Supplementary Material

1 Supplementary Tables

Supplementary Table 1. Geographic locations of the IPTNS 1964/68 series used to fit and validate the TraitSDM. Height data of 10 experiments directly measured or interpolated (indicated by *) to common age of 11 years were used to fit the TraitSDM (32 site locations and a total of 97 individual blocks of 100 provenances), while independent data of seven experiments measured at different age (15 site locations and 47 blocks) were used to evaluate model performance.

EXP	Country	Trial site location	Lat.	Long.	Elev.	Provenance block	Juvenile height			Data source (by EXP)
							age	used in TraitSDM for: model fitting	used in TraitSDM for: vali-dation	
4	Norway	Ilsvåg	59.52	5.82	150	1-2-3-5-7-8-9-10	11	X		(Dietrichson et al., 1976)
		Vats	59.48	5.75	150	4-6-11	11	X		
5	Norway	Bjerköy	59.20	10.47	10	4-5-8-9	11	X		(Dietrichson et al., 1976)
						3-6	10		X	
		Overud	60.17	11.07	200	1-2-7-10-11	11	X		
6	Sweden	Hjuleberg	56.93	12.73	60	all	9		X	(Dietrichson et al., 1976)
7	Sweden	Lisjö	59.72	16.08	65	2-3-4-5-7-10-11	11	X		(Dietrichson et al., 1976)
8	Sweden	Lappkojberg	63.42	18.62	190	all	11	X		(Dietrichson et al., 1976)
10	France	Amance	48.78	6.30	240	all	9		X	(Dietrichson et al., 1976)
11	Belgium	Herbeumont	49.80	5.25	410	2	10		X	(Dietrichson et al., 1976)
		Rocherath	50.47	6.33	600	6	10		X	
12	Belgium	Gendron-Celle	50.25	5.00	250	3	12		X	(Dietrichson et al., 1976)
13	Germany	Deuselbach	49.75	7.10	640	1-4	10, 13	X*		(Liepe et al., unpublished data)
		Brandscheid	50.50	6.67	620	2-3-6-10	10, 13	X*		
		Kell-Nord	49.63	7.00	620	5	10, 13	X*		
		Ruppertsweiler	49.18	7.68	305	7	10, 13	X*		
		Kindsbach	49.07	7.12	240	8	10, 13	X*		
		Nister	50.67	7.85	380	9	10, 13	X*		
		Bellerhof	50.62	7.90	440	11	10, 13	X*		
14	Germany	Holzerode	51.67	10.12	250	1-6-7-8	10, 13	X*		(Liepe et al., unpublished data)
		Rüdershausen	51.57	10.27	235	2-10-11	10, 13	X*		
		Schoningen	51.63	9.70	305	3-9	10, 13	X*		
		Delliehausen	51.67	9.70	305	4	10, 13	X*		
		Hörden	51.62	10.27	235	5	10, 13	X*		
15	Germany	Gerershagen	51.95	7.57	400	1	10, 13	X*		(Liepe et al., unpublished data)
		Brüggen	51.23	6.10	40	2	10, 13	X*		
		Romberger	51.64	7.69	250	3	10, 13	X*		
		Gedern	50.42	9.13	340	4	10, 13	X*		
		Rheinbrohl	50.60	7.33	340	5-6	10, 13	X*		
		Sassmanshausen	51.00	8.50	400	7-8	10, 13	X*		
		Rankenhohn	50.82	7.50	200	9	10, 13	X*		
		Daubenscheid	50.47	6.35	625	10	10, 13	X*		
		Hümmerich	50.57	7.48	290	11	10, 13	X*		
16	Scotland	Drummond Hill	56.58	-4.08	160	8-9	11	X		(Dietrichson et al., 1976)
		Minard Forest	56.17	-5.25	170	10-11	11	X		
17	Czech Republic	Dolni Kralovice	49.67	15.23	390	7-9	9		X	(Dietrichson et al., 1976)
		Zahradka	49.68	15.23	390	1-2-3-4-5-6	9		X	

EXP	Country	Trial site location	Lat.	Long.	Elev.	Provenance block	Juvenile height			Data source (by EXP)
							age	used in TraitSDM for		
								model fitting	vali-dation	
		Borovsko	49.63	15.25	390	10-11	9		X	
18	Austria	Klein Mariazell	48.05	15.97	460	1-2	14		X	(König, 1981)
		Stollberg	48.08	15.85	520	3-4	14		X	
		Ottenstein	48.62	15.28	550	5-6	14		X	
		Landsee	47.57	16.32	600	7-8	14		X	
		Klaus/Phyrenabhn	47.85	14.12	550	9	14		X	
		Kelchsau	47.37	12.13	1020	11	14		X	
19	Poland	Krynica1	49.47	21.02	750	1-3-4-5-7-8-9	9, 12	X*		(Bałut and Sabor, 2002)
		Krynica2	49.35	20.97	757	2-6-10	9, 12	X*		
20	Hungary	Nyírjes	47.89	19.95	600	all	9, 14	X*		(Ujvári-Jármay et al., 2016)

Data references

Bałut, S., and Sabor, J. (2002). Inventory provenance test of Norway spruce (Picea abies (L.) Karst.) IPTNS-IUFRO 1964/68 in Krynica. Part II: Test results of 1968-1984. Geographical variability of traits in the whole range of species. Kraków.

Dietrichson, J., Christophe, C., Coles, J., De Jamblinne, A., Krutzsch, P., König, A., et al. (1976). The IUFRO provenance experiment of 1964/68 on Norway spruce (Picea abies L. Karst). in *Proceedings of the 16th IUFRO World Congress* (Oslo, Norway: Norwegian Forest research Institute), 14.

König, A. (1981). Einige Ergebnisse aus dem IUFRO-Fichtenprovenienzversuch von 1964/68 in der Bundesrepublik Deutschland. *Allg. Forstzeitung* 92, 300–303.

Liepe, K.J., König, A., and Liesebach, M. (unpublished data). Access to height data of age 11 from the three German experiments of the IPTNS 1964/68 series will be provided upon request to the corresponding author katharina.liepe@thuenen.de.

Ujvári-Jármay, É., Nagy, L., and Mátyás, C. (2016). The IUFRO 1964/68 inventory provenance trial of Norway spruce in Nyírjes, Hungary - Results and conclusions of five decades. *Acta Silv. Lignaria Hungarica* 12, 177. doi:10.1515/aslh-2016-0001.

Supplementary Table 2. Stepwise procedure to fit the TraitSDM. For each step the top ten models based on the proportion of variance explained (R^2) and Akaike Information Criterion (AIC) are reported. As stated in Equation 2 all climate variables for site (*S1* and *S2*) and provenance (*P*), entered the model as linear and squared term. The same applies for the geographic variables (*G*).

Step 1: models using one climate variable for site

	S1	R^2	AIC	p
1	FFP_s	0.587	5969	0.00E+00
2	DD.5_s	0.581	6096	0.00E+00
3	MAT_s	0.578	6173	0.00E+00
4	MCMT_s	0.531	7181	0.00E+00
5	DD.0_s	0.489	7991	0.00E+00
6	TD_s	0.487	8025	0.00E+00
7	SHM_s	0.415	9270	0.00E+00
8	MSP_s	0.271	11366	0.00E+00
9	AHM_s	0.216	12062	0.00E+00
10	MWMT_s	0.162	12699	0.00E+00

Step 2: models using two climate variables for site

	S1	S2	R^2	AIC	p
1	FFP_s	SHM_s	0.730	1917	0.00E+00
2	FFP_s	MSP_s	0.690	3236	0.00E+00
3	SHM_s	MCMT_s	0.683	3443	0.00E+00
4	SHM_s	MAT_s	0.682	3492	0.00E+00
5	FFP_s	ADI_s	0.677	3639	0.00E+00
6	SHM_s	DD.5_s	0.674	3729	0.00E+00
7	FFP_s	CMD_s	0.671	3818	0.00E+00
8	FFP_s	AHM_s	0.671	3822	0.00E+00
9	FFP_s	MDMP_s	0.659	4156	0.00E+00
10	FFP_s	DD.5_s	0.658	4189	0.00E+00

Step 3: models using one climate or geographic variable for provenance

	P1	R^2	AIC	p
1	LAT_p	0.022	14163	6.80E-47
2	MAT_p	0.011	14266	2.32E-24
3	DD.0_p	0.010	14284	1.61E-20
4	DD.5_p	0.008	14295	3.71E-18
5	FFP_p	0.008	14301	7.25E-17
6	MCMT_p	0.008	14304	2.85E-16
7	TD_p	0.006	14321	1.69E-12
8	AHM_p	0.006	14322	3.43E-12
9	MWMT_p	0.005	14330	1.65E-10
10	ADI_p	0.005	14330	1.40E-10

Step 4: models using one climate and one geographic variable for provenance; combinations of climate and geographic variables had a better fit than any combination of two climate variables

	P	G	R^2	AIC	p
1	ADI_p	LAT_p	0.027	14122	2.08E-54
2	TD_p	LAT_p	0.027	14123	3.35E-54
3	AHM_p	LAT_p	0.026	14125	8.81E-54
4	SHM_p	LAT_p	0.025	14138	4.46E-51
5	MWMT_p	LAT_p	0.024	14146	2.95E-49
6	CMD_p	LAT_p	0.024	14147	5.94E-49
7	MAT_p	LAT_p	0.023	14156	3.75E-47
8	MCMT_p	LAT_p	0.023	14157	6.65E-47
9	FFP_p	LAT_p	0.023	14161	5.03E-46
10	MAT_p	LONG_p	0.019	14198	3.60E-38

Step 5: models using one climate variable for site and one for provenance

	S1	S2	R^2	AIC	p
1	FFP_s	MAT_p	0.601	5645	0.00E+00
2	FFP_s	DD.0_p	0.600	5675	0.00E+00
3	FFP_s	MCMT_p	0.597	5743	0.00E+00
4	FFP_s	FFP_p	0.596	5763	0.00E+00
5	DD.5_s	MAT_p	0.594	5820	0.00E+00
6	FFP_s	TD_p	0.594	5817	0.00E+00
7	MAT_s	MAT_p	0.592	5851	0.00E+00
8	FFP_s	MWMT_p	0.592	5865	0.00E+00
9	FFP_s	AHM_p	0.592	5850	0.00E+00
10	DD.5_s	DD.0_p	0.592	5856	0.00E+00

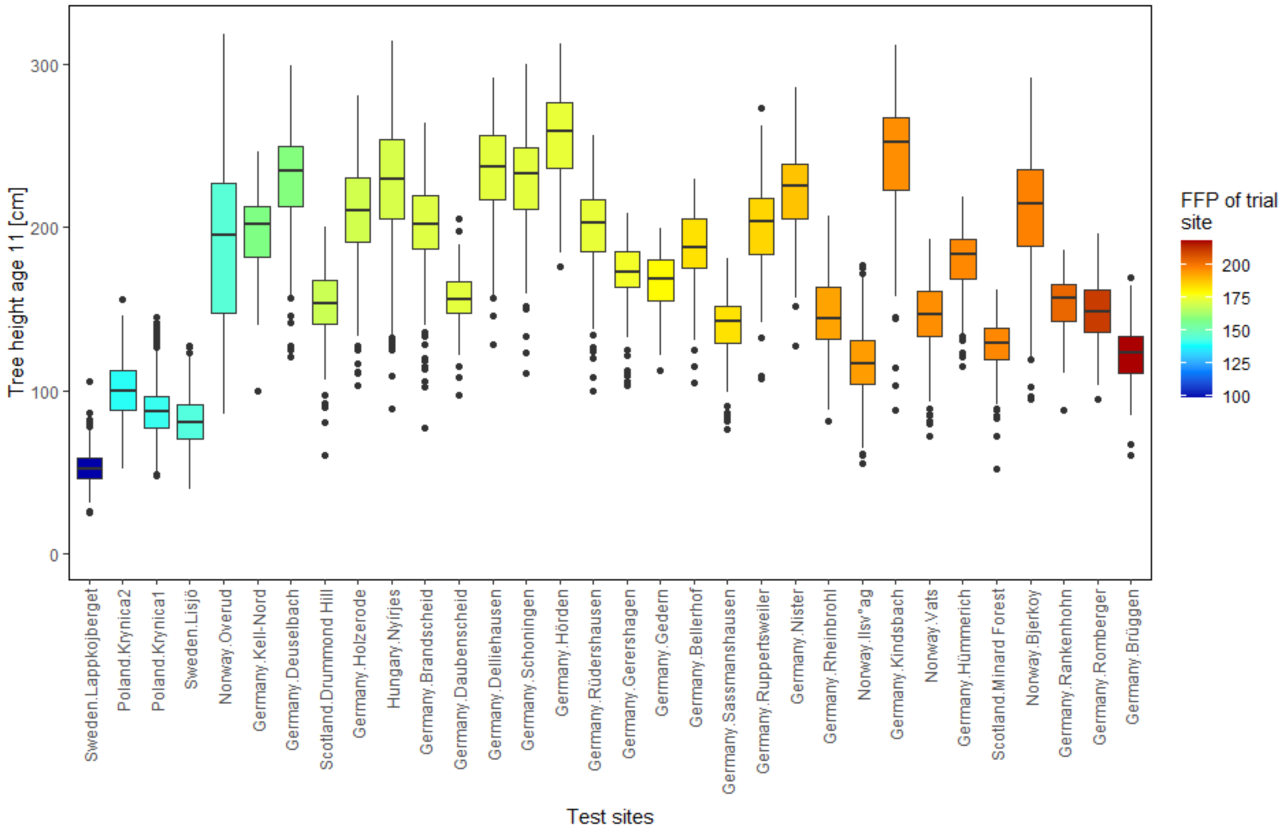
Step 6: models using two climate variables for site and one for provenance

	S1	S2	P1	R^2	AIC	p
1	SHM_s	FFP_s	MAT_p	0.7443	1421	0.00E+00
2	SHM_s	FFP_s	DD.0_p	0.7432	1462	0.00E+00
3	SHM_s	FFP_s	MCMT_p	0.7403	1570	0.00E+00
4	SHM_s	FFP_s	DD.5_p	0.7398	1588	0.00E+00
5	SHM_s	FFP_s	FFP_p	0.7394	1603	0.00E+00
6	SHM_s	FFP_s	TD_p	0.7375	1671	0.00E+00
7	SHM_s	FFP_s	AHM_p	0.7357	1735	0.00E+00
8	SHM_s	FFP_s	MWMT_p	0.7352	1754	0.00E+00
9	SHM_s	FFP_s	ADI_p	0.7350	1760	0.00E+00
10	SHM_s	FFP_s	MAP_p	0.7336	1813	0.00E+00

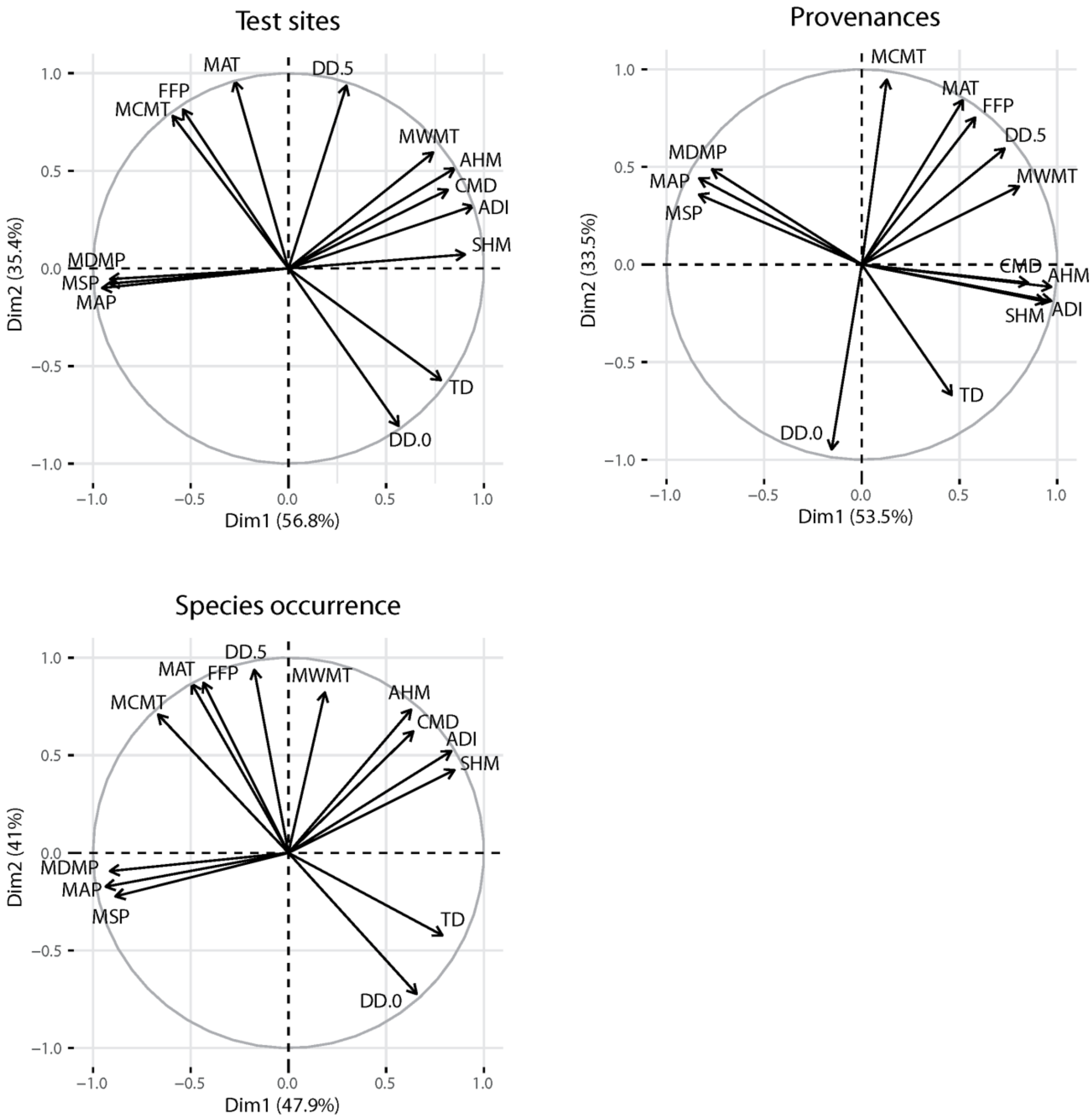
Step 7: models using two climate variables for site and one for provenance, as well as one geographic variable for provenance; geographic variables do not interact with site climate variables

	S1	S2	P	G	R^2	AIC	p
1	SHM_s	FFP_s	TD_p	LAT_p	0.7584	887	0.00E+00
2	SHM_s	FFP_s	ADI_p	LAT_p	0.7571	938	0.00E+00
3	SHM_s	FFP_s	AHM_p	LAT_p	0.7567	952	0.00E+00
4	SHM_s	FFP_s	DD.0_p	LAT_p	0.7566	959	0.00E+00
5	SHM_s	FFP_s	MAT_p	LAT_p	0.7561	976	0.00E+00
6	SHM_s	FFP_s	SHM_p	LAT_p	0.7560	981	0.00E+00
7	SHM_s	FFP_s	MCMT_p	LAT_p	0.7558	988	0.00E+00
8	SHM_s	FFP_s	DD.5_p	LAT_p	0.7556	997	0.00E+00
9	SHM_s	FFP_s	MWMT_p	LAT_p	0.7549	1023	0.00E+00
10	SHM_s	FFP_s	CMD_p	LAT_p	0.7546	1037	0.00E+00

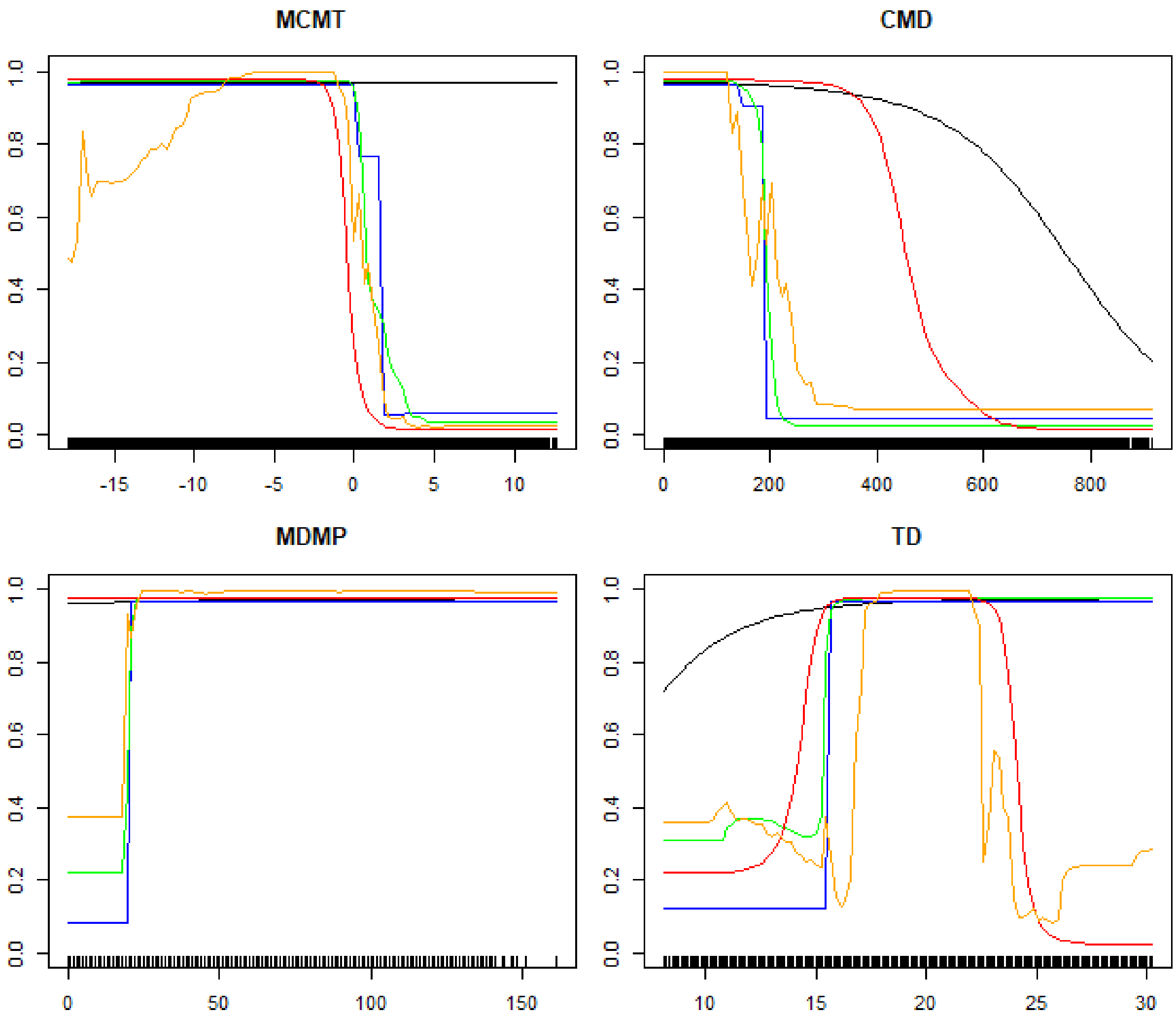
2 Supplementary Figures



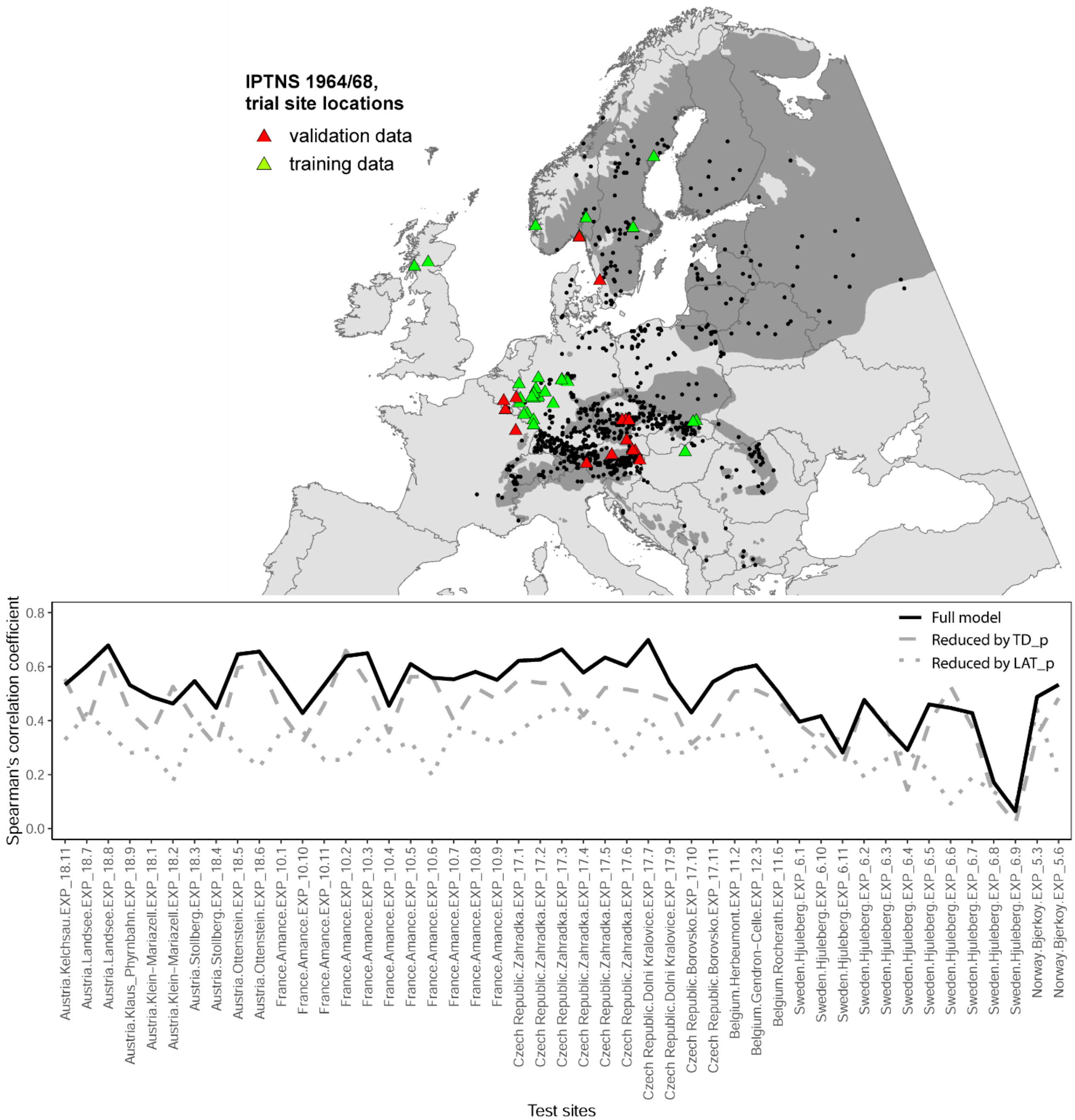
Supplementary Figure 1. Distribution of data for height age 11 used to fit the TraitSDM by trial site location. Sites are ordered along the x-axis by increasing length of the frost-free-period (FFP).



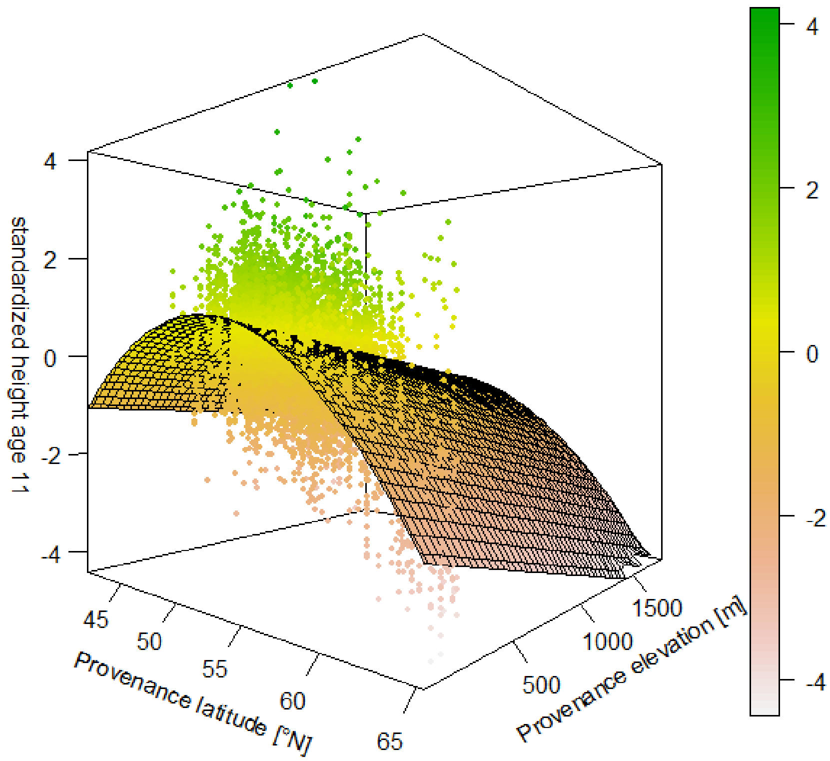
Supplementary Figure 2. Principal component analysis of climate to inspect co-linearity. Each set of climate variables is extracted from *ClimateEU* for a different time interval: 1968-1975 for test sites to characterize conditions from planting to measurement, 1941-1970 for populations to characterize the conditions to which they had adapted and the widely used reference period 1961-1990 for species occurrence. The variance explained by the first two axes is indicated in the figures.



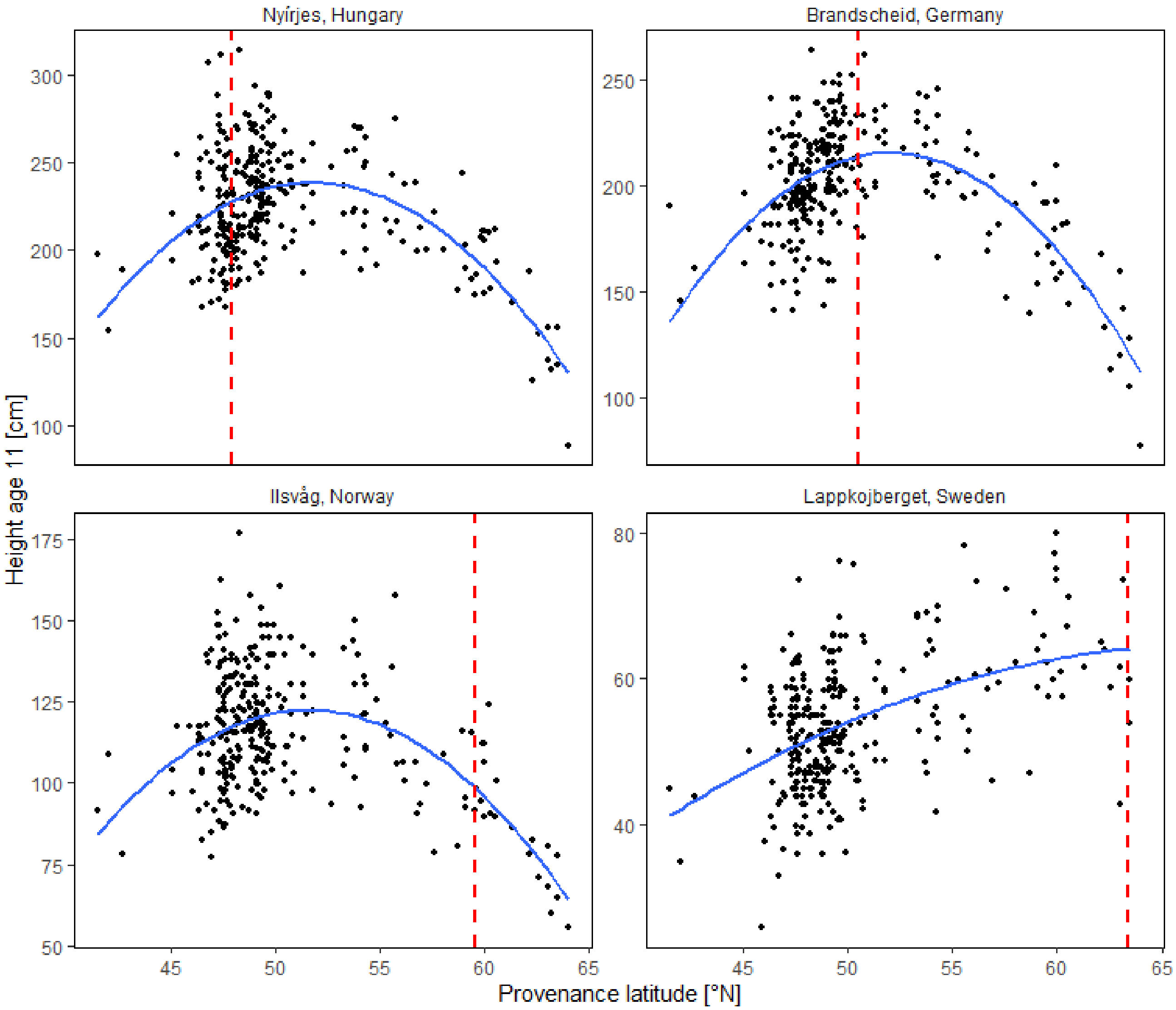
Supplementary Figure 3. Partial response curves by climatic predictor variables used in the OccurrenceSDM. For building the response curves, n-1 variables are set constant to their median, while only the remaining one varies across its whole range, i.e. the curve shows the sensibility of the model to that specific variable. Curves do not account for interactions among variables. Colors indicate the different algorithms: GLM (black), CTA (blue), GBM (green), ANN (red), RF (orange).



Supplementary Figure 4. Spearman's rank correlation coefficients between predicted and observed heights measured at independent trial sites, calculated for each block of 100 provenances separately (test sites). Lines connect all correlation coefficients that are based on the predictions of a particular model, where 'Full model' equals the model as specified in Table 4, 'Reduced by TD_p' is the full model reduced by TD_p, its' transformation and its' interaction with FFP_s, and 'Reduced by LAT_p' is the full model reduced by LAT_p and its' transformation. The map in the background illustrates the geographic location of the trial sites used for model evaluation (validation data) in comparison with those used to fit the model (training data).



Supplementary Figure 5. 3D-surface of the productivity-oriented threshold applied to translate growth potential from the TraitSDM to binary species presence/absence. Provenance mean heights were standardized for each site of 100 provenances by subtracting the mean and dividing by the standard deviation. These standardized values were used as response variable in the regression. Provenance latitude entered the linear regression both as linear and quadratic term, provenance elevation entered as linear term.



Supplementary Figure 6. Transfer functions by four individual trial sites illustrating the pattern of height growth as a function of geographic latitude (LAT_p) of the provenance (blue line). As the representation of provenance blocks varies across locations, graphs only show functions derived across 300 provenances (blocks 2, 3 and 10) planted at each of the four locations. Black dots represent provenance means. The vertical red line indicates the latitude of the trial site location, i.e. it indicates the local provenance. The shape of the transfer functions, with low performance of provenances from high latitudes, is highly consistent across all trial sites used to fit the TraitSDM, despite for the northernmost site in Lappkojberget, Sweden, were local provenances do perform well.