APENDIX. SUPPLEMENTARY INFORMATION

Expanding Blue Intensity applications: exploring compression wood proportions in cross-sections of treeline *Picea abies* seedlings

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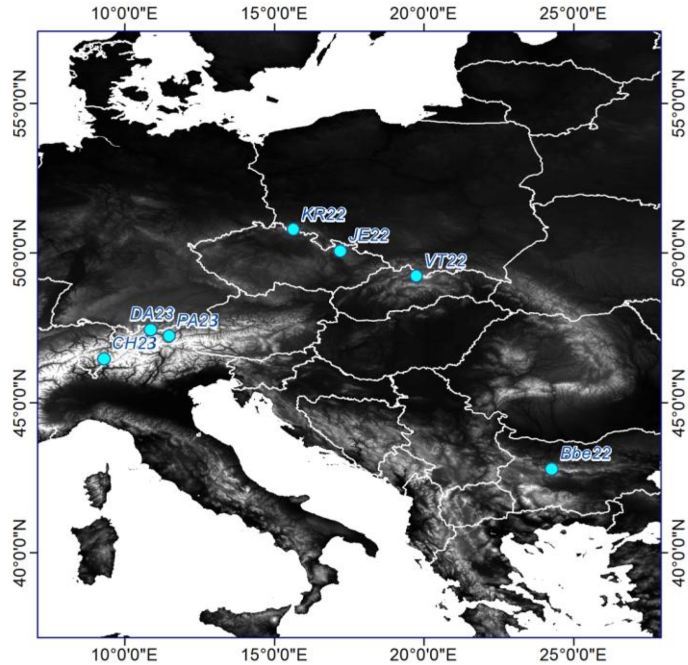


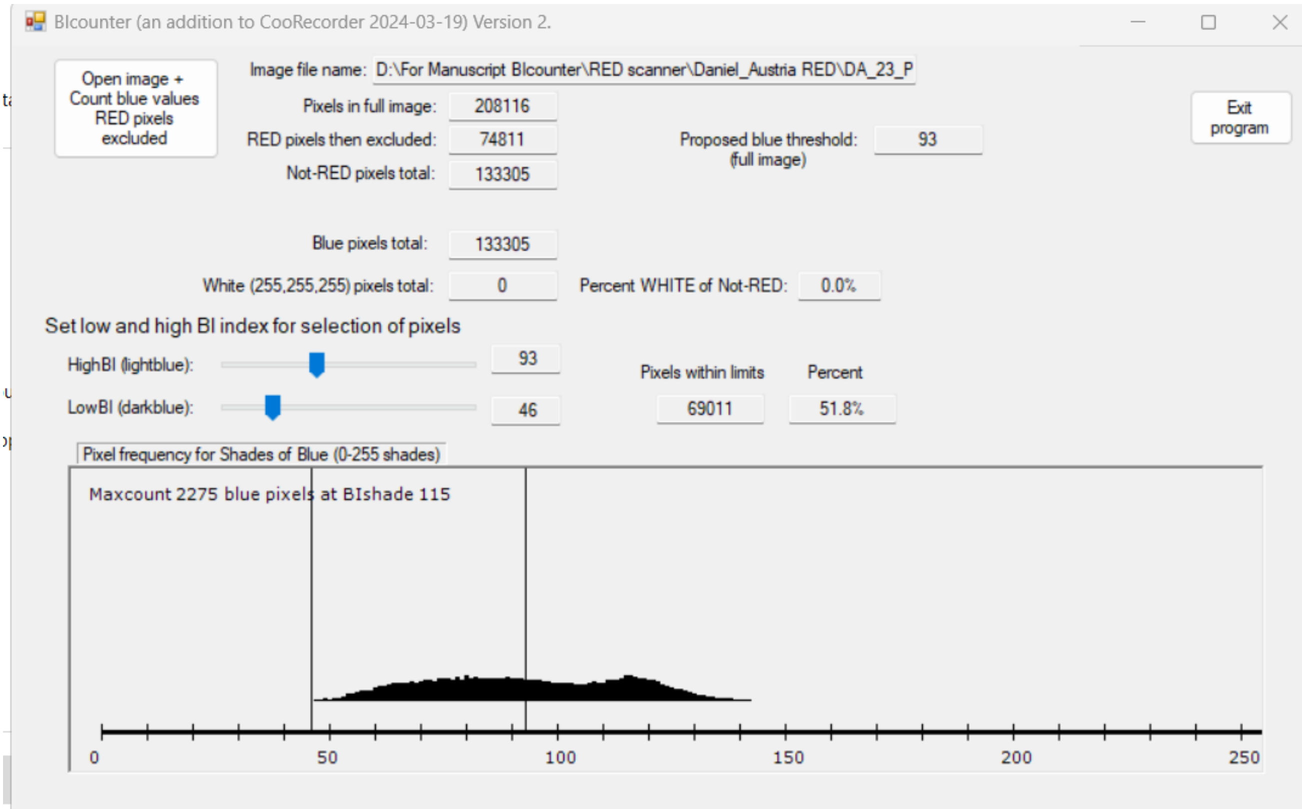
Supplementary Fig. 1. Geographical distribution of sites where *Picea abies* seedlings were collected in seven European treeline sites. Each tree symbol corresponds to one treeline site: Czech Republic, Jeseniky (JE22) and Krkonoše-Žižak (KR22); Austria, Innsbruck (PA23); Austria, Daniel (DA23); Italy, Chiavenna (CH23); Bulgaria, Boatin (Bbe22).

Supplementary Table 1. Study site characteristics. Acronyms: Ind. Number of seedlings sampled; growing season length (gsl; days), growing degree days heat sum above 5°C (gdd5), growing season mean temperature (gst; °C), growing season mean daily precipitation (gsmdp; Kg m^{-2} day^{-1})

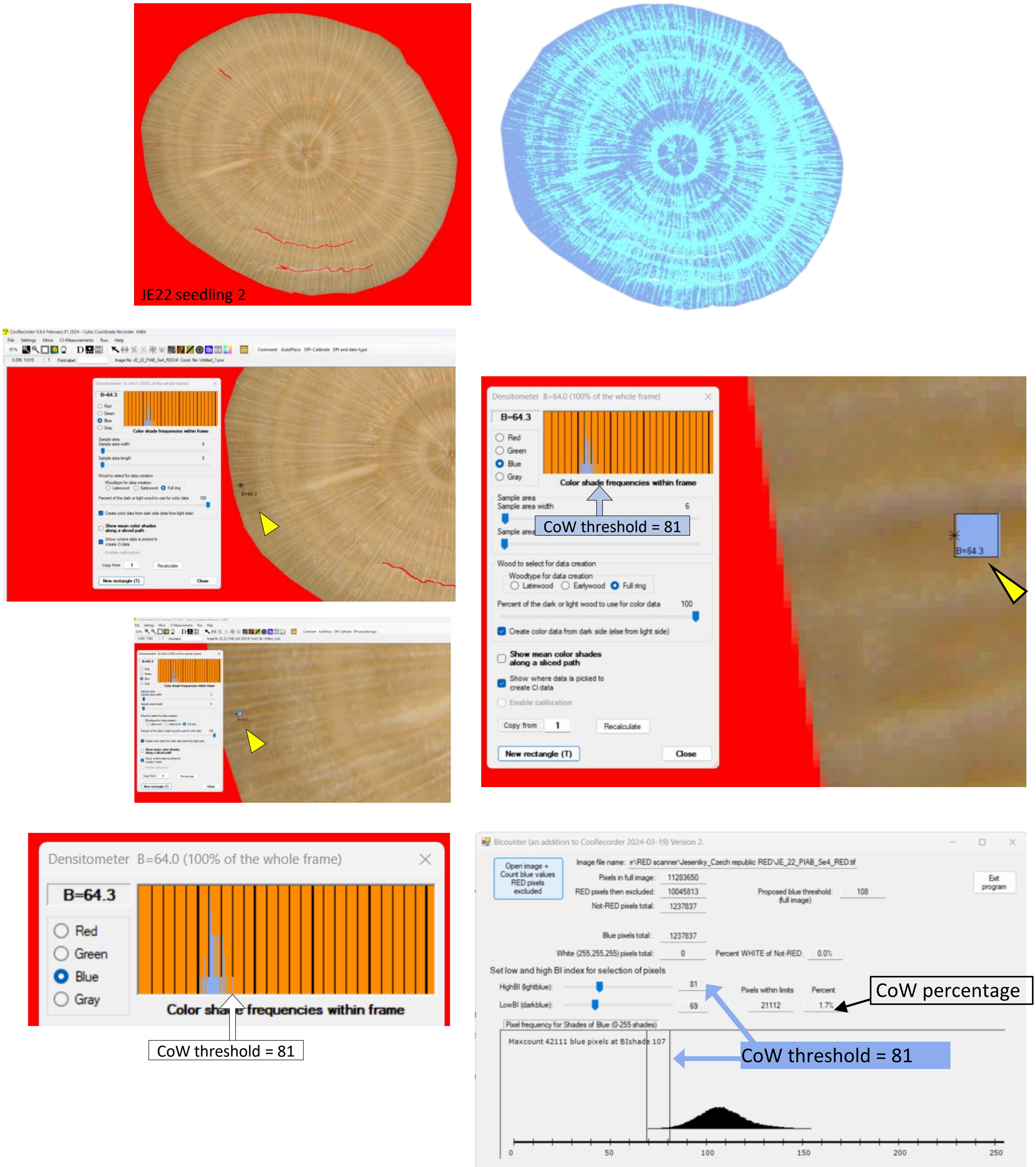
Country	Site	Site	Latitude	Longitude	Ind.	Slope	Facing slope	Elevation (m)	dsdp	gsl	gdd5	gst	gsmdp
Czechia	Krkonoše	KR22	50.7602	15.6456	6	10-15°	West	1348	3.7	124	534.7	7.65	4.9
Bulgaria	Boatin	Bbe22	42.7792	24.2772	10	15-20°	South	1695	2.3	171	879.1	9.65	3.7
Austria	Daniel	DA23	47.4272	10.8761	9	25°	South	1904	3.8	99	243.9	6.25	5.8
Austria	Innsbruck	PA24	47.2056	11.4606	10	10-15°	West	2178	2.8	98	253.8	6.45	6.2
Slovakia	Spálená dolina	VT22	49.2066	19.7258	5	20°	North-East	1642	4.8	108	336.7	6.75	6.7
Italy	Chiavenna	CH24	46.4494	9.3052	9	10-15°	East	2147	6.5	107	463.3	7.65	7.2
Czechia	Jeseniky	JE22	50.0587	17.2253	10	5-10°	South	1444	2.5	156	566.9	7.95	3.9

Supplementary Table 2. Seedlings' allometric data per site.

Country	Site	Site ID	Mean Basal area	Standard deviation Basal area	Mean stem basal diameter	Standard deviation stem basal diameter	Mean height	Standard deviation Height
Czechia	Krkonoše, Žižak	KR22	0.1117	0.1419	0.4833	0.3312	21.0833	9.5311
Bulgaria	Boatin	Bbe22	0.5470	0.3496	1.2450	0.5002	27.5000	3.5668
Austria	Daniel	DA23	0.2011	0.1033	0.7344	0.2427	24.0000	7.5705
Austria	Patscherkofel Innsrbruck	PA24	0.1700	0.1239	0.7040	0.2869	18.9500	3.3702
Slovakia	Western Tatras, Spálená dolina	VT22	0.3180	0.1445	0.8640	0.1834	31.4000	3.0496
Italy	Chiavenna	CH24	0.2867	0.1670	0.9578	0.3486	23.3333	7.5911
Czechia	Jeseniky	JE22	0.2810	0.2090	0.9500	0.6864	29.0000	7.7028



Supplementary Fig. 2. BIcounter program detail. BIcounter was created to detect and calculate the absolute number of pixels with specific blue light intensity values; it uses the CooRecorder color segmentation algorithm, which was previously limited to tree-ring-level measurements. BIcounter gives a threshold for each cross-section uploaded (step 1), segregating high wood density areas (HighWD) from low wood density areas (LowWD). Red pixels are excluded automatically. The user can also adjust the threshold manually . BIcounter then counts the total number of blue pixels with BI values corresponding to HighWD and calculates the proportion of HighWD to LowWD for the cross-section (as a percentage).



Supplementary Fig. 3. Estimation of proportions of severe compression wood (CoW) using densitometer in CooRecorder and BIcounter. HighWD in each cross-section was subdivided into CoW and the proportion of unaffected latewood (LW). Note that the threshold set manually in step 3 differs from the threshold given by BIcounter, which subdivides the cross-section into high wood density areas (HighWD = CoW + LW) and low wood density areas (LowWD = 1 - HighWD). A seedling with a low proportion of CoW is depicted as an example (CoW = 0.2). Latewood or full ring were selected in densitometer, depending on the size, shape and contrast of the darker area chosen in the cross section.

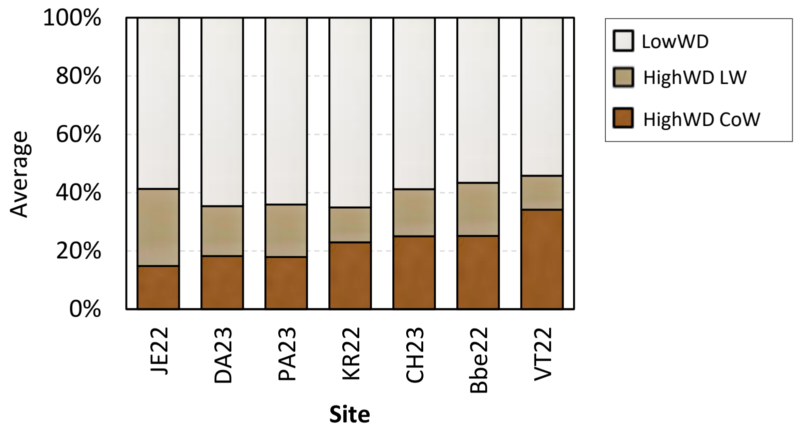
Supplementary notes of statistical analyses, section 2.7 in main text

To estimate mean stem eccentricity, high WD and low WD, including compression wood (CoW), we developed Bayesian generalized linear models (BGLMs). Using Bayesian methods allowed us to obtain a posterior distribution for these estimates, rather than relying on single point estimates, and we based our measures of uncertainty on this distribution. For the proportion variables, we modeled their means assuming a beta distribution, which is appropriate for this type of variable. For the statistical analysis, we transformed the Eccentricity Index into a proportion using its multiplicative inverse. In addition to the mean estimates, we also estimated the variance (or dispersion) of each response variable within the same Bayesian framework. To minimize potential bias in the results, we used weakly informative priors for both the mean and variance parameters in the posterior distribution.

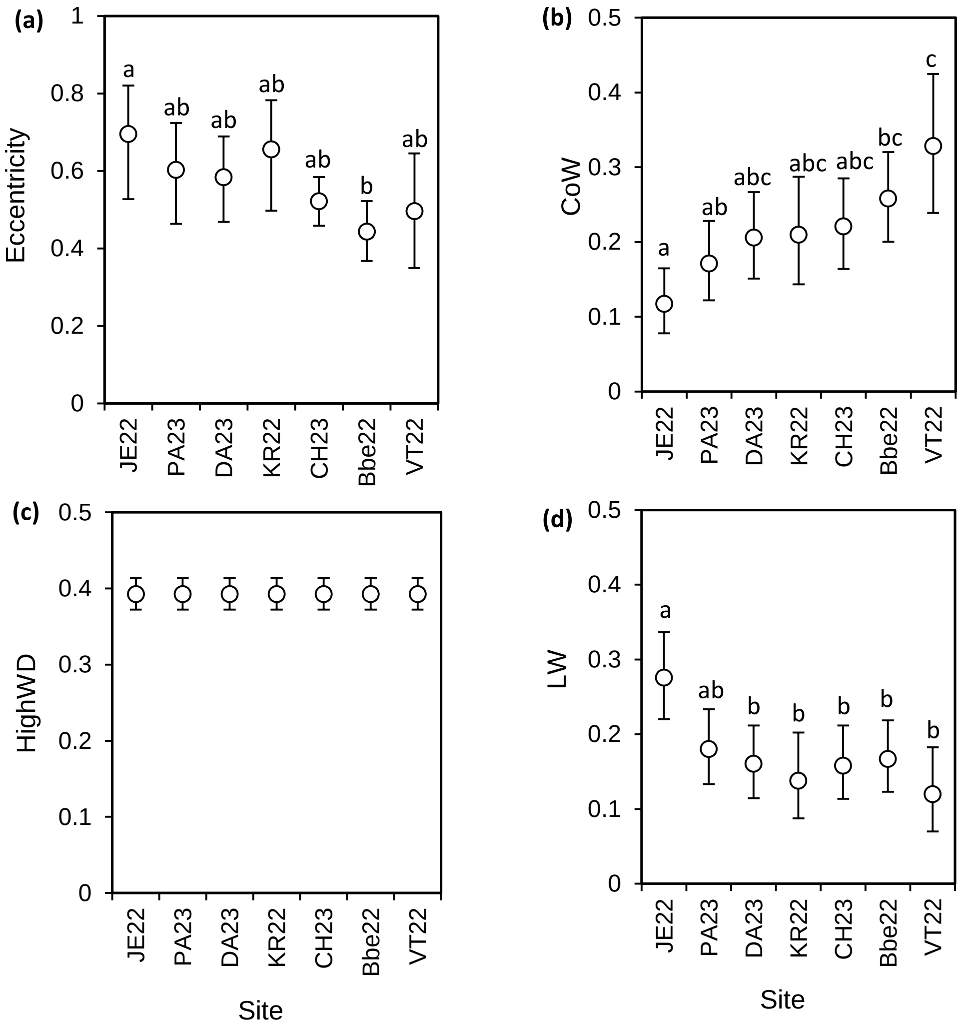
We compared the means and variances of the response variables across sites (treelines) through four BGLMs for each response variable. The models either included or excluded the "site" factor in the mean and/or the variance of the posterior probability distributions. After building the four models for each response variable, we evaluated the existence of site-specific differences by identifying and selecting the best-supported model using the Pareto Smoothed Importance Sampling Leave-One-Out Information Criterion (PSIS-LOOIC; Vehtari et al., 2017). Thus, for example, if the null model (*i.e.*, that in which the site has no effect on the mean and variance parameters) is the best supported, the estimated mean and variance are the same for all sites. From the best-supported model, we extracted the median of the posterior distribution for both the mean and variance parameters. Additionally, we calculated 95% credibility intervals based on the parameters' posterior distributions to identify the differences between the sites, thereby providing robust estimates.

Finally, we examined the potential correlations between CoW and Eccentricity, CoW and HighWD, and CoW and LW under a Bayesian framework. We constructed multi-response generalized linear models (BMGLMs) with the same model structure as the best-supported models in the previous paragraph but including correlation parameters between the pairs of response variables mentioned above. From these models, we extracted the median of the posterior distributions of these correlations, as well as their 95% credibility intervals, which contain 95% of the posterior distribution of the parameters.

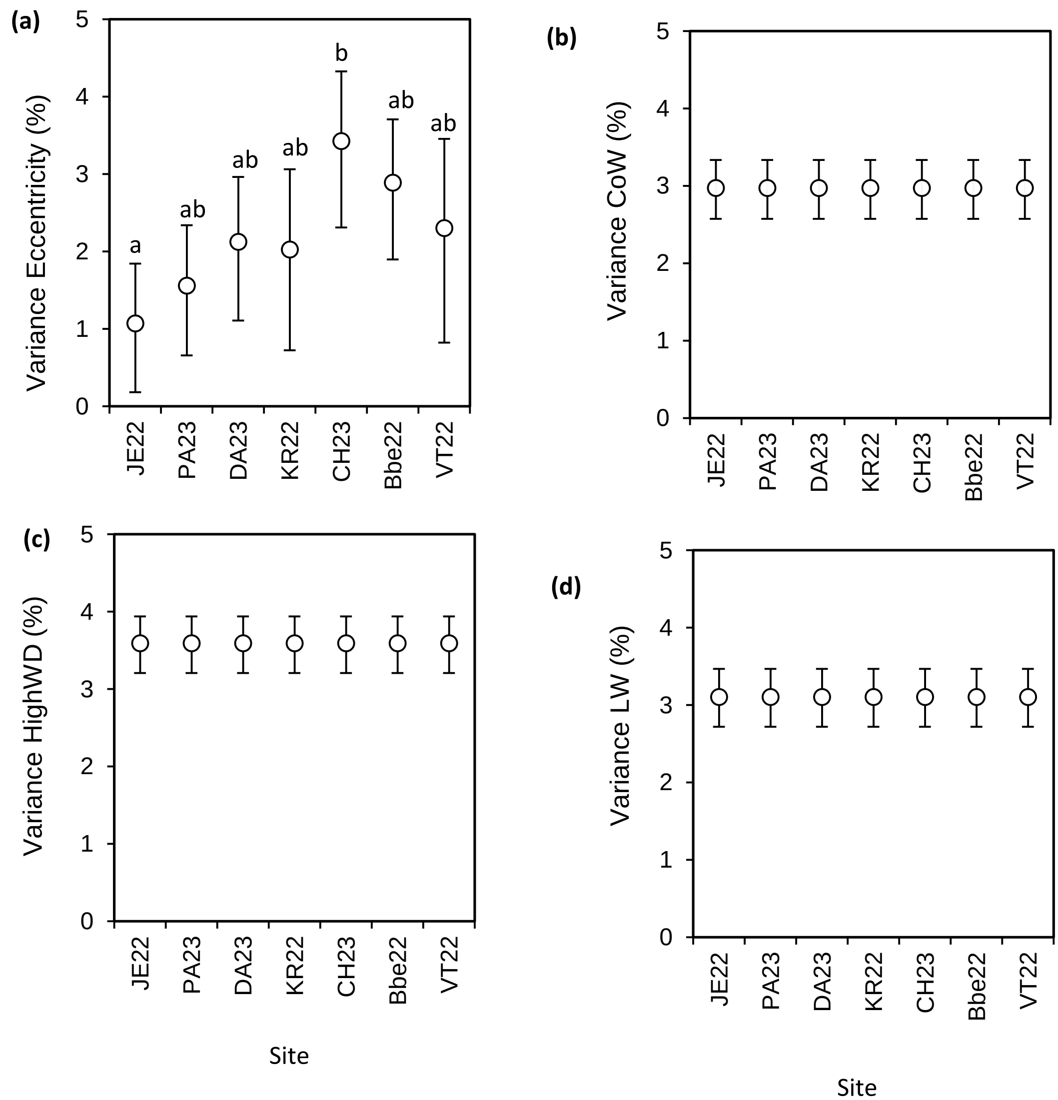
We fitted these models and the ones described above in R (R Core Team, 2024) using the brms package (Bürkner, 2017). The correlation with eccentricity was done as a proportion, not as an index, and thus the correlation between CoW and the Eccentricity index has the opposite sign.



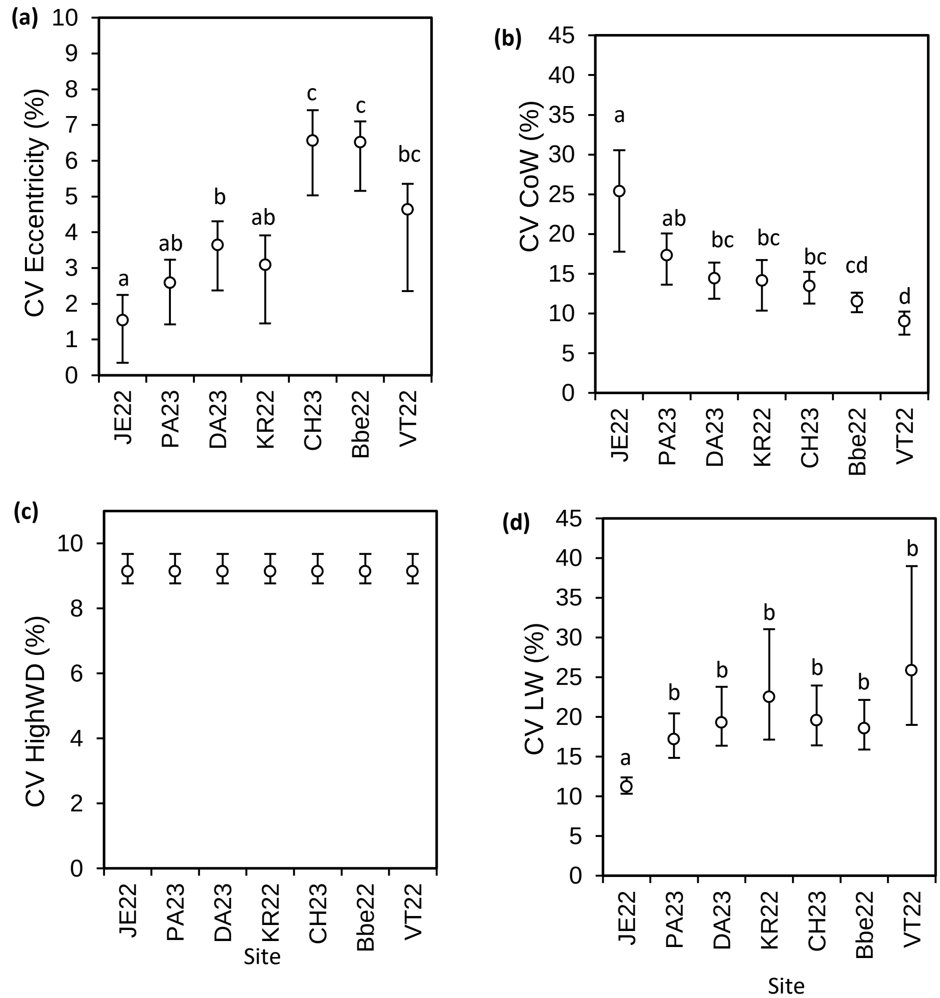
Supplementary Fig. 4. Average proportions of wood density variations across the entire stem cross-sections of *Picea abies* treeline seedlings. The seedlings were sampled from seven European treeline sites: Czech Republic (Jeseníky, JE22; Krkonoše-Žižak, KR22), Austria (Innsbruck, PA23; Daniel, DA23), Italy (Chiavenna, CH23), and Bulgaria (Boatin, Bbe22). Average proportions of compression wood (CoW; darker brown filling) were determined with Blue Intensity, using the densitometer in CooRecorder; CoW may include affected earlywood, latewood or both. The proportion of high wood density (HighWD) was determined using BI in the BIcounter program. HighWD was subdivided into CoW and into (d), the unaffected latewood proportion (LW; calculated as HighWD minus CoW); both CoW and LW are expressed in relation to the entire stem cross-section. Low wood-density proportions (LowWD; light filling) were calculated for each cross section as 1 minus HighWD.



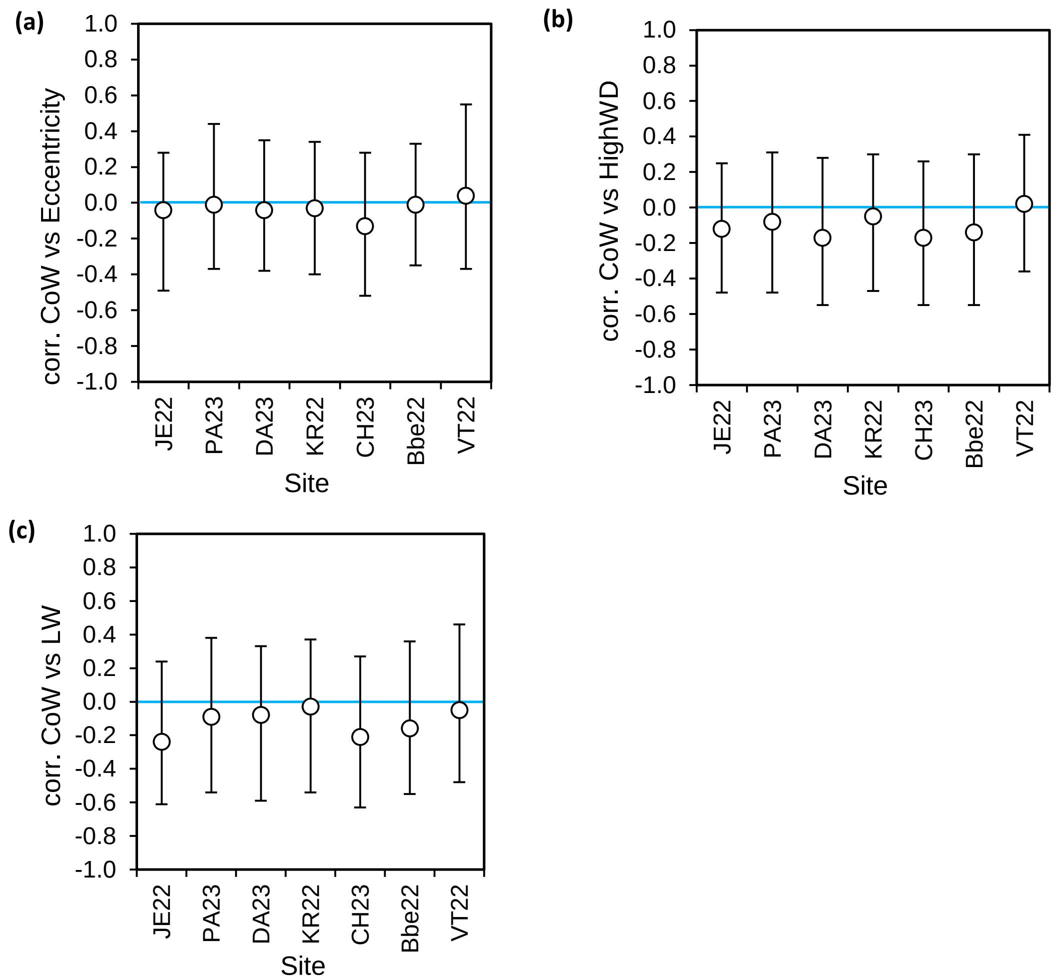
Supplementary Fig. 5. Estimated mean of wood density proportions across the entire stem cross-sections of *Picea abies* treeline seedlings, and their stem eccentricity. The seedlings were sampled from seven European treeline sites: Czech Republic (Jeseníky, JE22; Krkonoše-Žižak, KR22), Austria (Innsbruck, PA23; Daniel, DA23), Italy (Chiavenna, CH23), and Bulgaria (Boatin, Bbe22). The values were derived using Bayesian generalized linear models. Vertical lines indicate 95% credibility intervals; overlapping intervals indicate no clear statistical differences between the means. Horizontal lines and shared letters indicate no clear statistical differences between site variances. (a) Stem eccentricity index, where a value of 1 denotes a circular stem (the lowest eccentricity). (b) Estimated proportion of compression wood (CoW), determined with Blue Intensity (BI), using densitometer in CooRecorder. (c) Proportion of high wood density (HighWD) obtained using BI measurements from the BIcounter program. HighWD was subdivided into CoW and into (d), the unaffected latewood proportion (LW; calculated as HighWD minus CoW); both CoW and LW are expressed in relation to the entire stem cross-section.



Supplementary Fig. 6. Estimated mean variance of wood density proportions across the entire stem cross-sections of *Picea abies* treeline seedlings, and their stem eccentricity. The seedlings were sampled from seven European treeline sites: Czech Republic (Jeseníky, JE22; Krkonoše-Žižak, KR22), Austria (Innsbruck, PA23; Daniel, DA23), Italy (Chiavenna, CH23), and Bulgaria (Boatin, Bbe22). Estimates correspond to the medians of the posterior distributions of the mean parameters of the Bayesian generalized linear models. Vertical lines correspond to 95% credibility intervals; overlapping intervals indicate no clear statistical differences between the means. (a) Estimated stem eccentricity index, where a value of 1 denotes a circular stem (the lowest eccentricity). (b) Estimated proportion of compression wood (CoW), determined with Blue Intensity (BI), using densitometer in CooRecorder. (c) Estimated proportion of high wood density (HighWD) obtained using BI with the BIcounter program. HighWD was subdivided into CoW and into (d), the unaffected latewood proportion (LW = HighWD – CoW); both CoW and LW are expressed in relation to the entire stem cross-section.



Supplementary Fig. 7. Calculated coefficient of variation (CV) of wood density variations across the entire stem cross-sections of *Picea abies* treeline seedlings, and their stem eccentricity. The seedlings were sampled from seven European treeline sites: Czech Republic (Jeseníky, JE22; Krkonoše-Žižak, KR22), Austria (Innsbruck, PA23; Daniel, DA23), Italy (Chiavenna, CH23), and Bulgaria (Boatin, Bbe22). CV was calculated using the mean and variance values derived using Bayesian generalized linear models. Vertical lines indicate 95% credibility intervals; overlapping intervals indicate no clear statistical differences between the CVs. Shared letters indicate no clear differences in CV. (a) Estimated stem eccentricity index, where a value of 1 denotes a circular stem (the lowest eccentricity). (b) Estimated mean proportion of compression wood (CoW), determined with Blue Intensity (BI), using densitometer in CooRecorder; CoW may include affected earlywood, latewood or both. (c) Estimated mean proportion of high wood density (HighWD) obtained using BI with the BIcounter program. HighWD was subdivided into CoW and into (d), the unaffected latewood proportion (LW = HighWD – CoW); both CoW and LW are expressed in relation to the entire stem cross-section.



Supplementary Fig. 8. Estimated correlations (dots) between pairs of variables measured across the entire cross-section of *Picea abies* treeline seedlings, using Bayesian multi-response generalized linear models. Seedlings were collected from seven European treeline sites: Czech Republic (Jeseníky, JE22; Krkonoše-Žižak, KR22), Austria (Innsbruck, PA23; Daniel, DA23), Italy (Chiavenna, CH23), and Bulgaria (Boatin, BBe22). Vertical lines represent 95% credibility intervals, with those not intersecting the zero being clearly different from it. (a) Correlation between the estimated means of severe compression wood (CoW; estimated using the densitometer in CooRecorder and BIcounter) and the Eccentricity index. (b) Correlation between CoW and the proportion of high wood density (HighWD; estimated with BIcounter).(c) Correlation between CoW and the percentage of unaffected latewood (LW, calculated as HighWD minus CoW). CoW, HighWD and LW are expressed as a proportion of the whole cross section. CoW may include both earlywood and latewood.