frontiers

Supplementary Material and Methods 2

1 Supplementary Material 2. Development of the height models

1.1 Nordic model

A linear mixed-effects model was used to predict tree height as a function of the transfer distance in latitude (Δenv=ΔLAT) being a proxy primarily for photoperiod. In addition, the GDD5 was used to describe the climate of the field trial and was used in interaction terms with the latitudinal transfer distance. These variables were included as fixed effects and the field trial site as a random effect, to account for unexplained environmental variation. This model was established by a hypothesis-driven process, building on the work of previous regional modeling (Persson and Ståhl, 1993; Persson, 1994; Berlin et al., 2016; Eriksson, 2008). Logarithm-transformed LS-means of tree height estimated for each provenance-field trial combination ($\ln(H_{jk})$) were fitted as follows:

$$\ln(H_{jk}) = \alpha_0 + \alpha_1 \ln(AGE_k) + \alpha_2 \ln(EST_k - 1945) + \alpha_3 \ln(GDD5\_s_k) + \alpha_4 \Delta LAT_{jk} + \alpha_5 \Delta LAT_{jk}^2 + \alpha_6 GDD5\_s_k \times \Delta LAT_{jk} + \alpha_7 GDD5\_s_k \times \Delta LAT_{jk}^2 + \beta(Trial) + \varepsilon_{jk}$$

where AGE_k is the tree age for the kth field trial at measurement, EST_k is the establishment year of the kth field trial where the term α_2 accounts for rapid silvicultural improvements made after the 2nd World War. AGE and EST are both technical variables included to properly adjust the data collected from the substantial but very heterogeneous set of Nordic field trials. However, these variables are not critical *per se* for the assessment of climate change and associated prediction uncertainty. In contrast, the accumulated growing day degrees GDD5_s_k) is an environmental variable associated with the kth field trial averaged from the year of planting to the year of height measurement. In addition, ΔLAT_{jk} is the latitudinal transfer distance between the kth field trial and the jth provenance present at the kth field trial. Finally, β is the random field trial effect and ε_{ijk} is the residual distribution of the jth provenance at the kth field trial following a Gaussian distribution.

The Nordic tree height model used in this study consists of the same variables as the model developed in Berlin et al. (2016). However, in that study an older, regional climate data set (PTHBV/FINADAPT) for the time period 1961-2007 was used and here all coefficients were re-estimated using the more advanced and modern CRU-TS data set and trial-wise time periods between establishment and assessment. Given that the current re-analysis of the model both included a new climate data set with another spatial resolution and different time spans we performed a number of comparisons to ensure that the model structure would still be valid. We concluded that it was, as all model coefficients were still highly significant, with the same sign and magnitude and that the resulting transfer effect patterns were very similar. Consequently, as there were no new model development procedures performed for the Nordic tree height model in this study, we refer to the detailed description given in Berlin et al. (2016).

1.2 Spanish model

We used linear mixed-effects models to predict tree height as a function of the environmental transfer distance of the Summer Heat Moisture index (Δenv=ΔSHM), the spring precipitation climate at the field trial site (SPR_s) and the Temperature Differential at the field trial site (TD_s) following previous

models of the species in Spain (Vizcaíno-Palomar et al., 2019). In the model, climatic variables were included as fixed effects and specifically we modelled the linear, quadratic and linear interaction terms of ΔSHM and SPR_s, and the linear term for the covariate TD_s. In the random part of the model, we included provenance for unaccounted environmental variation among populations. We did not include blocks nested within field trials and field trials as random effects because they captured most of the available phenotype variability among field trials. We rather preferred to explain this variation by known fixed effects than to relate them to unspecified environmental drivers.

The final model was built based upon a hierarchical backward selection procedure from the most complex model, that is, the model that contains all possible variable combinations as the model described above (Supplementary Table S1). We used the AIC criteria to select the terms of the final model by following the rule that net increments of lower than two units of AIC associated with the elimination of any parameter in the full model determined the exclusion of the parameter from the final model (Akaike et al., 1992, Bolker et al., 2009). We started with the selection of the two-variable interaction (round 1) and then tested the quadratic effects of both climate variables, ΔSHM and SPR_s (rounds 2 & 3), and so on downwards the main effects of each predictor, ΔSHM, SPR_s and TD_s (round 4). Fixed effects were tested using the maximum likelihood (ML), and random effects were tested using the restricted maximum-likelihood method (REML). The final Spanish model for individual tree height, H_{ijk}, was fitted as follows:

$$H_{ijk} = \alpha_0 + \alpha_1 TD\_s_{ik} + \alpha_2 SPR\_s_{ik} + \alpha_3 SPR\_s_{ik}^2 + \alpha_4 \Delta SHM_{ijk} + \alpha_5 \Delta SHM_{ijk}^2 + \alpha_6 SPR\_s_{ik} \times \Delta SHM_{ijk} + \beta(Provenance) + \varepsilon_{ijk}$$

where H_{ijk} is tree height growth of the ith individual of the jth provenance in the kth field trial. α_s is the set of n parameters associated with the fixed effects of the model, ΔSHMijk is the environmental transfer distance computed for the SHM index, as the difference between the SHM values at the provenance origin of the ith individual of the jth provenance; clim_s_{ik} is the climate (spring precipitation, SPR and temperature differential, TD) at the field trial of the ith individual in the kth field trial. β are the random effects. ε_{ijk} is the residual distribution of the ith individual of the jth population in the kth field trial following a Gaussian distribution.

Supplementary Table S1. Fixed effects selection for the tree height model following a hierarchical backward procedure using AIC (Akaike et al., 1992). d.f.: degrees of freedom, AIC: Akaike values, ΔAIC: difference in AIC values between alternative models. MR^2 is the percentage of the variance explained by the fixed effects of the model. CR^2 is the percentage of the variance explained by the fixed and random effects of the model. MR^2 and CR^2 values are given for the best supported mixed-effect model.

Fixed effect selection	**df**	**AIC**	**ΔAIC**	**MR^2**	**CR^2**
(round # 1)					
full model	9	53961.39	0.00		
no PREC.spr_s × ΔSHM	8	53989.14	27.76		
(round # 2)					
full model	9	53961.39	0.00		
no quadratic effect ΔSHM	8	54169.17	207.78		
(round # 3)					
full model	9	53961.39	0.00		
no quadratic effect PREC.spr_s	8	54212.78	251.39		
(round # 4)					
full model	9	53961.39	0.00	39.46	42.97
no ΔSHM	6	54287.94	326.55		
no PREC.spr_s	6	54806.44	845.06		
no TD_s	8	54047.65	86.27		
intercept model	3	56221.14	2259.75		

1.3 Reference list of Supplementary Material 2

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