Supplementary Materials

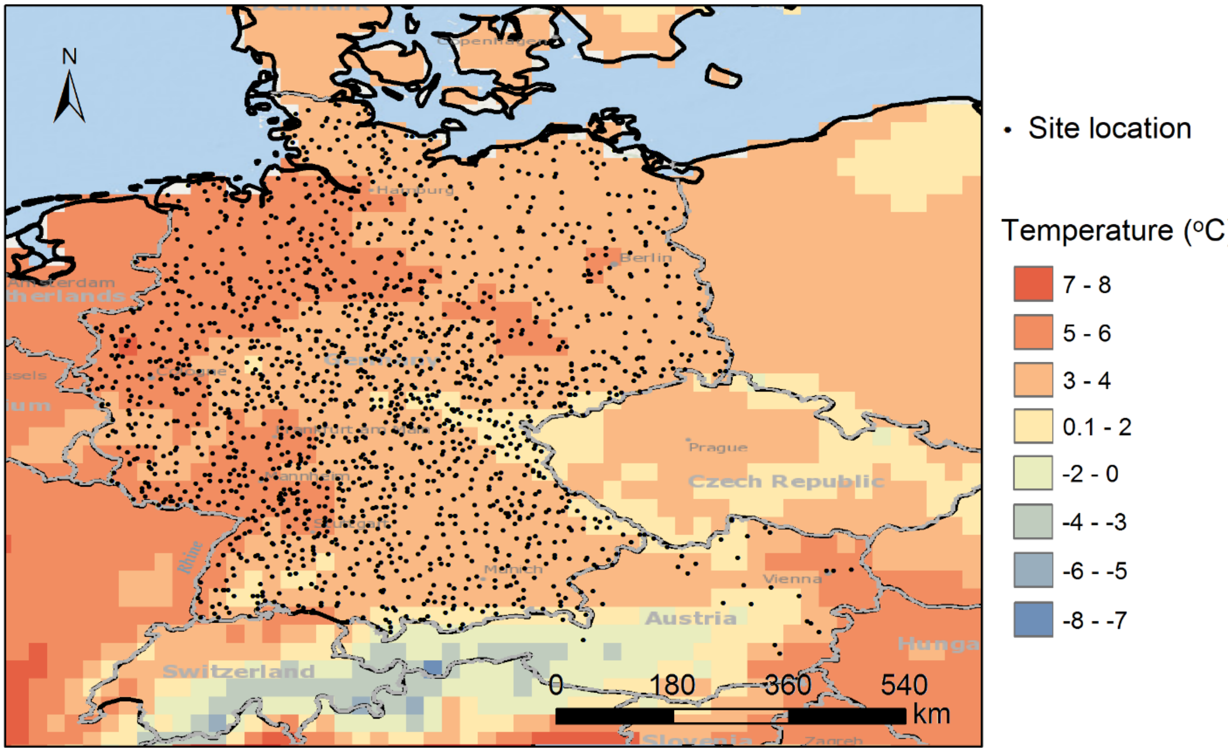

Fig. S1 Spatial distribution of temperature across the study area. Temperature is the long-term mean spring temperature (January 1st to April 30th) during 1980-2016. Site location of *Aesculus hippocastanum* is shown here.

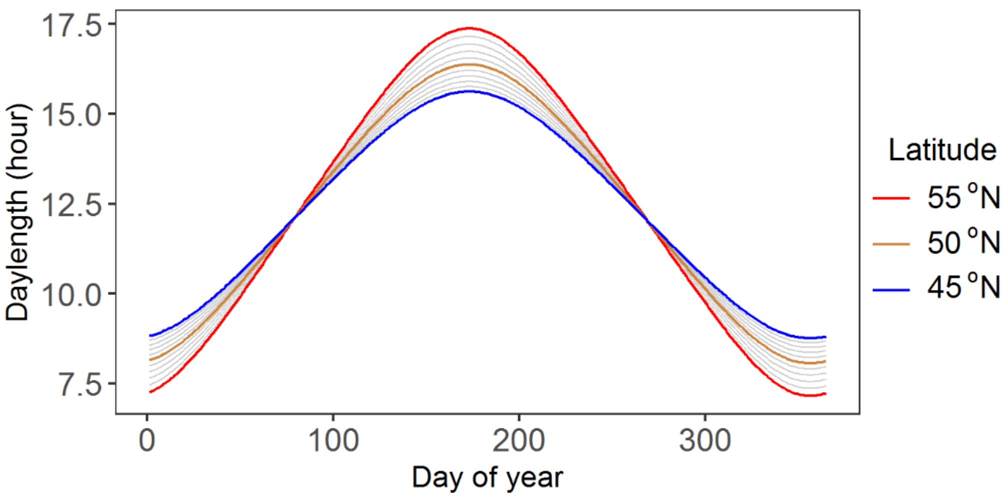

Fig. 2 Seasonal changes in daylength across latitudes. Red, yellow, and blue lines represent daylength at three example latitudes and gray lines represent daylength at a 1° latitude interval from 45 to 55° N.

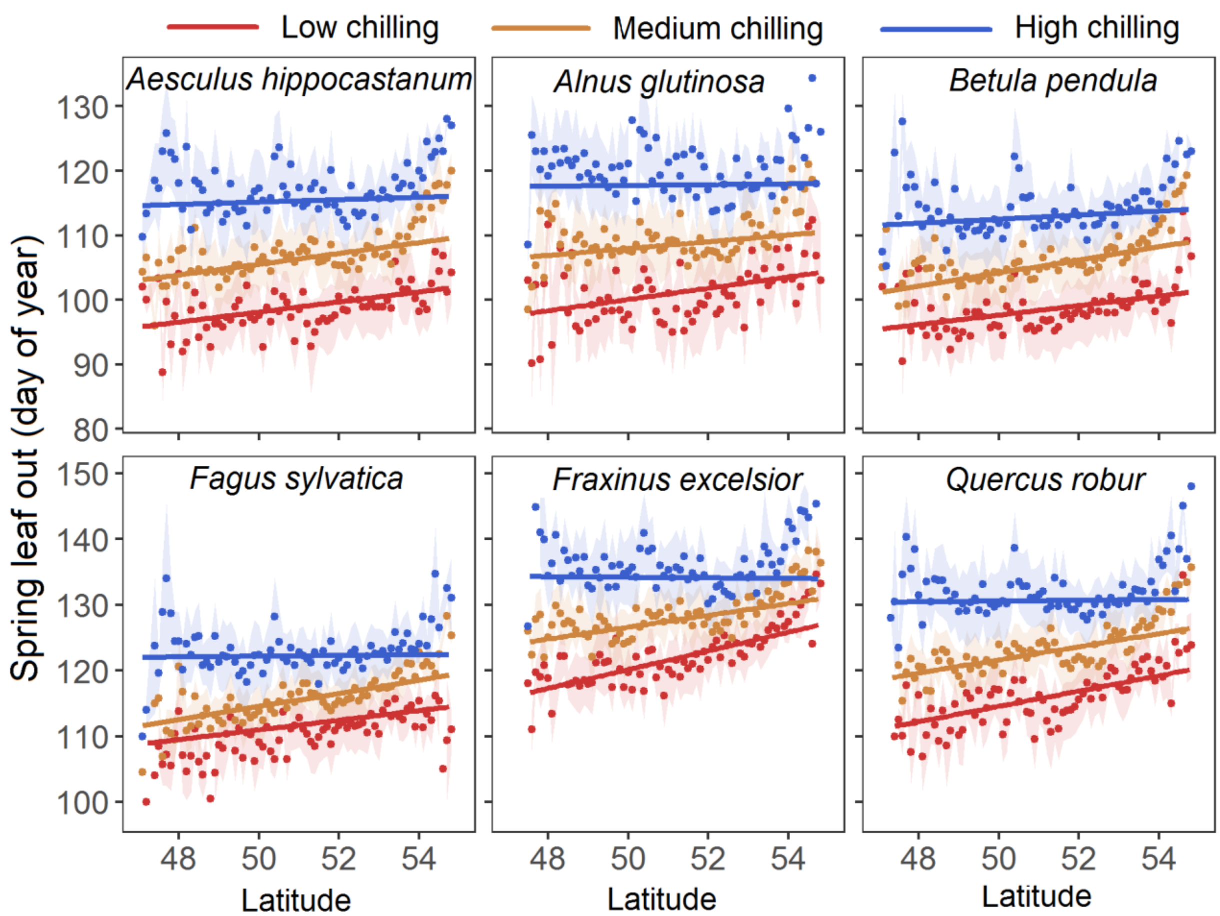

Fig. S3 Changes in spring leaf-out across latitudes in the high forcing group. Points and shaded areas represent mean and uncertainty (i.e., 50% of standard deviation), respectively, of spring leaf-out at a 0.1° latitude. We stratified the data into nine temperature groups based on three forcing and three chilling accumulations at high, medium, and low levels for each deciduous tree species based on the 33.3% and 66.6% quantiles of forcing or chilling accumulations during the period 1980-2016. Chilling was calculated as the number of days when the daily mean temperature was below 5 °C from November 1st in the preceding year to leaf-out. Fitted linear regression lines for spring leaf-out with latitude are shown in each chilling group. Results at medium and low forcing groups are shown in Figs. 3 and S4.

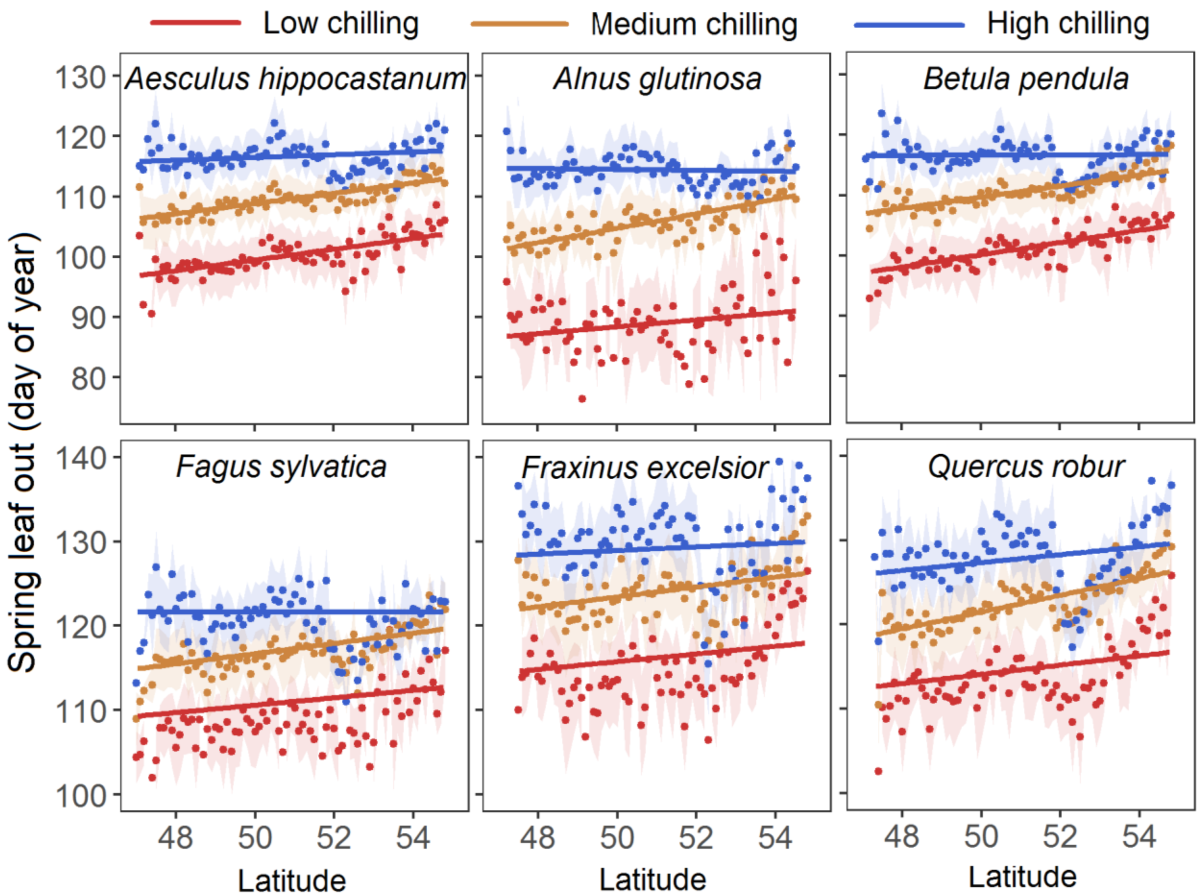

Fig. S4 Changes in spring leaf-out across latitude in the low forcing group. Points and shaded areas represent mean and uncertainty (i.e., 50% of standard deviation), respectively, of spring leaf-out at a 0.1° latitude. We stratified the data into nine temperature groups based on three forcing and three chilling accumulations at high, medium, and low levels for each deciduous tree species based on the 33.3% and 66.6% quantiles of forcing or chilling accumulations during the period 1980-2016. Chilling was calculated as the number of days when the daily mean temperature was below 5 °C from November 1st in the preceding year to leaf-out. Fitted linear regression lines for spring leaf-out with latitude are shown in each chilling group. Results at the medium and high forcing groups are shown in Figs. 3 and S3.

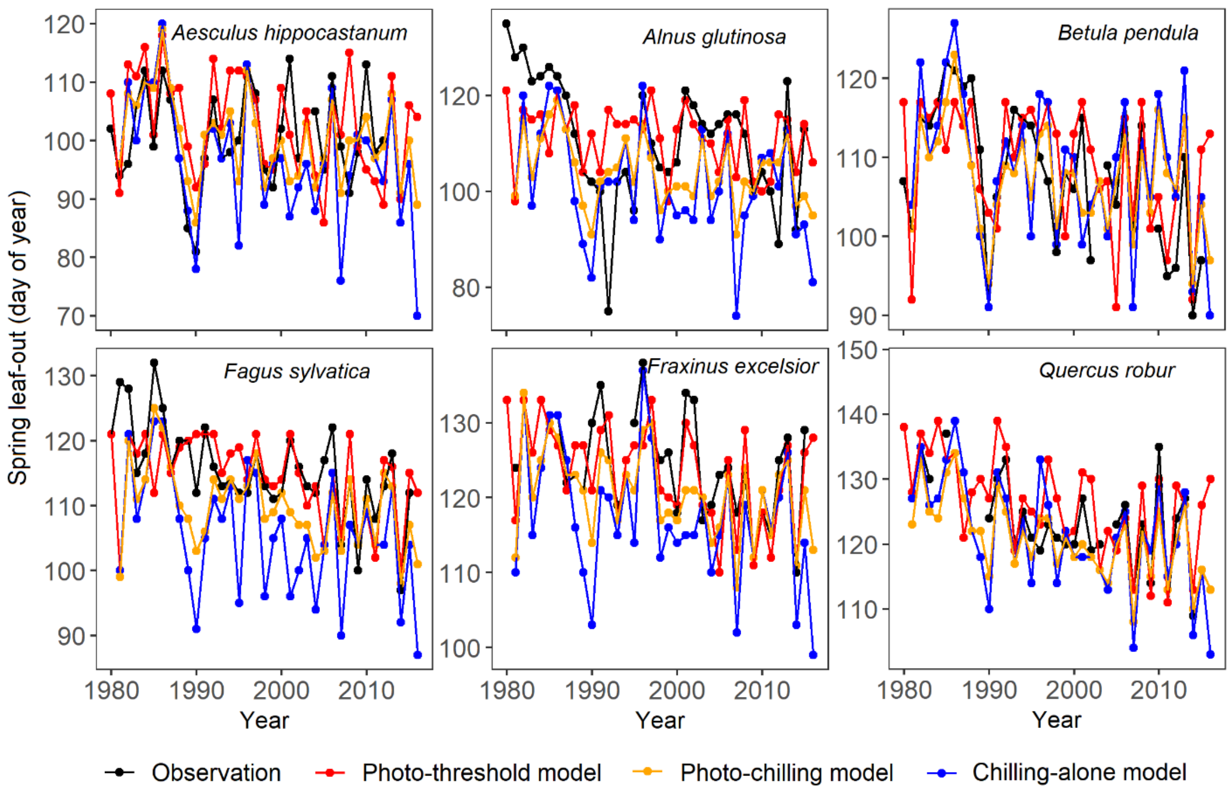

Fig. S5 Interannual variation of spring leaf-out of six species from observation and model prediction during 1980-2016. The figures show the time series of spring leaf-out at one site (Site_ID: 164, latitude: 53.73 ºN, longitude: 9.78 ºE).

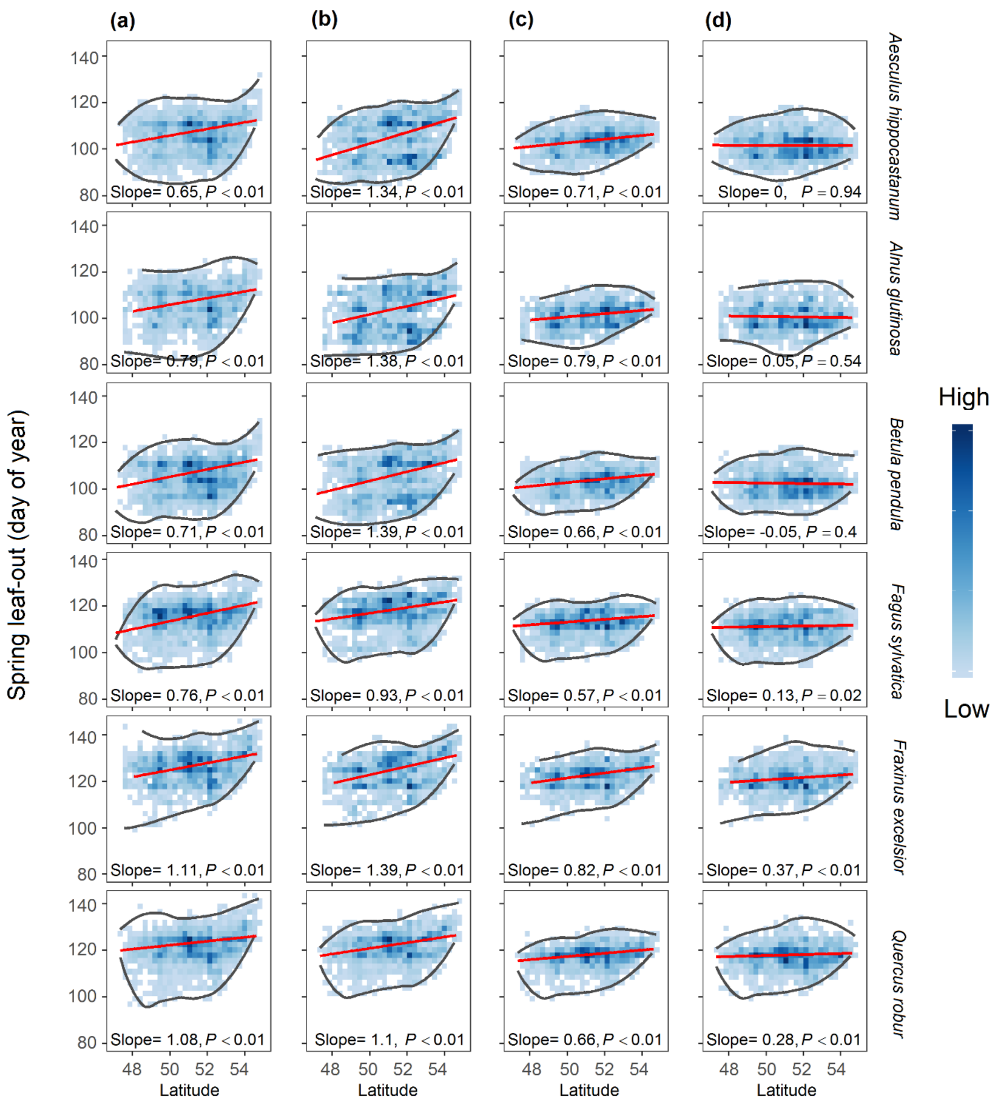

Fig. S6 Observed (a) and predicted spring leaf-out by the photo-threshold model (b), photo-chilling model (c), and chilling-alone model (d) across latitudes. Same as Fig. 6 but with wider selection criteria. Color of pixels represents the number of observations. Spring leaf-out data were selected from all site-year data during the period1980-2016 based on the following criteria: (1) forcing accumulation was within 60-80% quantiles of all forcing accumulations and (2) chilling accumulation was within 20-40% quantiles of all chilling accumulations. Gray lines represent the boundary of data distribution, fitted by a Loess smooth approach using the maximum and minimum spring leaf-out at each 0.1° latitude. Linear regression lines, slopes, and *P*-values for spring leaf-out against latitudes are shown.

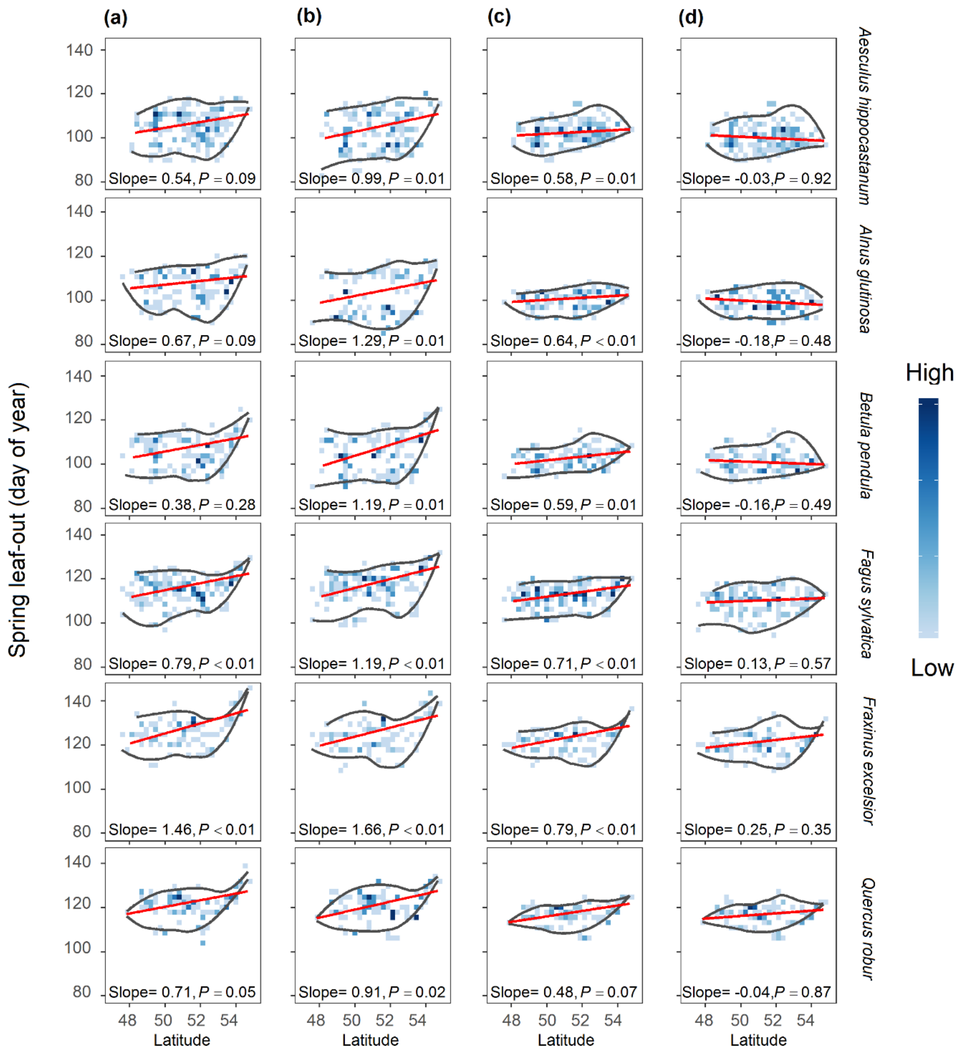

Fig. S7 Observed (a) and predicted spring leaf-out from the photo-threshold model (b), photo-chilling model (c), and chilling-alone model (d) across latitudes. Same as Fig. 6 but with narrower selection criteria. Color of pixels represents the number of observations. Spring leaf-out data were selected from all site-year data during 1980-2016 based on the following criteria: (1) forcing accumulation was within 70-75% quantiles of all forcing accumulations and (2) chilling accumulation was within 25-30% quantiles of all chilling accumulations. Gray lines represent the boundary of data distribution, fitted by a Loess smooth approach using the maximum and minimum spring leaf-out at each 0.1° latitude. Linear regression lines, slopes, and *P*-values for spring leaf-out against latitudes are shown.

Table S1 Root-mean-square error (RMSE) of interannual variation of spring leaf-out of six species between observation and model prediction during 1980-2016. The data is shown in Fig. S5. Mean and standard deviation of RMSE (unit: days) across species are shown as the bottom row of the table.

Species	**Photo-threshold model**	**Photo-chilling model**	**Chilling-alone model**
Aesculus hippocastanum	9.36	6.96	9.42
Alnus glutinosa	13.87	12.69	15.42
Betula pendula	7.29	6.53	8.06
Fagus sylvatica	7.35	8.29	11.91
Fraxinus excelsior	5.19	6.77	10.50
Quercus robur	4.79	4.48	5.90
All species	7.97 ± 3.33	7.62 ± 2.77	10.20 ± 3.28

Table S2 Linear regressions between chilling or forcing and latitude for the six species. Data used here were the same with data used in Figs.5 and 6, i.e., selected from all site-year data during the period 1980-2016 based on the following criteria: (1) forcing accumulation was within the 65-75% quantiles of all forcing accumulations and (2) chilling accumulation was within the 25-35% quantiles of all chilling accumulations. Forcing accumulation was defined as an integration of daily mean temperature above 5 °C throughout the preseason (from November 1st in the preceding year until leaf-out). Chilling accumulation was defined as the number of days when the daily mean temperature was below 5 °C.

Species	Forcing		Chilling	
	Slope	***P* value**	**Slope**	***P* value**
Aesculus hippocastanum	-0.09	0.48	0.00	0.99
Alnus glutinosa	0.35	0.04	0.05	0.33
Betula pendula	0.03	0.81	0.04	0.29
Fagus sylvatica	-0.24	0.13	0.05	0.17
Fraxinus excelsior	0.09	0.63	0.02	0.73
Quercus robur	0.01	0.96	0.00	0.95