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Original Research

Interpopulation Variation of Individual Tree Response to Pollution: Evidence from Scots Pine Dendrochronological Data

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Abstract

The results of a dendrochronological investigation carried out on Scots pine (*Pinus sylvestris* L.) in the vicinity of JSC 'Achema' are presented. We found that pines sensitive and resistant to pollution exist in the population. Trees judged to be sensitive to pollution grew much faster in the period before the pollution occurred in comparison to resistant trees (p=0.00). We found that the dominant and codominant crown classes are more common among sensitive pines, while emergent crowns are twice as common among resistant trees. However, the differences are not statistically significant. We did not find an obvious difference between morphological bark forms of pines in respect to their sensitivity to pollution. The frequency of missing rings during the strongest depression period is much higher for sensitive pines (p=0.00).

Keywords: dendrochronology, pollution, Scots pine, sensitive and resistant trees

Introduction

Dendrochronological methods were developed in the second half of the 19th century [1]. The rapid development of investigation techniques allowed for the wide application of dendrochronology in the assessment of natural and anthropogenic environmental changes [2, 3]. Increasing anthropogenic pressure on forest ecosystems together with a global climate change have created new challenges for dendrochronology [4-8], because dendrochronology allows for the assessment of anthropogenic pressure during the entire period of a tree's growth.

The first signs of forest decline in the areas surrounding 'Achema' were observed in 1972 [9]. Numerous investigations, mostly based on crown defoliation, were carried out in the surrounding forests, although only in certain studies [10-12] were tree-ring widths utilized as an indicator of pollution disturbances [13-15]. The effect of environmental pollution in all dendrochronological investigations was assessed by analyzing the average tree-ring width chronologies and neglecting the different responses of individual trees to pollution. In a very limited number of studies, individual trees were analyzed and their radial growth explored for the investigation of environment-tree growth relationships [16-19].

The aim of this study is to investigate, using dendrochronological techniques, the sensitivity of Scots pine radial growth in the areas surrounding 'Achema', and to assess the pines differently regarding their responses to pollution. Based on recent studies, the response of trees to environmental pollution is individual: there are sensitive and resistant trees among the same population. We assume that the sensitivity of pines might be related to the morphological features of trees and the frequency of missing rings may serve as an indicator of tree sensitivity to pollution.

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Experimental Procedures

The fertilizer plant 'Achema' is located in central Lithuania, approximately 35 km from Kaunas (the second biggest city in Lithuania) (Fig. 1). The plant was founded in 1965. Nitrogen fertilizers are the main 'Achema' production. The total emissions of 'Achema' in the 1980s comprised 35-40 thousand tons annually, which was reduced almost eight times by the 2000s. The composition of aerial emissions in the 1980s included carbon monoxide 26.5%, sulphur dioxide 12.4%, nitrogen oxides 10.3%, ammonia 10.1%, and mineral dust 37.3% [15].

The first signs of forest damage at the local level were observed in 1972. Forest damage gradually increased until it became severe in 1979, when the highest pollution rates coincided with extreme climatic conditions. Coniferous forests have completely disappeared at a distance of 3 kms from 'Achema'. Despite a fundamental reduction of pollutants at the beginning of the 1980s due to pollution mitigation measures, the area of damaged pine stands continued to increase for several years. According to the investigations, the recovery of the severely damaged pine stands located within a 5 km distance from the plant began in the transition from the 1980s to the 1990s when emissions were dramatically reduced [15].

Scots pine stands in the areas surrounding the plant were selected for the study. For the purposes of the study, three experimental plots (202 semi-mature trees, the average age of trees – 97.6±1.3 years) located 3.34-3.78 km northeast of the plant were selected. The terrain is 90-100 m above Baltic Sea level.

Samples from 202 pines of dominant, codominant, and emergent crown classes were taken by inserting an increment borer at chest height. The morphological bark form and crown class of pines were examined visually compared to the "standard tree" described in the dendrological references [22]. Crown class is the category of tree based on its crown position relative to adjacent trees [21]. The crown of dominant trees is well developed; it extends above the general canopy layer of the stand and intercepts direct sunlight.

Fig. 1. Location of experimental plots (black square) of Scots pine in Lithuania.

The codominant crowns form the main crown canopy for the stand. The crown is of medium size, well developed and intercepts direct sunlight across the top. The intermediate crown extends into the lower part of the main canopy and intercepts direct sunlight only at a limited area on the top.

Nine forms of pines classified according to morphological bark type and stem surface have been documented in Lithuania. Three bark forms predominate in Lithuanian forests: *P. s.* f. *kienitzii* Seitz. (80%), *P. s.* f. *bonapartei* Seitz. (19%), and *P. s.* f. *seitzii* Schwerin (2-3%). The other six forms are rarely found or only a few trees of them have ever been reported [22].

Tree-ring widths were measured to within 0.001 mm accuracy using a LINTAB tree ring measuring table and a WinTSAP 0.30 (F. Rinn Engineering Office and Distribution, Heidelberg). The measured series were cross-dated by visual comparison [23] of ring-width graphs and checked statistically using the Cofecha 3.00P computer program (R. L. Holmes, Tucson) [24]. We investigated the occurrence of missing rings in the radial growth series of pines during the strongest pollution period. This was done in order to improve our understanding of how the number of missing rings serves as an indicator of tree sensitivity to pollution. A missing ring is a tree ring that is absent in a sample (increment core or stem disc) due to a failure in cambial activity [25].

The period of the strongest depression in the radial growth of pines was assessed by comparing the radial growth patterns to pine stands located 20-50 km distant from 'Achema'. The methodology is discussed in detail by R. Erlickytė and R. Juknys [13-15]. As a result, two periods were selected for further investigation:

(i) a 24-year period before the growth depression (1952-75), and
(ii) a 9-year period of the strongest depression (1979-87).

The decrease percentage (D_n) of the radial growth for an individual tree was calculated according to formula 1:

$$D_n = \frac{\overline{X}_2 - \overline{X}_1}{\overline{X}_2} \cdot 100 \quad (1)$$

...where:
$\overline{X}_2$ – the average radial growth of a tree in 1952-75,
$\overline{X}_1$ – the average radial growth of the same tree in 1979-87.

Trees were judged to be sensitive (*Ts*) if the decrease in radial growth was bigger than the average for all of the trees, plus the standard deviation. Similarly, trees were judged as resistant (*Tr*) if the decrease was smaller than the average for all of the trees minus the standard deviation (formula 2 and 3).

$$Ts \geq \overline{Xn} + S \quad (2)$$

$$Tr \leq \overline{Xn} - S \quad (3)$$

...where: $\overline{Xn}$ – average decrease in the radial growth for all investigated trees, S – standard deviation of the decrease.

The growth rate of sensitive and resistant pines to pollution in the period before the pollution occurred (1921-75) was compared. This period covers all trees growing in three experimental plots. The significance of the differences was evaluated using a t-test. Analysis was performed using Statistica 6.0 (Statsoft Inc., Tulsa).

Results

The constructed tree-ring width chronology is presented in Fig. 2. Two periods were distinguished: 'A' – a period before the heaviest pollution (1952-75), and 'B' – the strongest depression period (1979-87), which was followed by a recovery phase. The average tree-ring widths in 1979-80 were reduced to less than 0.50 mm per annum (Fig. 2).

The total number of detected sensitive and resistant trees is 31 and 29, respectively. The radial growth dynamic of both pine groups before pollution was highly synchronous (r=0.90, p=0.00). In comparison to 24 years before, the average decrease in the radial growth of sensitive trees during the 1979-87 period was 1.6 mm, while the growth of resistant trees decreased by only 0.2 mm. The average tree-ring widths for both sensitive and resistant pines in the period before pollution occurred (1921-75) are shown in Fig. 3. It is evident that the growth rate of the trees is clearly different. The trees judged to be sensitive to pollution grew much faster in the period before pollution in comparison to resistant trees: 2.48±0.08 mm and 1.56±0.08 mm, respectively (Fig. 3). A t-test confirms that these differences are highly significant (p=0.00).

We investigated the relationships between the sensitivity of trees to pollution and the morphological features of trees: crown class and morphological bark type. About half of the trees (52%) in all the experimental plots belong to the codominant crown class. The number of dominant and emergent trees comprises approximately 28% and 19% of the pines, respectively (two trees were not investigated because they were cut during the study time). Fig. 4 shows that dominant and codominant crown classes are more common among sensitive pines in comparison to resistant trees. On the other hand, trees with emergent crowns are twice as common among the resistant trees. However, the differences are not statistically significant (p=0.74, 0.44, and 0.19, respectively).

Two morphological bark forms of pines were found: *P. s.* f. *kienitzii* Seitz. – 154 trees (76.2%) and *P. s.* f. *bonapartei* Seitz. – 46 trees (22.8%). Two trees from 202 were cut during the investigation time; consequently this information on bark form is missing. The distribution of the morphological bark form of pines in relation to the sensitivity of pines to pollution is presented in Fig. 5. The figure shows that there is no obvious difference between these two groups of pines in respect to their sensitivity to pollution. A t-test confirms that the differences are insignificant (p=0.86 and 0.84, respectively).

Missing rings were detected in the period 1979-1985 for sensitive trees and in the period 1979-1980 for resistant pines (Fig. 6). The frequency of missing rings is much higher for sensitive trees (p=0.00). The difference in missing rings between sensitive and resistant trees is significant for 1979, 1981, 1982, and 1983 (p=0.04, 0.02, 0.03, and 0.03, respectively). The maximum number of missing rings per tree is six in the nine-year period (1979-87).

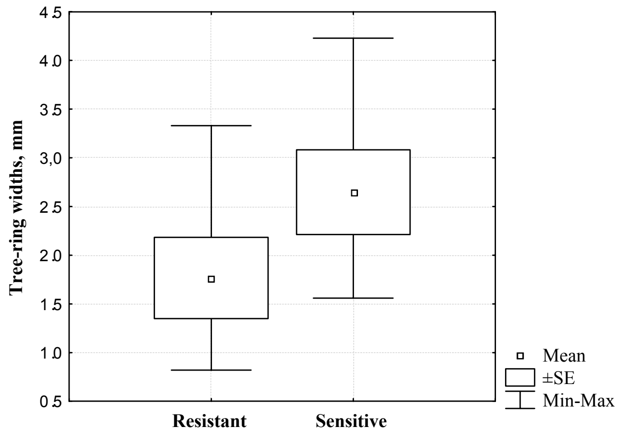

Fig. 3. The Box-Whiskey-plots of the average tree-ring widths for pines sensitive and resistant to pollution during the period 1921-75.

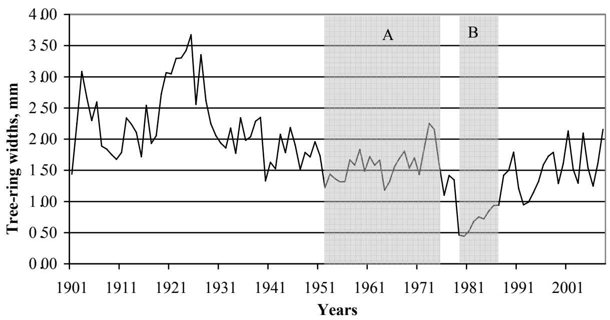

Fig. 2. The average chronology of pine radial growth. A – the period (1952-75) before the growth depression occurred, B – the period (1979-87) of the strongest depression of radial growth.

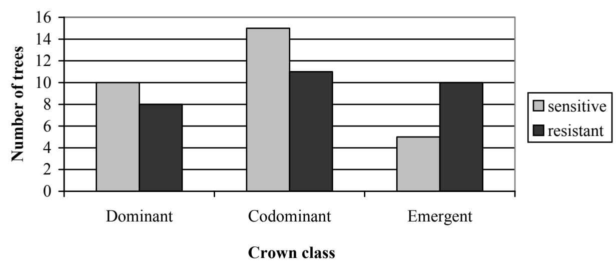

Fig. 4. The distribution of pines among the crown classes in relation to their sensitivity to pollution.

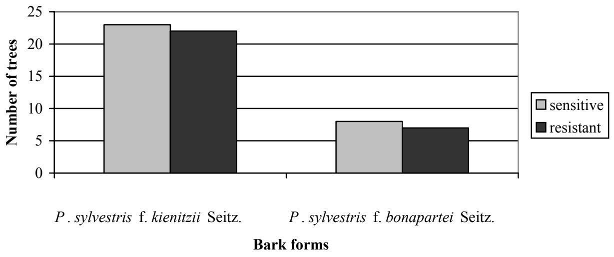

Fig. 5. Distributions of pine trees among morphological bark types in respect to their sensitivity to pollution.

Discussion of Results

Many studies have been carried out in which the radial growth of trees is applied to the assessment of environmental pollution [9, 15, 26, 27]. This is because the main advantage of dendrochronological techniques is in documenting the growth response of individual trees over their lifetime [28, 26]. It has been documented in certain studies that the sensitivity of trees in a particular stand is different [16, 20, 29, 30], although the number of these studies is limited. It is supposed that the sensitivity of a tree to environmental stressors (cold, drought, pollution, etc.) is determined by internal limiting factors (e.g. enzymes and growth regulators) that are genetically controlled by the tree [17-19, 31-34].

Trees that are judged to be sensitive and resistant to pollution show a similar growth pattern before the pollution occurred (1921-75), although the growth rate of the trees was fundamentally different. Trees sensitive to pollution grew much faster ($p=0.00$) during the period 1921-75 in comparison to resistant trees (Fig. 3). We found that dominant and codominant crown classes are common for sensitive pines (Fig. 4). This is in accordance with the well-known fact that dominant and codominant trees have faster growth rates in comparison to trees with emergent crowns [35]. Almost 30 years have passed since the highest pollution period, which was marked by a sharp decrease in the radial growth of pines. It is known that some trees from a particular stand may transform from one crown class to another during their lifetime due to ecological succession [1, 29]. However, this hypothesis has no foundation because trees that grew faster in the period before the pollution and are currently the dominant.

Numerous investigations have affirmed that the crown shape, branch shape, and morphological bark type are interconnected in relation to the sensitivity of trees [17] and that they are genetically controlled [33, 34]. We found two pine forms among the investigated trees: *P. s.* f. *kienitzii* (76%) and *P. s.* f. *bonapartei* (23%). However, the relationship between the sensitivity of pines and their morphological bark type is absent (Fig. 5). These studies are complicated because certain bark forms are common to a specific tree population [20] as they are determined genetically. For example, we did not discover a *P. s.* f. *seitzii* during this investigation, although this form was found to be common in eastern Lithuania [20].

The decline of trees, followed by a sharp decrease in radial growth during the period 1979-87, is closely related to the development of missing rings (rings which in a sample are absent due to a failure in cambial activity). The highest probability of missing rings among the investigated trees was observed in 1979, where one in every three pines that was sensitive to pollution developed a missing ring. This tendency gradually decreases to less than 10 trees in the period 1984-85. The frequency of missing rings among resistant trees is much lower in comparison to sensitive trees (Fig. 6). The difference in the frequency of missing rings among sensitive and resistant trees is statistically significant for four years (1979, 1981, 1982, and 1983). This difference points to the distinctive response of the cambial activity to pollution for both groups of pines. Therefore, the extensive development and frequency of missing rings is a reliable indicator of tree sensitivity to pollution. This is in accordance with Schmid-Haas' [36] observations that point to the high probability of missing rings among the declined trees due to environmental pollution.

Further investigations are needed in the future in order to more precisely define the relationships between the morphological characteristics of pines in respect to their sensitivity to pollution. Due to the limited extent of this study (202 trees), the following questions cannot be answered:

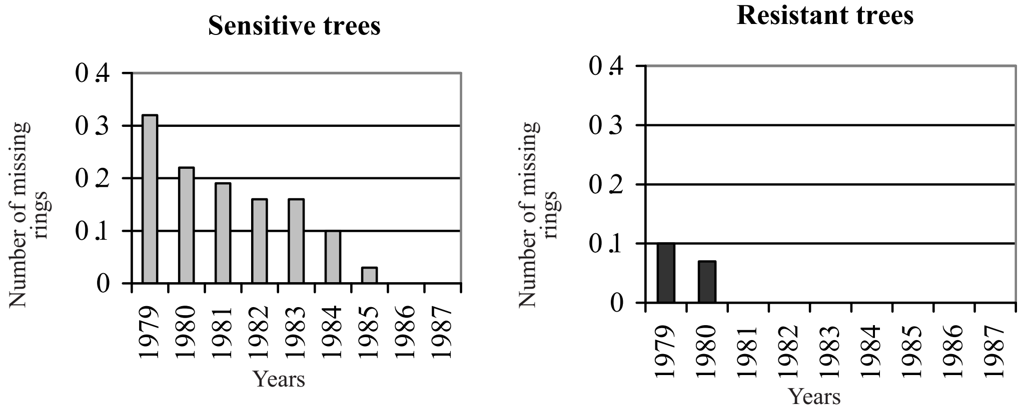

Fig. 6. The average number of missing rings in the period 1979-87 per tree among sensitive and resistant pines.

(i) Are other morphological bark forms related to the sensitivity of trees to pollution and, if so, how?
(ii) Why are trees with higher growth rates more sensitive to pollution than slower-growing trees?

In spite of these limitations, our investigation extends the current knowledge by pointing out that the population includes trees sensitive and resistant to the same pollution emissions. This study has also highlighted the fact that radial growth is a reliable indicator assessing the interpopulation variation of pines to environmental pollution.

Conclusions

1. This investigation has revealed that the population includes pines sensitive and resistant to pollution emissions and that radial growth is a reliable indicator of this response.
2. Pines sensitive to pollution grew much faster (p=0.00) during the period before pollution (1921-75) in comparison to resistant trees.
3. We did not observe a relationship between morphological bark form and the sensitivity of pines to pollution. The dominant and codominant crown classes are more common for sensitive pines and emergent crowns are twice as common among the resistant trees. However, the differences are insignificant.
4. The frequency of missing rings among sensitive trees is much higher in comparison to resistant trees. Therefore, the frequency of missing rings is a reliable indicator of tree sensitivity to pollution.

References

1. SCHWEINGRUBER F. H. Tree rings: basics and applications of dendrochronology. Kluwer Academic Publishers: Dordrecht, pp. 276, **1988**.
2. HELAMA S., LINDHOLM M., TIMONEN M., MERILÄINEN J., ERRONEN M. The supra-long Scots pine tree-ring record for Finnish Lapland: Part 2, Interannual to centennial variability in summer temperatures for 7500 years. The Holocene, **12**, (6), 681, **2002**.
3. SCHWEINGRUBER F. H., ECKSTEIN D., SERRE-BACHET F., BRÄKER O. U. Identification, presentation of event years and pointer years in Dendrochronology. Dendrochronologia **8**, 9, **1990**.
4. CHERUBINI P. Tree-Ring research beyond the climate change: “Quo vadis?” Dendrochronologia **18**, 91, **2000**.
5. CHIESI M. MASELLI F., BINDI M., FIBBI L., CHERUBINI P., ARLOTTA E. TIRONE G., MATTEUCCI G., SEUFERT G. Modelling carbon budget of Mediterranean forests using ground and remote sensing measurements. Agricultural and Forest Meteorology **135**, 22, **2005**.
6. D’ARRIGO R. D., KAUFMANN R. K., DAVI N., JACOBY G. C., LASKOWSKI C., MYNENI R. B., CHERUBINI P. Thresholds for warming-induced growth decline at elevational tree line in the Yukon territory, Canada. Global Biogeochemical Cycles 18, GB3021, doi:10.1029/2004 GB002249, **2004**.
7. ROIG F. A., LE-QUESNE C., BONINSEGNA J. A., BRIFFA K. R., LARA A., GRUDD H., JONES P. D., VILLAGRAN C. Climate variability 50.000 years ago in mid-latitude Chile as reconstructed from tree rings. Nature **410**, 567, **2001**.
8. SCHULZE E. D. Air pollution and forest decline in a spruce (*Picea abies*) forest. Science **244**, 776, **1989**.
9. ARMOLAITIS K., BARTKEVIČIUS E., JUKNYS R., RAGUOTIS A., ŠEPETIENĖ J. The influence of JSC “Achema” pollution to forest ecosystems. In: The state of Lithuanian forests and its determining factors (Ed. R. Ozolinčius). Lututė: Kaunas, pp. 44-65, **1999** [In Lithuanian].
10. ARMOLAITIS K. The monitoring of forest ecosystems: the influence of JSC “Achema” pollution; the work ordered by municipality of Jonava district in 2002 No. 02/03-35. Girionys, pp. 76, **2002** [In Lithuanian].
11. AUGUSTAITIS A. A., MASTAUSKIS M. M., SIDARAVIČIUS J. M. Influence of atmospheric pollution to the productivity and vitality of pine stands in the zone of impact of nitrogen fertilizer plant. In: Bio-monitoring of Forest Ecosystems. Kaunas, pp. 228-234, **1987**.
12. STRAVINSKIENĖ V. Scots pine (*Pinus sylvestris* L.) radial growth in the vicinity of nitrogen fertilizers plant “Achema” in Lithuania. Ekologia (Bratislava) **23**, (4), 438, **2004**.
13. ERLICKYTĖ R. Regularities of Scots pine (*Pinus sylvestris* L.) radial increment formation due to variation of emissions of "Akmenės cementas" and "Achema" plants. Doctoral dissertation; VDU: Kaunas, pp. 107, **2007** [In Lithuanian].
14. JUKNYS R., STRAVINSKIENĖ V., VENCLOVIENĖ J. Tree-ring analysis for the assessment of anthropogenic changes and trends. Environmental Monitoring and Assessment **77**, 81, **2002**.
15. JUKNYS R., VENCLOVIENĖ J., STRAVINSKIENĖ V., AUGUSTAITIS A., BARTKEVIČIUS E. Scots pine (*Pinus sylvestris* L.) growth and condition in a polluted environment: from decline to recovery, Environmental Pollution **125**, 205, **2003**.
16. KLEIN B. The connections between emissions and drought-resistance of spruce, *Picea abies* (L.) Karst. European Journal of Forest Pathology **10**, 186, **1980** [In German].
17. KARPAVIČIUS J. Individual and group fluctuation of the radial growth of Scots pine in zone of mixed forests. Summary of dissertation. Minsk, pp. 19, **1984** [In Russian].
18. KRAL F., MAYER H. The results of comparative resistance investigations in fir origins. Schweizarische Zeitshrift für Forstwesen **136**, 41, **1985** [In German].
19. LINGG W. The dendroecologocal study on coniferous trees in the Alps of Trockental Wallis (Switzerland). Eidgenössische Anstalt für das forstliche Versuchswesen (Birmensdorf), Berichte **287**, 81, **1986** [In German].
20. VITAS A. Sensitivity of Scots pine trees to winter colds and summer droughts: dendroclimatological investigation. Baltic Forestry **12**, (2), 220, **2006**.
21. HELMS. J. A. The dictionary of forestry. Cabi Publishing: Wallingford, pp. 210, **1998**.
22. NAVASAITIS M., OZOLINČIUS R., SMALIUKAS D., BALEVIČIENĖ J. Dendroflora of Lithuania. Lututė: Kaunas, pp. 576, **2003** [In Lithuanian].
23. ECKSTEIN D. Measurement and dating procedures in dendrochronology. In: Methods of dendrochronology (Eds. L. Kairiukštis, Z. Bednarz, E. Feliksik); IIASA: Warsaw, **3**, 35, **1987**.
24. HOLMES R. L. Dendrochronology program library. Laboratory of Tree-ring Research, University of Arizona: Tucson, **1994**.

25. KAENNEL M., SCHWEINGRUBER F. H. Multilingual glossary of dendrochronology. Paul Haupt: Berne, Stuttgart, Vienna, pp. 467, **1995**.
26. MCLAUGHLIN S., BRÄKER O. U. Methods for evaluating and predicting forest growth responses to air pollution. Experientia **41**, 310, **1985**.
27. VINŠ B. Dendroclimatologic evidence of the smoke damage. Proceedings of the III Bioklim. Conf. Prague, pp. 337-352, **1963**.
28. BITVINSKAS T. Dendroclimatologic investigations. Gidrometeoizdat: Leningrad, pp. 172, **1974** [In Russian].
29. SCHWEINGRUBER F. H. Tree rings and the world of dendroecology. Lis: Vologda, pp. 474, **1993** [In German].
30. VITAS A. Influence of local pollution to the radial growth of Scots pine (*Pinus sylvestris* L.): dendrochronological analysis. Proc. of the Int. Conf. Human and Nature Safety 2007. Akademija: LŽŪU, pp. 209-211, **2007** [In Lithuanian].
31. HURME P. Genetic basis of adaptation: bud set date and frost hardiness variation in Scots pine. Dissertation. Oulu University: Oulu, pp. 33, **2000**.
32. KUPČINSKIENĖ E. Latent injuries of Scots pine under influence of local pollution. Lututė: Kaunas pp. 256, **2006** [In Lithuanian].
33. RUBY J. L. The correspondence between genetic, morphological and climatic variation patterns in Scots pine. Ph.D. Thesis. Michigan State University: East Lansing, **1964**.
34. WRIGHT J. W. Introduction to forest genetics. Academic Press: New York, San Francisco, London, pp. 463, **1976**.
35. FRITTS H. Tree Rings and Climate. IIASA, Polish Academy of Sciences, Systems Research Institute: Warsaw, **1-2**, 567, **1987**.
36. SCHMID-HAAS P., MASUMY S. A., NIEDERER M., SCHWEINGRUBER F. H. The growth and crown analysis of declined firs. Schweiz. Z. Forstwes. **137**, 811, **1986**. [In German].