Climatic Sensitivity of the Top-Performing Provenances of Scots Pine in Latvia

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Abstract

Provenance experiments are established to assess growth of diverse population in novel environmental conditions. Productivity has been the main trait for quantification of sufficiency of the provenances under current conditions. Information on climate-growth relationships can provide deeper insight regarding growth potential, especially considering climatic change. In this study, sensitivity of tree-ring width of two top-performing provenances of Scots pine originating from Northern Germany rowing in two trials differing by continentality in Latvia was assessed. Tree-ring width of both provenances was affected by climatic factors, yet the sets of significant factors differed between stands and provenances. Under milder climate, both provenances were sensitive to temperature in December and temperature in July, suggesting effect of cold damage and water deficit. The less productive provenance (Rostock) was additionally sensitive to conditions in winter. The specific climate growth relationships suggested that the more productive provenance (Neubrandenburg) was able to benefit from longer vegetation season. Under harsher climate, both provenances showed similar growth patterns and were sensitive to conditions in spring and preceding summer, which affect nutrient reserves. The provenance-specific responses were less pronounced. Rostock provenance was additionally sensitive to temperature in April, while Neubrandenburg provenance benefited from warmer summers. Considering the observed climate-growth relationships, the Neubrandenburg provenance appeared more suitable for wider application.

Keywords: provenance trial, *Pinus sylvestris*, tree-rings, dendroclimatology, tree growth, transfer

Introduction

Under warming climate, Scots pine (*Pinus sylvestris* L.), which is one of the main forestry species in Northern Europe, has been projected to decrease growth and survival due to competition and influence of herbivores and/or pests in a large part of its current distribution area (Reich and Oleksyn 2008, Hickler et al. 2012). Sensitivity to unfavourable weather conditions (e.g. water deficit, late frosts, etc.), which decrease vigour, and hence resilience of trees, has been considered as an important factor affecting growth and survival (Bolte et al. 2009, Martķnez-Vilalta et al. 2012, Taeger et al. 2013). Accordingly, reaction of trees to meteorological factors has been among the most studied issues in forest science during the past decades (Lindner et al. 2010), aiming for reduction of potential losses due to climatic changes (Bolte et al. 2009, Hanewinkel et al. 2012).

The sensitivity of Scots pine to weather conditions differs among regions and populations due to evolutionary adaptation of trees to specific conditions (Rehfeldt et al. 2002, Taeger et al. 2013). However, recent climatic changes are occurring faster than tree populations could adjust naturally, hence management appears necessary for maintaining forest productivity (Lindner et al. 2010). Application of the reproductive material from populations (provenances) better suited for future climates have been advised as one of the means for minimization of the negative effects of changing climate (Ledig and Kitzmiller 1992, Bolte et al. 2009, Huang et al. 2010). Already at present, results from provenance trials indicate that north-transferred (to harsher climate) forest reproductive material has improved productivity, compared to local material (Gunderson et al. 2012, Schreiber et al. 2013). Still, such transfer can result in increased risk of frost damages (Rehfeldt et al. 2003, Schreiber et al. 2013, Aarrestad et al. 2014). The effect of transfer also features regional specifics (Aarrestad et al. 2014).

Selection of the reproductive material (species, provenances, etc.) is mainly based on growth performance (Burton 2012), which summarizes compatibility of tree genetics and environmental conditions (Channel 1989, Ledig and Kitzmiller 1992). Due to changing climate, such compatibility is dynamic (Huang et al. 2010), and growth of trees can change notably (Wilmking et al. 2004). Considering the long-term nature of forestry decisions, information about the sensitivity of trees to meteorological conditions and their extremes (Taeger et al. 2013) can provide better insight in potential growth in future (Fritts 2001), aiding for application of the most suitable reproductive material, hence sustainability of stands (Burton 2012). In this regard, retrospective analysis of tree-ring width (TRW) can provide detailed information about the sensitivity of tree growth to climatic factors (Fritts 2001). The aim of this study was to assess sensitivity of TRW of two top-performing provenance of Scots pine originating from northern Germany in provenance trials differing by continentality in Latvia (hemiboreal zone). We hypothesized that the north-transferred provenances were sensitive to conditions in winter, and such relationships were stronger in sites with harsher climate.

Material and Methods

Studied trials and provenances

Two IUFRO 1975 trials of Scots pine provenances originating from Central and Eastern Europe (Jansons and Baumanis 2005) were studied. The studied trials were located near Liepāja (56.26°N, 21.12°E; coastal conditions) and near Kalsnava (56.79°N, 25.88°E; inland conditions). The sites differed by climate. In Liepāja site, climate was milder; the mean annual temperature (± confidence interval) during 1986–2015 was 7.8 ± 0.7° C; the mean monthly temperature ranged from 1.4 ± 1.3 to 17.8 ± 0.6° C in February and July, respectively. The annual sum of precipitation was 745 ± 37 mm; the mean monthly precipitation sums were the highest in summer months (ranging from 56 ± 8 to 81 ± 16 mm in June and August, respectively). In the Kalsnava site, climate was harsher and drier. The mean annual temperature was 6.3 ± 0.9° C and the mean monthly temperature ranged from 4.3 ± 1.3 to 18.0 ± 0.61° C in January and July, respectively. The mean annual precipitation sum was 655 ± 28 mm; the mean monthly precipitation sum during the summer months (June–August) was 68 ± 14 mm.

Both trials were located on a flat topography with oligotrophic well drained sandy soils (podzols). The trials were established by one-year-old bare-rooted seedlings, cultivated in local nurseries from seeds acquired from open-pollinated stands. The seedlings were planted in 2 × 1 m grid in 7 × 5 tree blocks. Blocks were randomly distributed in six replications. One thinning, leaving ca. 1/3 of the initially planted trees, was performed at the age of 21 years.

Provenance had significant and consistent effect on survival and growth of the studied trees (Jansons and Baumanis 2005). The inventory conducted at the age of 28 years (in 2003) showed that provenances from northern Germany were among the top-performing, yet their superiority compared to the mean of the plantations was more pronounced under milder climate in Liepāja trial. Based on the repeated inventory (in 2017, age: 42 years), Neubrandenburg (53.50° N, 13.25° E) and Rostock (54.15°N, 12.16° E) provenances were selected for sampling. In Liepāja trial, both provenances were among the top-ten according to their yield, yet stem diameter of the sampled trees was higher for Neubrandenburg provenance (Table 1). Under harsher climate in Kalsnava trial, trees were smaller, yet stem diameter of the sampled trees was practically similar for both provenances. Neubrandenburg provenance was among the top-five performers, while the performance of Rostock provenance was lower due to higher mortality, on average ranking 12. Still, performance of both provenances was above the mean value of the trials.

Sampling and measurements

The selected provenances were sampled in 2017 at the age of 42 years. In each trial, 18 dominant trees (three per replication) of each provenance were sampled. Two increment cores from opposite sides of stem at 1.3 m height above the base were collected form each tree with a 5-mm increment borer. Leaned trees were not sampled to avoid reaction wood.

In the laboratory, samples were glued into fixation planks and their surface was gradually grinded with sandpaper of three roughness grits (120, 240, and 400). Tree-ring widths were measured manually under a microscope, using LINTAB 5 (RinnTech, Heidelberg, Germany) measuring device. The accuracy of measurements was 0.01 mm.

Table 1. Mean diameter at breast height of the sampled trees and statistics of tree-ring width chronologies

	Liepāja trial		Kalsnava trial	
	Neubrandenburg	Rostock	Neubrandenburg	Rostock
Mean stem diameter at breast height (± conf. int.), cm	25.02±1.91	22.41±2.09	17.48±1.43	17.41±0.95
Mean TRW (± conf. int.), mm	3.54±0.14	3.20 ± 0.14	2.41±0.10	2.42±0.10
Number of trees	18	17	16	17
First order autocorrelation	0.82	0.83	0.79	0.77
Mean interseries correlation (*r*-bar)	0.41	0.40	0.34	0.42
Gleichläufigkeit	0.63	0.71	0.65	0.67
Expressed population signal	0.92	0.91	0.88	0.92
Signal-to-noise ratio	10.85	9.63	7.2	10.87

Data analysis

Time-series of TRW of each sample were crossdated by graphical inspection (Fritts 2001) and statistically, using program COFECHA (Grissino-Mayer 2001). The crossdated time-series were averaged for trees. To assess high-frequency variation, residual chronologies of TRW were produced. Time-series were detrended by modified negative exponential curve and then by cubic spline with the wavelength of 20 years, preserving 50% of variance. Autocorrelation was removed by autoregressive modelling (“AR”). Chronologies were built by averaging the detrended time-series of trees, using the biweight robust mean. Mean interseries correlation (*r*-bar), first order autocorrelation (AC), Gleichläufigkeit (GLK), expressed population signal (EPS; Wigley et al. 1984), and signal-to-noise ratio (SNR) were calculated for description of the chronologies.

The effect of climatic factors on high-frequency variation of TRW was assessed by bootstrapped (Johnson 2001) Pearson correlation analysis (10^4 iterations). The tested climatic factors were minimum, mean, and maximum monthly temperature, monthly precipitation sum, and standardized precipitation evapotranspiration index (SPEI) (Vicente-Serrano et al. 2010), calculated with the respect for previous three months. Climatic data were obtained from the gridded dataset provided by the Climatic Research Unit of University of East Anglia (Harris et al. 2014) for the stations located at < 20 km distance from the trials. Climatic window from July in the year preceding formation of tree-ring to September in year of tree-ring formation was used. Collinearity of climatic factors was assessed, and only non-collinear factors were presented.

Results

Most of the time-series of trees (≥ 16 per provenance; Table 1) were crossdated and passed quality checking. In both trials, mean time-series (variation) of TRW of the studied provenances (Figure 1) were highly similar (*r* ≥ 0.97). Nevertheless, in Liepāja trial, TRW of Neubrandenburg provenance consequently exceed Rostock one (except first three years). In Kalsnava trial, the TRW of the dominant trees of both provenances was practically the same (Figure 1, Table 1). The trials differed by growth trends. In the Liepāja trial, where trees were larger (Table 1), TRW followed negative exponential curve (Figure 1), while almost linear decrease was observed in the Kalsnava trial. All time-series of TRW contained high autocorrelation (AC ≥0.75) indicting effect of preceding growth.

High-frequency variation of TRW was similar among trees of each provenance/trial, as indicated by high *r* bar and GLK values (≥ 0.34 and ≥ 0.63, respectively; Table 1). Accordingly, the produced chronologies of TRW (Figure 1) contained common environmental signal (SNR e” 7.20) and EPS exceeded 0.85 (cf. Wigley et al. 1984). The developed chronologies (Figure 1) were significantly correlated indicating presence of common environmental signals (Table 2). The highest correlation (*r* ≥ 0.86) was observed between the chronologies from the same trial, similarly to mean times-series of TRW. The correlation between chronologies from different stands was considerably weaker, irrespectively of provenance (*r* = ~0.50), indicating regional specifics in environmental forcing of TRW. Nevertheless, common decrease in TRW was observed in all chronologies in 1997, 1999, and 2013 (Figure 1), when springs had extreme temperature contrasts (warm weather followed by cold spells). Common increase of TRW occurred in 1983, 1996, and 2016, when May was warmer than usual, yet early summer were cool.

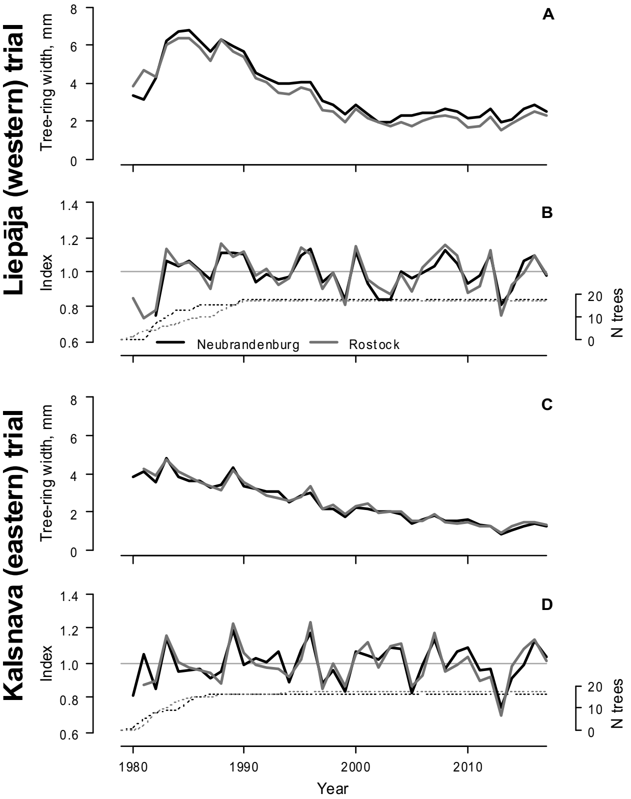

Figure 1. Mean time-series (A and C) and residual chronologies of tree-ring width (B and D) of the Neubrandenburg and Rostock provenances of Scots pine in the Liepāja (western) and Kalsnava (eastern) trials in Latvia for the period of 1980–2017. In B and D, fine dotted lines indicate sample depth (number of crossdated trees)

The developed residual chronologies of TRW significantly correlated with 10 of the tested climatic factors, yet the sets of significant factors differed by trials and provenances (particularly in Liepāja trial) (Figure 2). In Liepāja trial, where climate was milder, both provenances were sensitive to maximum temperature in December and July. Rostock provenance was specifically sensitive to mean temperature in March and April and to minimum temperature in January. Neubrandenburg provenance showed specific sensitivity to September temperature and drought index (SPEI) in May. Under harsher climate in Kalsnava trial, both provenances were sensitive to temperature in March and preceding September, and to SPEI in preceding July. Rostock provenance was specifically sensitive to temperature in April, while Neubrandenburg provenance to temperature in preceding July. In contrast to Liepāja one, in Kalsnava trial, temperature in July had a positive effect on TRW.

Discussion and Conclusions

Both north-transferred provenances were productive (Figure 1), as observed by Jansons and Baumanis (2005) and other studies (cf. Gunderson et al. 2012, Schreiber et al. 2013). In Liepāja trial, dominant trees differed by radial increment (Figure 1), implying that individuality of the provenances was expressed in the climatic conditions that were more similar to Northern Germany. Although in Kalsnava trail rankings of the studied provenances differed (Jansons and Baumanis 2005), patterns of TRW of the dominant trees were similar (Figure 1), indicating common environmental limitation of growth. The differences in productivity observed by Jansons and Baumanis (2005), apparently, were caused by trees of lower canopy status. The differences in growth curves might be related to growing conditions (Figure 1), as in harsher conditions radial increment is lower, yet culminates faster (Donis and Šņepsts 2015).

Presence of clear environmental signals in TRW (SNR > 7.20; Table 1) showed that the radial increment of the studied provenances has been sensitive to the meteorological conditions (Fritts 2001), similarly to trees from local populations (cf. Jansons et al. 2016). The high AC in TRW (Table 1) implied the radial increment has been affected by previous growth (Fritts 2001), likely via assimilation of nutrient reserves (Pallardy 2008). The correlations among the chronologies (Table 2) highlighted local patterns in the variation of TRW, which are common for species in the non-marginal parts of their range (Fritts 2001, Jansons and Baumanis 2005).

Although in both trials, the provenances showed common sensitivity to certain factors, provenance-specific sensitivity was more pronounced under milder climate in the Liepāja trial (Figure 2). Apparently, milder

		Liepāja trial		Kalsnava trial	
		Neubrandenburg	Rostock	Neubrandenburg	Rostock
Liepāja trial	Neubrandenburg		0.93	0.52	0.47
	Rostock	<0.001		0.53	0.53
Kalsnava trial	Neubrandenburg	0.001	0.001		0.86
	Rostock	0.004	0.001	<0.001	

Table 2. Pearson correlation coefficients (upper diagonal part) and their *p*-values (lower diagonals part) between residual chronologies of tree-ring width of the studied provenances/trials

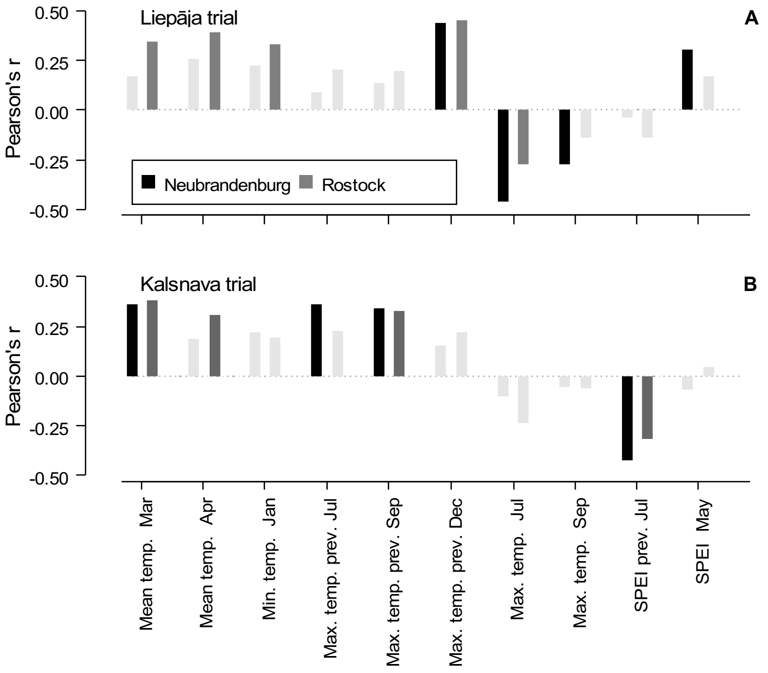

Figure 2. Pearson correlation coefficients between residual chronologies of tree-ring width of Neubrandenburg and Rostock provenances of Scots pine and local climatic factors in Liepāja (A) and Kalsnava (B) trials in Latvia for the period of 1985–2015. Significant correlations are shown by the intensive shades. The significance of the correlations (at α = 0.05) was determined by bootstrapping. Only the factors showing significant correlations are plotted

climate allowed clearer expression of genetically determined adaptation to specific micro-conditions at the areas of their origin (Rehfeldt et al. 2003, Taeger et al. 2013). The common sensitivity of both provenances to temperature in December (Figure 2) might be related with cold damage (Repo et al. 1994, Pearce 2001), particularly considering frequently shifting weather conditions in winter (frequent thaws) in the western part of Latvia (Harris et al. 2014). The correlation of TRW with temperature in July (Figure 2) might be related to physiological water deficit conditions in response to increased transpiration under raised temperature (Pallardy 2008).

The specific response of Rostock provenance, which originated from coastal region with milder climate, to winter and spring temperature in Liepāja trial (Figure 2) indicated increased susceptibility to conditions in the dormant period (Pearce 2001), due to northern transfer of the material (Schreiber et al. 2013). Alternatively, such connection (Figure 2) might be related to alterations in root dynamics (Jalkanen 1993), hence affected water relations in the following season (Pallardy 2008). The additional sensitivity to winter-spring conditions (Figure 2), which are often unstable, might explain lower productivity of Rostock provenance (Figure 1, Table 1). Neubrandenburg provenance was specifically sensitive to factors related to water availability at the beginning and at the end of vegetation season (Figure 2), suggesting non-sufficient water supply. Considering higher increments (Figure 1) and sensitivity to conditions in May and September (Figure 2), under milder climate, this provenance, apparently, was able to benefit from longer vegetation season.

Under harsher climate in Kalsnava trial, limitation of TRW by meteorological conditions, apparently, was stronger (Fritts 2001), suppressing specific responses of the provenances (Figure 2). Both provenances were sensitive to temperature in March (Figure 2), suggesting effect of cold damage (Pearce 2001) and/or affected root dynamics (Jalkanen 1993). The positive correlation with temperate in September in the year preceding formation of tree-ring (Figure 2) might be explained by additional nutrient assimilation (Oleksyn et al. 2000) due to extended vegetation season (Menzel and Fabian 1999). The negative correlation with drought index in May (Figure 2) is difficult to explain. Probably, such correlation might be related to decreased radiation in years with precipitation-rich springs. Rostock provenance appeared additionally sensitive to temperature in April, similarly as in Liepāja trial (Figure 2). The positive correlation with temperature in July of the year preceding growth (Figure 2), suggested that in cooler climate, Neubrandenburg provenance, benefited from warmer summers (cf. Helama et al. 2005).

As hypothesised, TRW of both north-transferred provenances showed sensitivity to weather conditions in winter, and climatic factors, apparently, had stronger effect in trial with harsher climate. Although both provenances were among the most productive, the sets of climatic factors significant for TRW were diverse, implying different climatic sensitivity. Considering the observed climate-growth relationships, Neubrandenburg provenance appeared more suitable for conditions in Latvia, as it was less sensitive to conditions in winter and was able to benefit from increasing length of vegetation season. Neubrandenburg provenance was more productive compared to Rostock one in Liepāja trial; accordingly, its superiority might be expected in the western part of Latvia, where climate is milder.

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