# CLIMATE SUITABILITY EFFECT ON TREE GROWTH AND SURVIVAL FOR SCOTS PINE PROVENANCES IN LATVIA

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**Abstract**
Climate in Latvia has been changing in last decades, and it is predicted to continue changing; therefore, it is important for forestry sector to understand how these climatic changes might affect tree growth and survival. In order to assess climate suitability effect on Scots pine (*Pinus sylvestris* L.) provenances in Latvia, height and survival data from a Scots pine provenance trial located in three geographically distant places in Latvia were analysed together with several climatic indices. Provenances in the corresponding trial originated from Latvia, Poland, Germany, Belarus, Russia and Ukraine. Thirty year average climate data values from 1961 – 1990 for the 64 origins of provenances were acquired from the WorldClim project. Correlation analysis between provenance average values for height and survival and climate index values for the origins of the provenances confirm that there is a relation between these amounts, and the relation differs between the three site locations, indicating that suitability of climate is an important factor affecting the results of provenance trials. Cluster analysis confirmed that provenances from distant origins might have a very similar growth and survival rates; therefore, geographical location of the provenance origins cannot be considered as the only influential factor on these rates and the results from provenance trials have to be analysed together with climate data in order to make conclusions about the suitability of the provenances.
**Key words**: provenance, suitability, spatial analysis, Scots pine, climate.

## Introduction

Forestry sector plays an important role in Latvia's economy, ensuring employment for 8% of the workforce and creating from 18% to 37% of the annual export value in the last decade; therefore, steady supply of high quality round wood for processing is a long term important objective of forest policy. However, rapid climatic changes are occurring and affecting the forest, as demonstrated by numerous observations e.g. of tree ring chronologies (D'Arrigo et al., 2008) and phenological indicators (as compiled in Pan European Phenology database – www.pep725.eu); the rate of change is predicted to increase in future (Solomon et al., 2007). Therefore, intensive work has been carried out to better understand the changes at local and a landscape scale in different countries including Latvia (Jansons, 2010). Results have been linked to characteristics of individual tree growth, stand development dynamics, from which country-wide or global predictions of impacts of climatic change on forest ecosystems are created (Read et al., 2009; Seppälä et al., 2009; Lindner et al., 2010) and coupled with the recommendations for forest management measures to boost adaptive capacity and reduce the possible harmful effects to forest stands (Lindner et al., 2008).

According to data from the National Forest Inventory, the forest in Latvia is dominated by Scots pine (*Pinus sylvestris* L.) (29%), birch — predominantly silver birch (*Betula pendula* Roth) — (28%) and Norway spruce (*Picea abies* (L.) Karst.) (17%). Each of these species has a wide geographical distribution; therefore, different genotypes grow in very different climatic conditions. Numerous provenance trials, including the International Union of Forest Research Organizations (IUFRO) series and Pravdins series (in the former Soviet Union) have been established (Giertych, 1979; Shutyaev and Giertych, 2000). The results clearly demonstrate provenance differences in survival and/or growth. Some provenances tried in Latvia (e.g. Scots pine from the Angasyak region close to the Ural Mountains) are very poor even though performance is good in the native region and despite the fact that transfer is good within the boundaries of the species natural distribution area. Notable variation among provenances in traits important for adaptation like bud burst, growth cessation, and frost hardiness, also occurs (Hurme, 2000). Results suggest that even for species with relatively high phenotypic plasticity as Scots pine, Norway spruce and Silver birch (Koskela et al., 2007) natural selection has played an important role in adaptation to local environmental conditions. Therefore, even if the climate change predicted in the future is within the range of climatic conditions that occurred in Latvia since the glacial period, the rate of change might cause considerable mortality due to natural selection in native populations of these species. A combination of different adaptation mechanisms, like intensive gene flow also from far distances via wind pollination and seed dispersal, may ensure the survival of species, but is unlikely to meet the human interest in maintaining productive forest stands in successive generations. Tree quality, including traits like stem straightness, thin branches, wide branch angle etc., is important for timber processing and is incorporated in the selection index in most of the breeding programs in Northern European countries. However, natural selection might not affect these traits to large extent. Therefore, to ensure both productivity and good timber quality of forest stands in Latvia, through a rapidly changing climate, active measures need to be taken. Provenances of the main species suitable for predicted climatic conditions need to be identified and included in breeding programs to produce material for forest regeneration.

Questions of possible impacts of climatic change on forest ecosystems and the need for adaptation has formed an important research agenda during the last decade in most of European countries. Special emphasis has been in the regions where the impact is already affecting practical forestry (like droughts and forest fires in Mediterranean region). As the future climate projections for Latvia suggest, survival and productivity of stands of our main tree species might be severely affected. Therefore, it might be an advantage to use provenances from Poland and/or Germany or other regions that could be better suited to predicted climatic conditions. However, detailed analysis on complex effects of environmental factors like soil characteristics and wind regime needs to be considered along with a complex analysis of climatic conditions and their effect on different traits of tree quality and yield before any recommendations could be drawn. So far in Latvia the research field of forest adaptation has focused on the impacts of wind, drought (and related increased fires risks) as well as pests and diseases. Advanced research in physiological reaction to particular meteorological conditions (e.g. increase in soil temperature) has also been carried out. Genetic factors, with few exceptions, were included into adaptation research only within the last few years. Such studies have been dedicated mostly to resistance against pests and pathogens and to gene migration. Therefore, the aim of this paper is to provide qualitatively new, broader scale information on the suitability of provenances to climatic conditions in Latvia that could trigger further national research activities dealing with more detailed analysis of the suggested provenances and role of genetic factors to ensure forest adaptation and adaptability in general.

## Materials and Methods

Climate data were analysed together with Scots pine provenance trial data. The trial was established in 1975 with one year old seedlings in three geographically distant places in Latvia with similar ecological conditions (Liepaja, Zvirgzde and Kalsnava). Seed material from 64 different origins was planted, including 27 provenances from Germany, 8 from Poland, 3 from Russia, 1 from Belarus, 1 from Ukraine and 18 provenances and 6 seed orchards from Latvia. The same material was used in all three locations. Trial design — two blocks with 6 replications, 7 by 5 plants in a parcel with the initial spacing 2 by 1 m. Height data at the age of 11 and 21 as well as survival rate at the age of 10 and 21 (before the first thinning) at provenance mean level were used in the analysis, no thinning had been carried out prior to the measurements. The climate data were extracted for specific coordinates that were based on provenance trial data about the origins of the provenances and the locations of trial sites.

The climate data have been taken from the WorldClim project (Hijmans et al., 2005). The data represents monthly average values for the 1960 – 1990 period, that have been interpolated to get data layers for 30 arc-second resolution grid (1 km$^2$ resolution). Precipitation and temperature values have been taken and other indices have been derived based on those values, such as moisture deficit, accumulated temperature sum, and Conrad's continentality index (Conrad, 1946). The moisture deficit is the accumulated difference between potential evapotranspiration (estimated by Hargreaves formula, Hargreaves and Samani, 1982) and precipitation from the months when precipitation level is lower than potential evapotranspiration, which is mainly during the growing season. It represents the possibility of drought occurrence during the vegetation period. Accumulated temperature sum is the yearly average sum of degrees above 5 °C for the days when mean daily temperature is above 5 °C. In this case only mean monthly temperatures were available, so accumulated temperature sum was estimated by taking the sum of degrees above 5 °C and multiplying it with the count of days in the month. A coefficient of continentality was formulated by V. Conrad in 1946 (1), and it represents the influence of landmass (the opposite of oceanicity), which is calculated as the difference between mean temperatures of the warmest and coldest months of the years, divided by the sine of the latitude, as the temperature difference increases with the latitude:

$$k = \frac{1.7A}{\sin(\varphi + 10°)} - 14 \qquad (1)$$

where $k$ — continentality, $A$ — difference between the mean temperature (°C) of the warmest and coldest months and $\varphi$ is the latitude of the place in question.

Correlation analysis was used to evaluate relations between the provenance mean data at each location and the average climate, latitude, longitude and altitude data for the origins of the provenances. Cluster analysis with k means algorithm was used to group provenances based on each trait at each location. The number of clusters in each case was determined graphically by the bend in a within groups sum of squares by the number of clusters plot. Afterwards the average climate data for each cluster and the difference from the site location's climate data was calculated to evaluate the climatic suitability effect on height and survival. Spatial analysis was done to map the results of the cluster analysis and to visually assess the geographical influence on traits. Mathematical analysis was carried out using statistical software R 3.0.2, while spatial analysis was done using QGIS 2.2.0-Valmiera.

**Results and Discussion**

As the three site locations have slightly different climatic conditions, it was expected that the results would differ among the sites. Kalsnava has the most continental climate with mean annual temperature 5.4 °C and 673 mm of precipitation per year, from which larger part is concentrated in the warmest months of the year, while Liepaja is closer to the sea and has the least continental climate from the three sites with mean annual temperature 6.8 °C and 692 mm of precipitation, which is distributed more evenly through the year. Zvirgzde is located approximately in the middle between Kalsnava and Liepaja, and also climatically is somewhere in between with mean annual temperature 6.2 °C and 637 mm of precipitation per year.

Several authors suggest that latitude is one of the most influential factors for growth traits (Andrzejewski et al., 1998; Kohlstock and Schneck, 1998; Matras, 1998), which seems to be true in most cases in our analysis (Table 1), especially for the results from Kalsnava, but for Liepaja and Zvirgzde there is almost no correlation between height and latitude, except for the height at the year 21 in Zvirgzde, which suggests that other factors, such as climate both in origin's and site locations, could have a stronger influence on growth traits than latitude. This statement is also validated by the different correlations of traits with continentality for different locations. For example, there is a statistically significant ($p<0.01$) positive correlation between survival and continentality in Kalsnava, while in Liepaja this correlation is very weak, but it is negative, which means that provenances from origins with more continental climate have a greater probability of survival if they are planted in a site with more continental climate. In Liepaja, there is a significant negative correlation for height with the coefficient of continentality, which becomes more pronounced at the age 21 than at the age 11, while in Kalsnava the correlation is positive, but very weak. It means that provenances in Liepaja have similar probability of survival regardless of the suitability of continentality, but less suitable provenances will grow more slowly; on the other hand, in Kalsnava more suitable provenances have greater survival probability and if they managed to survive, they showed similar height growth rates as other provenances.

Accumulated temperature and moisture deficit showed very similar effect on both traits at all locations and ages. Provenances in Kalsnava from origins with high moisture deficit (or accumulated temperature) had a very low survival rate, which could be due to frost resistance, because high moisture deficit an accumulated temperature is typical for places with warmer climate than in Kalsnava. This relation becomes more pronounced in the western part of Latvia (in other words – in sites with less continental climate), which also approves the previous statement as the winters are much milder in the western part of Latvia with rarer spring and autumn frosts. The same geographical trend is applicable also for the height; however, correlation is weaker in this case. Precipitation was the only variable that had a statistically significant correlation in all the cases, showing the trend that provenances from origins with higher annual precipitation level have both higher survival and height. Mean annual temperature was another variable that confirmed the importance of climatic suitability on height growth and survival rate, as the geographic trend was valid in all the cases, confirming that provenances from warmer places have worse results in a colder site and also the other way round. As Ā. Jansons and I. Baumanis (2008) point out, other traits, such as stem straightness and branch thickness, also have to be assessed, as provenances from abroad might succeed in one trait while failing in other, which is also proven by the fact that some provenances had a good height rate despite having a very low survival rate.

Correlation analysis showed no relation with altitude; therefore, altitude was excluded from further analysis. It could be mainly due to the small range of altitudes at provenances origins (15 – 201 m above sea-level) that is basically the same altitude level as in Latvia.

Cluster analysis based on provenance average values for traits was done in order to see if the provenances would group mainly according to their geographic origins. As it was expected, the influence of location on the clusters was apparent, but also provenances from geographically distant origins had very similar patterns both in height growth and survival rates. In some cases provenances from Latvia grouped together with provenances from Germany, mainly when height data were used for clustering, but also for survival in Liepaja and Zvirgzde. For example, when clustering by survival at the age 21 in Liepaja (which is located close to the Baltic sea), provenances from Latvia and Germany with origins close to the sea grouped together and showed the second best survival rate. On the other hand, when clustering by height at

Table 1

**Pearson's correlation coefficients between traits and climatic and geographical indices for different locations and ages**

| Location | Age | Trait | Altitude | Continen-tality | Accumulated temperature | Moisture deficit | Latitude | Longitude | Precipita-tion | Tempera-ture |
|---|---|---|---|---|---|---|---|---|---|---|
| Kalsnava | 10 | survival | 0.02 | 0.42** | -0.72** | -0.7** | 0.81** | 0.02 | 0.62** | -0.53** |
| Liepaja | 10 | survival | 0.05 | -0.04 | -0.29* | -0.29* | 0.45** | -0.52** | 0.54** | 0.10 |
| Zvirgzde | 10 | survival | 0.03 | 0.14 | -0.38** | -0.42** | 0.53** | -0.37** | 0.53** | -0.07 |
| Kalsnava | 21 | survival | 0.02 | 0.37** | -0.69** | -0.68** | 0.76** | -0.09 | 0.64** | -0.44** |
| Liepaja | 21 | survival | 0.01 | -0.08 | -0.27* | -0.29* | 0.44** | -0.53** | 0.53** | 0.11 |
| Zvirgzde | 21 | survival | 0.04 | 0.11 | -0.20 | -0.24 | 0.46** | -0.39** | 0.43** | 0.05 |
| Kalsnava | 11 | height | -0.09 | 0.16 | -0.41** | -0.38** | 0.52** | -0.32* | 0.53** | -0.13 |
| Liepaja | 11 | height | 0.08 | -0.29* | -0.01 | 0.03 | 0.12 | -0.7** | 0.42** | 0.34** |
| Zvirgzde | 11 | height | 0.01 | -0.17 | 0.06 | 0.09 | 0.14 | -0.53** | 0.28* | 0.29* |
| Kalsnava | 21 | height | -0.07 | 0.04 | -0.39** | -0.34** | 0.47** | -0.46** | 0.56** | -0.01 |
| Liepaja | 21 | height | 0.05 | -0.41** | 0.13 | 0.13 | 0.07 | -0.78** | 0.44** | 0.45** |
| Zvirgzde | 21 | height | -0.02 | -0.15 | -0.02 | -0.02 | 0.28* | -0.54** | 0.39** | 0.23 |

* – significant at 0.05 level; ** – significant at 0.01 level

the age 21 in Kalsnava, provenance groups with the best height data consisted of provenances all across Latvia, Germany and Poland, but in the same time the second worst height data were for a set of German provenances originating from very close locations to those of the best height data, showing no clear trend. The only clear trend was that provenances from Ukraine and Russia had the lowest height, possibly indicating that these provenances originated from places with more unsuitable climate for growing in Kalsnava. Of course, the small number of provenances from that region limits our possibilities to make accurate conclusions.

In order to explore the suitability of climate indices, values of the indices were expressed as a percentage of the respective climate index value at each of three site locations. Then these values were analysed in accordance with the cluster average trait values. The results showed a tendency that provenance groups (clusters) with the best growth and survival rates were from origins with very similar climatic conditions to that of the site location, while the worst trait rates were observed for provenance groups with the largest deviations in climatic conditions (Figure 1). It means that climatic conditions have a complex influence on the growth and survival rates and analysis of singular climatic variables could lead to inaccurate conclusions. This observation suggests that it might be possible to select provenances from distant regions, but with similar climate conditions as in the planned forest regeneration location, which would result in good height and survival rates. Also, it would be possible to select seed material that is more suitable for the projected future climatic conditions, taking into consideration more influential factors and resulting in a lower risk of uncertainty in forest adaptation.

## Conclusions

It is clear that suitability of climate has a direct effect on both height and survival of Scots pine;

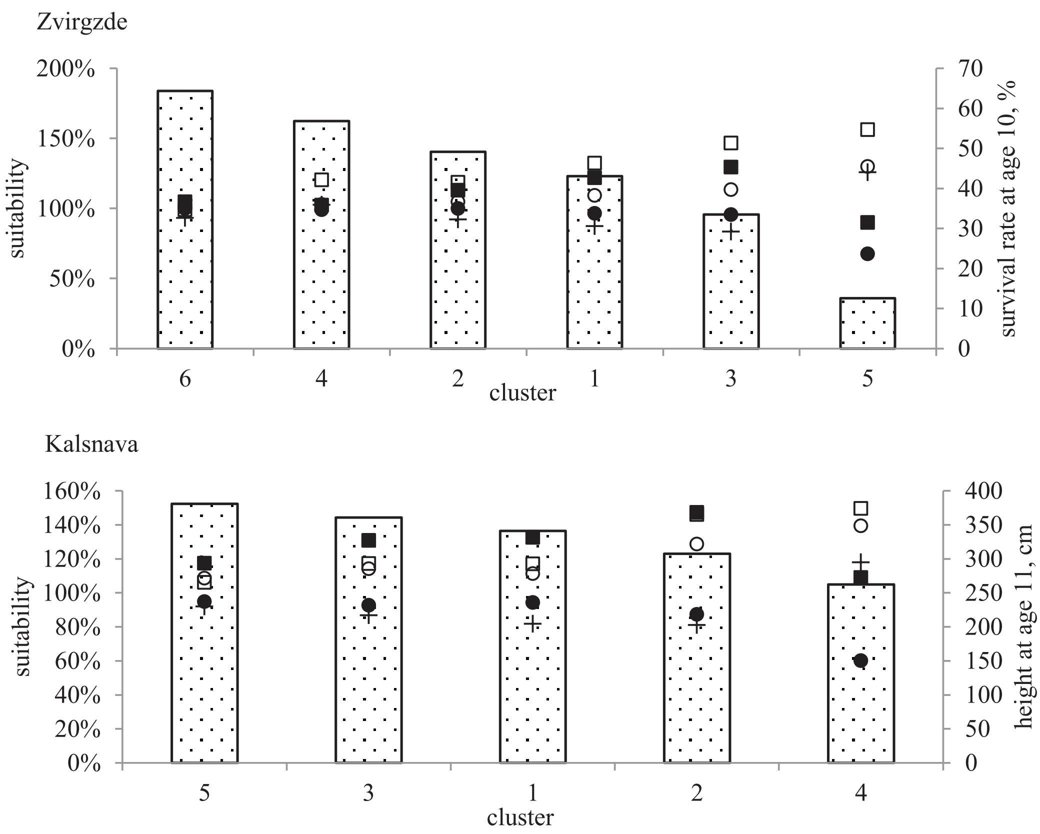


Figure 1. Differences between average climate indices for origins and trial locations in relation to provenance groups clustered by similar trait patterns: left axis: □ moisture deficit; ■ temperature; ● precipitation; ○ accumulated temperature sum; + continentality; right axis: Zvirgzde – survival; Kalsnava – height.

therefore, results from provenance trials need to be analysed along with the climate data from the origins of provenances. That way a better understanding about the results can be acquired than by using just the information about latitude and longitude of the origins. As it can be seen from the results, the best height and survival rates were for provenance groups that had very similar climatic conditions as in the respective site location, but additional climate and soil data should be incorporated in further research in order to obtain more precise results.

In order to compare differences in climatic conditions for specific periods of time, more specific climate data from stations close to the origins of the provenances is needed, which would be very useful for assessing the effect of climate change on Scots pine.

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