarify that your RPP synthesis is made in a different way (different rules) than those by Githumbi et al. (2022) for Europe and Li et al. (2018) for China. For China, the improvement is that you have added new recent RPP values from recent papers.

-Finally, your new REVEALS dataset should be presented as **an alternative dataset that is more flexible that the earlier continental ones as it allows users to amalgamate the REVEALS estimates in space choosing various sizes of grid cells, and in time choosing various length of time windows.** It should be stated, however, that mean REVEALS estimates over space do not weight the K coefficient according to lake/bog size, and that mean REVEALS estimates over time are not as reliable as REVEALS estimates based on the total pollen count in a time window (see my comment above). With flexibility you loose reliability. **This should be clarified for the users.**

LegacyVegetation 1.0: ~~Global~~ Northern Hemisphere reconstruction of vegetation composition and forest cover from pollen archives of the last ~~50~~ 14 ka

Laura Schild[1,2], Peter Ewald[1,2], Chenzhi Li[1,2], Raphaël Hébert[1], Thomas Laepple[1,3], and Ulrike Herzschuh[1,2,4]

[1]Helmholtz Centre for Polar and Marine Research, Research Unit Potsdam, Alfred Wegener Institute (AWI), Germany
[2]Institute of Environmental Sciences and Geography, University of Potsdam, Karl-Liebknecht-Straße 24-25, Potsdam, Germany
[3]MARUM-Center for Marine Environmental Sciences and Faculty of Geosciences, University of Bremen, Germany
[4]Institute of Biochemistry and Biology, University of Potsdam, Karl-Liebknecht-Straße 24-25, Potsdam, Germany

Correspondence: Ulrike Herzschuh (ulrike.herzschuh@awi.de)

Abstract. With rapid anthropogenic climate change future vegetation trajectories are uncertain. Climate-vegetation models can be useful for predictions but need extensive data on past vegetation for validation and improving systemic understanding. Even though pollen data provide a great source of this information, the data is compositionally biased due to differences in taxon-specific relative pollen productivity (RPP) and dispersal.

Here we present a Northern Hemisphere reconstruction of quantitative regional vegetation cover from a ~~global~~ sedimentary pollen data set for the last ~~50~~ 14 ka using the REVEALS model to correct for taxon- and basin-specific biases. ~~In a first~~ For the reconstruction, we ~~used previously published ,~~ expanded on a previously published synthesis of continental RPP values. ~~For a second reconstruction, we statistically optimized RPP values for common taxa with the goal of improving the fit of reconstructed forest cover from modern pollen samples with remote sensing forest cover.~~

The data sets include taxonomic compositions as well as reconstructed forest cover for each original pollen sample. ~~Relative~~ 80% pollen sources areas were ~~also calculated~~ calculated for large lakes and are included in the data set~~of the original REVEALS run~~. Additional metadata includes modeled ages, age model sources, basin locations, types and sizes.

The improvements in forest cover reconstructions with the REVEALS reconstruction using ~~original/optimized parameters range from 1/0% (Australia and Oceania/Australia and Oceania) to 58/65~~continental RPP values range from 24% (North America) to 72% (Europe~~/North America~~) relative to the mean absolute error (MAE) ~~in~~ of the pollen-based reconstruction. ~~Optimizations were considerably more successful in reducing MAE when more records and RPP estimates were available. The optimizations were purely statistical and only partly ecologically informed and should, therefore, be used with caution depending on the study matter~~The dataset can be used as a grid with binned and aggregated samples (adjustable script provided on Zenodo; https://zenodo.org/doi/10.5281/zenodo.12800290) or as individual timeseries if the record's basin size exceeds 50 ha.

This improved quantitative reconstruction of vegetation cover is ~~invaluable~~ beneficial for the investigation of past vegetation dynamics and modern model validation. By collecting more RPP estimates ~~for taxa in the Southern Hemisphere~~ especially in

North America and adding more records to existing pollen data syntheses, reconstructions may be improved even further. ~~Both reconstructions are~~ The REVEALS reconstruction is freely available on PANGAEA (see Data availability section).

1 Introduction

Anthropogenic climate change is driving vegetation shifts that could lead to disruptions in ecosystem functions and services, and even trigger feedback effects with other earth system elements (IPCC, 2023; Armstrong McKay et al., 2022). Predicting these changes through modeling is challenging. A sufficient mechanistic understanding of vegetation dynamics and interactions with climate is needed, which requires validation and testing of model data with extensive vegetation data across climatic transitions ~~akin~~ comparable to those anticipated in the future (Dearing et al., 2012). Given the relatively brief duration of available instrumental climate and vegetation data, there is a clear need for long-term ~~environmental~~ vegetation records derived from paleoecological archives that cover broader climatic gradients than modern datasets (Dearing et al., 2010; Dallmeyer et al., 2023).

Pollen data as a direct proxy for paleo-vegetation is especially useful for comparisons with modeled data as it can be used to reconstruct land-use (Fyfe et al., 2015; Davis et al., 2015), biomes (Woodbridge et al., 2014; Prentice et al., 1996), and climate (Herzschuh et al., 2023a, b; Bartlein et al., 2011; Viau et al., 2012). The compilation of pollen data syntheses is essential to aid this purpose (Anderson et al., 2006; Gaillard et al., 2010; Strandberg et al., 2014). Several subcontinental and continental collections of pollen data already exist, spanning regions such as Europe, North America, Africa, Siberia, and China (Fyfe et al., 2009a; Whitmore et al., 2005; Vincens et al., 2007; Cao et al., 2014, 2020) and have been integrated into the global database Neotoma (Williams et al., 2018). To allow for a broader application of pollen data, LegacyPollen 2.0 (Li et al., 2024b) offers a global, harmonized pollen dataset that underwent taxonomic standardization, metadata verification and consistent age modeling (Li et al., 2022a, 2021; Herzschuh et al., 2022). This taxonomic harmonization trades off higher taxonomic resolution of some datasets for equivalence, resulting in overall comparability useful for analyses at large spatial scales. Despite advances in harmonization, the use of pollen data remains limited due to the fact that pollen compositions do not accurately reflect vegetation (Davis, 1963; Prentice, 1985; Prentice and Webb III, 1986). This limitation arises from variations in taxon-specific parameters ~~like~~ such as relative pollen productivity (RPP) and pollen dispersal characteristics, leading to discrepancies between the pollen record and ~~real~~ actual past vegetation. This hinders quantitative vegetation assessment as taxa with high pollen productivity and efficient pollen dispersal tend to be overrepresented in the pollen record, while those with low pollen productivity and less effective dispersal are underrepresented. These factors, together with the compositional nature of pollen data, result in a non-linear relationship between pollen and vegetation (Prentice and Webb III, 1986). Approaches such as the R-value model (Davis, 1963; Webb et al., 1981) and the extended R-value model (Parsons and Prentice, 1981) were created to address this issue and were refined with Sugita's (2007) model for "Regional Estimates of Vegetation Abundance from Large Sites" (REVEALS) . By accounting for taxon-specific RPP and fall speed values, as well as basin-specific parameters such as basin size and type, REVEALS models quantitative vegetation cover in ~~relevant pollen source areas~~ the region surrounding a basin from pollen compositions. The model has been applied in several regional-scale studies ~~(Nielsen et al., 2012; Mazier et al., 2015; Hellman et al., 2008; Nielsen and Odgaard, 2010)~~ (Nielsen et al., 2012; Mazier et al., 2015; Hellman et al., 2008) and multiple validations have demonstrated its ~~accuracy~~ ability in approximating actual vegetation (Sugita et al., 2010; Hellman et al., 2008; Soepboer et al., 2010; Mazier et al., 2012), even though the model's performance heavily relies on accurate taxon-specific parameters. While Wieczorek and Herzschuh (2020) and Githumbi et al. (2022)provide a comprehensive compilation of RPP and fall speed values for taxa of the Northern Hemisphere, the overall availability of RPP studies is still limited and regional variations in RPP values exist (Harris et al., 2020; Broström et al., 2008; Li et al., 2017; Mazier et al., 2012). This makes the application of REVEALS on larger scales particularly challenging. Only some (sub-) continental REVEALS reconstructions are available for Europe ~~(Trondman et al., 2015; Roberts et al., 2018;~~ (Trondman et al., 2015; Roberts et al., 2018; Githumbi et al., 2022; Serge et al., 2023), Asia (Cao et al., 2019; Li et al., 2022b, 2023, 2024a) and North America ~~(Dawson et al., 2018)~~(Dawson et al., 2024). Currently, no global or Northern Hemispheric quantitative vegetation cover reconstructions using REVEALS exist.

With its importance for the assessment of biome stability, carbon storage, climatic feedbacks, and land-use-change, forest cover is an often reconstructed variable ~~(e.g. Fyfe et al., 2015; Githumbi et al., 2021; Serge et al., 2023)~~(e.g. Fyfe et al., 2015; Githumbi et . Due to the global availability of remote sensing data on contemporary forest cover, it also offers good opportunities for the validation of reconstructions (Hjelle et al., 2015; Roberts et al., 2018). Yet, only Serge et al. (2023) and Pirzamanbein et al. (2014) use this opportunity for extensive validation and even improvement of reconstructions from European pollen records. No ~~site-wise validations or attempts at improvements of forest cover reconstructions by adjusting RPP values exist for other regions or on global scales~~grid-cell based validations exist for the Northern Hemisphere.

Here we present ~~global~~ reconstructed quantitative vegetation cover for the Northern Hemisphere from the LegacyPollen2.0 dataset - an updated global taxonomically and temporally standardized fossil pollen dataset of ~~3728~~ 3680 palynological records - using REVEALS spanning ~~primarily the last 50k years, with some records reaching back even further~~the last 14k years. The data sets were created using existing estimates of taxon-specific parameters~~and also applied an optimization approach to improve parameters. Using remote sensing forest cover we adjust RPP values for the ten most common taxa on each continent for better agreement of reconstructed with remote sensing forest cover. The REVEALS reconstructions with original and optimized parameters include~~ . The REVEALS reconstruction includes corrected vegetation compositions as well as reconstructed forest cover.

2 Methods

2.1 Pollen Data Set

The pollen data synthesis LegacyPollen2.0 (Li et al., 2024b) includes ~~3728~~ 3680 temporally resolved records (time-series) distributed globally. Data were collected from individual publications and the Neotoma Paleoecology Database which includes data from the European Pollen Database, the QUAVIDA data base for Australasia, the Latin American Pollen Database, the

African Pollen Database and the North American Pollen database (Flantua et al., 2015; Fyfe et al., 2009b; Giesecke et al., 2014; Lézine et a . An overview of Neotoma records included in LegacyPollen 2.0 and this reconstruction can be found in S1. Sediment and peat cores used for the creation of pollen data are of lacustrine, peat and marine origin. For the REVEALS reconstruction only lake and peat records in the Northern Hemisphere were used (n = 2732) Analogous to the preceding LegacyPollen 1.0 dataset (Herzschuh et al., 2022), the data synthesis involved revising age modeling and taxonomic harmonization for consistency of records. Spatial data coverage of records in the reconstruction is ~~densest in North America (1132~~ dense in Europe (1275 records) and ~~Europe (1451) , sparser~~ North America (1016 records) and sparsest in Asia (~~706) and very scattered in South America (191), Africa (164) and Australia and Oceania (84,~~ 441) (see Fig. 1). The records~~primarily span the last 50 ka with temporal coverage being a lot sparser before 20 ka BP~~' sample density decreases with age (see Fig. 2).

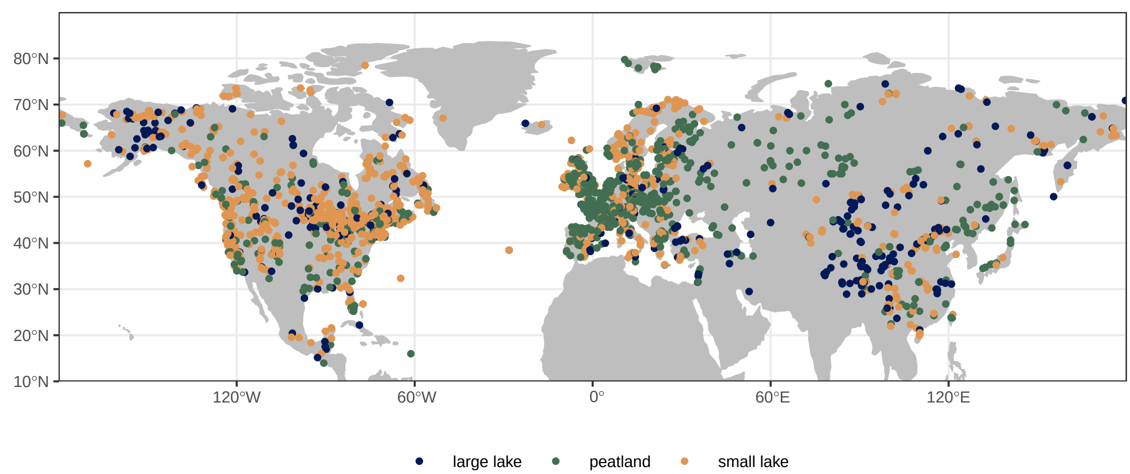

Figure 1. Pollen record locations in the LegacyVegetation dataset. Colors indicate record type (large lake ≥ 50 ha). Record density is ~~highes~~ highest in Europe and Eastern North America, and lowest in ~~Africa~~ Northern and ~~Australia and Oceania~~Central Asia.

2.2 Implementing REVEALS

The REVEALS model ("Regional Estimates of Vegetation Abundance from Large Sites") estimates quantitative vegetation coverage from pollen assemblages using site and taxon-specific parameters (Sugita, 2007). Based on wind speed and taxon-specific fall speed, pollen dispersal is modeled in ring sources around the basin and deposition over the basin is integrated to give pollen influx. Together with RPP this dispersal factor is used to correct original pollen counts to better represent ~~real~~ actual vegetation (see Equation 1 and Table 1). By running the model with variations of relative pollen productivity (RPP) values, a statistical distribution of results is calculated.

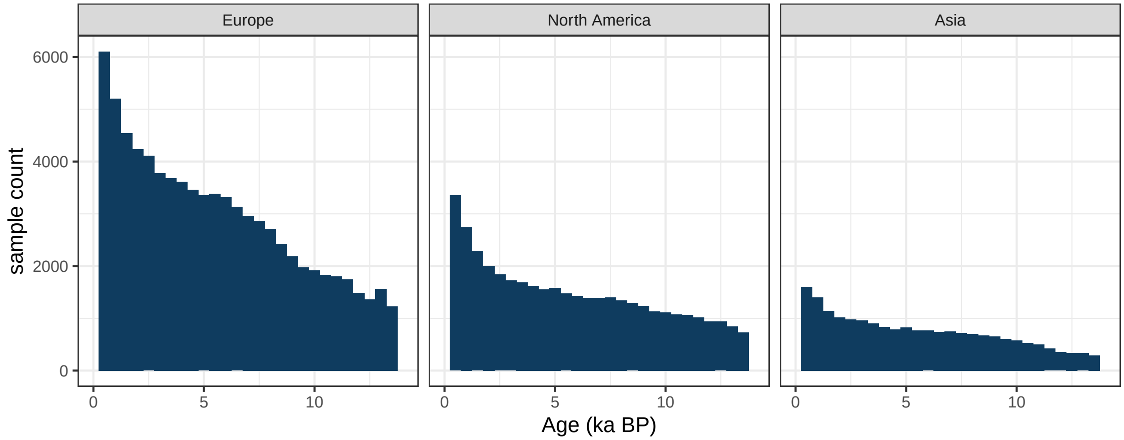

Figure 2. Temporal coverage of records in the LegacyVegetation dataset per continent. Bins are ~~1000~~ 500 years wide. Sample count decreases with age ~~with a noticeable drop in~~ and Europe has the most samples ~~at 20 ka BP~~overall.

$$\hat{V}_i = \frac{n_{i,k}/\hat{\alpha}_i \int_R^{Z_{max}} g_i(z)dz}{\sum_{j=1}^{m}(n_{j,k}/\hat{\alpha}_j \int_R^{Z_{max}} g_i(z)dz)} \quad (1)$$

The REVEALS model follows a set of assumptions. Firstly, neither directionality nor pollen transport through agents other than

Table 1. Algebraic terms in the REVEALS equation (see Equation 1)

Function term	~~explanation~~ definition
$\hat{V}_i$	vegetation estimate of taxon i
$n_{i,k}$	pollen counts of taxon i at site k
α_i	relative pollen productivity of taxon i
R	basin radius
Z_{max}	maximum extent of regional vegetation
z	distance from a point in the center of a basin
g_i	dispersal and deposition function for taxon i

wind are considered in the model. Additionally, it is assumed that the basin is circular with no source of pollen within the basin radius. The peatland and bog sites used in our reconstructions inherently violate this assumption. Nevertheless, the quantitative reconstruction of vegetation cover from peatland cores is possible by using Prentice's deposition model (Prentice, 1985, 1988) instead of Sugita's deposition model (Sugita, 1993) in the dispersal and deposition function (see Eq. 1; Sugita, 2007). Previous studies show that results from small bogs are still reliable when aggregated, while results from large bogs tend to deviate from those of large lakes ~~(Trondman et al., 2015; Mazier et al., 2012)~~(Trondman et al., 2015; Mazier et al., 2012; Trondman et al., 2016) . Using peatland records for reconstructions is, therefore, appropriate ~~. All sitesthat were not classified as lakes were run with peatland settings~~when spatially averaging multiple sites. We use the implementation of REVEALS from the R package REVEALSinR (Theuerkauf et al., 2016).

2.2.1 ~~Parameters~~

~~For each site,~~ For further details on the REVEALS model ~~also requires information on basin type, basin size and original pollen counts, all of which were collected in the LegacyPollen 2.0 dataset (Li et al., 2024b).~~see the original publication Sugita (2007) or Githumbi et al. (2022).

2.2.1 Parameters and Model Settings

For each taxon, values for RPP (with uncertainties provided as standard deviation) and fall speeds are used. ~~When available, we use continent-specific values in our reconstruction following~~ We made use of the synthesis of Northern Hemisphere RPP and fall speed values by Wieczorek and Herzschuh (2020). Several RPP studies published since this synthesis were added to the compilation (Geng et al., 2022; Li et al., 2022b; Wang et al., 2021; Huang et al., 2021; Zhang et al., 2021a, b; Wan et al., 2020, 2023; Jian . The methods by Wieczorek and Herzschuh (2020) were followed fore study selection and calculation of synthesis values. An overview of original values and synthesized values can be found in Appendix A and B respectively.

When available, we use continent-specific values in our reconstruction. For taxa with no continental values present, we use ~~northern hemispheric~~ Northern Hemispheric values. If no values exist for a taxon, RPP is set to a constant (RPP = 1, σ=0.25) and fall speeds are filled with mean continental fall speeds~~(see Appendix A: Original RPP and fall speed values per continent~~. Continental RPP values are available for the majority of pollen counts in all three continents (see Fig. 3). The fraction of pollen counts for which ~~RPP estimates are available are much higher in the Northern Hemisphere than in the Southern Hemipshere (see Fig. 3).~~ standard RPP values were assumed is highest in North America but still < 10%. For each site, the REVEALS model also requires information on basin type, basin size and original pollen counts, all of which were collected in the LegacyPollen 2.0 dataset (Li et al., 2024b). Apart from taxon- and basin-specific parameters the REVEALS model requires several constant parameters to be set, which can be found in Table 2.

2.2.2 Modifications in REVEALSinR

We calculate the radius of ~~relevant~~ the 80% pollen source area by finding the radius in which the median influx of all taxa is 80% of the total influx (as defined by the total influx in the maximum extent of regional vegetation chosen). This is calculated by employing the lake deposition model in REVEALSinR (Theuerkauf et al., 2016). Starting from z_{max} the deposited pollen is calculated per taxon. This is assumed to be the total pollen each taxon deposits. In a step-wise process the radius around the basin is increased and the deposited pollen relative to the total influx at z_{max} is calculated for each taxon. We define our 80%

Table 2. Static model parameters and model settings for REVEALS runs using REVEALSinR (Theuerkauf et al., 2016).

Parameter	Values and settings used in model run
atmospheric model	unstable atmosphere
dispersal model	gaussian plume
wind speed	$3m \times s^{-1}$
maximum extent of regional vegetation (region cutoff)	1000 km
number of RPP variations	2000
peatland basin radius	100 m
function to randomize pollen counts	rmultinom_reveals

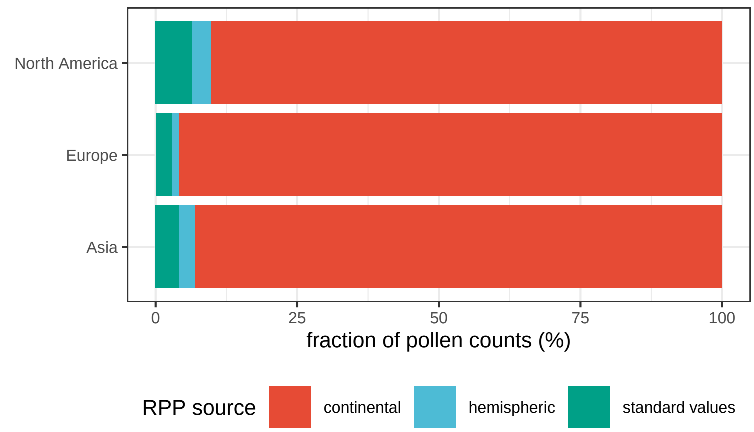

Figure 3. ~~Percentage~~ Regional source of RPP values for percentage of pollen counts per continent~~for which RPP estimates are available~~. A ~~higher~~ majority of pollen counts is covered by continental RPP values with the highest fraction in Europe. Only a small percentage of pollen counts has only hemispheric RPP ~~information in the Northern Hemisphere compared~~ values available. No available RPP values lead to the ~~continents~~ use of ~~the Southern Hemisphere~~a standardized RPP value of 1±0.25.

pollen source radius as the radius where the median of the relative influx of all taxa reaches 80%. The primary objective of this calculation is to provide a clear understanding of the scale of the source area for users unfamiliar with pollen data. It highlights the regional nature of lacustrine pollen data and demonstrates the influence of lake size on this source area.

We also reduced computational effort in REVEALSinR by implementing a maximum number of steps in the lake model used to model mixing in the basin. The number of steps was set to 500 unless n falls below that maximum value for $n = basin\,radius/10$ for basins with a radius of at least 1000 m and $n = basin\,radius/2$ for basins with a radius smaller than 1000 m.

2.3 Reconstruction of forest cover and validation

Forest cover was reconstructed by summing up percentages of arboreal taxa (see ~~S1~~S2: List of arboreal taxa) with Betulaceae, *Betula*, and *Alnus* being classified as arboreal at sites below 70° N. The mean reconstructed compositional coverages from the REVEALS results were used for the forest cover reconstructions. REVEALS results were then rasterized to aggregate and include records from smaller basins as well. Reconstructed time series were averaged in 500 year bins and then rasterized in grids of differing spatial resolution. A grid cell was classified as having a valid reconstruction when it contained records from at least one large lake (>= 50 ha) or at least two small basins following Serge et al. (2023). Standard deviations of the REVEALS estimates were aggregated by applying the delta method by Stuart and Ord (1994), using the same equation as Wieczorek and Herzschuh (2020). We provide a script for rasterization with adjustable temporal and spatial resolution for users of the dataset on Zenodo (https://zenodo.org/doi/10.5281/zenodo.12800290). For validation, the reconstructed forest cover of the past ~~500 years was~~ 100 years was rasterized and compared to modern remote sensing forest cover. Only valid grid cells as defined above were used for validation. Average tree canopy cover ~~within pollen source areas of all sites~~ for all grid cells was extracted from the Landsat Global Forest Cover Change (GFCC) data set from the temporal average of the years 2000, 2005, 2010 and 2015 (Sexton et al., 2013; Townshend, 2016). An openness correction was applied to sites containing urban areas and paved surfaces within the 80% pollen source areas (PSA) to correct for areas without any pollen sources and thus ~~improve~~ ensure comparability to modern remote sensing forest cover (see Equations 2-4). For this, the percentage of unvegetated land cover classes for the year 2015 in the ESA CCI land cover data set was used (ESA, 2017, see Table 3). Areas covered by water or ice are already considered as missing values in the remote sensing forest cover data set and do not need to be corrected for. Forest cover was validated ~~site-wise~~ for each grid cell and mean absolute error (MAE) and correlation coefficients calculated for each continent. No openness correction was applied to the reconstruction values in the final dataset. Validation for a 2x2° grid is included in the results section. Further validations using 1°,5°, and 10° resolution are included in the supplementary material (S3: Validation results for different spatial resolutions).

Table 3. Unvegetated land cover classes in ESA CCI LC chosen for the openness correction.

Name	Code
Urban areas	190
Bare areas	200
Consolidated bare areas	201
Unconsolidated bare areas	202

$$unvegetated\ classes = \{190, 200, 201, 202\} \tag{2}$$

$$unvegetated\,(\%) = \frac{\sum cells\ in\ PSA \in open\ classes}{\sum cells\ in\ PSA}\frac{\sum cells\ in\ PSA \in unvegetated\ classes}{\sum cells\ in\ PSA} \quad (3)$$

$$corrected\,tree\,cover = reconstructed\,tree\,cover \times (1 - unvegetated) \quad (4)$$

2.4 Optimization

In addition to the REVEALS approach, which is motivated by a biophysical model but also based on a large number of model choices and parameters, we also apply a statistical approach. Here, RPP values for common taxa are estimated by minimizing the misfit of reconstructed and remote sensing forest cover. For the optimization we rely on the "L-BFGS-B" method (Byrd et al., 1995), which allows for box constraints, and minimize the residual sum of squares (RSS) of reconstructed forest cover with remote sensing forest cover. RPP values were bound by upper and lower limits based on original RPP values (see Equation ??). Fall speeds and standard deviations of RPP were kept constant to the REVEALS approach.

$$original\ RPP \times 0.25 < new\ RPP < original\ RPP \times 4$$

The RPP values were optimized for the ten most common taxa in the REVEALS reconstruction for all sites on a continent, forest cover reconstructed, and the residual sum of squares (RSS) with remote sensing forest cover calculated. The results were validated using a spatial leave-one-out (SLOO) cross-validation. In this cross-validation one site and all sites within a predefined radius (exclusion buffer) were excluded from the optimization to account for spatial autocorrelation. The optimized RPP values were then applied to the forest cover reconstruction of the site left-out and the absolute error with remote sensing forest cover recorded. This was repeated with 20 sites to estimate the spread of MAE. The exclusion buffer around the validation site was set to 200 km. Due to computational limitations (roughly 3 hours for one continental SLOO fold using 20 threads with 1.2 GHz CPU each), the number of sites used per continental optimization during the cross-validation was limited to 100, leading to a rather conservative estimate of the true error.

3 Data summary

3.1 80% Pollen Source Areas

Using REVEALSand original RPP values, radii of relevant 80% pollen source areas were calculated for all sites large lakes(see Fig. 4). The relevant pollen source areas radii indicate in which area 80% of the deposited pollen originated from (see Section 2.2.2) and yield an understanding of which area the pollen record is representative of. The , which is especially useful when individual time series from large lakes are being used for analyses. The 80% pollen source areas are roughly a function of basin size (see Fig. 5) and range between 68 km and 729 155 km and 762 km. The median 80% pollen source radius is 86 225 km including all basins and 138 km including only lakes. large lakes.

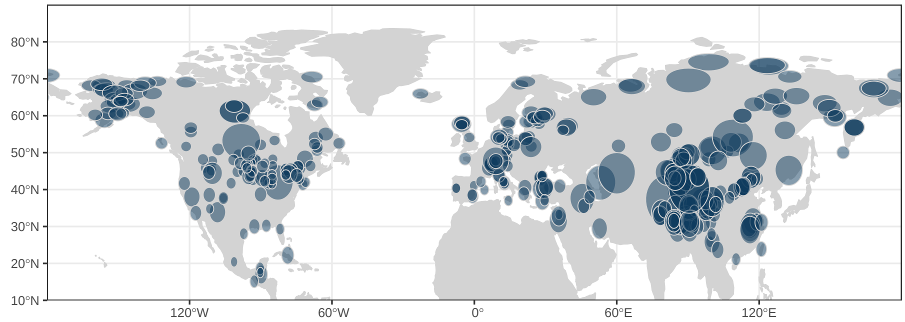

Figure 4. Map indicating the ~~size of~~ relevant pollen source areas for ~~all records~~large lakes. Many small basins in Europe lead to smaller 80% pollen source areas. Several large basins and correspondingly large 80% pollen source areas exist in Asia. In general the 80% pollen source areas highlight the regional nature of the pollen record signal.

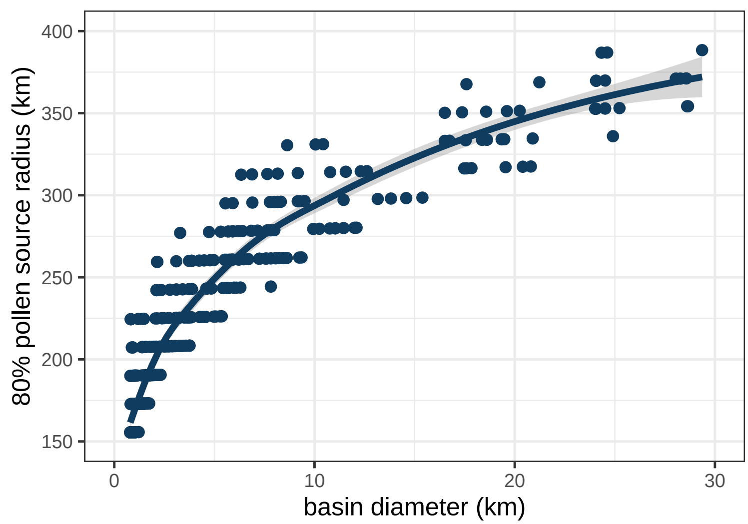

Figure 5. ~~Scatter plot~~ Scatterplot of basin diameter and 80% pollen source ~~radius~~ area of ~~a subset of~~ large lakes in the REVEALS ~~records with original RPP values~~data set. ~~Larger~~ In general, larger basins have larger pollen source areas with the relationship between ~~basin~~ diameter and 80% pollen source radius being roughly logarithmic.

3.2 ~~Comparison of original and optimized RPP values~~

~~The calculated pollen source areas (see section 3.1) were used to extract modern remote sensing forest cover per site. Within the optimization, RPP values were adjusted for the ten most common taxa per continent to improve the fit between reconstructed and remotely sensed modern forest cover. The RPP values are one of the main correction factors applied in REVEALS. Here we compare original and optimized RPP values for the relevant continental taxa.~~

The magnitude of adjustment from original to optimized RPP values differs between continents (see Fig. ??). The highest and lowest absolute change respectively occurred for *Quercus* (4.08) and Fabaceae (0.09) in Africa, for *Picea* (87.81) and *Ephedra* (0.43) in Asia, for *Pinus* (32.58) and Asteraceae (0.16) in Europe, for *Alnus* (1.79) and Amaranthaceae (in which we included Chenopodiaceae, 0.02) in Australia and Oceania, for Amaranthaceae (63.81) and *Tsuga* (0.43) in North America, and for Amaranthaceae (15.91) and Melastomataceae (0.74) in South America (see Appendix B). Relative change of RPP values is mostly positive with many taxa reaching an increase of three times the original RPP value. This is the maximum RPP value that can be reached, as the upper constraint for RPP optimization was set as 4 times the original RPP value (see Section 2.4). In most cases RPP values for arboreal taxa are increased. This increase represents reconstructed forest cover being regulated down as can be seen in the validations (see Fig. 9). Dumbbell graph illustrating original and optimized RPP values per continent and taxon. Arboreal taxa such as Pinus, Picea, Quercus have increases that are especially large.

3.2 Reconstructed compositions

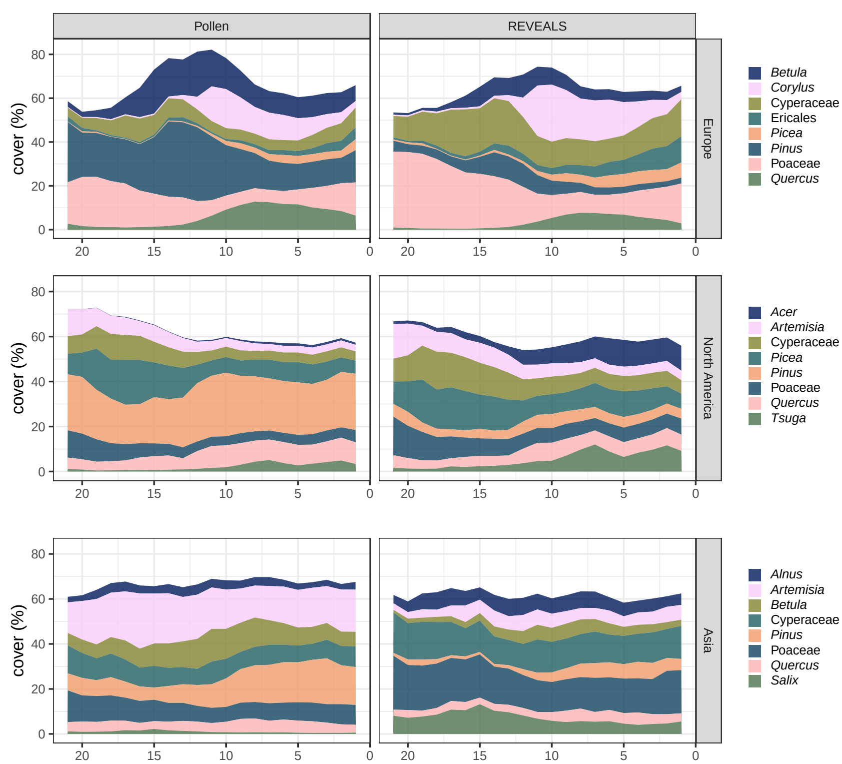

Figure 6. Average continental taxonomic coverages per reconstruction for the 8 most common taxa per continent. Compositional differences Differences are more pronounced in especially evident for Pinus, Artemisia, and Betula, which all have decreased coverages after the Northern Hemisphere due to the availability application of more RPP valuesREVEALS, as well as Poaceae and Cyperaceae with increased coverages.

~~Both the original and optimized RPP values were used to run REVEALS and~~ REVEALS was used to reconstruct quantitative vegetation cover. ~~Due to the differences in RPP values the reconstructed compositions differ between both REVEALS runs.~~ Here we compared these reconstructed compositions ~~among each other and with~~ to the original pollen composition.

Differences in composition ~~are especially apparent for~~ between Pollen data and REVEALS are apparent for all continents of the Northern Hemisphere. ~~For example, compared to the original pollen composition REVEALS runs with the original and the optimized RPP values both increase *Larix* cover in Asia, Ericales cover in Europe, and decrease *Picea* cover in North America, although the version with optimized RPP values does so more strongly (see Fig. 6). The original and the optimized version also diverge in the adjustment of some taxa. *Artemisia* cover in Asia is reduced by the original version and increased by the optimized one. *Picea* cover stays roughly the same with original RPP values in North America and decreases with optimized ones and while Asteraceae cover in Europeis increased in the REVEALS version with original RPP values, it is considerably higher in the optimized one.~~

~~In the Southern Hemisphere the differences between reconstructions are much less pronounced (see Fig. 6). The REVEALS reconstruction with original RPP values is almost indistinguishable from the original pollen spectra and adjustments in the optimized version are also much smaller than in the Northern Hemisphere. An increase in Cyperaceae cover in Australia and Oceania, decreases of Asteraceae and Cyperaceae in South America, and~~ Some clear examples include: increases of Cyperaceae in all continents, decreases of ~~*Quercus* in Africa are evident in the REVEALS run with optimized RPP values.~~

~~The difference in reconstructions between the hemispheres is most likely due to the availability of regional RPP and fall speed values. For South American taxa many RPP values are unknown and for remaining taxa average values of Northern Hemispheric studies were used~~ Betula in Europe, decreases of Pinus in all continents, and increases of Acer in North America with the application of REVEALS and its intended correction of taxon-sepcific biases (see Fig. ~~3 and Appendix A).These are often close to 1 and, therefore, do not change the original compositions drastically. Improving reconstructions without more available RPP estimates for Southern Hemispheric taxa is unrealistic.~~ 6).

3.3 Reconstructed forest cover

Using the compositional data available from the original pollen data ~~, the REVEALS run with original RPP values,~~ and the REVEALS run~~with optimized RPP values (see section 3.3)~~, we reconstructed forest cover for all sites and samples and rasterized the result with different spatial resolutions. The temporal trend in Northern Hemisphere forest cover is the same for ~~all three~~ both reconstructions. Forest cover increases from ~~20~~ 14 ka BP until roughly 6 ka BP and decreases again towards the present (see Fig. 7). REVEALS reconstructed forest cover is generally lower than forest cover from original pollen compositions. On average forest cover values from the REVEALS run ~~with original/optimized RPP values are roughly 11/19~~are roughly 14.54% lower than values from original pollen compositions. The temporal trends in Asia and North America are positive, whereas forest cover in Europe has its maximum around 6 ka BP and has been decreasing since.

Forest cover is ~~higher in the Northern Hemisphere in all time slices and reconstructions with the exception of the Eurasian Steppe, which is always characterized by a low reconstructed forest cover~~ generally highest in Eastern North America. This

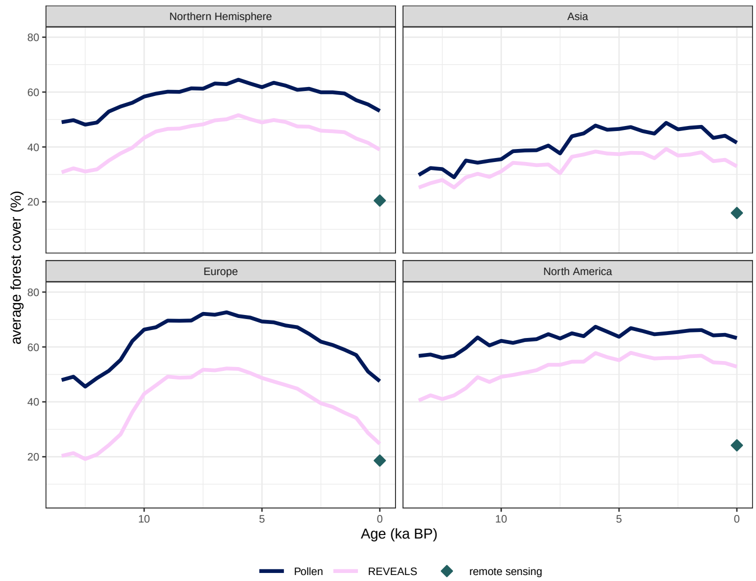

Figure 7. ~~Global~~ Northern Hemisphere and continental average forest cover from ~~10x10~~2x2° grid cell means for raw pollen data ~~, the REVEALS reconstruction with original RPP values,~~ and the REVEALS reconstruction ~~with optimized RPP values~~(Northern Hemisphere and continental averages from different grid cell resolutions are available in S2: Reconstruction results for different spatial resolutions). Remotely sensed global average forest ~~cover~~ clover for the grid cells with valid pollen ~~record locations~~ coverage is indicated with the diamond. Temporal trends are the same, but absolute forest cover is reduced in the REVEALS reconstructions compared to the original pollen data. ~~Forest cover from REVEALS~~ Both reconstructions ~~with optimized RPP is lowest~~still overestimate forest cover.

is also where data coverage is best in North America (see Fig. 8). ~~Within REVEALS reconstructions, forest cover is reduced more in~~ Density of valid grid cells is very high in Europe, where forest cover increases until roughly 6 ka BP and then decreases. Data coverage in Asia is sparse, but valid grid cells indicate higher forest cover on the Southeastern coast and in the boreal biome. Rather open areas exist at the Tibetan Plateau and at very high latitudes. The forest cover derived from the ~~Northern Hemisphere than in the Southern Hemisphere. A continuous band of highly forested boreal forest is visible in the REVEALS reconstructions using original RPP values. The intensity of this band is reduced in the~~ REVEALS reconstruction ~~using optimized RPP values~~is generally lower. However, ~~areas in northeastern Siberia, China, and eastern North America remain strongly forested~~the difference between Pollen and REVEALS forest cover is smaller in North America than in Europe and Asia.

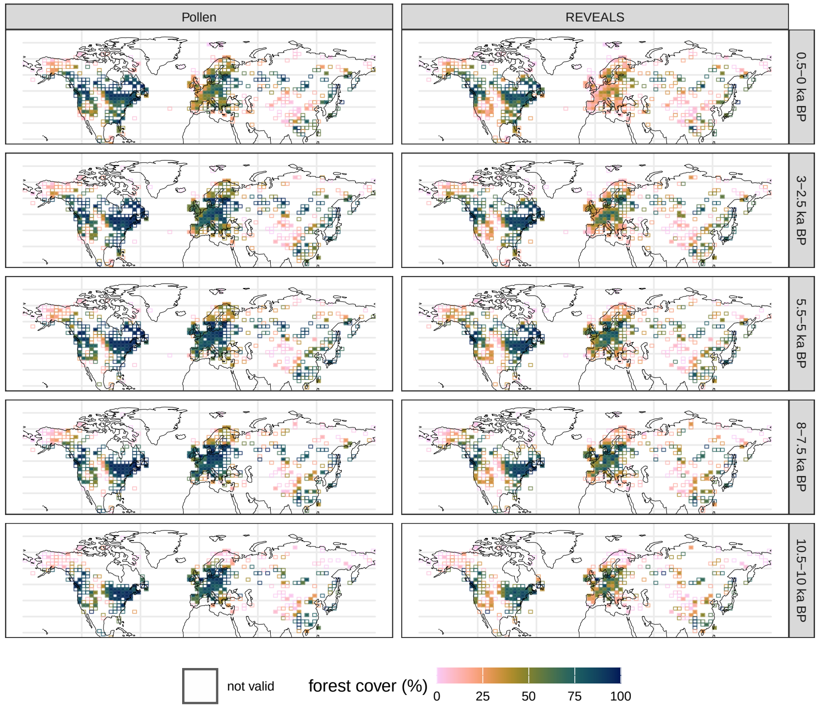

Figure 8. Reconstructed forest cover in 10x102x2° grid cells from raw pollen data , the REVEALS reconstruction with original RPP values, and the REVEALS reconstruction for 5 example time slices (reconstructions with optimized RPP valuesdifferent grid cell sizes are available in the in S2: Reconstruction results for different spatial resolutions). Valid cells are filled and include reconstructions from at least one large lake (≥ 50 ha) or several smaller basins. Forest cover in Eastern North America is generally higher than in the Northern HemisphereEurope and Asia. Reductions of REVEALS reconstructed forest cover with the REVEALS is generally lower than raw pollen reconstructionsare higher in the Northern Hemisphere.

3.4 Validation with gridded data sets

3.4.1 Validation with complete data sets

Remote sensing forest cover within relevant pollen source areas was used to validate the modern, reconstructed forest cover from the original pollen data and both REVEALS runs for each site. As the true error for the optimization results will be underestimated here, we also present results from the SLOO validation is Section 3.5.2. the REVEALS run for each grid cell. Here we present validation of gridded data with a 2° spatial resolution. Validations with additional spatial resolutions differ only marginally and are included in the supplementary materials (S3: Validation results for different spatial resolutions). Forest cover reconstructed from original pollen data is predominantly higher than remote sensing forest cover with a global mean absolute error (MAE) of 34.39% 33.05% in the Northern Hemisphere (see Fig. 10a). As reconstructed forest cover is much lower for both REVEALS runs the REVEALS reconstruction (see Fig.7), MAE values are reduced for both REVEALS

~~reconstructions. Using the original RPP values yields an MAE of 20.35% of reconstructed to remotely sensed forest cover. This is further reduced to 14.36% using the optimized RPP values~~ the MAE value is reduced significantly to 19.73% (see Fig. 9a).

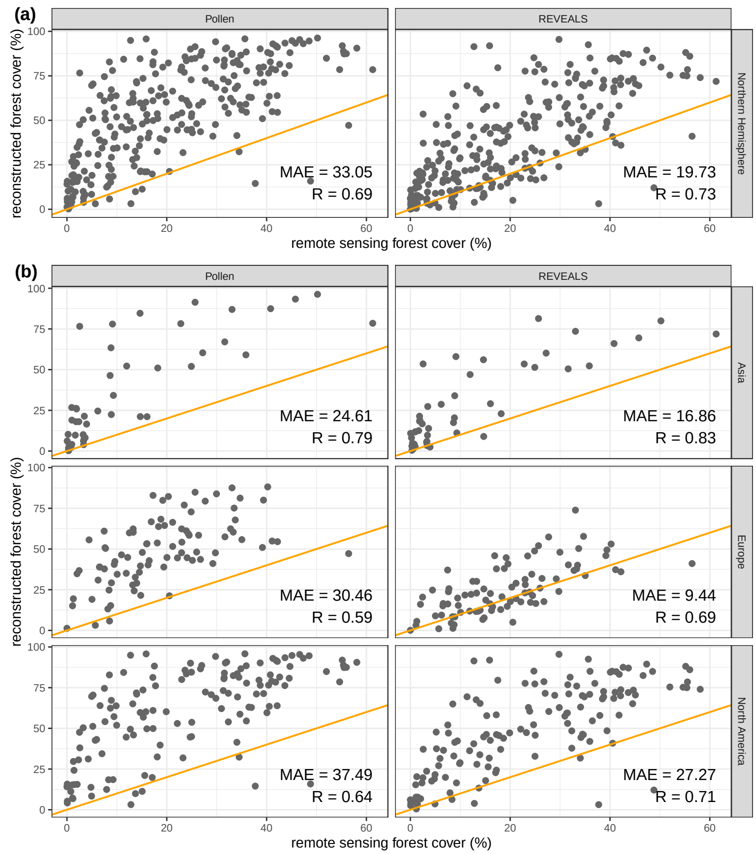

Figure 9. Remote sensing forest cover (LANDSAT) and modern reconstructed forest cover from Pollen ~~, REVEALS with original RPP values,~~ and REVEALS (< 100 years BP) in 2x2° grid cells with ~~optimized RPP values globally~~ mean absolute errors (~~a~~MAE) and ~~for all continents~~ correlation coefficient (~~b~~R) per group. Reconstructed forest cover from the original pollen data tends to overestimate observed (remote sensing) forest cover. ~~This is improved~~ Improvements with the REVEALS ~~run using original RPP values and even more so~~ reconstruction are especially high in Europe. Validations with different grid cell sizes are available in the ~~REVEALS run using optimized RPP values~~supplement (S3: Validation results for different spatial resolutions).

Continental mean absolute errors (MAE) in forest cover from original pollen data range from ~~12.44% (Africa) to 44.22~~24.61% (Asia) to 37.49% forest cover (North America, see Fig. 9b). All continental MAE values are lower for the REVEALS reconstruction ~~with original RPP values~~ and range from ~~12.33% (Africa) to 28.73~~9.44% (Europe) to 27.27% (North America). The improvement is largest in Europe (~~58~~72% relative to the initial MAE of the pollen-based reconstruction, see Fig. 9 and 10) and smallest in Africa (1North America (24%). Forest cover from the REVEALS reconstruction with optimized RPP values reduces continental MAE values even further with values ranging between 9.1% (Africa) and 21.08% forest cover (South America). MAE are generally improved more with optimized RPP values with the exception of records in Australia and Oceania. The largest improvement (relative to the pollen-based forest cover MAE) was achieved in North America (65%) but reconstructions in Europe (61%) and Asia (48%) also reduced the original MAE by more than or roughly half. The REVEALS runwith optimized RPP valuesREVEALS reconstructed forest cover also has higher correlation coefficients in all continents. The REVEALS run, therefore, produced the reconstructed forest cover that corresponds best with better remote sensing forest cover, with the exception of records from Australia and Oceania. Additionally, the reduction of forest cover MAE, and therefore the reconstruction improvement, was much larger in the continents of the Northern Hemisphere for both REVEALS runs. Nevertheless, forest cover still tends to be overestimated.

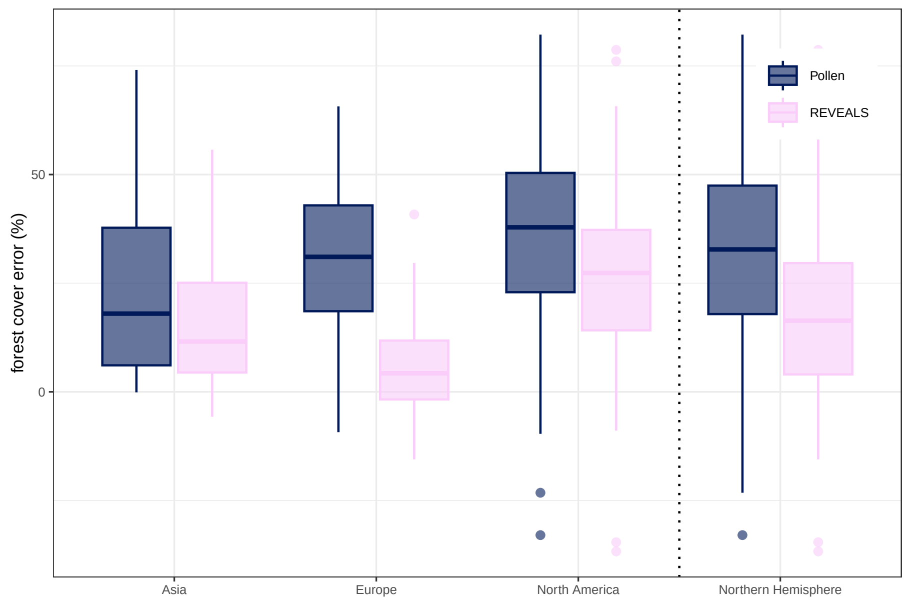

Figure 10. Bar graph of MAE improvement relative to the MAE of the pollen-based Forest cover reconstruction error per continent and REVEALS for a gridded 2x2° reconstruction. The absolute MAE reduction is shown in Mean errors decreased with the text labels. Except for Australia and Oceania, the REVEALS reconstruction with optimized RPP values achieves higher improvements. Improvements for all continents but are still generally higher > 0 (overestimation of forest cover). Lowest errors are present in the Northern HemisphereEurope.

Spatial patterns are present for the errors of all three both forest cover reconstructions (see Fig. 11). In the Southern Hemisphere, especially western South America, forest cover is predominantly underestimated by the reconstructions. The highest errors in reconstructed forest cover occur in continents of the Northern Hemisphere where forest cover is predominantly overestimated by the pollen-based reconstruction. In Europe the REVEALS reconstructions manage reconstruction manages to reduce errors extensively. In eastern North Americasome records still tend Eastern and coastal Northwestern North America, the

REVEALS reconstruction still tends to overestimate forest cover~~, even with the application of REVEALS and after optimizing~~. This could be due to a lack of continental RPP values. ~~The same is the case for several records in eastern Asia~~In North America, few RPP studies are available (see Appendix A) and more taxa are assigned hemispheric or standardized values than in the other continents.

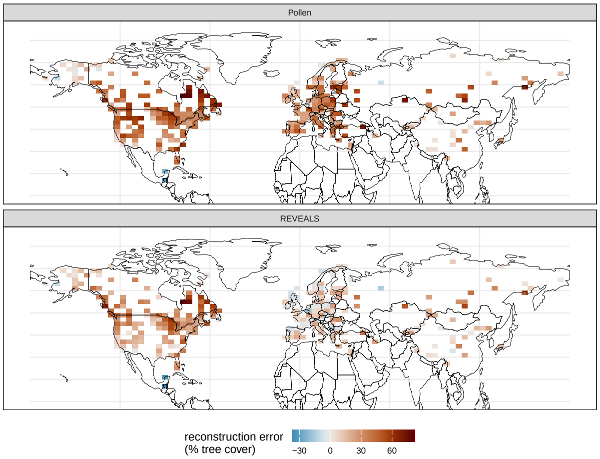

Figure 11. Map of the reconstruction error (in % forest cover) for forest cover reconstructed from Pollen ~~, REVEALS with original RPP values~~ and REVEALS data. Remaining errors with ~~optimized RPP values~~the overall better REVEALS reconstructions are especially high in North America (Northern West Coast, Labrador Peninsula).

The large difference between forest cover reconstructed from original pollen compositions and remote sensing forest cover could be due to the difference in the signal that is recorded. Remote sensing forest cover records the canopy, whereas pollen data also records the vegetation present below the tallest canopy. Several layers of trees could, therefore, increase the percentage of arboreal taxa recorded. Even though this comparison between these data sources may not be straightforward, it is still necessary for this large-scale validation of reconstruction as few other vegetation data is available globally. Additionally, it is more likely that the overestimation of forest cover in the initial pollen data is due to the higher production of pollen by trees than by non-arboreal taxa. This leads to an overrepresentation of arboreal taxa in the pollen record. By using REVEALS, the pollen productivity of taxa is taken into account and corrected for. The proportion of arboreal taxa is therefore strongly reduced in the vegetation compositions reconstructed using REVEALS.

~~The reasons for the difference in reconstruction improvements between the hemispheres could lie both in the smaller number of records available and the lack of regional RPP estimates for continents of the Southern Hemisphere. The latter play an important role as the optimization is based on the original RPP estimates and can only determine better values if these are in~~

the range of the original RPP values described in Equation ?? (see Sect. 2.6). An effective optimization of RPP values may, therefore, rely on some existing continental RPP estimates that can be refined with the optimization approach.

Optimizing more RPP could also solve the lack of regional improvements in eastern North America. This area is, amongst others, dominated by *Acer* which is not one of the ten most common taxa in the RPP optimization in North America. Optionally, this could also be solved by optimizing on subcontinental scales, though this requires a sufficient amount of regional records.

3.4.1 SLOO Validation of Optimization

A spatial leave-one-out validation was conducted by excluding a subset of available records in the optimization (see Sect. 2.4). By separating testing and training sites, the true spread of forest cover error from the optimization of RPP values can be evaluated. This also indicates the potential error if the optimized parameters were to be applied to new records. The distribution of absolute error from the SLOO validation is comparable to that of the reconstruction utilizing the complete optimization for Africa, Asia, Europe and South America (see Fig. ??). In North America, the absolute error spread and media are larger in the SLOO validation than in both REVEALS reconstructions. As errors in North America were comparably large to begin with (see Fig. 10 and 12), this could be due to the small number of folds conducted in the SLOO validation (n = 20) as well as the small number of records used (n = 100). The same could be the case for Australia and Oceania. Additionally, the spatial buffer in the SLOO validation leads to even fewer records being available for optimization. This could further decrease improvements in Australia and Oceania optimization. Overall the SLOO validation results indicate that the optimization success is relatively stable in Africa, Asia, Europe and South America. In North America, the spatial variability leads to higher uncertainty and in Australia and Oceania the optimization is not able to decrease absolute errors considerably. Boxplot of absolute errors from continental SLOO validations (20 folds) and from validations with complete Pollen, REVEALS (original RPP) and REVEALS (optimized RPP) data sets. The SLOO validation shows how reliable the optimized parameters are when testing sites were not included in the optimization. Variance and averages of absolute errors are comparable to the entire optimization dataset for Africa, Europe, Asia and South America. Errors are larger in Australia and Oceania and North America.

4 Dataset applications and limitations

Our reconstructed quantitative vegetation cover datasets using REVEALS provide global coverage reconstructions of taxonomic compositions as well as forest cover and extend to 50 ka BPand beyondin Europe, Asia, and North America and extend to 14 ka BP. The reconstructions made use of taxon-specific parameters and were, thus, able to correct some of the compositional biases present in pollen compositions. Notably, the error in modern reconstructed forest cover was reduced compared to pollen-based reconstructions on all continents which shows that improvements in forest cover reconstructions from both REVEALS applications are considerable.

Reconstruction results are also similar to available large-scale pollen-based vegetation reconstructions. Increases in forest cover in northern and eastern Asia up until the Holocene thermal maximum as seen in our results are consistent with reconstructions by Cao et al. (2019) and Tian et al. (2016). The reconstructed spatial patterns of forest cover in China with low forest cover in the North China plain and the Tibetan Plateau and a higher forest cover along the east coast and the south agree with previous reconstructions as well (Li et al., 2023, 2022b, 2024a). Results for European forest cover also roughly correspond with previous REVEALS applications and show an increase of forest cover after the last glacial maximum until roughly ~~4 ka BP (Githumbi et al., 2021; Fyfe et al., 2015; Serge et al., 2023)~~6 ka BP (Githumbi et al., 2022; Fyfe et al., 2015; Serge et al., 2023; Strandberg . The gridded reconstruction by Serge et al. (2023) was even validated with modern remote sensing forest cover and showed a good fit.

The REVEALS forest cover reconstructions presented here offer valuable insight into past vegetation changes. The global dataset provides an opportunity to explore past vegetation dynamics, gaining a deeper understanding of responses, trajectories, and potential feedback mechanisms. Given the increasing discussions surrounding the possibility of tipping events in vegetation cover (Armstrong McKay et al., 2022; Lenton and Williams, 2013), this could be of considerable use. While a reconstruction of exact tree lines is not trivial with pollen data, the application of REVEALS and subsequent biomization improve treeline reconstructions as shown by Binney et al. (2011). Additionally, this dataset can address unanswered questions about Holocene vegetation dynamics, including the deglacial forest conundrum ~~(Dallmeyer et al., 2022)~~(Dallmeyer et al., 2022; Strandberg et al., 2022) . It also serves as a valuable tool for validating models with coupled climate and vegetation, ~~relying~~ which rely on extensive time series and vegetation data for accurate predictions ~~(Dallmeyer et al., 2023).~~ (Dallmeyer et al., 2023; Dawson et al., 2024). Comparing modeled vegetation to reconstructed vegetation could help uncover missing dynamics in coupled climate-vegetation models. New insights gained from these applications could enhance our ability to predict future changes.

However, the reconstructions are associated with some of the limitations of sedimentary pollen data. This includes age uncertainty, temporal mixing, and irregular spatial and temporal resolution of records. Age uncertainty is already treated as best as possible through consistent age modeling of the pollen dataset (Li et al., 2022a, 2021). Nevertheless, in general, replicating sediment and peat cores could provide more accurate estimates.

Moreover, there is uncertainty surrounding the success of the compositional reconstructions. As global compositional vegetation data is not readily available, using remote sensing forest cover poses as the best option for validation. Even with an accurate forest cover reconstruction, uncertainties persist regarding the abundance of individual taxa due to the aggregated nature of the forest cover measure. To address this, global syntheses of forest and other plant inventories or compositional remote sensing products could offer better validation. ~~The optimized RPP set can produce very unrealistic compositions, for example regarding Asteraceae in Europe. The optimization was conducted purely statistically and limited ecological information was provided as input. The use of original RPP values, originating from physical studies, is, therefore, the more conservative approach for compositional reconstructions and the optimized data set should be used with caution for compositional applications. Although, many missing RPP and fall speed values, especially for taxa in the Southern Hemisphere, result in uncertainties in the original REVEALS reconstruction as well. A higher number of RPP estimates could help increase not only the confidence~~

in compositional reconstructions, but also the optimization success in continents of the Southern Hemisphere, where the small amount of information led to lower improvements in forest cover reconstruction.

Another challenge lies in validating the results with past vegetation data. It is uncertain whether RPP values have remained stable over time, and historical compositional data are not only scarce but likely too recent to test this assumption (Baker et al., 2016). Vegetational compositions from sedimentary ancient DNA could provide a solution. Local aDNA vegetation signals could be averaged across multiple records within a pollen source area to generate a comparable reconstructed vegetation composition using a different proxy and to compare to pollen-based results (Niemeyer et al., 2017).

To ensure the correct utilization of the dataset and to obtain reliable analysis results, several key considerations should be followed. Firstly, rasterization mitigates individual errors by temporal and spatial averaging. This process is particularly useful in reducing the variance that might arise from individual measurements, providing a more reliable representation of the underlying signal.The reliability of reconstructions varies among different taxa due to the quality of RPP values, and this is explicitly documented in a supplementary file that outlines the sources of RPP values (see Section Code and Data availability). Reconstructions of taxa with continental RPP values are the most reliable, followed by those based on hemispheric data, with standardized RPP values being the least reliable. This hierarchy should be taken into account when interpreting the results. Higher certainty is associated with forest cover reconstruction, as it is based on aggregation among taxa. Reconstructions of temporal forest cover trends are reliable, as evidenced by high correlation coefficients, despite a tendency for absolute values to be overestimated, particularly in North America. For individual time series, the reliability of data varies with the size of the lakes from which samples were taken. Only data derived from large lakes ($\geq$ 50 ha) are reliable for site-wise analyses. This distinction is clearly indicated with validity flags in the dataset. Reconstructions from smaller basins should not be used alone.

5 Conclusions

We present data sets of reconstructed compositional vegetation and forest cover from a globally distributed in the Northern Hemisphere from a sedimentary pollen data set using the REVEALS model. We used published (original), continental synthesized RPP values for one reconstruction , while in a second reconstruction, we optimized continental RPP values for common taxa by incorporating remote sensing forest cover datareconstruction and made use of hemispheric or standardized values, when continental ones were not available. This approach allowed us to address some of the inherent biases in pollen compositionsand suggests a method for enhancing taxon-specific RPP estimates. Considerable improvement in the reconstruction of forest cover is especially achieved in the continentsof the Northern Hemisphere. Even though improvements of reconstructions in the Southern Hemisphere were largely possible as well, the collection of more regional RPP values is indispensable for better reconstructionsachieved in all continents. Improvements were smallest in North America, which suggest a need for further RPP studies.

Accurate data on past vegetation is invaluable for the validation of coupled climate-vegetation models and the testing of hypotheses on feedback effects and vegetation dynamics. This knowledge is essential for modeling and predicting vegetation trajectories under anthropogenic climate change.

6 Code and data availability

The produced datasets are freely available from PANGAEA (, , Herzschuh et al. 2023c; Schild et al. 2023Zenodo (https://doi.org/10.5281/zenodo.12800159).

Input data from LegacyPollen 2.0 is available on PANGAEA as well (https://doi.pangaea.de/10.1594/PANGAEA.965907, Li et al. 2024b).

The code used to produce the datasets is and adjustable rasterization code are freely available from Zenodo (https://doi.org/10.5281/zenodo.10191859, https://doi.org/10.5281/zenodo.12800291, Schild and Ewald 2023).

~~Appendix A: Original RPP and fall speed values per continent~~

~~Taxon~~	~~Continent~~	~~RPP~~	~~RPP SD~~	~~Fallspeed~~
~~Acer~~	~~Asia~~	~~0.23~~	~~0.04255715~~	~~0.056~~
~~Acardiaceae~~	~~Asia~~	~~0.45~~	~~0.07~~	~~0.027~~
~~Salix~~	~~Asia~~	~~0.5366667~~	~~0.02995367~~	~~0.0218125~~
~~Rosaceae~~	~~Asia~~	~~0.53~~	~~0.04924429~~	~~0.0165~~
~~Tilia~~	~~Asia~~	~~0.4~~	~~0.1~~	~~0.02966667~~
~~Moraceaea~~	~~Asia~~	~~1.1~~	~~0.55~~	~~0.016~~
~~Cupressaceae~~	~~Asia~~	~~1.11~~	~~0.09~~	~~0.01~~
~~Larix~~	~~Asia~~	~~1.6033333~~	~~0.20374276~~	~~0.1194~~
~~Rubiaceae~~	~~Asia~~	~~1.23~~	~~0.36~~	~~0.019~~
~~Corylus~~	~~Asia~~	~~3.17~~	~~0.2~~	~~0.012~~
~~Populus~~	~~Asia~~	~~1.5866667~~	~~0.5363353~~	~~0.02566667~~
~~Ulmus~~	~~Asia~~	~~2.24~~	~~0.46179~~	~~0.02433333~~
~~Fagus~~	~~Asia~~	~~2.35~~	~~0.10692677~~	~~0.056~~
~~Fraxinus~~	~~Asia~~	~~1.05~~	~~0.17755281~~	~~0.0195~~
~~Quercus~~	~~Asia~~	~~2.284~~	~~0.07116179~~	~~0.02125~~
~~Juglans~~	~~Asia~~	~~2.8033333~~	~~0.11259564~~	~~0.0315~~
~~Carpinus~~	~~Asia~~	~~3.0933333~~	~~0.28446949~~	~~0.0415~~
~~Castanea~~	~~Asia~~	~~5.87~~	~~0.24505102~~	~~0.014~~
~~Picea~~	~~Asia~~	~~29.4~~	~~0.87~~	~~0.0819~~
~~Abies~~	~~Asia~~	~~6.875~~	~~1.44191713~~	~~0.12~~
~~Betula~~	~~Asia~~	~~12.45~~	~~0.1459452~~	~~0.0164~~
~~Alnus~~	~~Asia~~	~~7.334~~	~~0.17397803~~	~~0.021~~
~~Pinus~~	~~Asia~~	~~16.684~~	~~0.50916009~~	~~0.032425~~
~~Juniperus~~	~~Asia~~	~~14.305~~	~~1.00124922~~	~~0.016~~
~~Thymelaceae~~	~~Asia~~	~~33.05~~	~~3.78~~	~~0.009~~
~~wild.herbs~~	~~Asia~~	~~0.07~~	~~0.07~~	~~0.03425~~
~~Equisetum~~	~~Asia~~	~~0.09~~	~~0.02~~	~~0.021~~
~~Convolvulaceae~~	~~Asia~~	~~0.18~~	~~0.03~~	~~0.043~~
~~Fabaceae~~	~~Asia~~	~~0.2033333~~	~~0.05259911~~	~~0.0195~~
~~Orobanchaceae~~	~~Asia~~	~~0.33~~	~~0.04~~	~~0.038~~
~~Ericales~~	~~Asia~~	~~0.4475~~	~~0.01328768~~	~~0.03165~~

Taxon	Continent	RPP	RPP SD	Fallspeed
Brassicaceae	Asia	0.89	0.18	0.02
Poaceae	Asia	1	0.03166667	0.0211625
Lamiaceae	Asia	1.235	0.18668155	0.015
Asteraceae	Asia	3.2725	0.18848077	0.02911667
Sambucus nigra-type	Asia	1.3	0.12	0.013
Cyperaceae	Asia	3.3666667	0.12712243	0.02853333
Rumex	Asia	1.462	0.07139076	0.0148
Liliaceae	Asia	1.49	0.11	0.0135
Amaryllidaceae	Asia	1.64	0.09	0.0125
Corceae	Asia	1.72	0.14	0.044
Apiaceae	Asia	2.1266667	0.41013548	0.042
Campanulaceae	Asia	2.29	0.14	0.022
Cerealia	Asia	2.3625	0.42228545	0.069
Ranunculaceae	Asia	7.86	2.65	0.007
Platagiceae	Asia	2.8722222	0.10746231	0.0255
Caryophyllaceae	Asia	4.075	0.09899495	0.02573333
Thalictrum	Asia	4.65	0.3	0.013
Chenopodiaceae	Asia	5.5566667	0.6647413	0.01418333
Urtica	Asia	10.52	0.31	0.007
Artemisia	Asia	15.065	0.38084336	0.01016667
Elaeagnaceae	Asia	13.64	0.68622154	0.0124
Humulus	Asia	16.43	1	0.01
Amaranthaceae	Asia	21.35	2.34	0.0104
Sanguisorba	Asia	24.07	3.5	0.012
Acer	Europe	0.23	0.04255715	0.056
Acardiaceae	Europe	0.45	0.07	0.027
Salix	Europe	0.39	0.05840472	0.028125
Rosaceae	Europe	0.9725	0.10908712	0.012
Tilia	Europe	0.93	0.08736367	0.032
Moraceaea	Europe	1.1	0.55	0.016
Cupressaceae	Europe	1.11	0.09	0.01
Larix	Europe	0.16	0.05	0.126
Rubiaceae	Europe	1.56	0.11789826	0.019

Taxon	Continent	RPP	RPP SD	Fallspeed
Corylus	Europe	1.0533333	0.02947964	0.025
Populus	Europe	3.42	1.6	0.025
Ulmus	Europe	2.24	0.46179	0.032
Fagus	Europe	2.35	0.10692677	0.056
Fraxinus	Europe	2.972	0.25196031	0.022
Quercus	Europe	2.924	0.09826495	0.035
Juglans	Europe	2.8033333	0.11259564	0.0315
Carpinus	Europe	3.0933333	0.28446949	0.0415
Castanea	Europe	5.87	0.24505102	0.014
Picea	Europe	1.645	0.15323593	0.056
Abies	Europe	6.875	1.44191713	0.12
Betula	Europe	4.94	0.44296664	0.024
Alnus	Europe	8.4925	0.21539337	0.021
Pinus	Europe	10.86	0.79845945	0.036
Juniperus	Europe	7.94	1.28	0.016
Thymelaceae	Europe	33.05	3.78	0.009
wild.herbs	Europe	0.07	0.07	0.03425
Equisetum	Europe	0.09	0.02	0.021
Convolvulaceae	Europe	0.18	0.03	0.043
Fabaceae	Europe	0.4	0.07	0.021
Orobanchaceae	Europe	0.33	0.04	0.038
Ericales	Europe	0.4357143	0.01518592	0.0300625
Brassicaceae	Europe	0.07	0.04	0.022
Poaceae	Europe	1	0.01231474	0.035
Lamiaceae	Europe	1.0633333	0.12727922	0.019
Asteraceae	Europe	0.21875	0.01777287	0.032
Sambucus-nigra-type	Europe	1.3	0.12	0.013
Cyperaceae	Europe	0.555	0.01892969	0.035
Rumex	Europe	0.5766667	0.03076073	0.018
Liliaceae	Europe	1.49	0.11	0.0135
Amaryllidaceae	Europe	1.64	0.09	0.0125
Corceae	Europe	1.72	0.14	0.044
Apiaceae	Europe	2.1266667	0.41013548	0.042

Taxon	Continent	RPP	RPP SD	Fallspeed
~~Campanulaceae~~	~~Europe~~	~~2.29~~	~~0.14~~	~~0.022~~
~~Cerealia~~	~~Europe~~	~~2.3625~~	~~0.42228545~~	~~0.069~~
~~Ranunculaceae~~	~~Europe~~	~~0.9933333~~	~~0.12064641~~	~~0.014~~
~~Platagiceae~~	~~Europe~~	~~2.48625~~	~~0.11451665~~	~~0.02766667~~
~~Caryophyllaceae~~	~~Europe~~	~~2.9166667~~	~~0.06806859~~	~~0.03164~~
~~Thalictrum~~	~~Europe~~	~~4.65~~	~~0.3~~	~~0.0125~~
~~Chenopodiaceae~~	~~Europe~~	~~4.28~~	~~0.27~~	~~0.019~~
~~Urtica~~	~~Europe~~	~~10.52~~	~~0.31~~	~~0.007~~
~~Artemisia~~	~~Europe~~	~~4.33~~	~~1.59198775~~	~~0.014~~
~~Elaeagnaceae~~	~~Europe~~	~~13.64~~	~~0.68622154~~	~~0.0124~~
~~Humulus~~	~~Europe~~	~~16.43~~	~~1~~	~~0.01~~
~~Amaranthaceae~~	~~Europe~~	~~21.35~~	~~2.34~~	~~0.0104~~
~~Sanguisorba~~	~~Europe~~	~~24.07~~	~~3.5~~	~~0.012~~
~~Acer~~	~~North America~~	~~0.23~~	~~0.04255715~~	~~0.056~~
~~Acardiaceae~~	~~North America~~	~~0.45~~	~~0.07~~	~~0.027~~
~~Salix~~	~~North America~~	~~0.6833333~~	~~0.01333333~~	~~0.0155~~
~~Rosaceae~~	~~North America~~	~~0.35~~	~~0.03~~	~~0.0145~~
~~Tilia~~	~~North America~~	~~0.7975~~	~~0.0701301~~	~~0.03025~~
~~Moraceaea~~	~~North America~~	~~1.1~~	~~0.55~~	~~0.016~~
~~Cupressaceae~~	~~North America~~	~~1.11~~	~~0.09~~	~~0.01~~
~~Larix~~	~~North America~~	~~1.2425~~	~~0.15331748~~	~~0.126~~
~~Rubiaceae~~	~~North America~~	~~1.4775~~	~~0.12616953~~	~~0.019~~
~~Corylus~~	~~North America~~	~~1.5825~~	~~0.05467028~~	~~0.0185~~
~~Populus~~	~~North America~~	~~0.67~~	~~0.085~~	~~0.026~~
~~Ulmus~~	~~North America~~	~~2.24~~	~~0.46179~~	~~0.02625~~
~~Fagus~~	~~North America~~	~~2.35~~	~~0.10692677~~	~~0.056~~
~~Fraxinus~~	~~North America~~	~~2.4228571~~	~~0.18698467~~	~~0.02033333~~
~~Quercus~~	~~North America~~	~~2.08~~	~~0.43~~	~~0.035~~
~~Juglans~~	~~North America~~	~~2.8033333~~	~~0.11259564~~	~~0.0315~~
~~Carpinus~~	~~North America~~	~~3.0933333~~	~~0.28446949~~	~~0.0415~~
~~Castanea~~	~~North America~~	~~5.87~~	~~0.24505102~~	~~0.014~~
~~Picea~~	~~North America~~	~~2.8~~	~~0.1773728~~	~~0.056~~
~~Abies~~	~~North America~~	~~6.875~~	~~1.44191713~~	~~0.12~~

Taxon	Continent	RPP	RPP SD	Fallspeed
Betula	North America	6.1875	0.14926905	0.05066667
Alnus	North America	2.7	0.12	0.021
Pinus	North America	14.0955556	0.45381374	0.03314
Juniperus	North America	20.67	1.54	0.016
Thymelaceae	North America	33.05	3.78	0.009
wild.herbs	North America	0.07	0.07	0.03425
Equisetum	North America	0.09	0.02	0.021
Convolvulaceae	North America	0.18	0.03	0.043
Fabaceae	North America	0.02	0.02	0.021
Orobanchaceae	North America	0.33	0.04	0.038
Ericales	North America	0.53	0.01328768	0.038
Brassicaceae	North America	0.48	0.09219544	0.021
Poaceae	North America	1	0.04828302	0.026
Lamiaceae	North America	0.72	0.08	0.031
Asteraceae	North America	0.5866667	0.13148722	0.02525
Sambucus-nigra-type	North America	1.3	0.12	0.013
Cyperaceae	North America	0.975	0.025	0.0305
Rumex	North America	2.79	0.1724094	0.014
Liliaceae	North America	1.49	0.11	0.0135
Amaryllidaceae	North America	1.64	0.09	0.0125
Corceae	North America	1.72	0.14	0.044
Apiaceae	North America	2.1266667	0.41013548	0.042
Campanulaceae	North America	2.29	0.14	0.022
Cerealia	North America	2.3625	0.42228545	0.069
Ranunculaceae	North America	1.95	0.1	0.0145
Platagiceae	North America	5.96	0.31	0.019
Caryophyllaceae	North America	0.6	0.05	0.0405
Thalictrum	North America	4.65	0.3	0.012
Chenopodiaceae	North America	5.2375	0.50310467	0.011
Urtica	North America	10.52	0.31	0.007
Artemisia	North America	1.35	0.24	0.016
Elaeagnaceae	North America	13.64	0.68622154	0.0124
Humulus	North America	16.43	1	0.01

Taxon	Continent	RPP	RPP SD	Fallspeed
Amaranthaceae	North America	21.35	2.34	0.0104
Sanguisorba	North America	24.07	3.5	0.012
Acer	Southern Hemisphere	0.23	0.04255715	0.056
Acardiaceae	Southern Hemisphere	0.45	0.07	0.027
Salix	Southern Hemisphere	0.5366667	0.02995367	0.0218125
Rosaceae	Southern Hemisphere	0.7571429	0.06404718	0.01433333
Tilia	Southern Hemisphere	0.7975	0.0701301	0.03025
Moraceaea	Southern Hemisphere	1.1	0.55	0.016
Cupressaceae	Southern Hemisphere	1.11	0.09	0.01
Larix	Southern Hemisphere	1.2425	0.15331748	0.1216
Rubiaceae	Southern Hemisphere	1.4775	0.12616953	0.019
Corylus	Southern Hemisphere	1.5825	0.05467028	0.0185
Populus	Southern Hemisphere	1.5866667	0.5363353	0.02566667
Ulmus	Southern Hemisphere	2.24	0.46179	0.02625
Fagus	Southern Hemisphere	2.35	0.10692677	0.056
Fraxinus	Southern Hemisphere	2.4228571	0.18698467	0.02033333
Quercus	Southern Hemisphere	2.5563636	0.0675975	0.024
Juglans	Southern Hemisphere	2.8033333	0.11259564	0.0315
Carpinus	Southern Hemisphere	3.0933333	0.28446949	0.0415
Castanea	Southern Hemisphere	5.87	0.24505102	0.014
Picea	Southern Hemisphere	6.4633333	0.1773728	0.06463333
Abies	Southern Hemisphere	6.875	1.44191713	0.12
Betula	Southern Hemisphere	7.0569231	0.21223103	0.02781818
Alnus	Southern Hemisphere	7.334	0.17397803	0.021
Pinus	Southern Hemisphere	14.0955556	0.45381374	0.03314
Juniperus	Southern Hemisphere	14.305	1.00124922	0.016
Thymelaceae	Southern Hemisphere	33.05	3.78	0.009
wild.herbs	Southern Hemisphere	0.07	0.07	0.03425
Equisetum	Southern Hemisphere	0.09	0.02	0.021
Convolvulaceae	Southern Hemisphere	0.18	0.03	0.043
Fabaceae	Southern Hemisphere	0.206	0.03475629	0.01992857
Orobanchaceae	Southern Hemisphere	0.33	0.04	0.038
Ericales	Southern Hemisphere	0.4475	0.01328768	0.03165

Taxon	Continent	RPP	RPP SD	Fallspeed
Brassicaceae	Southern Hemisphere	0.48	0.09219544	0.021
Poaceae	Southern Hemisphere	1	0.01231474	0.0233
Lamiaceae	Southern Hemisphere	1.0633333	0.12727922	0.019
Asteraceae	Southern Hemisphere	1.1066667	0.05751197	0.02883571
Sambucus-nigra-type	Southern Hemisphere	1.3	0.12	0.013
Cyperaceae	Southern Hemisphere	1.3981818	0.03645908	0.02968889
Rumex	Southern Hemisphere	1.462	0.07139076	0.0148
Liliaceae	Southern Hemisphere	1.49	0.11	0.0135
Amaryllidaceae	Southern Hemisphere	1.64	0.09	0.0125
Corceae	Southern Hemisphere	1.72	0.14	0.044
Apiaceae	Southern Hemisphere	2.1266667	0.41013548	0.042
Campanulaceae	Southern Hemisphere	2.29	0.14	0.022
Cerealia	Southern Hemisphere	2.3625	0.42228545	0.069
Ranunculaceae	Southern Hemisphere	2.558	0.53529431	0.0125
Platagiceae	Southern Hemisphere	2.8722222	0.10746231	0.0255
Caryophyllaceae	Southern Hemisphere	2.9166667	0.06806859	0.03164
Thalictrum	Southern Hemisphere	4.65	0.3	0.0125
Chenopodiaceae	Southern Hemisphere	5.2375	0.50310467	0.0143875
Urtica	Southern Hemisphere	10.52	0.31	0.007
Artemisia	Southern Hemisphere	11.1555556	0.43626926	0.01188889
Elaeagnaceae	Southern Hemisphere	13.64	0.68622154	0.0124
Humulus	Southern Hemisphere	16.43	1	0.01
Amaranthaceae	Southern Hemisphere	21.35	2.34	0.0104
Sanguisorba	Southern Hemisphere	24.07	3.5	0.012

Taxa	optimized RPP value	original RPP value	Continent
Cyperaceae	0.84654833	1.3981818	Africa
Asteraceae	0.76957547	1.1066667	Africa
Quercus	6.63958404	2.5563636	Africa
Ericales	1.04432639	0.4475	Africa
Podocarpus	0.75657208	1	Africa
Amaranthaceae	12.7898744	21.35	Africa
Euphorbiaceae	2.58335787	1	Africa
Olea	2.68441315	1	Africa
Rosaceae	1.99969879	0.7571429	Africa
Fabaceae	0.11735178	0.206	Africa
Artemisia	3.76625	15.065	Asia
Pinus	66.2779324	16.684	Asia
Amaranthaceae	5.34429663	21.35	Asia
Cyperaceae	13.4666668	3.3666667	Asia
Betula	33.8326975	12.45	Asia
Quercus	6.00064546	2.284	Asia
Alnus	11.1999651	7.334	Asia
Asteraceae	12.8740069	3.2725	Asia
Picea	117.210682	29.4	Asia
Ephedra	1.42698032	1	Asia
Pinus	43.44	10.86	Europe
Cyperaceae	0.18727252	0.555	Europe
Betula	19.7593317	4.94	Europe
Quercus	11.6005902	2.924	Europe
Alnus	2.12408706	8.4925	Europe
Ericales	0.10892858	0.4357143	Europe
Picea	6.48965812	1.645	Europe
Fagus	0.75915903	2.35	Europe
Corylus	0.83090779	1.0533333	Europe
Asteraceae	0.0546875	0.21875	Europe
Cyperaceae	0.34954545	1.3981818	Indopacific

Taxa	optimized RPP value	original RPP value	Continent
Nothofagus	0.53271905	1	Indopacific
Eucalyptus	1.86489233	1	Indopacific
Asteraceae	1.65106629	1.1066667	Indopacific
Alnus	9.12264565	7.334	Indopacific
Amaranthaceae	21.3676454	21.35	Indopacific
Melaleuca	0.39986185	1	Indopacific
Casuarinaceae	1.32091314	1	Indopacific
Ericales	0.59118499	0.4475	Indopacific
Phyllocladus	1.88815046	1	Indopacific
Pinus	32.245235	14.0955556	North America
Betula	22.1069251	6.1875	North America
Quercus	4.14832091	2.08	North America
Asteraceae	0.14668529	0.5866667	North America
Picea	11.1892262	2.8	North America
Alnus	10.3752134	2.7	North America
Cyperaceae	0.24375	0.975	North America
Tsuga	1.43191981	1	North America
Artemisia	0.85660575	1.35	North America
Amaranthaceae	85.1564704	21.35	North America
Cyperaceae	5.58206159	1.3981818	South America
Nothofagus	3.99593442	1	South America
Asteraceae	4.4266668	1.1066667	South America
Urticaceae	0.25	1	South America
Euphorbiaceae	3.99999539	1	South America
Amaranthaceae	5.36450324	21.35	South America
Rhizophora	3.99998911	1	South America
Melastomataceae	0.25682559	1	South America
Alchornea	4	1	South America
Cecropia	0.25293954	1	South America

Appendix A: Original RPP values

Taxon	Continent	RPP	SE	reference	study DOI
Acer	Asia	0.0869	0.0621	Li M. et al. 2022	https://doi.org/10.1016/j.quaint.2022.03.010
Alnus	Asia	0.85	1.53	Geng et al. 2022	https://doi.org/10.3389/fevo.2022.837857
Amaranthaceae	Asia	21.01	2.47	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Amaranthaceae	Asia	3.57	0.81	Li et al. in prep (in Li et al. 2018)	https://doi.org/10.3389/fpls.2018.01214
Amaranthaceae	Asia	0.18	0.16	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Amaranthaceae	Asia	5.379	1.077	Wang and Herzschuh 2011	https://doi.org/10.1016/j.revpalbo.2011.09.004
Amaranthaceae	Asia	7.72	1.47	Zhang et al. 2020	https://doi.org/10.1007/s00334-020-00779-x
Amaranthaceae	Asia	21.35	2.34	Ge et al. 2017	https://doi.org/10.1016/j.scitotenv.2017.02.027
Amaranthaceae	Asia	28.39	1.62	Wang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.19
Amaranthaceae	Asia	27.9	2.9	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Amaranthaceae	Asia	10.6	0.6	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Amaranthaceae	Asia	7.72	1.47	Zhang et al. 2021a	https://doi.org/10.1007/s00334-020-00779-x
Amaryllidaceae	Asia	1.64	0.4	Ge et al. 2017	https://doi.org/10.1016/j.scitotenv.2017.02.027
Anacardiaceae	Asia	0.45	0.07	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Anacardiaceae	Asia	1.77	0.04	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Anacardiaceae	Asia	0.4478	0.0746	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Artemisia	Asia	19.33	0.41	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Artemisia	Asia	19.03	0.27	Li et al. in prep (in Li et al. 2018)	https://doi.org/10.3389/fpls.2018.01214
Artemisia	Asia	24.7	0.36	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Artemisia	Asia	3.267	0.628	Wang and Herzschuh 2011	https://doi.org/10.1016/j.revpalbo.2011.09.004
Artemisia	Asia	21.53	2.16	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Artemisia	Asia	5.77	0.35	Zhang et al. 2020	https://doi.org/10.1007/s00334-020-00779-x
Artemisia	Asia	3.4	0.18	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Artemisia	Asia	21.33	0.4	Ge et al. 2017	https://doi.org/10.1016/j.scitotenv.2017.02.027
Artemisia	Asia	16.15	1.41	Wang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.19
Artemisia	Asia	5.77	0.35	Zhang et al. 2021a	https://doi.org/10.1007/s00334-020-00779-x
Artemisia	Asia	1.81	0.3	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Asteraceae	Asia	7.73	0.54	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Asteraceae	Asia	1.26	0.4	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Asteraceae	Asia	0.86	0.11	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Asteraceae	Asia	3	0.32	Zhang et al. 2020	https://doi.org/10.1007/s00334-020-00779-x
Asteraceae	Asia	1.1	0.12	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Asteraceae	Asia	8.85	0.51	Ge et al. 2017	https://doi.org/10.1016/j.scitotenv.2017.02.027
Asteraceae	Asia	20.5	2.68	Wang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.19
Asteraceae	Asia	8.15	0.45	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Asteraceae	Asia	1.8	0.2	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Asteraceae	Asia	3	0.32	Zhang et al. 2021a	https://doi.org/10.1007/s00334-020-00779-x
Asteraceae	Asia	8.74	0.05	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Asteraceae	Asia	0.31	0.25	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Betula	Asia	12.52	0.37	Li et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.02.003
Betula	Asia	13.16	0.08	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Betula	Asia	11.67	0.22	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Betula	Asia	7.8	0.51	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Betula	Asia	2.82	0.28	Geng et al. 2022	https://doi.org/10.1016/j.scitotenv.2017.02.027
Betula	Asia	1.59	5.86	Geng et al. 2022	https://doi.org/10.3389/fevo.2022.837857
Betula	Asia	5.171	0.2259	Li M. et al. 2022	https://doi.org/10.1016/j.quaint.2022.03.010

Betula	Asia	4.97	0.08	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Brassicaceae	Asia	0.89	0.18	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Brassicaceae	Asia	3.4	0.2	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Camellia	Asia	0.5832	0.0194	Wan et al. 2023	https://doi.org/10.1016/j.scitotenv.2017.02.027
Carpinus	Asia	1.5416	0.3029	Li M. et al. 2022	https://doi.org/10.1016/j.quaint.2022.03.010
Caryophyllaceae	Asia	78.2	5.85	Li et al. in prep (in Li et al. 2018)	https://doi.org/10.3389/fpls.2018.01214
Caryophyllaceae	Asia	0.87	0.14	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Caryophyllaceae	Asia	7.28	0.14	Zhang et al. 2020	https://doi.org/10.1007/s00334-020-00779-x
Caryophyllaceae	Asia	25.75	2.35	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Caryophyllaceae	Asia	7.28	0.14	Zhang et al. 2021a	https://doi.org/10.1007/s00334-020-00779-x
Caryophyllaceae	Asia	11.86	0.87	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Castanea	Asia	11.49	0.49	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Castanea	Asia	0.25	0.01	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Castanea	Asia	0.2537	0.0149	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Castanopsis	Asia	19.44	0.17	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Convolvulaceae	Asia	0.18	0.03	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Corylus	Asia	3.17	0.2	Zhang et al. 2020	https://doi.org/10.1007/s00334-020-00779-x
Corylus	Asia	3.17	0.2	Zhang et al. 2021a	https://doi.org/10.1007/s00334-020-00779-x
Cupressaceae	Asia	1.11	0.09	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Cyclobalanopsis	Asia	2.4106	0.1361	Wan et al. 2023	https://doi.org/10.1016/j.scitotenv.2017.02.027
Cyperaceae	Asia	8.9	0.33	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Cyperaceae	Asia	0.21	0.07	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Cyperaceae	Asia	0.66	0.021	Wang and Herzschuh 2011	https://doi.org/10.1016/j.revpalbo.2011.09.004
Cyperaceae	Asia	0.54	0.19	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Cyperaceae	Asia	0	0.0071	Geng et al. 2022	https://doi.org/10.1016/j.scitotenv.2017.02.027
Cyperaceae	Asia	0.016	4.86	Geng et al. 2022	https://doi.org/10.3389/fevo.2022.837857
Cyperaceae	Asia	20.8	0.65	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Cyperaceae	Asia	1.6	0.12	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Cyperaceae	Asia	0.04	0.03	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Cyperaceae	Asia	0.5373	0.194	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Elaeagnaceae	Asia	8.88	1.3	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Elaeagnaceae	Asia	18.4	0.44	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Ephedraceae	Asia	22.87	0.76	Wang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.19
Ericaceae	Asia	1.57	0.2	Geng et al. 2022	https://doi.org/10.1016/j.scitotenv.2017.02.027
Ericaceae	Asia	1.57	0.2	Geng et al. 2022	https://doi.org/10.3389/fevo.2022.837857
Euphorbiaceae	Asia	2.21	0.08	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Euphorbiaceae	Asia	5.22	0.1	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Fabaceae	Asia	0.2	0.1	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Fabaceae	Asia	0.78	0.03	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Fabaceae	Asia	0.21	0.07	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Fabaceae	Asia	0.2	0.1	Ge et al. 2017	https://doi.org/10.1016/j.scitotenv.2017.02.027
Fabaceae	Asia	0.209	0.0746	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Fraxinus	Asia	1.89	0.35	Li et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.02.003
Fraxinus	Asia	0.21	0.06	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Hippophae	Asia	18.38	1.27	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Humulus	Asia	16.3	1	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Ilex	Asia	6.7068	0.5832	Wan et al. 2023	https://doi.org/10.1016/j.scitotenv.2017.02.027
Juglandaceae	Asia	1.8955	0.0896	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Juglans	Asia	4.82	0.22	Li et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.02.003
Juglans	Asia	0.3	0.05	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Juglans	Asia	7.69	0.49	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Juglans	Asia	1.69	0.24	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24

Juglans	Asia	1.9	0.09	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Lamiaceae	Asia	0.2	0.13	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Lamiaceae	Asia	2.27	0.35	Li et al. in prep (in Li et al. 2018)	https://doi.org/10.3389/fpls.2018.01214
Lamiaceae	Asia	1.9	0.3	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Larix	Asia	0.74	0.1	Li et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.02.003
Larix	Asia	3.87	0.6	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Larix	Asia	4.41	0.15	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Larix	Asia	0.2	0.06	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Larix	Asia	2.18	0.36	Geng et al. 2022	https://doi.org/10.1016/j.scitotenv.2017.02.027
Larix	Asia	6.61	3.5	Geng et al. 2022	https://doi.org/10.3389/fevo.2022.837857
Liliaceae	Asia	1.49	0.11	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Liliaceae	Asia	2.45	0.4	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Liquidambar	Asia	2.255	0.1166	Wan et al. 2023	https://doi.org/10.1016/j.scitotenv.2017.02.027
Mallotus	Asia	10.8475	1.7107	Wan et al. 2023	https://doi.org/10.1016/j.scitotenv.2017.02.027
Malus	Asia	0.0869	0.0372	Li M. et al. 2022	https://doi.org/10.1016/j.quaint.2022.03.010
Moraceae	Asia	6.52	0.08	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Papilionaceae	Asia	2.66	0.05	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Picea	Asia	29.4	0.87	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Picea	Asia	3.4	0.83	Geng et al. 2022	https://doi.org/10.3389/fevo.2022.837857
Pinus	Asia	7.72	0.25	Li et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.02.003
Pinus	Asia	8.96	0.23	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Pinus	Asia	29.55	1.77	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Pinus	Asia	18.82	0.54	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Pinus	Asia	13.24	1.19	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Pinus	Asia	12.85	1.26	Zhang et al. 2020	https://doi.org/10.1007/s00334-020-00779-x
Pinus	Asia	31.3	1.97	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Pinus	Asia	16.22	5.86	Geng et al. 2022	https://doi.org/10.3389/fevo.2022.837857
Pinus	Asia	1.9637	0.0894	Li M. et al. 2022	https://doi.org/10.1016/j.quaint.2022.03.010
Pinus	Asia	12.85	1.26	Zhang et al. 2021a	https://doi.org/10.1007/s00334-020-00779-x
Pinus	Asia	32.1	1.94	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Pinus	Asia	13.2388	1.194	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Poaceae	Asia	1	0	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Poaceae	Asia	1	0	Li et al. in prep (in Li et al. 2018)	https://doi.org/10.3389/fpls.2018.01214
Poaceae	Asia	1	0	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Poaceae	Asia	1	0	Wang and Herzschuh 2011	https://doi.org/10.1016/j.revpalbo.2011.09.004
Poaceae	Asia	1	0	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Poaceae	Asia	1	0	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Poaceae	Asia	1	0.19	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Poaceae	Asia	1	0	Zhang et al. 2020	https://doi.org/10.1007/s00334-020-00779-x
Poaceae	Asia	1	0	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Poaceae	Asia	1	0	Ge et al. 2017	https://doi.org/10.1016/j.scitotenv.2017.02.027
Poaceae	Asia	1	0	Geng et al. 2022	https://doi.org/10.1016/j.scitotenv.2017.02.027
Poaceae	Asia	1	0	Geng et al. 2022	https://doi.org/10.3389/fevo.2022.837857
Poaceae	Asia	1	0	Wang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.19
Poaceae	Asia	1	0	Zhang et al. 2021a	https://doi.org/10.1007/s00334-020-00779-x
Poaceae	Asia	1	0	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Poaceae	Asia	1	0	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Polygonaceae	Asia	26.35	1.85	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Potentilla	Asia	1.4	0.2	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Quercus	Asia	2.48	0	Li et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.02.003
Quercus	Asia	4.89	0.16	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9

Quercus	Asia	5.48	0.11	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Quercus	Asia	1.75	0.31	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Quercus	Asia	1.49	0	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Quercus	Asia	0.81	0.07	Zhang et al. 2020	https://doi.org/10.1007/s00334-020-00779-x
Quercus	Asia	0.6	0.08	Li et al. 2017b	https://doi.org/10.1007/s00334-017-0636-9
Quercus	Asia	0.81	0.007	Zhang et al. 2021a	https://doi.org/10.1007/s00334-020-00779-x
Quercus	Asia	2.69	0.08	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Ranunculaceae	Asia	7.86	2.65	Zhang et al. 2017	https://doi.org/10.11928/j.issn.1001-7410.2017.06.24
Rhododendron	Asia	2.48	0.27	Zhang et al. 2021b	https://doi.org/10.1016/j.ecolind.2021.107928
Rosaceae	Asia	0.22	0.09	Ge et al. 2015	https://doi.org/10.11928/j.issn.1001-7410.2015.04.15
Rosaceae	Asia	0.84	0.04	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Rosaceae	Asia	0.8358	0.0448	Jiang et al. 2020	https://doi.org/10.1002/jqs.3197
Rubiaceae	Asia	1.23	0.36	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Rubiaceae	Asia	1.29	0.02	Wan et al. 2020	https://doi.org/10.1016/j.ecolind.2020.106297
Salix	Asia	0.23	0.11	Geng et al. 2022	https://doi.org/10.1016/j.scitotenv.2017.02.027
Sanguisorba	Asia	24.07	3.5	Li et al. in prep (in Li et al. 2018)	https://doi.org/10.3389/fpls.2018.01214
Symplocos	Asia	0.2138	0.0389	Wan et al. 2023	https://doi.org/10.1016/j.scitotenv.2017.02.027
Syringa	Asia	3.3936	0.216	Li M. et al. 2022	https://doi.org/10.1016/j.quaint.2022.03.010
Tamaricaceae	Asia	1.5	0.13	Wang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.19
Thalictrum	Asia	2.8	0.4	Huang et al. 2021	https://doi.org/10.11928/j.issn.1001-7410.2021.06.18
Thymelaceae	Asia	33.05	3.78	Li et al. in prep (in Li et al. 2018)	https://doi.org/10.3389/fpls.2018.01214
Tilia	Asia	0.4	0.1	Li et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.02.003
Ulmus	Asia	3.48	0.87	Li et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.02.003
Ulmus	Asia	1	0.31	Li et al. 2017a	https://doi.org/10.1007/s00334-017-0636-9
Ulmus	Asia	1.5962	0.1539	Li M. et al. 2022	https://doi.org/10.1016/j.quaint.2022.03.010
Abies	Europe	9.92	2.86	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Abies	Europe	3.83	0.37	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Acer	Europe	0.32	0.09	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Acer	Europe	0.3	0.09	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Acer	Europe	0.07	0.01	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Alnus	Europe	2.56	0.32	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Alnus	Europe	8.74	0.35	Bunting et al. 2005	https://doi.org/10.1191/0959683605hl821rr
Alnus	Europe	19.96	1.6	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Alnus	Europe	15.95	0.6622	Baker et al. 2016	https://doi.org/10.1177/0959683615596822
Alnus	Europe	6.42	0.42	Niemeyer et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.06.008
Alnus	Europe	2.86	0.07	Niemeyer et al. 2015	https://doi.org/10.1177/0959683615596822
Amaranthaceae	Europe	4.28	0.27	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Apiaceae	Europe	0.26	0.01	Hjelle 1998	https://doi.org/10.1007/BF01373926
Apiaceae	Europe	0.21	0.03	Hjelle 1998	https://doi.org/10.1007/BF01373926
Apiaceae	Europe	5.91	1.23	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Artemisia	Europe	2.77	0.39	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Artemisia	Europe	5.89	3.16	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Asteraceae	Europe	0.06	0.004	Hjelle 1998	https://doi.org/10.1007/BF01373926
Asteraceae	Europe	0.1	0.01	Hjelle 1998	https://doi.org/10.1007/BF01373926
Asteraceae	Europe	0.05	0.02	Hjelle 1998	https://doi.org/10.1007/BF01373926
Asteraceae	Europe	0.09	0.02	Hjelle 1998	https://doi.org/10.1007/BF01373926
Asteraceae	Europe	0.24	0.06	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Asteraceae	Europe	0.17	0.03	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Asteraceae	Europe	0.16	0.1	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Asteraceae	Europe	0.68	0.06	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Asteraceae	Europe	0.65	0.06	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026

Asteraceae	Europe	0.28	0.04	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Betula	Europe	6.18	0.35	Bunting et al. 2005	https://doi.org/10.1191/0959683605hl821rr
Betula	Europe	4.6	0.7	Räsänen et al. 2007	https://doi.org/10.1016/j.revpalbo.2007.04.004
Betula	Europe	12.38	2.48	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Betula	Europe	13.94	0.2293	Baker et al. 2016	https://doi.org/10.1177/0959683615596822
Betula	Europe	1.8	0.26	Niemeyer et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.06.008
Betula	Europe	2.24	0.2	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Betula	Europe	2.42	0.39	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Betula	Europe	1.82	0.33	Niemeyer et al. 2015	https://doi.org/10.1177/0959683615596822
Brassicaceae	Europe	0.07	0.04	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Carpinus	Europe	12.17	0.66	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Carpinus	Europe	4.48	0.0301	Baker et al. 2016	https://doi.org/10.1177/0959683615596822
Carpinus	Europe	4.56	0.85	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Carpinus	Europe	0.24	0.07	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Carpinus	Europe	0.1	0.01	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Cerealia	Europe	0.0462	0.0018	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Cerealia	Europe	0.75	0.04	Nielsen 2004	https://doi.org/10.1111/j.1365-2699.2004.01080.x
Cerealia	Europe	11.58	2.48	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Cerealia	Europe	5.25	1.24	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Cerealia	Europe	3.023	1.14	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Cerealia	Europe	0.22	0.12	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Corylus	Europe	1.51	0.06	Bunting et al. 2005	https://doi.org/10.1191/0959683605hl821rr
Corylus	Europe	1.35	0.0512	Baker et al. 2016	https://doi.org/10.1177/0959683615596822
Corylus	Europe	2.58	0.25	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Corylus	Europe	0.3	0.04	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Cyperaceae	Europe	0.29	0.01	Hjelle 1998	https://doi.org/10.1007/BF01373926
Cyperaceae	Europe	0.13	0.03	Hjelle 1998	https://doi.org/10.1007/BF01373926
Cyperaceae	Europe	0.53	0.06	Niemeyer et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.06.008
Cyperaceae	Europe	1	0.16	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Cyperaceae	Europe	0.89	0.03	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Cyperaceae	Europe	0.72	0.07	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Cyperaceae	Europe	0.11	0.075	Niemeyer et al. 2015	https://doi.org/10.1177/0959683615596822
Cyperaceae	Europe	0.77	0.05	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Ericales	Europe	1.1	0.05	Nielsen 2004	https://doi.org/10.1111/j.1365-2699.2004.01080.x
Ericales	Europe	0.07	0.06	Räsänen et al. 2007	https://doi.org/10.1016/j.revpalbo.2007.04.004
Ericales	Europe	0.01	0.01	Räsänen et al. 2007	https://doi.org/10.1016/j.revpalbo.2007.04.004
Ericales	Europe	1.07	0.03	Hjelle 1998	https://doi.org/10.1007/BF01373926
Ericales	Europe	0.33	0.03	Niemeyer et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.06.008
Ericales	Europe	4.69	0.7	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Ericales	Europe	0.11	0.03	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Ericales	Europe	0.07	0.04	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Ericales	Europe	0.3	0.03	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Fabaceae	Europe	0.4	0.07	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Fagus	Europe	5.09	0.22	Nielsen 2004	https://doi.org/10.1111/j.1365-2699.2004.01080.x
Fagus	Europe	7.5	0.58	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Fagus	Europe	0.76	0.17	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Fagus	Europe	1.2	0.16	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Fagus	Europe	0.06	0	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Fraxinus	Europe	1.11	0.09	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Fraxinus	Europe	0.7	0.06	Bunting et al. 2005	https://doi.org/10.1191/0959683605hl821rr
Fraxinus	Europe	8.67	0.87	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z

Fraxinus	Europe	1.39	0.21	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Fraxinus	Europe	2.99	0.88	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Juniperus	Europe	7.94	1.28	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Larix	Europe	11.29	2.33	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Larix	Europe	0.16	0.05	Niemeyer et al. 2015	https://doi.org/10.1177/0959683615596822
Picea	Europe	1.19	0.42	Nielsen 2004	https://doi.org/10.1111/j.1365-2699.2004.01080.x
Picea	Europe	2.04	0.36	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Picea	Europe	2.78	0.21	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Picea	Europe	0.57	0.16	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Picea	Europe	8.5	0.3	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Picea	Europe	0.36	0.02	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Pinus	Europe	6.17	0.41	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Pinus	Europe	8.4	1.34	Räsänen et al. 2007	https://doi.org/10.1016/j.revpalbo.2007.04.004
Pinus	Europe	7.29	0	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Pinus	Europe	23.12	0.2388	Baker et al. 2016	https://doi.org/10.1177/0959683615596822
Pinus	Europe	21.58	2.87	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Pinus	Europe	1.35	0.45	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Plantaginaceae	Europe	3.7	0.7	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Plantaginaceae	Europe	1.27	0.18	Nielsen 2004	https://doi.org/10.1111/j.1365-2699.2004.01080.x
Plantaginaceae	Europe	1.99	0.04	Hjelle 1998	https://doi.org/10.1007/BF01373926
Plantaginaceae	Europe	0.48	0.02	Hjelle 1998	https://doi.org/10.1007/BF01373926
Plantaginaceae	Europe	12.83	1.85	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Plantaginaceae	Europe	0.24	0.15	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Plantaginaceae	Europe	1.29	0.18	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Plantaginaceae	Europe	0.74	0.14	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Plantaginaceae	Europe	0.58	0.32	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Plantaginaceae	Europe	9.84	0.24	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Poaceae	Europe	1	0	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Poaceae	Europe	1	0	Nielsen 2004	https://doi.org/10.1111/j.1365-2699.2004.01080.x
Poaceae	Europe	1	0	Räsänen et al. 2007	https://doi.org/10.1016/j.revpalbo.2007.04.004
Poaceae	Europe	1	0	Hjelle 1998	https://doi.org/10.1007/BF01373926
Poaceae	Europe	1	0	Hjelle 1998	https://doi.org/10.1007/BF01373926
Poaceae	Europe	1	0	Baker et al. 2016	https://doi.org/10.1177/0959683615596822
Poaceae	Europe	1	0	Niemeyer et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.06.008
Poaceae	Europe	1	0	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Poaceae	Europe	1	0	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Poaceae	Europe	1	0	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Poaceae	Europe	1	0	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Poaceae	Europe	1	0	Niemeyer et al. 2015	https://doi.org/10.1177/0959683615596822
Poaceae	Europe	1	0	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Poaceae	Europe	1	0	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Populus	Europe	3.42	1.6	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Quercus	Europe	1.76	0.2	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Quercus	Europe	5.83	0	Bunting et al. 2005	https://doi.org/10.1191/0959683605hl821rr
Quercus	Europe	2.77	0.22	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Quercus	Europe	18.47	0.1032	Baker et al. 2016	https://doi.org/10.1177/0959683615596822
Quercus	Europe	2.56	0.39	Soepboer et al. 2007	https://doi.org/10.1177/0959683607073279
Quercus	Europe	1.1	0.35	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Quercus	Europe	1.7	0.03	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Ranunculaceae	Europe	0.7	0.004	Hjelle 1998	https://doi.org/10.1007/BF01373926
Ranunculaceae	Europe	0.08	0.02	Hjelle 1998	https://doi.org/10.1007/BF01373926

Ranunculaceae	Europe	3.91	0.72	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Ranunculaceae	Europe	2.31	0.35	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Ranunculaceae	Europe	0.59	0.09	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Rosaceae	Europe	0.14	0.005	Hjelle 1998	https://doi.org/10.1007/BF01373926
Rosaceae	Europe	0.18	0.04	Hjelle 1998	https://doi.org/10.1007/BF01373926
Rosaceae	Europe	2.46	0.85	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Rosaceae	Europe	2.45	0.4	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Rosaceae	Europe	0.97	0.12	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Rosaceae	Europe	0.29	0.12	Grindean et al. 2019	https://doi.org/10.1016/j.revpalbo.2019.02.007
Rubiaceae	Europe	0.42	0.01	Hjelle 1998	https://doi.org/10.1007/BF01373926
Rubiaceae	Europe	0.13	0.03	Hjelle 1998	https://doi.org/10.1007/BF01373926
Rubiaceae	Europe	3.95	0.59	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Rubiaceae	Europe	3.5	0.35	Mazier et al. 2008	https://doi.org/10.1007/s00334-008-0143-0
Rubiaceae	Europe	0.76	0.05	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Rumex	Europe	1.56	0.09	Nielsen 2004	https://doi.org/10.1111/j.1365-2699.2004.01080.x
Rumex	Europe	0.13	0.004	Hjelle 1998	https://doi.org/10.1007/BF01373926
Rumex	Europe	0.04	0.02	Hjelle 1998	https://doi.org/10.1007/BF01373926
Rumex	Europe	4.74	0.83	Broström et al. 2004	https://doi.org/10.1191/0959683604hl713rp
Salix	Europe	1.19	0.12	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Salix	Europe	1.05	0.17	Bunting et al. 2005	https://doi.org/10.1191/0959683605hl821rr
Salix	Europe	0.03	0.03	Niemeyer et al. 2015	https://doi.org/10.1016/j.revpalbo.2015.06.008
Salix	Europe	0.09	0.03	von Stedingk et al. 2008	https://doi.org/10.1177/0959683607086769
Sambucus	Europe	1.3	0.12	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Tilia	Europe	1.36	0.26	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
Tilia	Europe	1.89	0.29	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Tilia	Europe	0.98	0.0263	Baker et al. 2016	https://doi.org/10.1177/0959683615596822
Tilia	Europe	0.45	0.02	Kunes et al. 2019	https://doi.org/10.1177/0959683619862026
Urtica	Europe	10.52	0.31	Abraham and Kozáková 2012	https://doi.org/10.1016/j.revpalbo.2012.04.004
wild herbs	Europe	0.07	0.07	Matthias et al. 2012	https://doi.org/10.1007/s00334-012-0373-z
Alnus	North America	2.7	0.12	Hopla 2017	https://eprints.soton.ac.uk/422162/
Artemisia	North America	1.35	0.24	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Asteraceae	North America	0.03	0.02	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Asteraceae	North America	1.36	0.36	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Asteraceae	North America	0.37	0.16	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Betula	North America	1.4	0.05	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Betula	North America	3.7	0.4	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Betula	North America	10.95	0.02	Hopla 2017	https://eprints.soton.ac.uk/422162/
Betula	North America	8.7	0.44	Hopla 2017	https://eprints.soton.ac.uk/422162/
Campanulaceae	North America	2.29	0.14	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Caryophyllaceae	North America	0.6	0.05	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Cornaceae	North America	1.72	0.14	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Cyperaceae	North America	0.95	0.05	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Cyperaceae	North America	1	0	Hopla 2017	https://eprints.soton.ac.uk/422162/
Equisetum	North America	0.09	0.02	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Ericales	North America	0.53	0	Hopla 2017	https://eprints.soton.ac.uk/422162/
Fabaceae	North America	0.02	0.02	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Juniperus	North America	20.67	1.54	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Lamiaceae	North America	0.72	0.08	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Moraceae	North America	1.1	0.55	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Orobanchaceae	North America	0.33	0.04	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Picea	North America	2.8	0	Hopla 2017	https://eprints.soton.ac.uk/422162/

Plantaginaceae	North America	5.96	0.31	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Poaceae	North America	1	0	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Poaceae	North America	1	0	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Poaceae	North America	1	0.07	Hopla 2017	https://eprints.soton.ac.uk/422162/
Poaceae	North America	1	0.18	Hopla 2017	https://eprints.soton.ac.uk/422162/
Populus	North America	1.23	17	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Populus	North America	0.11	0	Hopla 2017	https://eprints.soton.ac.uk/422162/

Quercus	North America	2.08	0.43	Commerford et al. 2013	https://doi.org/10.4236/ajps.2013.47A1001
Ranunculaceae	North America	1.95	0.1	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Rosaceae	North America	0.35	0.03	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Rumex	North America	3.53	0.3	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Rumex	North America	2.05	0.17	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Salix	North America	0.8	0	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003
Salix	North America	0.58	0	Hopla 2017	https://eprints.soton.ac.uk/422162/
Salix	North America	0.67	0.44	Hopla 2017	https://eprints.soton.ac.uk/422162/
Thalictrum	North America	4.65	0.3	Bunting et al. 2013	https://doi.org/10.1016/j.revpalbo.2012.11.003

Appendix B: RPP synthesis

		Asia				Europe				North America				Northern Hemisphere			
taxon	level	RPP	SD	n	vg	RPP	SD	n	vg	RPP	SD	n	vg	RPP	SD	n	vg
Acer	genus	0.087	0.062	1	0.019	0.23	0.043	3	0.056	-	-	-	0.056	0.152	0.037	3	0.038
Alnus	genus	0.85	1.53	1	0.021	8.492	0.215	4	0.02	2.7	0.12	1	0.021	6.538	0.154	6	0.02
Artemisia	genus	12.842	0.309	9	0.011	4.33	1.592	2	0.018	1.35	0.24	1	0.016	10.504	0.353	12	0.012
Betula	genus	7.492	0.127	6	0.016	4.94	0.443	6	0.024	6.188	0.149	4	0.038	6.361	0.362	18	0.024
Camellia	genus	0.583	0.019	1	0.023	-	-	-	-	-	-	-	-	0.583	0.019	1	0.023
Carpinus	genus	1.542	0.303	1	0.018	3.093	0.284	3	0.042	-	-	-	-	2.705	0.226	4	0.034
Castanea	genus	3.998	0.163	3	0.009	-	-	-	-	-	-	-	-	3.998	0.163	3	0.009
Castanopsis	genus	19.44	0.17	1	0.007	-	-	-	-	-	-	-	-	19.44	0.17	1	0.007
Corylus	genus	3.17	0.141	2	0.012	1.053	0.029	3	0.025	-	-	-	-	1.813	0.087	3	0.019
Cryptomeria	genus	-	-	-	0.015	-	-	-	-	-	-	-	-	-	-	1	0.015
Cyclobalanopsis	genus	2.411	0.136	1	0.011	-	-	-	-	-	-	-	-	2.411	0.136	1	0.011
Fraxinus	genus	1.05	0.178	2	0.02	1.83	0.303	3	0.022	-	-	-	-	1.616	0.195	5	0.021
Hippophae	genus	18.38	1.27	1	0.017	-	-	-	-	-	-	-	-	18.38	1.27	1	0.017
Humulus	genus	16.3	1	1	0.01	-	-	-	-	-	-	-	-	16.3	1	1	0.01
Ilex	genus	6.707	0.583	1	0.011	-	-	-	-	-	-	-	-	6.707	0.583	1	0.011
Juglans	genus	2.803	0.113	3	0.033	-	-	-	0.036	-	-	-	-	2.803	0.113	3	0.034
Larix	genus	2.8	0.181	4	0.12	5.725	1.165	2	0.126	-	-	-	0.126	3.002	0.596	6	0.121
Liquidambar	genus	2.255	0.117	1	0.031	-	-	-	-	-	-	-	-	2.255	0.117	1	0.031
Mallotus	genus	10.848	1.711	1	0.01	-	-	-	-	-	-	-	-	10.848	1.711	1	0.01
Malus	genus	0.087	0.037	1	0.028	-	-	-	-	-	-	-	-	0.087	0.037	1	0.028
Nitraria	genus	-	-	-	0.016	-	-	-	-	-	-	-	-	-	-	1	0.016
Picea	genus	16.4	0.601	2	0.09	1.645	0.153	4	0.056	2.8	0	1	0.056	3.04	0.154	7	0.09
Pinus	genus	16.475	0.691	10	0.048	10.86	0.798	4	0.038	-	-	-	0.028	14.58	0.476	16	0.043
Potentilla	genus	1.4	0.2	1	-	-	-	-	-	-	-	-	-	1.4	0.2	1	-
Quercus	genus	2.131	0.052	7	0.021	2.924	0.098	5	0.035	2.08	0.43	1	0.032	2.547	0.056	15	0.023
Rhododendron	genus	2.48	0.27	1	0.016	-	-	-	-	-	-	-	-	2.48	0.27	1	0.016
Salix	genus	0.23	0.11	1	0.022	0.39	0.058	3	0.028	0.683	0.147	3	0.019	0.57	0.081	6	0.024
Sanguisorba	genus	24.07	3.5	1	0.012	-	-	-	-	-	-	-	-	24.07	3.5	1	0.012
Selaginella	genus	-	-	-	0.041	-	-	-	-	-	-	-	-	-	-	1	0.041
Symplocos	genus	0.214	0.039	1	0.039	-	-	-	-	-	-	-	-	0.214	0.039	1	0.039
Syringa	genus	3.394	0.216	1	0.019	-	-	-	-	-	-	-	-	3.394	0.216	1	0.019
Thalictrum	genus	2.8	0.4	1	0.01	-	-	-	-	4.65	0.3	1	0.012	3.725	0.25	2	0.011
Tilia	genus	0.4	0.1	1	0.029	1.17	0.131	2	0.032	-	-	-	0.044	0.93	0.087	3	0.036
Ulmus	genus	2.025	0.312	3	0.022	-	-	-	0.032	-	-	-	-	2.025	0.312	3	0.022
Vitex	genus	-	-	-	0.016	-	-	-	-	-	-	-	-	-	-	1	0.016
Abies	genus	-	-	-	-	6.875	1.442	2	0.12	-	-	-	0.12	6.875	1.442	2	0.12
Aesculus	genus	-	-	-	-	-	-	-	0.029	-	-	-	-	-	-	1	0.029
Fagus	genus	-	-	-	-	2.35	0.107	3	0.057	-	-	-	0.057	2.35	0.107	3	0.057
Juniperus	genus	-	-	-	-	7.94	1.28	1	0.016	20.67	1.54	1	0.016	14.305	1.001	2	0.016
Populus	genus	-	-	-	-	3.42	1.6	1	0.025	0.67	8.5	2	0.026	1.587	5.692	3	0.026
Pterocarya	genus	-	-	-	-	-	-	-	0.042	-	-	-	-	-	-	1	0.042
Rumex	genus	-	-	-	-	0.577	0.031	3	0.018	2.79	0.172	2	0.014	1.817	0.089	4	0.016
Sambucus	genus	-	-	-	-	1.3	0.12	1	0.013	-	-	-	-	1.3	0.12	1	0.013
Urtica	genus	-	-	-	-	10.52	0.31	1	0.007	-	-	-	-	10.52	0.31	1	0.007
Equisetum	genus	-	-	-	-	-	-	-	-	0.09	0.02	1	0.021	0.09	0.02	1	0.021
Tsuga	genus	-	-	-	-	-	-	-	-	-	-	-	0.064	-	-	1	0.064
Altingiaceae	family	2.255	0.117	1	0.031	-	-	-	-	-	-	-	-	2.255	0.117	1	0.031

Amaranthaceae	family	13.156	0.643	8	0.013	4.28	0.27	1	0.019	-	-	-	0.011	12.17	0.573	9	0.014
Amaryllidaceae	family	1.64	0.4	1	0.013	-	-	-	-	-	-	-	-	1.64	0.4	1	0.013
Anacardiaceae	family	0.889	0.037	3	0.019	-	-	-	-	-	-	-	-	0.889	0.037	3	0.019
Apiaceae	family	-	-	-	0.011	2.127	0.41	3	0.042	-	-	-	-	2.127	0.41	3	0.027
Aquifoliaceae	family	6.707	0.583	1	0.011	-	-	-	-	-	-	-	-	6.707	0.583	1	0.011
Asteraceae	family	8.685	0.192	21	0.015	0.52	0.042	10	0.03	1.027	0.154	3	0.023	5.322	0.139	37	0.018
Betulaceae	family	5.442	0.592	10	0.016	5.195	0.145	21	0.028	5.033	0.202	3	0.033	5.394	0.181	38	0.025
Brassicaceae	family	2.145	0.135	2	0.012	0.07	0.04	1	0.028	-	-	-	-	1.453	0.091	3	0.019
Cannabaceae	family	16.3	1	1	0.01	-	-	-	-	-	-	-	-	16.3	1	1	0.01
Caryophyllaceae	family	13.043	0.628	4	0.024	-	-	-	-	0.6	0.05	1	0.04	10.608	0.504	5	0.03
Convolvulaceae	family	0.18	0.03	1	0.043	-	-	-	-	-	-	-	-	0.18	0.03	1	0.043
Cupressaceae	family	1.11	0.09	1	0.013	7.94	1.28	1	0.016	20.67	1.54	1	0.016	-	-	-	0.014
Cyperaceae	family	1.563	0.61	8	0.027	0.555	0.019	6	0.035	0.975	0.025	2	0.033	1.05	0.271	18	0.027
Elaeagnaceae	family	13.64	0.686	2	0.013	-	-	-	-	-	-	-	-	13.64	0.686	2	0.013
Eleagnaceae	family	18.38	1.27	1	0.017	-	-	-	-	-	-	-	-	18.38	1.27	1	0.017
Ephedraceae	family	22.87	0.76	1	0.014	-	-	-	-	-	-	-	-	22.87	0.76	1	0.014
Ericaceae	family	1.873	0.13	3	0.027	-	-	-	-	-	-	-	-	1.873	0.13	3	0.027
Euphorbiaceae	family	6.093	0.572	3	0.009	-	-	-	-	-	-	-	-	6.093	0.572	3	0.009
Fabaceae	family	0.209	0.051	2	0.016	0.4	0.07	1	0.021	0.02	0.02	1	0.021	0.244	0.038	5	0.017
Fagaceae	family	2.93	0.053	12	0.017	3.027	0.09	10	0.052	2.08	0.43	1	0.038	3.449	0.047	25	0.025
Gentianaceae	family	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	1	0.02
Iridaceae	family	-	-	-	0.012	-	-	-	-	-	-	-	-	-	-	1	0.012
Juglandaceae	family	2.576	0.087	4	0.033	-	-	-	0.039	-	-	-	-	-	-	-	0.035
Lamiaceae	family	1.457	0.16	3	0.015	-	-	-	-	0.72	0.08	1	0.031	-	-	-	0.018
Liliaceae	family	1.97	0.207	2	0.014	-	-	-	-	-	-	-	-	1.97	0.207	2	0.014
Malvaceae	family	0.4	0.1	1	0.029	1.17	0.131	2	0.032	-	-	-	0.044	0.93	0.087	3	0.036
Moraceae	family	6.52	0.08	1	0.008	-	-	-	-	1.1	0.55	1	0.016	3.81	0.278	2	0.012
Nitrariaceae	family	-	-	-	0.016	-	-	-	-	-	-	-	-	-	-	1	0.016
Oleaceae	family	1.831	0.139	3	0.019	1.83	0.303	3	0.022	-	-	-	-	1.912	0.167	6	0.02
Papilionaceae	family	2.66	0.05	1	0.007	-	-	-	-	-	-	-	-	2.66	0.05	1	0.007
Pinaceae	family	12.073	0.437	18	0.072	6.091	0.354	14	0.061	2.8	0	1	0.072	-	-	-	0.068
Plantaginaceae	family	-	-	-	0.013	2.486	0.107	8	0.028	5.96	0.31	1	0.019	2.872	0.101	9	0.022
Poaceae	family	1	0.012	16	0.023	1	0	14	0.036	-	-	-	0.031	1	0.008	34	0.024
Polygonaceae	family	26.35	1.85	1	0.024	0.577	0.031	3	0.018	2.79	0.172	2	0.014	2.402	0.181	5	0.02
Ranunculaceae	family	5.33	1.34	2	0.01	1.2	0.12	3	0.014	3.3	0.158	2	0.013	2.416	0.136	7	0.012
Rosaceae	family	0.824	0.057	4	0.015	0.973	0.109	4	0.012	0.35	0.03	1	0.014	0.921	0.089	11	0.014
Rubiaceae	family	1.26	0.18	2	0.015	1.56	0.118	3	0.019	-	-	-	-	1.44	0.101	5	0.015
Salicaceae	family	0.23	0.11	1	0.022	0.777	0.07	3	0.027	0.683	0.147	3	0.022	0.661	1.89	9	0.025
Sapindaceae	family	0.087	0.062	1	0.019	0.23	0.043	3	0.043	-	-	-	0.056	-	-	-	0.035
Selaginellaceae	family	-	-	-	0.041	-	-	-	-	-	-	-	-	-	-	1	0.041
Solanaceae	family	-	-	-	0.027	-	-	-	-	-	-	-	-	-	-	1	0.027
Symplocaceae	family	0.214	0.039	1	0.039	-	-	-	-	-	-	-	-	0.214	0.039	1	0.039
Tamaricaceae	family	1.5	0.13	1	-	-	-	-	-	-	-	-	-	1.5	0.13	1	-
Theaceae	family	0.583	0.019	1	0.024	-	-	-	-	-	-	-	-	0.583	0.019	2	0.024
Thymelaceae	family	33.05	3.78	1	0.009	-	-	-	-	-	-	-	-	33.05	3.78	1	0.009
Ulmaceae	family	1.298	0.173	2	0.022	-	-	-	0.032	-	-	-	-	1.298	0.173	2	0.022
Urticaceae	family	-	-	-	-	10.52	0.31	1	0.007	-	-	-	-	10.52	0.31	1	0.007
Viburnaceae	family	-	-	-	-	1.3	0.12	1	0.013	-	-	-	-	1.3	0.12	1	0.013
Campanulaceae	family	-	-	-	-	-	-	-	-	2.29	0.14	1	0.022	2.29	0.14	1	0.022
Cornaceae	family	-	-	-	-	-	-	-	-	1.72	0.14	1	0.044	1.72	0.14	1	0.044
Equisetaceae	family	-	-	-	-	-	-	-	-	0.09	0.02	1	0.021	0.09	0.02	1	0.021
Onagraceae	family	-	-	-	-	-	-	-	-	-	-	-	0.098	-	-	1	0.098

Orobanchaceae	family	-	-	-	-	-	-	-	-	0.33	0.04	1	0.038	0.33	0.04	1	0.038
Apiales	order	-	-	-	0.011	2.127	0.41	3	0.042	-	-	-	-	2.127	0.41	3	0.027
Aquifoliales	order	6.707	0.583	1	0.011	-	-	-	-	-	-	-	-	6.707	0.583	1	0.011
Asparagales	order	1.64	0.4	1	0.012	-	-	-	-	-	-	-	-	1.64	0.4	2	0.012
Asterales	order	8.685	0.192	21	0.015	0.52	0.042	10	0.03	1.027	0.154	3	0.023	5.242	0.136	38	0.018
Brassicales	order	2.145	0.135	2	0.012	0.07	0.04	1	0.028	-	-	-	-	1.453	0.091	3	0.019
Caryophyllales	order	13.408	0.39	16	0.017	1.99	0.095	3	0.018	2.06	0.116	3	0.026	9.65	0.263	24	0.019
Coniferales	order	29.4	0.87	1	0.071	-	-	-	0.056	-	-	-	0.064	-	-	-	0.071
Ephedrales	order	22.87	0.76	1	0.014	-	-	-	-	-	-	-	-	22.87	0.76	1	0.014
Ericales	order	1.241	0.095	3	0.028	0.436	0.015	7	0.032	0.53	0	1	0.038	-	-	-	0.028
Fabales	order	0.4	0.036	3	0.015	0.4	0.07	1	0.021	0.02	0.02	1	0.021	0.333	0.032	6	0.016
Fagales	order	4.063	0.206	30	0.02	4.786	0.096	33	0.036	4.295	0.186	4	0.036	-	-	-	0.027
Gentianales	order	1.26	0.18	2	0.017	1.56	0.118	3	0.019	-	-	-	-	-	-	-	0.017
Lamiales	order	1.567	0.145	4	0.016	2.673	0.117	13	0.026	2.337	0.108	3	0.029	-	-	-	0.022
Liliales	order	1.97	0.207	2	0.014	-	-	-	-	-	-	-	-	1.97	0.207	2	0.014
Malphighiales	order	2.553	0.056	3	0.015	0.777	0.07	3	0.027	0.683	0.147	3	0.022	1.053	1.553	11	0.022
Malphigiales	order	10.848	1.711	1	0.01	-	-	-	-	-	-	-	-	10.848	1.711	1	0.01
Malvales	order	16.725	1.891	2	0.022	1.17	0.131	2	0.032	-	-	-	0.044	1.17	0.098	4	0.031
Pinales	order	10.502	0.435	18	0.069	6.214	0.342	15	0.056	11.735	0.77	2	0.062	8.893	0.256	37	0.063
Poales	order	1.188	0.204	24	0.025	0.555	0.019	6	0.036	-	-	-	0.031	1.017	0.094	52	0.026
Ranunculales	order	5.33	1.34	2	0.01	1.2	0.12	3	0.014	3.3	0.158	2	0.013	2.416	0.136	7	0.012
Rosales	order	6.761	0.197	11	0.017	1.27	0.191	5	0.015	0.725	0.275	2	0.015	4.642	0.122	20	0.016
Sapindales	order	0.328	0.04	3	0.019	0.23	0.043	3	0.043	-	-	-	0.056	-	-	-	0.028
Saxifragales	order	2.255	0.117	1	0.031	-	-	-	-	-	-	-	-	2.255	0.117	1	0.031
Selaginellales	order	-	-	-	0.041	-	-	-	-	-	-	-	-	-	-	1	0.041
Solanales	order	0.18	0.03	1	0.035	-	-	-	-	-	-	-	-	0.18	0.03	2	0.035
Spaindales	order	-	-	-	0.016	-	-	-	-	-	-	-	-	-	-	1	0.016
Cerealia	order	-	-	-	-	2.311	0.422	4	0.069	-	-	-	-	2.311	0.422	4	0.069
Dipsacales	order	-	-	-	-	1.3	0.12	1	0.013	-	-	-	-	1.3	0.12	1	0.013
wild herbs	order	-	-	-	-	0.07	0.07	1	0.034	-	-	-	-	0.07	0.07	1	0.034
Cornales	order	-	-	-	-	-	-	-	-	1.72	0.14	1	0.044	1.72	0.14	1	0.044
Equisetales	order	-	-	-	-	-	-	-	-	0.09	0.02	1	0.021	0.09	0.02	1	0.021
Myrtales	order	-	-	-	-	-	-	-	-	-	-	-	0.098	-	-	1	0.098
Myrtales	order	-	-	-	-	-	-	-	-	-	-	-	0.098	-	-	1	0.098

Author contributions. UH conceptualized the data set production. CL curated the pollen dataset supervised by UH. CL revised age models supervised by UH. CL, PE and LS collected metadata for pollen records supervised by. PE set up, improved and tested code to run the REVEALS model and run the initial Reveals reconstructions supervised by UH. LS, TL, RH, and UH developed the optimization methodology. LS wrote optimization code, curated remote sensing data and executed optimization, final reconstructions and validations. TL, RH and UH provided supervision for LS. LS prepared the original draft supervised by UH. All authors reviewed and edited the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgements. We thank Thomas Böhmer for support with dataset curation and harmonization. The project was supported by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie through the German Climate Modeling Initiative PALMOD (grant no. 01LP1510C to UH), the European Union (ERC, GlacialLegacy grant no. 772852 to UH), and the China Scholarship Council (grant no. 201908130165 to CL). Data were partly obtained from the Neotoma Paleoecology Database (http://www.neotomadb.org) and its constituent databases (European Pollen Database, QUAVIDA data base for Australasia, Latin American Pollen Database, African Pollen Database and the North American Pollen database). The work of data contributors, data stewards, and the Neotoma community is gratefully acknowledged.

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