JOURNAL OF ENVIRONMENTAL ENGINEERING
AND LANDSCAPE MANAGEMENT
2009
17(3): 140–147

SCOTS PINE (*Pinus sylvestris* L.) RADIAL GROWTH DYNAMICS IN FOREST STANDS IN THE VICINITY OF "AKMENĖS CEMENTAS" PLANT

Vida Stravinskienė[1*], Regina Erlickytė-Marčiukaitienė[2]
[1*]*Dept of Environmental Sciences, Vytautas Magnus University, Vileikos g. 8, LT-44404 Kaunas, Lithuania*
[2]*Lithuaniam Energy Institute, Laboratory of Renewable Energy, Breslaujos g. 3, LT-44403 Kaunas, Lithuania*
E-mail: [1]*v.stravinskiene@gmf.vdu.lt;* [2]*regerl@mail.lei.lt*

Submitted 11 Dec. 2008; accepted 24 Apr. 2009

Abstract. Investigation of Scots pine annual radial increment was carried out in the surroundings of one of the largest pollution sources in Lithuania – the cement plant "Akmenės cementas". The main objective of the investigation was to analyse possible impact of climatic and anthropogenic factors on the radial growth of Scots pine (*Pinus sylvestris* L.) stands growing in the local impact zone of the plant. Investigation has shown that in peat-bog sites active vegetation period temperature higher than the long-term average influences the formation of radial increment positively (r = 0.22–0.34; $p < 0.05$), and July precipitation higher than the long-term average causes the reduction of radial increment ($r = -0.25$; $p < 0.05$) of the investigated pines. Analysis of the relation between pine radial increment and plant emissions has shown that the strongest correlations are in the closest vicinity of the plant ($r = -0.63$; $p < 0.05$). Weaker, but statistically significant relations were found between radial increment of pines growing at a distance of 5–10 km from the plant and plant emissions ($r = -0.49$; $p < 0.05$), and for the most distant pine correlations became insignificant ($p > 0.05$). Linear regression results have shown that changes of the radial increment of pine stands closest to the plant are the biggest and they decrease with distance from the plant.

Keywords: Scots pine, radial increment, air temperature, precipitation quantity, environmental pollution.

1. Introduction

Trees are considered one of the most sensitive indicators of the environmental condition from all life forms. They are most suitable for the evaluation of environmental changes. Due to the structure of the crown trees have better contact with the atmosphere, so they filter the flowing air mass better than other vegetation forms and consequently indicate the condition of the forest ecosystems by anatomical and morphological symptoms. Trees determine the processes in the ecosphere and react sensitively to the anthropogenic factors. Therefore, they reflect the impact of climate and pollution integrally. The growth and productivity of trees as the main components of the forest ecosystems are among the best indicators, reflecting general forest condition and ecological balance. Objective evaluation of condition of trees allows us to judge about the environmental condition and its suitability for prosperity of other life forms.

Forest ecosystems growing near pollution sources suffer the greatest impact because the concentration of harmful materials in the local pollution zone often exceeds permissible amounts. The extent of damage to trees is determined by the concentration of pollutants as well as the duration of their impact and their amount in trees.

Significant damages of tree stands have been determined in different regions of north-western Europe. Most scientists state that decline of forest condition is caused by a complex of various factors, but the main factor causing large-scale forest damage is environmental pollution, and other negative factors just strengthen the impact of pollutants (Innes 1998; Nihlgard 1997). Unfavourable climate conditions, invasions of forest pests, various diseases and forestry mistakes (Auclair *et al*. 1992; Houston 1992) are often mentioned together with different pollutants.

Trees are also considered to be sensitive indicators of anthropogenic activity, resembling environmental variations in their growth and condition. Conifers play the most important role. Most studies of researches in our country and abroad have proved that conifers are much more sensitive to environmental pollution than broadleaves, thus they are better indicators (Dagys 1980; Sporek 1981; Stravinskienė 2002). During tree growth annual tree rings accumulate information about environmental phenomena and can serve as natural monitors (Eckstein 1989; Schweingruber 1996; Stravinskienė 1997, 2002; Stravinskienė and Šimatonytė 2008).

The variations of annual radial increment of conifers provide unique and important information on ecological, climatic habitat peculiarities, which are indicated by early and late wood width and density variations (Lovelius 1997). Dendrochronological indication enables not only to assess tree stand condition during monitoring but also to restore retrospectively quantitative and qualitative

ISSN 1648–6897 print / ISSN 1822-4199 online
DOI: 10.3846/1648-6897.2009.17.140-147

indices of annual radial increment since tree's first year of growth (Stravinskienė 2002). Thus indicatory characteristics of annual tree rings are very important in the assessment of environmental condition and its changes.

The main objective of this work was to analyse possible impact of climatic and anthropogenic factors on the radial growth of Scots pine (*Pinus sylvestris* L.) stands growing in the local impact zone of "Akmenės cementas" plant.

2. Methodology

The study area is situated near the cement plant "Akmenės cementas" in Naujoji Akmenė (56°40' N, 22°87' E), in the north west of Lithuania. JSC "Akmenės cementas" is the largest company in the Baltics and the only one in Lithuania, producing cement and one of the largest cement and slate plants in Europe. It began operating in 1952. In the times of prosperity (the beginning of the seventies of the 20th century) the amount of pollutants discharged into the atmosphere consisted of 27 thou. tons of SO_2, 9–10 thou. tons of cement dust, 8.5 thou. tons of NO_x, 1 thou. tons of ash and other solid particles annually (Armolaitis *et al.* 1996, 1999). In the beginning of the 1990s due to the industrial decline and modernization of technologies emissions decreased gradually. In 1989–1991 the emissions amounted to 60–70 thou. tons. During transition period annual emissions decreased significantly due to decrease of plant production and improvement of production technology. In 2006 general emissions into the atmosphere were about 6.3 thou. tons, in 2007 – about 4.4 thou. tons (Fig. 1).

"Akmenės cementas" plant is surrounded by the forests of Naujosios Akmenės forestry of Mažeikiai forest enterprise. Investigation of peat-bog soils at different distances from the plant has revealed the increased amounts of Ca^{2+} (0.5–23.8 cmol/kg) and Mg^{2+} (0.5–2.5 cmol/kg) in the forest floor and the topsoil at distances up to 7–8 km from the plant. That causes alkalization of the topsoil and forest floor (Armolaitis *et al.* 1999).

Investigation has been performed in 65–80-year-old Scots pine (*Pinus sylvestris* L.) stands (I and II class according to Kraft's classification; stocking level 0.7–0.8) in *Carico–sphagno–Pinetum* forest type at different distances from the plant (up to 5 km, 5–10 km and further than 10 km). Control stand with analogical biometric indices was chosen in the site without local pollution in the direction of non-prevailing winds.

Annual radial increment was chosen as the main indicator of tree condition and its changes. Wood samples from selected pines were taken by the Pressler's borer at 1.3 m height from root collar, when the late wood of tree rings was fully formed.

For annual radial increment measurement and tree-ring structure assessment, LINTAB tree-ring measuring table and WinTSAP 0.30 computer program (F. Rinn Engineering Office and Distribution, Heidelberg, Germany) were used. Tree-ring widths were measured with an accuracy of ±0.001 mm. Primary tree-ring data were processed by mathematical statistics and dendrochronological analysis methods according to special TSAP programs: dating, synchronization, tree-ring averaging, calculating of indices, compiling of chronologies, etc.

Tree age also influences the width of tree rings: rings of a young tree are relatively wide, and rings of an older tree are narrower (Cook *et al.* 1990; Stravinskienė 1994, 2002). Radial increment data standardisation was carried out in order to eliminate the tree age influence on radial increment and to reveal the increment dynamics depending on climate variation.

Indices were calculated showing the relation between radial increment of a certain year and the norm of that year's increment. Indexing was carried out in two stages (Holmes 1994). The age curve was removed by using a negative exponential curve and linear regression and after applying the spline function. The program CHRONOL from the ITRDB Program Library compiled in the University of Arizona by R. L. Holmes was used.

"Statistica" and "Microsoft Excel" software were used for data analysis. The chronologies of radial increment from the stands at different distances from the plant were statistically compared by ANOVA (Fisher criterion *F*). Differences were considered statistically significant if $p < 0.05$ and $F > F_{cr}$.

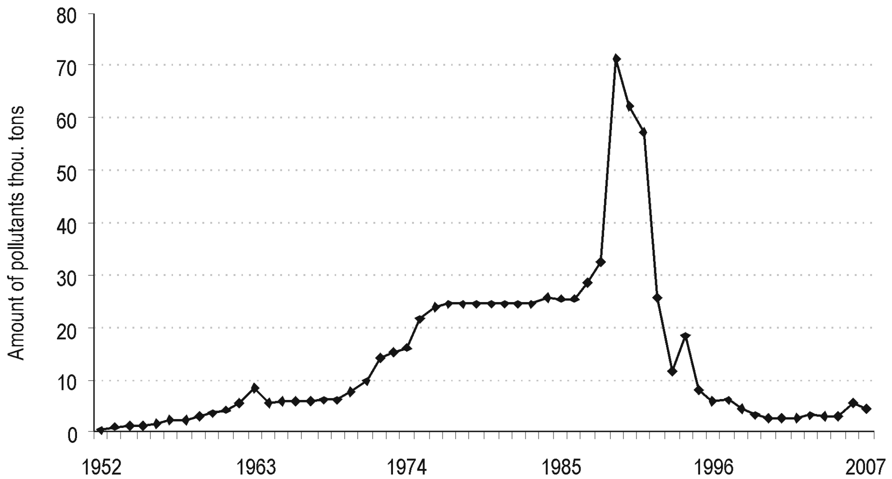

Fig. 1. Total annual emissions (thou. tons) of "Akmenės cementas" in 1952–2007

In the cases of significant effects the differences between each pair of chronologies were investigated by pairwise *t*-test for independent samples. *x* was considered statistically significantly less than *y* at $p < 0.05$ and $t < -t_{cr}$ (Student's criterion).

Pearson correlation analysis was applied for the determination of relations between radial increment and climatic as well as anthropogenic factors. Linear regression analysis was used to determine the factors causing the changes of radial increment and to evaluate the extent of these changes.

3. Results and discussion

According to heat and water balance the Lithuanian climate is ascribed to middle-latitude mixed-forest zone (Bukantis *et al*. 1998; Stravinskienė 2002). Long-term variations of climatic factors cause the peculiarities of annual tree radial increment dynamics (Bitvinskas 1997).

Analysis of the main climatic factors (air temperature and amount of precipitation) of different periods of the year was carried out in Naujoji Akmenė region in order to determine the impact of climatic factors on the radial increment of Scots pine. Šiauliai meteorological station data were used for the analysis of the dynamics of mean air temperature and amount of precipitation in winter months (December–February), the beginning of vegetation (April–May), active vegetation period (May–August) and summer (June–August) months.

3.1. Analysis of air temperature and precipitation impact on the formation of annual radial increment

Control stand with analogical biometric indices growing in relatively unpolluted environment 12 km south-west from the plant was chosen for the determination of relations between radial increment and climatic factors. According to literature (Armolaitis *et al*. 1999; Linderholm 2001; Juknys *et al*. 2002; Stravinskienė 2002; Pederson *et al*. 2004; Augustaitis 2005), last year's climatic conditions also have influence on tree growth and formation of radial increment. Therefore, long-term temperature and precipitation data of last year's January–December and current year's January–September were used in the analysis. Radial increment indices were calculated for the elimination of age influence on tree rings and in order to reveal increment dynamics due to variation of climatic conditions.

Although the relations between tree-rings and different climatic factors are rather weak and the correlation coefficient does not usually exceed 0.3–0.4 (Bitvinskas 1997; Juknys and Venclovienė 1998; Juknys *et al*. 2002), analysis indicates positive correlation between radial increment and precipitation of current year's January ($r = 0.37$; $p < 0.05$), and negative correlation with July's precipitation ($r = –0.25$; $p < 0.05$) (Table 1).

Positive correlation was found between radial increment and mean temperatures of current year's spring (April–May) and June ($r = 0.22–0.34$; $p < 0.05$). This shows that temperature of these months which is higher than the long-term average causes the increase of pine radial increment.

Analysis has revealed significant influence of last year's climatic conditions on the formation of radial increment. Statistically significant relations were found between radial increment and temperature as well as precipitation of last January ($r = 0.26$ and $r = 0.21$ respectively; $p < 0.05$). Radial increment correlated negatively with precipitation of last October and November (*r* equals to –0.25 and –0.31, respectively; $p < 0.05$) and positively with temperatures of last October and December ($r = 0.23$; $p < 0.05$). This corresponds with the results obtained by other authors (Juknys and Venclovienė 1998; Stravinskienė 2002) showing strong influence of last autumn's climatic conditions.

Results suggest that air temperature and precipitation of the period of active vegetation are important for the radial increment formation in boggy soils. Higher temperature of active vegetation period (April–August) and

Table 1. Pearson correlation coefficients *r* between annual radial increment of control pine stands and climatic parameters (air temperature and amount of precipitation)

Last year's months	Correlation coefficient		Current year's months	Correlation coefficient	
	Air temperature	Amount of precipitation		Air temperature	Amount of precipitation
January	**0.26** ($p = 0.003$)	**0.21** ($p = 0.000$)	January	**0.27** ($p = 0.000$)	**0.37** ($p = 0.000$)
February	0.11	0.10	February	0.05	0.10
March	0.13	0.07	March	0.13	–0.07
April	–0.10	–0.13	April	**0.30** ($p = 0.01$)	–0.04
May	0.15	–0.03	May	**0.22** ($p = 0.02$)	–0.12
June	0.14	**–0.19** ($p = 0.04$)	June	**0.34** ($p = 0.007$)	–0.03
July	–0.12	0.13	July	0.13	**–0.25** ($p = 0.04$)
August	0.07	–0.07	August	0.14	–0.08
September	–0.14	–0.01	September	0.11	–0.10
October	**0.23** ($p = 0.04$)	**–0.25** ($p = 0.04$)			
November	–0.11	**–0.30** ($p = 0.01$)			
December	**0.23** ($p = 0.017$)	0.11			

Note. Statistically significant *r* values ($p < 0.05$) are shown in bold characters.

precipitation lower than the long-term average cause drying processes in the habitat and stimulate the formation of radial increment. Summer precipitation higher than the long-term average and the shortage of warmth in the beginning of vegetation period induce habitat's microbogging processes, which cause significant decrease of radial increment.

3.2. Scots pine (*Pinus sylvestris* L.) annual radial increment changes due to local pollution of "Akmenės cementas" plant

Anatomical structure of trees allows to evaluate the tree growth rate retrospectively from the width of tree rings. Therefore, tree-ring analysis is one of the most promising and informative methods of estimating anthropogenic loads and environmental pollution impact on forest ecosystems (Schweingruber 1996; Armolaitis *et al.* 1999; Juknys *et al.* 2002).

There are relatively few investigations carried out on the impact of alkalizing pollutants on ecosystems. Conifer ecosystems with dominating acid mineral soils are considered to be among the most sensitive to the impact of alkaline pollutants (Kaasik *et al.* 2003). The main purpose of the investigation carried out in the impact zone of "Akmenės cementas" plant is to analyse the changes of radial increment in relatively differently damaged stands, determine the main factors causing radial increment changes and estimate the recovery possibilities of damaged pine stands of *Vaccinio-myrtillo-Pinetum* forest type after the reduction of emissions of alkaline pollutants.

Dynamics of annual radial increment of the investigated stands

Radial increment dynamics shows that before the beginning of pollution radial increment variations were similar in all the investigated stands (Fig. 2). 1952 is considered the start of pollution, although plant emissions were not high during the following two decades (Fig. 1). Due to increasing plant emissions decline of radial increment dependent on the distance from the pollution source is observed from 1970. Negative pollution impact was strengthened by an exclusively cold winter in 1987–1988.

The most significant changes of radial increment were determined in the closest zone (up to 5 km), where pollution is the most intensive, and the least significant – in the most distant zone (10–20 km). After the reduction of plant emissions increase of radial increment of stands closest to the plant is observed.

Industrial pollution impact on annual radial increment of pines growing at different distances from the plant

In order to estimate possible industrial pollution impact on the radial increment of pines growing near "Akmenės cementas" plant, firstly it was analysed whether differences between increment series are statistically significant or have an accidental nature. Statistical hypothesis H_0 (means of radial increment series from pines at different distances from the pollution source do not differ) with an alternative H_1 (at least two means differ) was formulated for the analysis. The value of Fisher's criterion F indicating statistically significant differences between the means of data groups equals to 41.36 ($p = 0.000$). This value $F = 41.36 > F_{cr}$ ($F_{cr} \approx 3$), where F_{cr} is critical F value at significance $\alpha = 0.05$ (Čekanavičius and Murauskas 2002). According to the rules of ANOVA, this denies hypothesis H_0 and shows that the means of at least two radial increment series differ statistically significantly. This suggests that the cause of these differences is an external factor – environmental pollution.

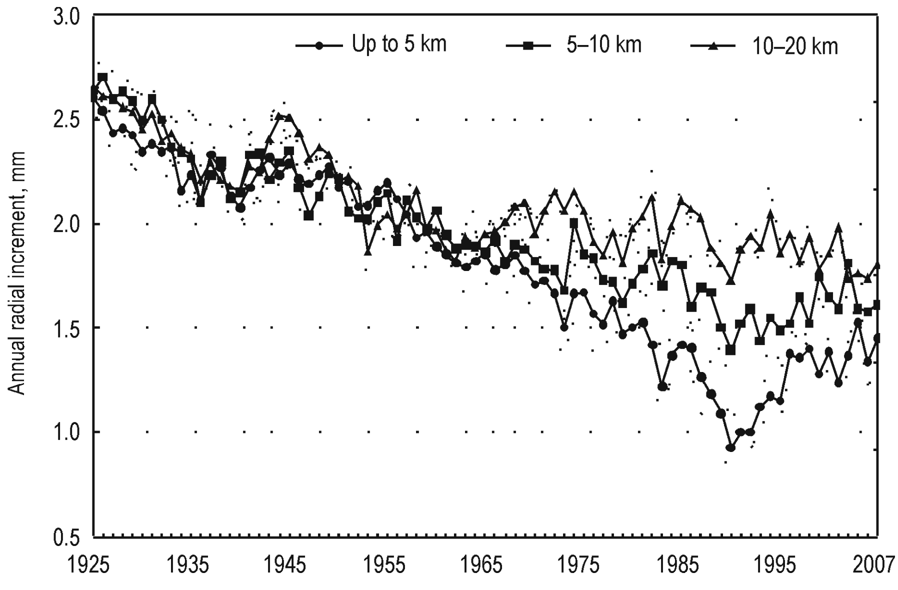

Fig. 2. Dynamics of annual radial increment of Scots pine (*Pinus sylvestris* L.) stands growing at different distances from the pollution source

Pairwise comparison of the series was performed using Fisher's LSD (*Least Significant Difference*) criterion, which corresponds to the *T*-test (Student's criterion *t*). It was determined that series mean from pines closest to the plant is statistically significantly less than that of pines at 5–10 km from the plant ($t = –5.0 < –t_{cr}$, $t_{cr} = 1.66$), and series mean of pines at 5–10 km is statistically significantly less than that of the most distant pines ($t = –4.63 < –t_{cr}$, $t_{cr} = 1.66$). This proves that radial increment increases with distance from the plant.

Dispersion analysis results (Fisher's and Student's criterions) suggest that differences of radial increment of pines growing at different distances from the plant are possibly caused by local pollution. Relationships between radial increment of pines and emissions were analysed in order to clarify possible reasons for radial increment changes. The strongest negative relation was found between radial increment of pines closest to the plant and total amount of pollutants ($r = –0.63$; $p < 0.05$) (Table 2). Correlations are weaker between the total amount of pollutants and radial increment of pines at a distance of 5–10 km from the plant ($r = –0.49$; $p < 0.05$) and become statistically insignificant for the most distant pines ($p > 0.05$).

Among the pollution components emissions of SO_2 and solid particles have the strongest relations with radial increment of pines closest to the plant ($r = –0.66$ and $r = –0.64$ respectively; $p < 0.05$). Slightly weaker correlations were found with emissions of NO_x ($r = –0.56$; $p < 0.05$). At a distance of 5–10 km from the plant correlations between radial increment and pollution components were weaker but significant, and for the most distant pines, correlations became insignificant ($p > 0.05$).

In order to detail possible pollution impact on radial increment, the period of pollution was divided into three stages according to the intensity of plant emissions:

1) the first stage continued from the start of pollution in 1952 till 1974, when annual emissions increased from 5–6 to 16 thou. tons;

2) 1975–1989 – the stage of the largest emissions (24 to 32 thou. tons annually; maximum – 71 thou. tons in 1989);

3) 1990–2007 – the stage of the reduction of emissions, which was caused by general industrial decline, modernization of technologies, later – by the effective use of resources. During this stage annual emissions decreased from 25 to 4 thou. tons.

Results have shown that the strongest and most significant negative correlations exist between radial increment of stands closest to the plant (up to 5 km) and the total emissions in all stages of pollution (*r* varies from –0.66 to –0.89; $p < 0.05$) (Table 2). Weaker but statistically significant relations were found between radial increment of pines at a distance of 5–10 km from the plant and total emissions in all stages of pollution (*r* varies from –0.61 to –0.66; $p < 0.05$).

Correlation analysis has confirmed a hypothesis that possible negative pollution impact is different for stands growing at different distances from the plant, and relationships between pollution and radial increment decrease with distance from the pollution source.

Linear one-variable regression analysis was carried out in order to determine the relative strength of possible pollution impact during different stages of pollution. Results show different strength of pollution impact on radial increment of pines growing in forest stands at different distances from the cement plant "Akmenės cementas" (Fig. 3).

At the beginning of the first stage of pollution radial increment of pines at distances of up to 5 km and 5–10 km was similar. Due to gradually increasing amount of plant emissions quantitative radial increment differences between these distances became significant (Fig. 3, a).

The impact strength and the rate of radial increment changes are determined by the values of linear regression equation's slope parameter *b*: the greater the absolute value of *b*, the stronger the impact and the higher the rate of radial increment change. Positive *b* sign indicates that *y* increases with increasing *x*, and negative sign means that *y* decreases with increasing *x* (Čekanavičius and Murauskas 2002).

Table 2. Pearson correlations between annual radial increment and emissions during the pollution period and in different stages of pollution intensity (*r* – Pearson correlation coefficient, *p* – significance)

	Total emissions	Solid particles	NO_x	SO_2	Total emissions		
		1952–2007			1952–1974	1975–1989	1990–2007
Up to 5 km							
r value	**–0.63**	**-0.64**	**–0.56**	**–0.66**	**–0.89**	**–0.66**	**–0.80**
p value	0.000	0.000	0.000	0.000	0.000	0.007	0.000
5–10 km							
r value	**–0.49**	**-0.49**	**–0.42**	**–0.55**	**–0.65**	**–0.66**	**–0.61**
p value	0.001	0.000	0.002	0.000	0.001	0.008	0.013
10–20 km							
r value	–0.14	–0.09	–0.06	–0.17	–0.31	–0.41	–0.06
p value	0.3	0.5	0.7	0.2	0.16	0.13	0.83

Note. Statistically significant *r* values ($p < 0.05$) are shown in bold characters.

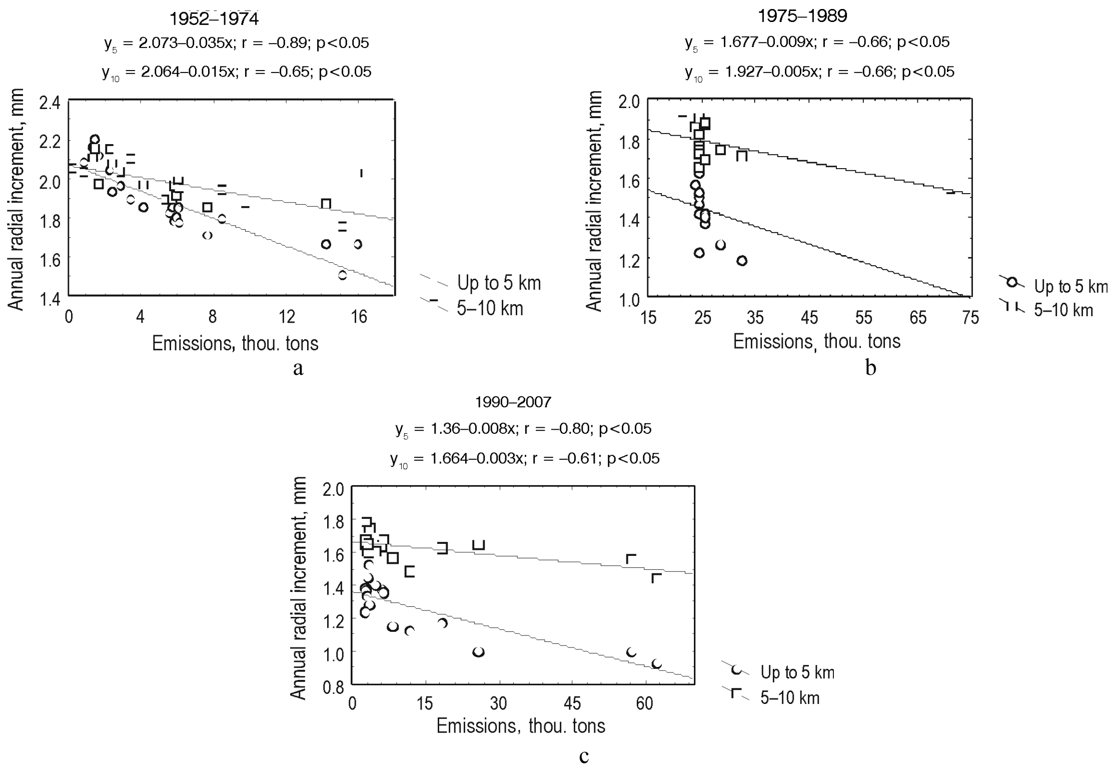

Fig. 3. Relationships between annual radial increment and emissions quantity in different stages of pollution intensity

Having compared the values of *b* for the pine stands growing at distances of up to 5 km and 5–10 km for the first stage 1952–1974 (–0.035 ($y = 2.073 - 0.035x$) and –0.015 ($y = 2.064 - 0.015x$), respectively), it is seen that pine stands closer to the plant are more affected by the pollution than the stands at 5–10 km distance (Fig. 3, a).

Negative sign of *b* means that radial increment decreases with increasing emissions. In 1975–1989 radial increment of pines at distances of up to 5 km and 5–10 km still reacts to the increasing pollution negatively, but the difference between the slopes of functions has reduced: –0.009 ($y = 1.677 - 0.009x$) and –0.005 ($y = 1.927 - 0.005x$), respectively (Fig. 3, b). This suggests that the reaction of pine increment to the amount of pollutants during that stage was similar. Since 1990 plant emissions start reducing (Fig. 1) and *b* values for the stage 1990–2007 are: –0.008 ($y = 1.36 - 0.008x$) and –0.003 ($y = 1.664 - 0.003x$) (Fig. 3, c). Negative sign of *b* shows that the reduction of pollution induces positive changes of radial increment.

Linear regression analysis also confirms a hypothesis that pollution impact is different for stands at different distances from the plant, and the impact decreases with distance. The scatter of data in Fig. 3 suggests that pollution is not the only factor causing the variation of radial increment of the investigated stands.

4. Conclusions

1. Variations of annual radial increment of pines growing in marshy soils in the surroundings of the cement plant "Akmenės cementas" are determined not only by habitat conditions but also by climatic factors – air temperature and the amount of precipitation.

2. Studies have indicated that the growth of annual radial increment is stimulated by temperature higher than the average norm and the amount of precipitation lower than the average norm. A lower temperature and higher precipitation limit the pine growth.

3. Correlation analysis has shown that average temperature of active vegetation period higher than the long-term average influences pine radial growth positively (r = 0.22 – 0.34; $p < 0.05$), and the amount of precipitation in July higher than the long-term average induces the decrease of radial increment (r = –0.25; $p < 0.05$) in peat-bog soils.

4. Linear regression analysis has determined linear relation between radial increment of pines close to the plant and plant emissions: r = –0.63 for pines at a distance of up to 5 km and r = –0.49 for pines at a distance of 5–10 km ($p < 0.05$).

5. No linear relations were determined between plant emissions and radial increment of pine stands, growing at a distance of more than 10 km from the source of pollution ($p > 0.05$).

References

Armolaitis, K.; Vaičys, M.; Kubertavičienė, L.; Raguotis, A. 1996. Influence of cement-mill emissions on physico-chemical properties of forest soils near the mill, *Eurasian Soil Science* 28: 212–220.

Armolaitis, K.; Vaičys, M.; Raguotis, A.; Kubertavičienė, L. 1999. AB „Akmenės cementas" teršalų poveikis miško ekosistemoms [Impact of "Akmenės cementas" plant emissions on forest ecosystems], iš Ozolinčius, R. (sud.). *Lietuvos miškų būklė ir ją sąlygojantys veiksniai* [Condition of Lithuanian forests and defining factors]. Kaunas: Lututė, 65–77.

Auclair, A. N. D.; Worrest, D.; Lachance, D.; Martin, H. C. 1992. Climatic perturbations as a general mechanism of forest dieback, in Manion, P. D.; Lachance, D. (Eds.). *Forest Decline Concepts*. APS Press, St. Paul, MN, 38–58.

Augustaitis, A. 2005. Natūralių ir antropogeninių aplinkos veiksnių kompleksiškos įtakos pušynų vidutinei defoliacijai vertinimas ir prognozė [Assessment and prediction of natural and anthropogenic factors' complex impact on the mean defolation of pine stands], *Miškininkystė* 2 (58): 51–62.

Bitvinskas, T. 1997. Climate of central Lithuania and increments of tree stands, in *Varietal Analysis in the Habitat (I). Zones of Ecological Optimum*. Vilnius, 9–11.

Bukantis, A.; Kazakevičus, S.; Korkutis, P.; Markevičienė, I.; Rimkus, E.; Rimkutė, L.; Stankūnavičius, G.; Valiuškevičienė, L.; Žukauskaitė, L. 1998. *Klimato elementų kintamumas Lietuvos teritorijoje* [Changeability of climatic elements in the territory of Lithuania]. Vilnius: Geografijos institutas. 171 p.

Cook, E. R.; Shiyatov, S. G.; Mazepa, V. 1990. Estimation of the mean chronology, in Cook, E.; Kairiūkštis, L. (Eds.). *Methods of Dendrochronology: applications in the environmental sciences.* Dordrecht: Kluwer Academic Publishers, 123–132.

Čekanavičius, V.; Murauskas, G. 2002. *Statistika ir jos taikymai* [Statistica and its applications]. II dalis. Vilnius: TEV. 272 p.

Dagys, J. 1980. *Augalų ekologija* [Plant ecology]. Vilnius: Mokslas. 239 p.

Eckstein, D. 1989. Qualitative assessment of past environmental changes, in Cook, E. and Kairiūkštis, L. (Eds.). *Methods of dendrochronology: applications in the environmental sciences.* Dordrecht: Kluwer Academic Publishers, 220–223.

Holmes, R. L. 1994. *Dendrochronology program library: User's manual*. Tucson: Laboratory of Tree-ring Research, University of Arizona. 51 p.

Houston, D. R. 1992. A host-stress-saprogen model for forest dieback-decline diseases, in Manion, P. D.; Lachance, D. (Eds.). *Forest Decline Concepts*. APS Press, St. Paul, MN, 3–25.

Innes, J. L. 1998. The impact of climatic extremes on forests: an introduction, in Beniston, M.; Innes, J. L. (Eds.). *The Impacts of Climate Variability on Forests*. Springer-Verlag, Berlin, 1–18. doi:10.1007/BFb0009762

Juknys, R.; Vencloviene, J. 1998. Quantitative analysis of tree rings series, in *Proceedings of International Conference Dendrochronology and Environmental Trends*. Kaunas, 237–249.

Juknys, R.; Stravinskienė, V.; Vencloviene, J. 2002. Tree-ring analysis for the assessment of anthropogenic changes and trends, *Environmental Monitoring and Assessment* 77(1): 81–97. doi:10.1023/A:1015718519559

Kaasik, M.; Ploompuu, T.; Alliksaar, T.; Ivask, J. 2003. Alkalisation and nutrient influx from the ai ras damaging factors for sub-boreal ecosystem, in *Proceedings of the 8th International Conference on Environmental Science and Technology*. Lemnos Island, Greece, 365–372.

Linderholm, H. W. 2001. Climatic influence on Scots pine growth on dry and wet soils in the central Scandinavian mountains, interpreted from tree-ring width, *Silva Fennica* 35 (4): 415–424.

Lovelius, N. V. 1997. *Dendroindication of natural processes and anthropogenic influenses.* St.-Peterburg. 320 p.

Nihlgard, B. 1997. Forest decline and environmental stress, in Brune, D.; Chapman, D. V.; Gwynne, M. D.; Pacyna, J. M. (Eds.). *The Global Environment: Science, Technology and Management*, 422–440.

Pederson, N.; Cook, E. R.; Jacoby, G. C.; Peteet, D. M.; Griffin, K. L. 2004. The influence of winter temperatures on the annual radial growth of six northern range margin tree species, *Dendrochronologia* 22: 7–29. doi:10.1016/j.dendro.2004.09.005

Schmidt, P. A. 1993. Veränderung der Flora und Vegetation von Wäldern unter Immissions Einfluβ, *Forstw. Cbl.* 112: 213–224. doi:10.1007/BF02742150

Schweingruber, F. H. 1996. *Tree rings and environment dendroecology.* Berne–Stuttgart–Vienna: Paul Haupt Publishers. 609 p.

Sporek, K. 1981. Zraznicovanis ilgiel pedu glowniego sosny zwyczajnej jako efect dzialania zaniec zyszcen powietrza, *Les Polski* 19: 13–15.

Stravinskienė, V. 1994. *Medžių gręžinių paėmimas ir radialinio prieaugio matavimas, atliekant dendrochronologinius ir dendroindikacinius tyrimus* [Taking of drilled material from trees and estimation of radial growth by the means of dendrochronological and dendroindicational studies] (in Lithuanian). Methodical recommendations. Kaunas – Girionys: Lithuanian Forest Research Institute. 24 p.

Stravinskienė, V. 1997. Pušynų dendroekologiniai tyrimai ir jų taikymas gamtinės aplinkos būklės pokyčių indikacijai [Dendroecological studies of pine forest and their application for the indication of the environmental status], *Ecology* 2: 62–72.

Stravinskienė, V. 2002. *Klimato ir antropogeninių aplinkos pokyčių dendrochronologinė indikacija* [Dendrochronological indication of climatic factors and anthropogenic environmental trends]. Kaunas: Lututė Publishing house. 172 p.

Stravinskienė, V.; Šimatonytė, A. 2008. Dendrochronological research of Scots pine (*Pinus sylvestris* L.) growing in Vilnius and Kaunas forest parks, *Journal of Environmental Engineering and Landscape Management* 16(2): 57–64. doi:10.3846/1648-6897.2008.16.57-64

PAPRASTOSIOS PUŠIES (*Pinus sylvestris* L.) RADIALIOJO PRIEAUGIO DINAMIKA „AKMENĖS CEMENTO" GAMYKLOS APLINKOS MEDYNUOSE

V. Stravinskienė, R. Erlickytė-Marčiukaitienė

Santrauka

Paprastosios pušies (*Pinus sylvestris* L.) metinio radialiojo prieaugio pokyčių tyrimai buvo atliekami cemento gamyklos „Akmenės cementas" aplinkoje. Pagrindinis šio tyrimo tikslas – nustatyti galimą klimato ir antropogeninių veiksnių įtaką paprastosios pušies (*Pinus sylvestris* L.) medynų radialiajam prieaugiui gamyklos aplinkoje. Nustatyta, kad gamyklos aplinkoje augančiuose raistašilio (*Carico–sphagnosa*) miško tipo pušynuose teigiamos įtakos pušų radialiojo prieaugio formavimuisi turi aukštesnė nei vidutinė daugiametė aktyviosios vegetacijos oro temperatūra (r = 0,22–0,34; p < 0,05), o didesnis nei vidutinis daugiametis liepos mėnesio kritulių kiekis lemia radialiojo prieaugio mažėjimą (r = –0,25; p < 0,05). Nagrinėjant pušų radialiojo prieaugio sąsają su gamyklos teršalų kiekiu, stipriausias koreliacinis priklausomumas nustatytas artimiausioje gamyklos aplinkoje (iki 5 km) (r = –0,63; p < 0,05). Silpnesnis, tačiau statistiškai patikimas priklausomumas nustatytas tarp vidutiniu atstumu nuo gamyklos (5–10 km) augančių pušų prieaugio ir gamyklos teršalų kiekio. Toliausiai nuo gamyklos (per 10–20 km) augančių pušų radialiojo prieaugio sąsaja su bendruoju ir pavienių teršalų kiekiu yra statistiškai nepatikima (p > 0,05). Iš tiesinės regresinės analizės rezultatų akivaizdu, kad pušynų artimiausioje gamyklos aplinkoje metinio radialiojo prieaugio pokyčiai yra didžiausi, o tolstant nuo gamyklos mažėja.

Reikšminiai žodžiai: paprastoji pušis, radialusis prieaugis, oro temperatūra, kritulių kiekis, aplinkos tarša.

ДИНАМИКА РАДИАЛЬНОГО ПРИРОСТА СОСНЫ ОБЫКНОВЕННОЙ (*Pinus sylvestris* L.) В ДРЕВОСТОЯХ, РАСТУЩИХ В ОКРЕСТНОСТЯХ ЗАВОДА „АКМЯНЕС ЦЕМЕНТАС“

В. Стравинскене, Р. Ерлицките-Марчюкайтене

Р е з ю м е

Исследования годового радиального прироста сосны обыкновенной (*Pinus sylvestris* L.) были проведены в окрестностях цементного завода „Акмянес цементас“. Главная цель исследования – определить возможное влияние климатических и антропогенных факторов на изменение радиального прироста сосны обыкновенной (*Pinus sylvestris* L.), произрастающей в окрестностях цементного завода. Исследования показали, что на формирование радиального прироста сосен, растущих в сосновых древостоях леса типа *Carico-sphagnosa*, позитивное влияние оказывает температура воздуха, превышающая среднюю многолетнюю температуру воздуха активной вегетации (r = 0.22–0.34; p < 0.05), а количество осадков в июле, превышающее среднее многолетнее количество, способствует уменьшению радиального прироста (r = –0.25; p < 0.05). Корреляционный анализ зависимости радиального прироста сосен от эмиссии завода показал сильнейшую связь (r = –0.63; p < 0.05) на расстоянии до 5 км от завода. На расстоянии 5–10 км от завода корреляционная связь уменьшается, а при дальнейшем удалении от завода статистически не доказана. Результаты линейной регрессии показали, что наибольшие изменения радиального прироста сосен происходят на расстоянии до 5 км от завода, а с увеличением расстояния от завода они уменьшаются.

Ключевые слова: сосна обыкновенная, радиальный прирост, температура воздуха, количество осадков, загрязнение окружающей среды.

Vida STRAVINSKIENĖ. Dr Habil, Prof, Dept of Environmental Sciences, Vytautas Magnus University (VMU).
Employment: Professor (2001); Associate Professor (1998). Publications: author of 1 monograph, 5 textbooks and study-guides, over 100 scientific publications. Research interests: ecology and environmental sciences, dendrochronology, assessment of anthropogenic impact on natural and urban ecosystems, forest monitoring, biotesting.

Regina ERLICKYTĖ-MARČIUKAITIENĖ. Doctor (2007), research worker, Laboratory of Renewable Energy, Lithuanian Energy Institute (LEI).