Relationships of Height Growth of Lodgepole Pine (*Pinus contorta* var. *latifolia*) and Scots Pine (*Pinus sylvestris*) with Climatic Factors in Zvirgzde, Latvia

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Abstract

Lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) is one of the few exotic tree species that has been successfully used in forestry in Northern Europe. Considering the increasing demand for energy wood and timber, this species could be applied in plantation forestry in Latvia; however, knowledge about its growth dynamics in relation to environmental factors is necessary for sustainable management. Annual height increment (HI) was measured for 297 lodgepole pine trees from three provenances (Pink Mountain, Fort Nelson and Summit Lake) and for 135 Scots pine (*Pinus sylvestris* L.) trees for the period from 1990 to 2009. Mean HI and diameter between species and provenances was compared by ANOVA. Height-growth-climate relationships were assessed using dendrochronological methods. Chronologies of HI were produced based on cross-dated time-series; the effects of climatic factors on yearly variation of HI were determined by Pearson correlation analysis.

There were no significant differences in diameter between species and provenances; however, HI of Summit Lake provenance and Scots pine was the highest. Common signatures in yearly variation of HI were observed in ~ 40 and ~60 % of lodgepole pine and Scots pine trees, respectively, suggesting effect of climatic factors. Sets of climatic factors affecting HI differed between species and provenances. Temperature in spring, summer and precipitation in the dormant period showed the strongest effect (positive) on HI of Pink Mountain, Fort Nelson and Summit Lake provenances, respectively. In contrast, HI of Scots pine was sensitive to climatic factors related to water deficit in May and June of the year preceding growth. Apparently height growth of Scots pine was more affected by conditions in the year preceding growth than in current year, compared with lodgepole pine.

Key words: shoot elongation, introduced species, adaptation, climate, pine species

Introduction

Lodgepole pine is native to North America, where it is commercially important species. Its native distribution area lies between the latitudes of 30 and 64°N and vertical distribution spreads from sea level to 3900 m elevation (Wheeler and Critchfield 1985). Scots pine is a species of pine native to Latvia. Although it has a wide geographic range (most of moderate and sub-arctic climate zone of Eurasia), the vertical distribution limit of this species is lower, about 1200–2600 m a.s.l. (Farjon 2005). Both pine species have a wide range of environmental tolerance; they can grow in continental, maritime and subalpine conditions in various site types (habitats) including areas with very wet or dry soils (Pfister and Daubenmire 1975). Lodgepole pine has been introduced as an exotic species for wood production in New Zealand (Miller and Ecroyd 1987), Scotland (Lines 1996), Ireland (Gallagher et al. 1987), Iceland (Sigurgeirsson 1988), Denmark (Larsen 1980) and Fennoscandia (Routsalainen and Velling 1993, Rosvall et al. 1998). Varieties *contorta* and *latifolia* have been most often used in forestry due to their faster growth; variety *latifolia* has been shown as especially productive in Fennoscandia (Elfving et al. 2001). In Northern Europe, this species has been the first to be introduced systematically on a large scale, i.e. in Sweden extensive establishment of lodgepole pine plantations was started around 1970 (Elfving et al. 2001). According to results of Scandinavian experiments (Routsalainen and Velling 1993, Rosvall et al. 1998), wood quality of lodgepole pine is similar to Scots pine, grown under similar conditions (Sable et al. 2012). Lodgepole pine has slightly lower wood density, lower bark proportion in stem volume, higher proportion of heartwood and better stem form than Scots pine (Ståhl and Persson 1988, Persson 1993). It has been estimated to produce up to 36% more yield irrespective of the site index, its optimum rotation period is 10–15 years shorter and survival during initial stage of stand development is higher, compared with Scots pine (Gallagher et al. 1987, Elfving et al. 2001). However, there is also evidence that in Sweden lodgepole pine plantations lose more biomass due to wind and snow damage than Scots pine (Elfving and Norgren 1993).

In Latvia, the first lodgepole pine (var. *latifolia*) plantation was established in the middle of the 20th century. In the beginning of the1980s several lodgepole pine provenance trials were established in central and western part of the country (Baumanis et al. 1992). In total, there are 16 ha of experimental lodgepole pine plantations (register as long term forest experiments) (Baumanis et al. 2006). However, before any recommendations for wider use of this species in afforestation can be given, the knowledge on growth-weather relationships of lodgepole pine in Latvian condition is necessary. In forestry, the height growth of trees is a crucial parameter that influences wood quality and productivity of stand (Savill et al. 1997). Although it has been reported that HI of pine in Fennoscandia is controlled by temperature in the beginning of summer (Lindholm 1996, Jalkanen and Tuovinen 2001, Lindholm et al. 2009, Salminen et al. 2009), climate-growth relationships may vary regionally or even locally (Speer 2010), thus local information is crucial. Several studies have also suggested HI as an additional source of environmental information for dendroclimatological studies (Jalkanen and Tuovinen 2001, McCarroll et al. 2003, Pensa et al. 2005). However, there is still rather insufficient information about the HI – climate relationships for pine, likely due to laborious gathering of the data. The aim of this study was to characterize height growth of young (~25 years) lodgepole pine (provenances Pink Mountain, Fort Nelson and Summit Lake) and progenies of native Scots pine seed orchards and to determine the effect of climatic factors on their HI.

Materials and Methods

Study area

The study area was located in central part of Latvia, near Zvirgzde (56°41’ N lat., 24°27’ E long.) (Figure 1). The relief is flat; elevation is about 30 m a.s.l. According to data from Latvian Environment, Geology and Meteorology Centre (LEGMC) the mean annual temperature is ~ 5.5 °C, annual precipitation ranges

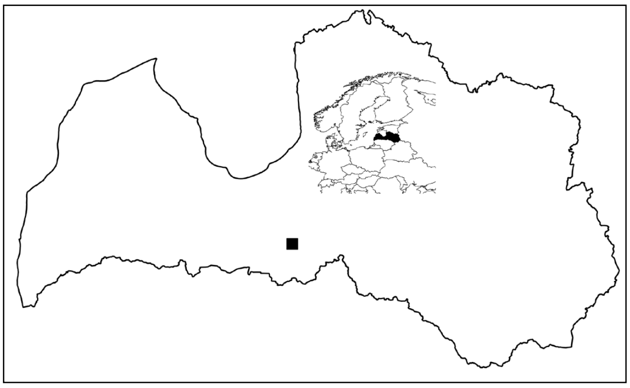

Figure 1. Location of sampling site (black square)

from 500 to 650 mm. January is the coldest month (mean temperature is ~ -5 °C) and July is the warmest (mean temperature is ~ 17 °C). Precipitation mainly exceeds evapotranspiration; most of the precipitation falls during summer. Length of the vegetation period (mean diurnal temperature >5 °C) is ~ 185–190 days. The mean annual temperature in the study period (1990–2009) varied from 5.5 to 8.3 °C, the mean temperature of the growing season varied from 13.8 to 16.6 °C, the mean winter temperature varied from -7.4 to 0.4 °C. Annual precipitation varied from 483 to 716 mm, the amount of precipitation in the growing season – from 203 to 412 mm.

The sampling site was provenance trials of lodgepole pine and Scots pine located directly besides it; both trials were planted in 1985 by two years old bare rooted seedlings in *Vacciniosa* forest type (according to classification by Bušs (1976)). Initial spacing of trees in both trails was 2x1m (5,000 trees per ha), no thinning was made prior to sampling. The trial consisted of three provenances (Pink Mountain (57°00’ N, 122°15’ W), Fort Nelson (58°38’ N, 122°41’ W) and Summit Lake (54°24’ N, 122°37’ W)) of lodgepole pine, each represented by 5 open-pollinated families, planted in 60 tree block plots and randomly distributed in 4 replications and open-pollinated progenies of local Scots pine (control) from the first generation seed orchards, planted in 50 or 100 tree block-plots and randomly distributed in 5 replications.

Sampling

Trees were sampled in autumn 2009; in total, 287 living lodgepole pine and 135 Scots pine trees, representing height and diameter variability of the plantation, were selected based on trial inventory. For measurements of HI, selected trees were felled; cutting was done maximally close to stem base. HI was measured as the distance on the stem between branch whorls (arbitrarily determined middle points of whorl, as all branches were not the same diameter and not at the same height). Although for lodgepole pine it might be difficult to distinguish between true branch whorls and internodal branches, during measuring of HI special attention was paid to correct identification of true branch whorls. Measurements of HI were done beginning from the top of the tree downwards for easier recognition of true whorls.

Climatic data

Climate data were obtained from LEGMC for Riga meteorological station, which is located approximately 35 km from study area. Climate data (the mean temperature and precipitation sums for months, growing season, calendar year, and periods from May to September, from July to September and from December to February) for current growing season (from October of previous year (t-1) to September of current year (t)) and previous growing season (from October of year (t-2) to September of year (t-1)) were used. Additionally, data on monthly minimum and maximum temperature and number of days with precipitation for months were obtained from Climatic Research Unit for the point located approximately 20 km from the study area (Mitchell and Jones 2005).

Data analysis

HI measurements for period from 1990 to 2009 were used; HI measurements prior 1990 (up to 6 first years) were not analysed to minimize establishment-related effects in HI series (Salminen and Jalkanen 2005). Equality of the variance of diameter (obtained from inventory database) and height (sum of HI) between provenances and control of Scots pine were assessed by Levene's test (Sokal and Rohlf 1995). The mean diameter and mean height between provenances of lodgepole pine and control (Scots pine) was compared with one-way ANOVA and Tukey HSD test (Sokal and Rohlf 1995). The proportion of variance of tree height explained by provenance including control was calculated as the division of sum of squares of factor "provenance" and the total sum of squares of dataset (Sokal and Rohlf 1995).

For the assessment of climate-height-growth relationships, measurement quality of HI was ensured by the cross-dating using programme COFECHA (Grissino-Mayer 2001) and by the graphical inspection of time-series. Residual chronology of HI for each provenance and control was established using programme ARSTAN (Cook and Holmes 1986). Single detrending by the cubic spline with a wavelength of five years and 50 % cut-off level was used. Autoregressive modelling was applied to remove autocorrelation from high-frequency variation of HI. Statistics of pooled datasets and chronologies (mean sensitivity, inter-series correlation and mean autocorrelation (first order)) were calculated using program COFECHA (Grissino-Mayer 2001); expressed population signal (EPS) (Wigley et al. 1984) and Gleichläufigkeit (GLK) indices were calculated in program R (R Core Team 2012) using library dplR (Bunn 2008). Significance of autocorrelation was determined by Student criteria (Sokal and Rohlf 1995). The effects of climatic factors on HI were assessed by Pearson correlation analysis between residual chronologies of HI produced by ARSTAN and climatic factors using program R (R Core Team 2012). Considering high number of tested climatic factors, p-values of correlation coefficients were not adjusted (Moran 2003).

Results

Studied provenances of lodgepole pine showed similar ranges of the stem diameter and height variation; however, the range of height variation was higher for Scots pine (Figure 2). Range of HI was slightly higher for Summit Lake provenance (Table 1). Variance of the diameter and height among lodgepole pine provenances and Scots pine was equal (p-value > 0.05). The mean diameter did not significantly differ between provenances of lodgepole pine and Scots pine (p-value > 0.05) (Table 2). The mean height was significantly higher for Summit Lake provenance and Scots pine compared with Pink Mountain and Fort Nelson provenances (p-value <0.01) (Figure 2); however, the proportion of variation of height explained by provenance and control of studied trees was rather low, about 8 %.

Cross-dating and quality checking of HI times-series have shown that only 52, 38 and 37% of measure-

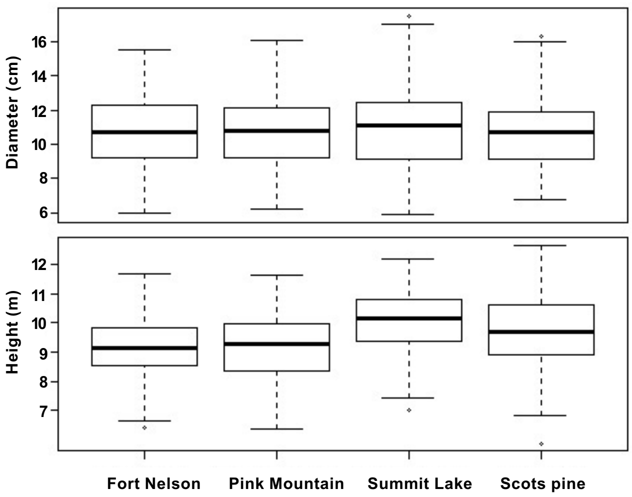

Figure 2. Mean stem diameter at breast height (cm) and height (m) (height increment for period from 1990 to 2009) of Scots pine and of three provenances (Pink Mountain, Fort Nelson and Summit Lake) of lodgepole pine

Table 1. Number of sampled trees, range and mean values annual height increment (for period from 1990 to 2009) and description of data used for establishment of height increment chronologies – number of suitable trees, mean interseries correlation, sensitivity, autocorrelation, EPS and Gleichläufigkeit index of pooled data of Scots pine and of three provenances (Pink Mountain, Fort Nelson and Summit Lake) of lodgepole pine

	Lodgepole pine provenance			Scots pine
	Pink Mountain	Fort Nelson	Summit Lake	
Measurements				
Total number of sampled trees	91	97	99	135
Annual height increment (cm)				
Min	6	7	3	10
Max	115	98	136	134
Mean	46.17	46.05	49.95	48.90
Height increment chronologies				
Number of crossdated trees (time-series)	47	38	39	86
Mean interseries correlation	0.4	0.44	0.41	0.69
Mean sensitivity	0.25	0.25	0.26	0.19
Mean autocorrelation (AC)	0.13	0.14	0.22	0.66
EPS	0.89	0.87	0.89	0.98
Mean Gleichläufigkeit (GLK)	0.53	0.53	0.54	0.63

Table 2. The effect of provenance (Pink Mountain, Fort Nelson and Summit Lake) on stem diameter at breast height and tree height (sum of HI for 1990–2009) of lodgepole pine (ANOVA)

Stem diameter at breast height					
	Df	Sum of Squares	Mean Squares	F-value	Sig.
Provenance	3	535	178.4	0.32	0.81
Residuals	418	232476	612556.8		
Tree height (sum of HI for 1990–2009)					
	Df	Sum of Squares	Mean Squares	F-value	Sig.
Provenance	3	482367	160789	12.17	<0.01
Residuals	418	5522104	13211		

ment series for provenances Pink Mountain, Fort Nelson and Summit Lake, respectively, expressed common signatures and were suitable for developing of HI chronologies (Table 1). In this regard, HI of Scots pine has shown stronger common signatures, and 62% of trees were selected for developing of chronology. There was no significant difference in the mean diameter and height between datasets of all measured trees and datasets selected for construction of chronologies for each provenance of lodgepole pine and Scots pine. The selected datasets showed rather high sensitivity and the EPS values were above 0.85. The mean autocorrelation (first order) of lodgepole pine HI time-series was low (≤ 0.22) and insignificant (at $\alpha = 0.05$), mean GLK indices and inter-series correlation were about 0.53 and 0.42, respectively. Autocorrelation in HI of Scots pine was higher (0.66) and significant (at $\alpha = 0.05$) and the mean sensitivity was lower (0.19); however, GLK (0.63) and interseries correlation (0.69) was higher compared to lodgepole pine. The index values of HI chronologies (Figure 3) ranged from 0.91 to 1.10; some common signatures might be spotted among chronologies in 1997, 2000, 2006 and 2007; however, they were hardly common for all four of the chronologies.

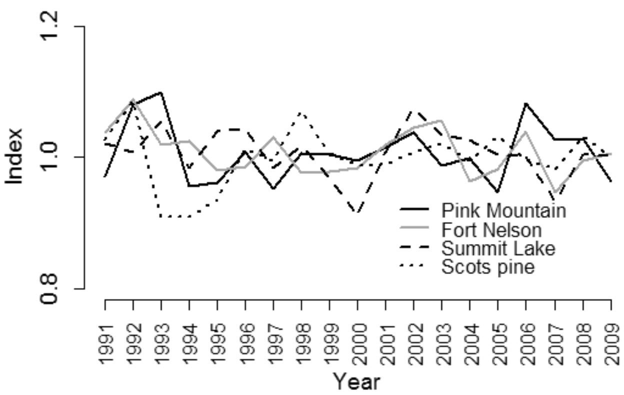

Figure 3. Residual chronologies of annual height increment of Scots pine and of three provenances of lodgepole pine (Pink Mountain, Fort Nelson and Summit Lake) for period from 1991 to 2009

From tested 142 climatic factors, 22 factors have shown the significant correlations with HI chronologies of lodgepole pine provenances and Scots pine (Table 3). The sets of climatic factors have shown the significant correlations with HI differed among provenances of lodgepole pine and Scots pine. Generally, climatic factors of current growing season showed highest correlation coefficients ($|r| \geq 0.50$) for lodgepole pine; climatic factors of previous growing season expressed the significant correlations with HI of Scots pine. HI of Pink Mountain provenance showed the highest correlations with mean, minimum and maximum temperature in May (positive) and the number of days with precipitation in May and June (negative). The mean and maximum temperature in July and April precipitation expressed the highest positive correlations with HI of Fort Nelson provenance, while the maximum temperature in April showed negative correlation. HI of Summit Lake provenance generally correlated with precipitation sums in the dormant period (November and February); however, there was also the significant positive correlation with May temperature. HI of Scots pine was sensitive to climatic factors (temperature in May and precipitation in June) of previous year.

Table 3. Significant Pearson correlation coefficients (r) (in Bold) between residual chronologies (for period from 1991 to 2009) of height increment of Scots pine and of three provenances of lodgepole pine (Pink Mountain, Fort Nelson and Summit Lake) and climatic factors: mean, maximum and minimum temperature, precipitation sums and number of days with precipitation for months for current growing season from October of year (t-1) to September of year (t) and previous growing season from October of year (t-2) to September of year (t-1) (significance level, *p*-values: * < 0.05, ** < 0.01)

	Pink Mountain	Fort Nelson	Summit Lake	Scots pine
Temperature				
Apr, maximum	-0.06	**-0.56***	-0.38	-0.26
May, mean	**0.66****	0.22	**0.49***	-0.11
May, maximum	**0.67****	0.1	0.26	-0.17
May, minimum	**0.53***	0.01	0.41	0.05
Jul, mean	-0.11	**0.63****	0.12	-0.03
Jul, maximum	-0.08	**0.59****	0.02	0.06
May-Sep, mean	0.13	**0.56***	0.23	0.22
Jul-Sep, mean	-0.24	**0.49***	0.12	0.14
Previous May, mean	-0.2	0.15	0.1	**-0.55***
Previous May, maximum	-0.22	0.12	-0.01	**-0.56***
Previous Aug, minimum	0.06	-0.02	0.15	**0.46***
Precipitation				
Nov, sum	0.27	0.1	**0.64****	0.2
Feb, sum	**0.46***	0.05	**0.54***	0.04
Apr, sum	0.02	**0.63****	0.09	0.05
May, days with prec.	**-0.51***	0.03	-0.07	0.05
Jun, days with prec.	**-0.5***	-0.45	0.13	0.12
Sep, days with prec.	**0.48***	0.17	0.01	-0.32
Previous Apr, sum	0.24	-0.19	**0.51***	-0.25
Previous Apr, days with prec.	0.07	-0.5	0.06	-0.11
Previous May, sum	0.44	0.21	0.1	**0.51***
Previous Jun, days with prec.	-0.15	0.3	-0.11	**0.64****
Previous Sep, sum	0.35	**0.46***	0.22	0.28

Discussion and conclusions

Provenance experiments are usually established for selection of trees showing higher yields in novel environments. Besides susceptibility to environmental hazards, dimensions of timber (stem diameter and height) are crucial parameters for description of wood production (Savill et al. 1997). Stem diameter, which is one of parameters in estimation of timber yields (Husch et al. 2002), did not differ significantly between Scots pine and three studied provenances of lodgepole pine (Figure 2). However, Summit Lake provenance showed significantly larger HI, implying higher stem volume increment and wood production compared with other two studied provenances. This was also evident in the same experiment in 1992 (Baumanis et al. 1992). In this respect, Summit Lake provenance appears to be the most suitable for plantation on sandy soils in Latvia. Faster height growth may also results in better quality of timber due to lower branchiness of logs (Houllier et al. 1995). However, HI of Summit Lake provenance was only slightly higher compared with local Scots pine (Figure 2) in contrast to Scandinavian findings in high northern latitudes (Routsalainen and Velling 1993, Rosvall et al. 1998).

For the analysis of relationships between climatic factors and HI data, quality check and cross-dating of measurements was done to ensure yearly resolution of measurements (Fritts 1976, Speer 2010). Measurement cross-dating and quality checking showed that rather high proportion of measurement time-series (from 48 to 63 % of trees for Pink Mountain and Summit Lake provenances, respectively and 38% for Scots pine) exhibited individual patterns of yearly variation. As climate is a large-scale environmental factor that causes large-scale signatures in tree growth (Kelly et al. 2002), the individuality in yearly variation of HI most likely was caused by effect of local factors, i.e. competition or microclimate (Drobyshev and Nihlgård 2000, Speer 2010). This was expected as both pine species in Latvia are located approximately in the middle part of their latitudinal distribution (Wheeler and Critchfield 1985, Farjon 2005), where climate is not considered as the main (strict) limiting factor for tree growth (Fritts 1976, Speer 2010). Therefore, it appears that present climatic conditions are suitable for these trees. However, Scots pine and Pink Mountain provenance showed the lowest proportion of trees with individuality in height growth that suggests more expressed effect of limiting factor on HI. Alternatively, the high proportions of trees showing low similarity of height growth might also be explained by difficulties in measuring of HI, as lodgepole pine can produce several whorls during one growing season (Mauriņš and Zvirgzds 2006). Also it was difficult to identify possible measurement inaccuracies during cross-dating due to short time-series of HI measurements (20 years). Series with low agreement were preferably omitted from further analysis than corrected. Nevertheless there were from 37 to 52 % of trees for Summit Lake and Pink Mountain provenances, respectively, and 62 % of Scots pine trees which showed common signatures of the height growth. Although GLK and inter-series correlation indices for lodgepole pine were about 0.53 and 0.42, respectively, the EPS values exceeded 0.85 (Table 1), suggesting that the datasets contain a common environmental signal (Wigley et al. 1984). The agreement between time-series of HI for Scots pine was higher (Table 1), suggesting that limiting factors are more expressed (Speer 2010). The established HI chronologies (Figure 3) showed several common signatures but most of them were expressed in two or three of the established chronologies, suggesting that sets of environmental (climatic) factors which affect HI differ between the provenances and control.

Several climatic factors showed a significant effect (significant correlations) on yearly variation of HI of Scots pine and the studied provenances of lodgepole pine (Table 3). HI of Pink Mountain provenance was sensitive to weather (climatic) conditions in spring, as shown by significant correlations with temperature and precipitation in May. Considering local phenology, the onset of shoot elongation of pines in Latvia occurs in mid-April, (Chuine et al. 2001, Fedorkov 2010, Jansons et al. 2011); however, the highest intensity of height growth is observed in the end of May (Jansons et al. 2011). A low temperature at that time can impede division and specialization of cambium and meristem cells (Pallardy 2008), thus decreasing growth. Additionally, rainy May in Latvia is usually cloudy and cool (LEGMC) that explain the negative correlation with number of days with precipitation (Table 3). Correlations with climatic factors after July of the current year most likely are coincidental as the height growth should have stopped by the end of July (Fedorkov 2010, Jansons et al. 2011). Height growth of Fort Nelson provenance showed positive correlation with summer temperature suggesting that it might favour warmer climate. Apparently in warmer years photosynthesis can be facilitated for the provenances from continental regions (Baumanis et al. 1992) resulting in faster growth (Medlyn et al. 2002, Pallardy 2008). Negative correlation with April temperature (Table 3) could be explained by the increase in frost susceptibility, if onset of growth occurs earlier in response to raised temperature (Gu et al. 2008). The growth of lodgepole pine has been linked with drought (Krajina 1969, Lloyd et al. 1990); a positive correlation with April precipitation (Table 3) suggests that the water availability is significant for HI of Summit Lake provenance in the beginning of growing period. As at the northern latitudes temperature in the dormant period and summer is considered as the main factor limiting tree growth (Mäkinen et al. 2003, Elferts 2008, Lindholm et al. 2009, Lo et al. 2010.), a sensitivity of HI of lodgepole pine to precipitation in the dormant period (Table 3) is quite difficult to explain. Increased precipitation in November can increase the soil water content during winter, altering fine root dynamics and water uptake in spring (Kramer 1951, Steudle 2000, Simard et al. 2007). Precipitation in February is usually in the form of snow (LEGMC); snow layer acts as an insulator affecting soil freeze (Hardy et al. 2001) that has been linked with dynamics of fine roots (Tierney et al. 2001).

HI of Scots pine was sensitive to weather conditions in year preceding growth (Table 3) as observed in Finland (Lindholm 1996, Jalkanen and Tuovinen 2001, Lindholm et al. 2009). The largest part of HI forms in the beginning of vegetation period (Jansons et al. 2011) and this process is depending on growth initials (Lanner 1976) and stored reserves (Pallardy 2008), thus explaining the effect of weather conditions of the year preceding growth. The negative effect of temperature in May and the positive effect of precipitation in May and June suggests that HI of Scots pine is limited by water deficit, similarly as observed in arid regions (Oberhuber et al. 1998, Martin-Benito et al. 2008).

Among the studied provenances of lodgepole pine, only Summit Lake showed slightly faster height growth compared with local Scots pine, thus suggesting this provenance as most suitable for afforestation on nutrient poor soils (Vacciniosa forest type). However, the different sets of significant climatic factors observed among provenances of lodgepole pine suggest that they might be suitable for variable climatic conditions. Pink Mountain provenance, which showed the highest sensitivity to temperature in spring (May), might be more suitable for regions with milder climate. Apparently Forth Nelson provenance favours regions with warmer summers as HI showed the highest sensitivity to temperature in summer, particularly in July. Although Summit Lake provenance showed the highest HI, sensitivity of HI to precipitation factors suggest that it might be better suited for moister growing conditions. Height growth of Scots pine was sensitive to water deficit in preceding summer, suggesting that Scots pine is more suitable for the regions where drought conditions occur rarely. Additionally common signatures in HI were weaker and the proportion of trees showing them was lower for lodgepole pine than for Scots pine (~ 40 and ~ 60 % of trees, respectively), suggesting weaker limitation of HI of lodgepole by climatic factors. However, more detailed study focusing on local and regional differences in climate-height-growth relationship should be conducted before any stricter recommendations could be given.

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ОТНОШЕНИЯ ПРИРОСТА В ВЫСОТЫ У СКРУЧЕННОЙ СОСНЫ (*PINUS CONTORTA* VAR. *LATIFOLIA*) И У СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS*) С КЛИМАТИЧЕСКИМИ ФАКТОРАМИ В ЗВИРГЗДЕ, ЛАТВИЯ

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Резюме

Скрученная широкохвойноя сосна (*Pinus contorta* var. *latifolia* Dougl.) является одним из немногих экзотических пород деревьев, которые были успешно использованы в лесном хозяйстве в Северной Европе. Учитывая растущий спрос на энергию на базе древесины и лесоматериалы, этот вид может быть применен в области лесоводства в Латвии, однако знания о динамике роста в ее связи с факторами окружающей среды необходима для устойчивого использования этого вида. Ежегодный прирост высоты за период с 1990 по 2009 год и диаметром на высоте груди были измерены для 297 скрученной широкохвойной сосны из трех областей происхождение (Pink Mountain, Fort Nelson и Summit Lake) и для 135 деревьев сосны обыкновенной. Диаметр и высота деревьев из разных видов и областей происхождения были сравнены с помощью дисперсионного анализа. Для анализа влияния климата на прирост в высоту, хронологии были созданы на основе проверены серии измерений. Влияние климатических факторов на прирост в высоту было определено на основе анализа корреляции Пирсона.

Различия в диаметре между деревьев из разных областей происхождения и видов были незначительными, однако прирост в высоту у деревьев с происхождением из Summit Lake и сосны обыкновенной был выше. Общие черты в изменении ежегодного прирост в высоту наблюдались в ~ 40% и ~ 60 % деревьев скрученной и обыкновенной сосны, соответственно, предполагая, влияние климатических факторов. Тем не менее, климатические факторы, значимые для прирост в высоту, отличались между деревьев из разных областей происхождения и видов. Температура весной, температура летом и количество осадков в период покоя были значимы для прироста в высоту у деревьев с областью происхождения из Pink Mountain, Fort Nelson и Summit Lake, соответственно. В противоположность этому, прирост в высоту сосны обыкновенной были чувствительны к дефициту воды в мае и июне предыдущего года. Видимо для сосны обыкновенной, запасы питательных веществ оказывает более выраженное влияние на прирост в высоту, чем у скрученной сосны.

Ключевые слова*: удлинение побегов, интродуцированный вид, адаптация, климат, сосны*