Sensitivity of Scots Pine Trees to Winter Colds and Summer Droughts: Dendroclimatological Investigation

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Abstract

Our research focuses on dendroclimatological assessment of Scots pine (*Pinus sylvestris* L.) trees, which are sensitive and resistant to low winter temperatures and summer droughts. Research was conducted on the experimental plot located in the northeastern Lithuania. Pines sensitive and resistant to climatic conditions were detected by using response function analysis. Investigation has revealed high heterogeneity among pine trees in respect to their response to low winter temperatures and summer droughts. It was found that trees characterised by similar response to contrast climatic conditions mostly are located in smaller or bigger clusters. Because the standard dendroclimatological techniques at present are not able to interpret the results we hypothesize that different sensitivity to climate conditions are determined by genetic features of trees.

Key words: dendroclimatology, summer droughts, resistance, response function, Scots pine, sensitivity, winter colds

Introduction

Winter colds, spring frosts and summer droughts have been acknowledged as important factors altering the state forest (Oberhuber 2001, Pederson *et al*. 2004). Influence of winter colds on the radial growth of Scots pine in Lithuania has been investigated from the early works on dendroclimatology (Битвинскас 1974, Битвинскас 1984), while the impact of summer droughts have acquired greater attention only at the end of the 20th century (Bitvinskas and Vitas 1999, Vitas 2004) as consequences of the global climate change (Hoerling and Kumar 2003).

The first trends of the global climate change have been observed in the middle of the 20th century. These tendencies as the global phenomenon were recognised only in the 1970s and 1980s. Warming trend of the cold year period was established as the first one (Bukantis 1994, Bukantis 1998, Bukantis *et al*. 2001) and a decrease in the amount of precipitation during the warmer year period was noticed later (Bukantis *et al*. 2001). These trends and frequent intensive droughts were established also in other countries and continents (Barbu and Popa 2003, Cook *et al*. 1988). The majority of scientists have acknowledged anthropogenic impact to the global climate change during the 20th century (Briffa and Osborn 1999, Hasselmann 1997, Kerr 2000, Lamb 1995). One of the causes of the regional decline of forests is connected to the more frequent droughts and a rise in temperatures (Parmesan and Yohe 2003, Rebetez 2002, Root *et al*. 2003, Smith 2005). It is supposed that more frequent droughts are possible consequences of the global climate change (Bukantis *et al*. 2001, Hoerling and Kumar 2003).

It was admitted by several investigations that individual trees growing in the same stand demonstrate different response and sensitivity to droughts (Kral and Mayer 1985, Lingg 1986), colds (Lingg 1986), and environmental pollution (Klein 1980). Dendrochronological investigation often reveals existence of trees, which radial growth patterns shows different growth dynamics than the majority of trees. This phenomenon usually involves from 10% to 30% of trees in the research plot (Stravinskienė 2002, Битвинскас 1974, Карпавичюс 1984, Розанов *et al*. 1975). However, the biggest part of dendrochronological research utilizes the radial growth of trees on a local or regional scale. This ordinary dendrochronological approach is based on one of the principles (Fritts 1987), which states that replicated measurements from a large number of trees provide the best estimate of climate. Therefore, investigations of the radial growth variability and climate-growth relationships of individual trees are scarce in spite of that research on trees' sensitivity to contrast environmental factors are valuable in forest improvement, planted forest stands more resistant to droughts, frosts and other contrast conditions (Wright 1976).

Aim of the research was to ascertain the differences of the impact of winter colds and summer droughts on Scots pine trees by applying dendroclimatological methods.

Materials and methods

Research was carried out at the research plot located in the Aukštaitija National Park – Vaišnoriškė (Ignalina Forest Enterprise, Vaišniūnai Forestry, block No. 74). Geographical coordinates of the area: 55°25‘54“ latitude (N) 26°01‘70“ longitude (E). Laboratory of Dendrochronology selected this research plot in 1976 for investigation of diurnal radial growth using band dendrometers. More than 200 mature and over-mature pines grow in the area of 1 ha (Fig. 1). Terrain is located 140-150 metres above sea level. In spite of the rising relief from southern to northern part of the research plot, the altitude difference reaches only 4-5 m. Fine fraction of the soil consists of sand. Typical insertions in the soil are coarse fragments (gravels and cobbles). The ground water table in research plot is deeper than 5 m.

Figure 1. Research area in Lithuanian scale

Fieldwork was carried out using standard methods of dendrochronological research (Eckstein 1987, Fritts 1987, Schweingruber 1988, Stravinskienė 1994, Битвинскас 1974). Samples from 108 pines of co-dominant, dominant and emergent crown classes were taken by inserting an increment borer at breast height. The bark type of pines was examined according to dendrological methods (Navasaitis 2003).

Tree ring widths were measured within 0.001 mm accuracy using LINTAB tree ring measuring table and WinTSAP 0.30 (F. Rinn Engineering Office and Distribution, Heidelberg). Dating quality control between the radial growth series were performed using visual and statistical dating techniques (COFECHA 3.00P, R.L. Holmes, Tucson) (Eckstein 1987). Standardisation of the series was carried out using CHRONOL 6.00P program (R.L. Holmes, Tucson). Each tree ring width series belonging to an individual tree was indexed separately. For the analysis of the impact of contrast climate factors on the radial growth of trees analysis of multiple regression – response function (Fritts 1987, Fritts and Dean 1992) was carried out. The long-term relationship was estimated during 1940-2002 using monthly air temperatures and monthly amount of precipitation. For this purpose we used PRECON 5.17B program (H. Fritts, Tucson).

Because individual pine trees show high individuality in the response to air temperatures and precipitation (e.g. some trees demonstrate significant links with temperature in January, others with temperature in February or March), for evaluation of the impact of winter temperatures coefficients of response function from January to March were used and for estimation of the influence of precipitation coefficients from May to August were used. Because the average coefficients of the response function for three (with air temperatures) and four months (with precipitation) provide slight variability among trees, sums of coefficients were used.

Pines according to response to low winter air temperatures were divided into five groups of sensitivity. For this purpose we counted sums of response coefficients between the radial growth of trees and air temperatures for three months (January, February, March). Conditional classes of sensitivity are: sensitive to colds (>0.50), slightly sensitive (0.40-0.49), indifferent (0.30-0.39), slightly resistant (0.20-0.29) and resistant (<0.19).

Trees were grouped according to sums of response coefficients between the radial growth of trees and amount of precipitation for May – August into five conditional classes. Sensitivity to summer precipitation classes are: sensitive to droughts (>0.40), slightly sensitive (0.30-0.39), indifferent (0.20-0.29), slightly resistant (0.10-0.19) and resistant (<0.09).

Results

Results have revealed that the high heterogeneity of trees in respect to contrast climatic conditions (winter colds and summer droughts) exists (Fig. 2, 3). The average coefficients of response function between the radial growth of pines and air temperature in January – March from sensitive to resistant trees to winter colds are presented in Figure 2. Sensitive trees to winter colds are characterised by statistically significant positive links with temperatures in February and March. The most stable links between the radial growth of pines and temperature in March are found. Trees belonging to indifferent, slightly resistant and resistant did not show statistically significant links with air temperatures in winter.

The average coefficients of response function between the radial growth of pines and precipitation in May – August from sensitive to resistant trees to summer droughts are presented in Figure 3. Trees sensitive to summer droughts are characterised by positive and significant links with amount of precipitation in summer. Despite the average coefficients are lower than with air temperatures, precipitation in June is the most important factor. Statistically significant coefficients with precipitation in June predominate among pines belonging to sensitive category. Coefficients for pines slightly sensitive to precipitation are already much lower compared to sensitive trees.

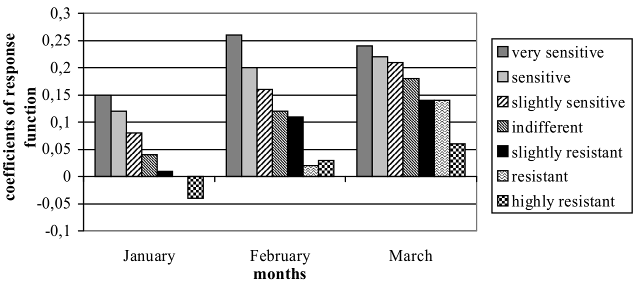

Figure 2. Average response function coefficients between the radial growth of individual pines and air temperature in January – March

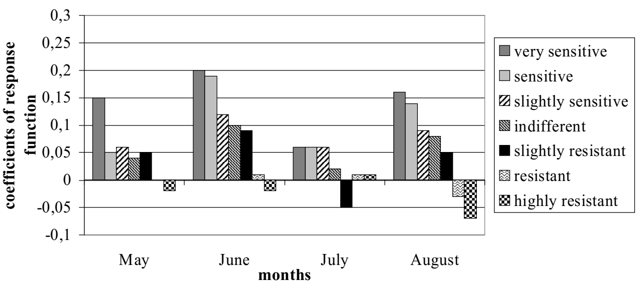

Figure 3. Average response function coefficients between the radial growth of individual pines and the amount of precipitation in May – August

Number of trees attributed to each class of sensitivity is similar, except pines sensitive to winter colds, which number is the biggest (Fig. 4). Two forms according to bark type have been detected among investigated pines: f. *kienitzii* Seitz. (76 trees) and f. *bonapartei* Seitz. (32 trees). Despite f. *bonapartei* Seitz. is more frequently distributed among trees sensitive and resistant to climate factors, comparatively a small number of trees investigated did not allow judging this difference as statistically significant (Fig. 4).

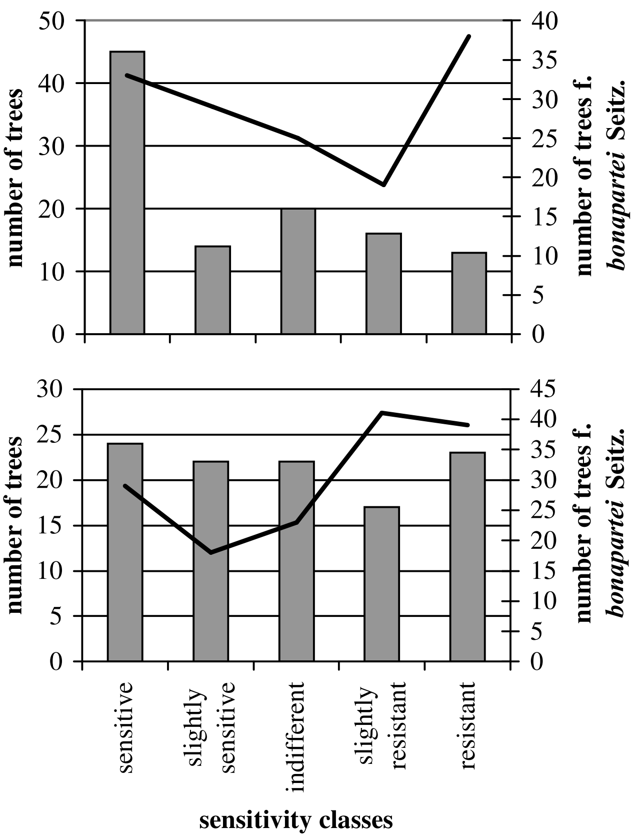

Figure 4. Number of trees characterised by different response to winter colds (A) and summer droughts (B). Columns indicate number of trees for each sensitivity category and lines show number of trees (%) belonging to f. *bonapartei* Seitz. according to bark type

Network of pines in research plot and spatial distributions of pines' sensitivity to winter colds and summer droughts are presented in Figures 5 and 6. It is obvious that trees with similar reaction to climate (sensitive and resistant to contrast climatic conditions) generally are located in bigger or smaller clusters. The biggest part of sensitive trees to winter colds grow in the southern and northeastern parts of the research plot (Fig. 5, groups A, B). The biggest number of pines resistant to winter colds (C) are located between groups A and B (south-eastern part) and in the northern part of the plot.

Trees sensitive to summer droughts are located in the central part of the plot (Fig. 6, group D) and pines resistant to summer droughts mainly are located in the northern part of the plot (Fig 6, group E).

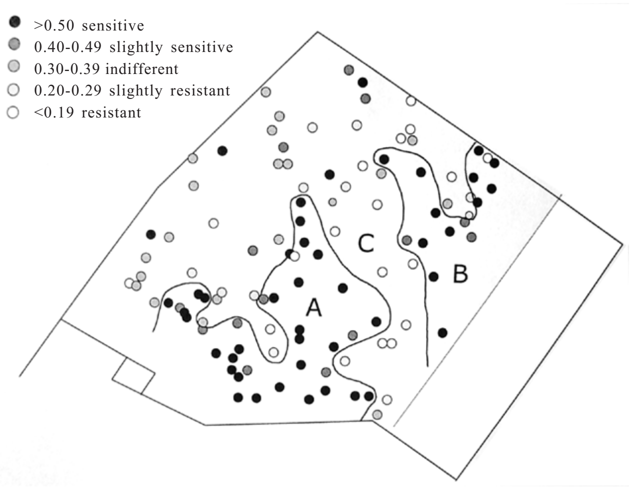

Figure 5. Network of pines in the research plot and spatial distribution of sensitive and resistant trees to winter colds. Sensitivity is expressed as sum of response coefficients between the radial growth of pines and air temperature in January – March

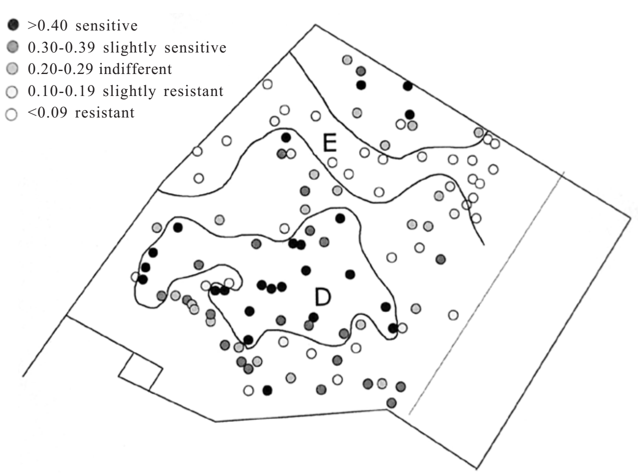

Figure 6. Network of pines in the research plot and spatial distribution of sensitive and resistant trees to summer droughts. Sensitivity is expressed as sum of response coefficients between the radial growth of pines and amount of precipitation in May – August

Discussion

Radial growth of trees is controlled by various external and internal factors in the forest environment. External factors are climate, carbon dioxide, oxygen and soil minerals. The most common internal limiting factors – available minerals, growth regulators, enzymes and water are often interconnected with external factors to complex interactions (Fritts 1987, Schweingruber 1993). Most internal factors like enzymes, growth regulators and other physiological features responsible for the surviving of trees under contrast environmental conditions are on the genetic control of a tree (Wright 1976). On the other hand interactions between trees and its surrounding environment at the stand level exist. These interactions are not understood adequately.

Internal limiting factors of tree and interactions between tree and stand lead to the radial growth differences among trees in the stand. The biggest part of previous dendrochronological research utilizes the radial growth of trees on a local or regional scale. This commonly used dendrochronological approach is based on one of the main principles of dendrochronology (Fritts 1987), which states that replicated measurements from a large number of trees provide the best estimate of climate. Therefore, studies on climate – radial growth relationships of individual trees are scarce and the radial growth variability of individual trees is poorly understood.

Effects of summer and winter contrasts (droughts and colds) are detectable by event and pointer year analysis, developed by Swiss scientists F.H. Schweingruber (Schweingruber *et al*. 1990), which introduced short-term analysis as a new discipline in dendrochronology. However, event and pointer year analysis (in this study years with particularly narrow or wide rings) is a more qualitative indicator than a quantitative measure (Schweingruber *et al*. 1990, Schweingruber *et al*. 1991). Originally event and pointer years have been estimated by visually assessing tree ring features from wood cores or cross-sections. Although for the assessment of event and pointer years several statistical methods were developed, it is still complicated how to integrate many pointer years into a feature, which will indicate individual tree as "tolerant" or "sensitive" to unfavourable climatic conditions.

Dendrochronological investigation often reveals that there exists a certain number of trees (10% to 30%) in the research plot, which radial growth patterns show different growth dynamics than the majority of trees (Stravinskienė 2002, Битвинскас 1974, Карпавиичюс 1984, Розанов *et al.* 1975). J. Karpavičius established that radial growth characteristics like sensitivity and response to climate factors of pines often are interconnected to other morphological features of a tree (crown class, bark type etc.) and hypothesised that this may be determined genetically (Карпавичюс 1984). Considerable experimental work on Scots pine taxonomy has revealed that morphological features of trees (growth rate, stem form, branchiness, response to contrast environmental conditions) are probably genetic in nature have been attributed to its genetic constitution (Ruby 1964, Wright 1976).

Five forms of Scots pine according to bark type have been discovered in Lithuania: f. *annulata* Caspary, f. *bonapartei* Seitz., f. *gibberosa* Kihlmann, f. *kienitzii* Seitz., f. *seitzii* Schwerin (Navasaitis 2003). The most common pine form in Lithuania is f. *kienitzii* Seitz, which is typical to 80% pines. It was found that besides pines f. *kienitzii* Seitz. (76 trees) other trees belong to f. *bonapartei* Seitz. (32 trees). Although, f. *bonapartei* Seitz. was found more frequently among trees sensitive and resistant to winter colds and summer droughts, small number of trees investigated did not allow to judge these differences as statistically significant (Fig. 4).

It is supposed that internal factors determine the sensitivity of tree to colds and droughts (Lingg 1986). W. Lingg (1986) has also pointed out that drought resistant ecotypes of Norway spruce (*Picea abies* (L.) Karsten) may be characterised by bark type and branch shape in the crown. Other researchers have also admitted that exist individual fir trees (Kral and Mayer 1985) resistant to droughts and Norway spruce trees resistant to environment pollution (Klein 1980).

Physiological effects of contrast climatic conditions are complicated and not fully understood. Droughts have direct influence causing damage to fine roots of Scots pine (Irvine *et al*. 1998). On the other hand less vigorous trees limit the ability to produce the defence compounds (Manion 1981). According to one of the main hypothesis, winter colds cause xylem embolism and this disturbs the conductance of water in the stem (Sperry *et al*. 1994). Another influence of colds is connected with mortality of fine roots, which depend on the thickness of the snow cover (Hardy *et al*. 2001).

There are no substantial differences in soil type, ground water level, no clear relationships between the relief and established locations of sensitive and resistant trees. Investigation of the distribution of pine forms has pointed out that pine form *bonapartei* Seitz. is more common to trees sensitive and resistant to winter colds and summer droughts. Due to a small number of trees it could be only hypothesized that this pine form is connected to the response of trees to climate. Pine grouping into smaller or bigger clusters according its response to climate (Fig. 5, 6), provide evidence that different response of pines to winter colds and summer droughts possibly are determined by genetic biodiversity of trees. In spite of that tree genetics has been in progress for the past 50 years (Wright 1976), its achievements at present (Williams *et al.* 1990, Žvingila *et al*. 2002) limits validation of our hypothesis.

Conclusions

1. Research has revealed that considerable differences of the radial growth response to contrast climate conditions among Scots pine trees growing at the same stand exists.
2. Scots pine trees characterised by similar response to contrast climatic conditions mostly are located in smaller or bigger clusters.
3. Pines f. *bonapartei* Seitz. according to bark type are more typical among trees sensitive and resistant to winter colds and summer droughts. However, a small number of trees investigated did not allow judging this dependence as statistically significant.
4. Because research carried out did not provide definite explanation why the response of pines to climate factors is so variable, it could be hypothesized that genetic features of trees determine different sensitivity of trees to climate.

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ЧУВСТВИТЕЛЬНОСТЬ ДЕРЕВЬЕВ СОСНЫ ОБЫКНОВЕННОЙ НА ЗИМНИЕ МОРОЗЫ И ЛЕТНИЕ ЗАСУХИ: ДЕНДРОКЛИМАТОЛОГИЧЕСКОЕ ИССЛЕДОВАНИЕ

А. Витас

Резюме

Наши исследования фокусируются на выявлении и дендроклиматичесском анализе чувствительных и резистентных к зимним холодам и летним засухам деревьев сосны обыкновенной (*Pinus sylvestris* L.). Исследования были проведены на пробной площади в северовосточной Литве. Сосны чувствительные и резистентные на климатические условия были выявлены при помощи функции отклика. Исследования показали большую разнообразность среди деревьев сосны по их реакции на низкие зимние температуры и летние засухи. Установлено, что деревья похожие по чувствительности к климатическим контрастам, в большинстве случаев расположены в группах с разной численностью деревьев. Потому что стандартные дендроклиматические достижения в настоящее время не позволяют интерпретаций полученых результатов, то что разная чувствительность деревьев на климатические условия предопределяет их генетические свойства, мы считаем гипотезой.

Ключевые слова: дендроклиматология, летние засухи, резистентность, функция отклика, сосна обыкновенная, чувствительность, зимние морозы