Aplinkos tyrimai, inžinerija ir vadyba, 2009. Nr. 2(48), P. 25-34 *ISSN 1392-1649*
Environmental Research, Engineering and Management, 2009. No. 2(48), P. 25-34

Impact of Sulphur and Nitrogen Dioxide Concentration on Radial Increment Dynamics of Scots Pine (*Pinus Sylvestris* L.) Growing in Cities

Asta Šimatonytė, Jonė Venclovienė
Vytautas Magnus University

(received in February, 2009; accepted in June, 2009)

Trees growing in city forest parks and parks are exposed to the permanent higher air pollution level than trees growing in the relatively clean environment. Study of tree response towards changes in acidifying pollutants' (SO_2 and NO_2) concentration dynamics is relevant, as forest parks and parks fulfil a lot of beneficial functions in cities. Scots pine (*Pinus sylvestris* L.) sample trees, growing in parks and forest parks in Vilnius and Kaunas cities, were chosen as the objects of this research. Wood samples were collected from 330 sample pines in 15 sample plots in Kaunas city and from 480 sample pines in 20 sample plots in Vilnius city. Dendroscales of radial increment of pines growing in cities were transformed into sequences of the radial increment ratio for eliminating an impact of tree age without removing a negative impact of anthropogenic pollution. Reduction in NO_2 and SO_2 concentration in the atmosphere could determine an increase in pine radial increment in 1990–2006: significant relation was estimated between radial increment and NO_2 concentration in Vilnius and Kaunas cities (mean correlation coefficient r was equal to– -0.61 and -0.62, respectively, p<0.05), also SO_2 – in Vilnius city (r=-0.65, p<0.05). In the period of 1990-2006 climatic factors determined a larger percentage of complex impact (74–88 %) on pine radial growth in comparison with the concentration of acidifying pollutants (12–26 %).

Key words: *Scots pine (Pinus sylvestris L.), radial increment, dendroscale, concentration of sulphur and nitrogen dioxides.*

Reference to this paper should be made as follows: Šimatonytė, A., Venclovienė, J. Impact of Sulphur and Nitrogen Dioxide Concentration on Radial Increment Dynamics of Scots Pine (Pinus Sylvestris L.) Growing in Cities. Environmental Research, Engineering and Management = Aplinkos tyrimai, inžinerija ir vadyba. 2009. Vol. 48, No. 2. pp. 25-34. Kaunas, Technologija. ISSN 1392-1679.

1. Introduction

Urban green areas are relevant for city's natural self-purification from polluting substances (Beckett 1998, Jankauskaitė 2002, Chakre 2006). Forest parks and parks perform a lot of beneficial functions in cities: they increase air humidity, act as noise barriers, decrease wind speed, increase aesthetical value of the locality, increase attraction of business development (Ozolinčius 1998), renew oxygen resources (Šešelgis 1991), spread antimicrobial phytoncides, reduce soil erosion (Bolund 1999), cause yearly and even daily temperature fluctuation (Ruseckas 2002), and are important for habitants' recreation (Riepšas 1981).

Sulphur and nitrogen dioxide pollution is 30–50 % greater in cities than in relatively clean Lithuanian districts (Perkauskas 1997). Moreover, concentration of polluting substances slightly differs in a peripheral-central gradient, usually the highest level being characteristic of central and industrial districts (Perkauskas 1998, Oro kokybė <…> 2006).

Trees growing in cities are affected by long-term atmosphere pollution, which may weaken tree vitality and resistance toward other limiting factors (Innes 1993, Chapelka 1995, Nihlgard 1997). The width of annual tree rings (radial increment) is a sensitive indicator of environmental changes. Unfavourable climatic conditions, damages of diseases and pests strengthen negative impact of anthropogenic pollution on tree annual radial increment (Juknys 2004, Stravinskienė 2003). Conifers are mostly affected by the total deposition of acidifying pollutants (Ozolinčius 1998). The condition of trees in Lithuania is influenced more by high concentration of acidifying pollutants (SO_2 and NO_2) in the atmosphere rather than the amount of acidifying pollutants in the total deposition (Augustaitis 2003). SO_2 concentration determined a significant decrease in black pine (*Pinus nigra* J. F. Arnold) radial increment in city forest parks in Japan compared with pines growing in relatively clean environment in 1960–1970 (Hirano 1999).

The aim of this study has been to analyze the impact of acidifying pollutants concentration on radial increment dynamics of Scots pine (*Pinus sylvestris* L.) growing in Vilnius and Kaunas parks and forest parks.

2. Methods

Scots pine (*Pinus sylvestris* L.) sample trees, growing in parks and forest parks in Vilnius and Kaunas cities, were chosen as research objects. This tree species is the most widespread in parks and forest parks, also it is sensitive to environmental changes. Vilnius and Kaunas cities were chosen for several reasons: 1) they are the largest cities in Lithuania by the covered area (Vilnius city area is 39.2 thou. ha, Kaunas – 15.7 thou. ha) and the number of habitants (number of habitants in Vilnius city was 554 thou., in Kaunas – 359 thou. in 2006), 2) impact of anthropogenic pollution in these cities is significant enough to be estimated by the methods of bio-indication, 3) parks and forest parks cover 31 % of the total Vilnius city and 24 % of the total Kaunas city area, thus it is a great probability to find several particular pine age sample plots with similar dendrometric characteristics.

2.1. Annual radial increment analysis

Wood samples were selected for the analysis of Scots pine (*Pinus sylvestris* L.) annual radial increment reaction to environmental changes. According to the methodological recommendations (Stravinskienė 1994), wood samples were taken from each sample tree by a Pressler‘s borer at 1.3 m from a root collar in the east–west direction. Dry wood samples were soaked for 2–4 hours, so that annual rings regained their former width before measurements. One side of sample wood was cut by a special knife, so that the contours of annual rings were clearly visible. Radial increment was measured by the tree-ring measuring system LINTAB and computer program WinTSAP 0.30. Accuracy of measurements was ±0.01 mm.

2.2. Characteristics of sample plots

Selection of a number of sample plots with similar site type characteristics in cities is a difficult task because the territory is large, which determines variation of plant species, landscape, soil fertility and humidity, microclimate, air masses movement and other parameters. It is difficult to find sample trees of the same age in plots with similar site type characteristics in different city districts. Sample plots were selected in the sites of normal humidity sandy loam (*Nb* habitat) and clay loam (*Nc* habitat) soils, (except the Pažaislis sample plot located on normal humidity sandy (*Na* habitat) soils which was chosen because of old sample trees – 170 year). Most common pine trees were 60–70, 80–90 and 160–180 year old.

Wood samples were collected from 330 sample trees in 15 sample plots in 7 Kaunas city districts and from 480 sample pines in 20 sample plots in 9 Vilnius city districts. Forest dendrometric characteristics of each sample plot in Kaunas and Vilnius cities are presented in Table 1.

Control stands were selected in the relatively clean environment in Lekėčiai forest district (30 km west from Kaunas city). Three 65, 85 and 160 year old pine (in total 72 sample trees) sample plots were chosen in the sites of normal humidity sandy loam (*Nb* habitat).

Table 1. Forest dendrometric characteristics of sample plots (P – pine, S – spruce, L – lime, M – maple, O – oak, A – aspen, B – birch)

Sample plot	City district	Pine age, years	Varietal composition	Stocking level	Volume m^3/1 ha	Site type	Number of sample trees
In Kaunas city parks and forest parks							
Botanical_garden	Aleksotas	60				*Nc*	8
Eiguliai	Kalniečiai	70	10P	0.7	260	*Nc*	24
Jachtklubas	Petrašiūnai	80	8P	0.7	210	*Nb*	24
Kleboniškis1	Kalniečiai	65	10P	0.8	240	*Nb*	24
Kleboniškis2	Kalniečiai	80	6P4S	0.6	150	*Nb*	24
Lampėdžiai	Vilijampolė	90	10P	0.6	220	*Nc*	24
Palemonas1	Palemonas	90	10P	0.7	220	*Nb*	24
Palemonas2	Palemonas	90	6P1S1L1M	0.7	200	*Nc*	24
Panemunė1	Panemunė	160	8P2S	0.6	250	*Nc*	24

Panemunė2	Panemunė	170	7P2M1S	0.6	240	*Nc*	24
Pažaislis	Petrašiūnai	170	8P2S+O	0.4	120	*Na*	24
Petrašiūnai	Petrašiūnai	65	10P	0.7	260	*Nb*	24
Raudondvaris1	Raudondvaris	65	10P	0.7	240	*Nb*	24
Raudondvaris2	Raudondvaris	180	10P	0.7	240	*Nb*	10
Romainiai	Vilijampolė	80	10P+A	0.6	140	*Nb*	24
In Vilnius city parks and forest parks							
Antakalnis1	Antakalnis	170	10P+O	0.7	250	*Nc*	24
Antakalnis2	Antakalnis	170	10P+O,S	0.6	210	*Nc*	24
Aukštagiris	Antakalnis	85	8P2B	0.8	340	*Nb*	24
Barsukynė	Naujoji Vilnia	70	10P	0.8	280	*Nc*	24
Bukčiai	Lazdynai	90	10P+O	0.8	330	*Nb*	24
Burbiškės	Naujininkai	70	7P2O1A+M	0.7	250	*Nc*	24
Dvarčionys	Antakalnis	85	10P	0.6	240	*Nc*	24
Gudeliai	Lazdynai	85	10P	0.7	300	*Nb*	24
Karoliniškės	Karoliniškės	70	10P+B	0.6	220	*Nc*	24
Road_of_crosses	Verkiai	160	8P2S+O	0.6	260	*Nc*	24
Lazdynėliai	Lazdynai	80	10P+O	0.8	340	*Nc*	24
Pilaitė	Pilaitė	60	10P	0.9	300	*Nb*	24
Plytinė	Antakalnis	80	10P	0.8	300	*Nc*	24
Riovonys	Vilkpėdė	65	7P2O1A	0.7	260	*Nc*	24
Santariškės	Verkiai	90	10P+M	0.7	240	*Nb*	24
Saulėtekis	Antakalnis	70	10P	0.7	300	*Nc*	24
Tuputiškės	Naujoji Vilnia	60	8P2S	0.8	320	*Nc*	24
Turniškės	Antakalnis	85	10P+B	0.8	320	*Nc*	24
Vingis1	Vilkpėdė	170	10P+O	0.6	310	*Nc*	24
Vingis2	Vilkpėdė	160	10P+O,L	0.7	330	*Nc*	24

2.3. Data transformation and statistical analysis

Dendroscales of pines growing in Kaunas and Vilnius parks and forest parks were divided by control dendroscales, thus transformed into the sequences radial increment ratio for eliminating the age trend impact without removing a negative impact of anthropogenic pollution to radial increment sequences. Unpaired t-test was used for comparison of the radial increment ratio means at certain periods.

The data on sulphur and nitrogen dioxides concentration in Kaunas and Vilnius cities was available since 1990 (Fig. 1). SO_2 and NO_2 concentration data was used for correlation analysis (to estimate the relation between pine radial increment dynamics and acidifying pollutants concentration dynamics) and for multiple regression models.

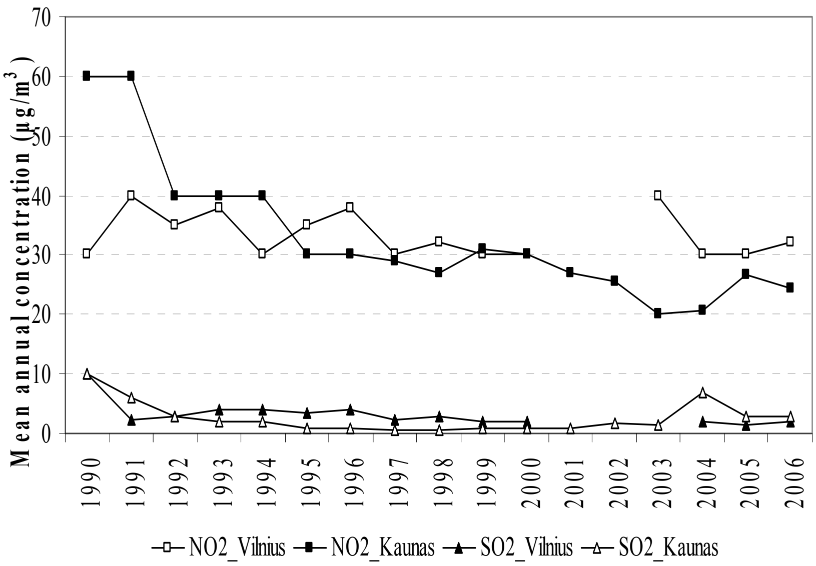

Fig. 1. Dynamics of sulphur and nitrogen dioxide concentration (µg/m^3) in the atmosphere of Vilnius and Kaunas cities

To estimate the changes of radial increment formation regularities that were determined by acidifying pollutants (nitrogen and sulphur dioxides) concentration in the atmosphere, when a complex of climatic and air pollution factors were affecting tree radial growth, linear multiple regression models were used and standardized coefficients β of each factor in a model were analyzed. Relative influence of independent variables (climatic parameters and acidifying pollutants concentration) on a dependent variable (radial increment) was described by standardized regression function coefficients β: the greater the absolute value of β - the stronger dependence y on x_i (Čekanavičius 2002).

The mean various months' temperature (^{o}C) and the amount of precipitation (mm) data (1990–2006) were obtained from the Kaunas and Vilnius meteorological stations archives. The data was used for multiple regression analysis in the models of radial increment determined by a complex impact of environmental factors.

3. Results and discussion

3.1. Dynamics of radial increment ratio

Dendroscales of the radial increment ratio of 60–70 (Fig. 2), 80–90 (Fig. 3) and 160–180 year old pines (Fig. 4) indicated similar tendencies – a significant decrease since 1960 (decrease especially sharpened in 1980–1995) and an increase after 1996 in comparison with the relatively clean environment (value t and its value p of a statistical test for comparison of means are given in Table 2).

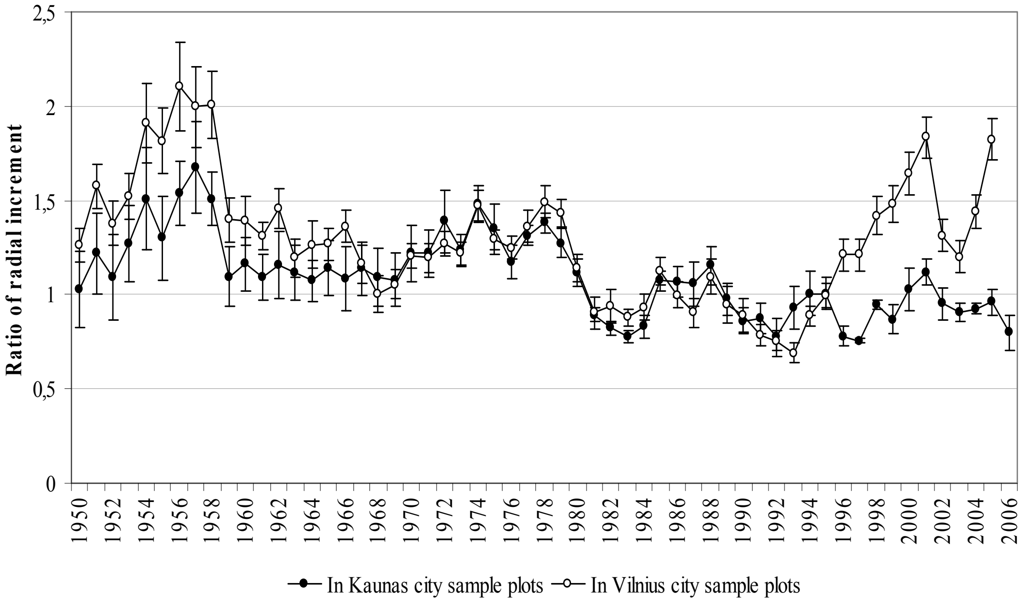

Fig. 2. *Ratio of annual radial increment of 60–70 year old pines growing in cities with radial increment of pines growing in the relatively clean environment*

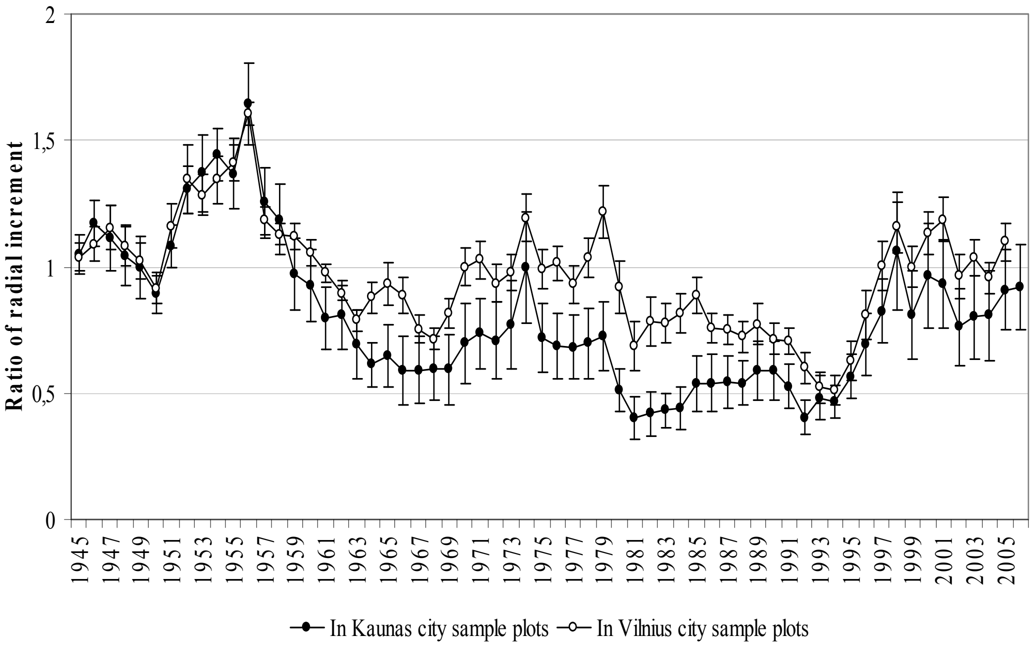

Fig. 3. *Ratio of annual radial increment of 80–90 year old pines growing in cities with radial increment of pines growing in the relatively clean environment*

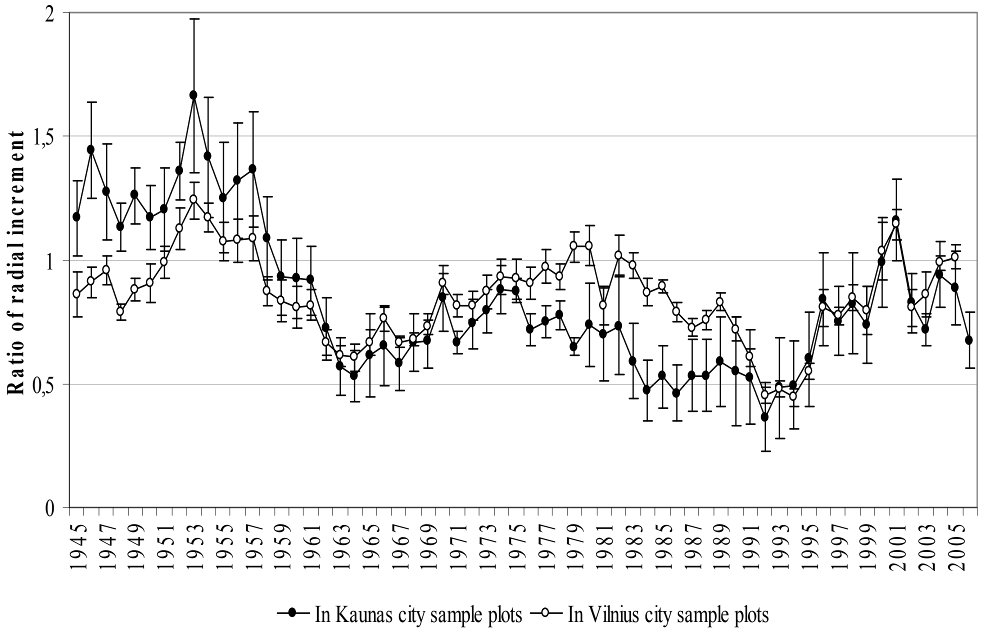

Fig. 4. *Ratio of annual radial increment of 160–180 year old pines growing in cities with radial increment of pines growing in the relatively clean environment*

Table 2. *Comparison of the radial increment ratio means at certain periods*

	Mean of 1945–1959 versus mean of 1960–1974	Mean of 1966–1980 versus mean of 1981–1995	Mean of 1985–1995 versus mean of 1996–2006
60-70 year old pines; Kaunas city	***t*=2.95 *p*=0.009**	***t*=6.65 *p*<0.000**	*t*=1.45 *p*=0.16
60-70 year old pines; Vilnius city	***t*=4.23 *p*=0.001**	***t*=7.21 *p*<0.000**	***t*=-6.60 *p*<0.000**
80-90 year old pines; Kaunas city	***t*=7.68 *p*<0.000**	***t*=5.61 *p*<0.000**	***t*=-9.37 *p*<0.000**
80-90 year old pines; Vilnius city	***t*=4.82 *p*<0.000**	***t*=5.60 *p*<0.000**	***t*=-7.72 *p*<0.000**
160-180 year old pines; Kaunas city	***t*=9.88 *p*<0.000**	***t*=5.76 *p*<0.000**	***t*=-7.17 *p*<0.000**
160-180 year old pines; Vilnius city	***t*=5.18 *p*<0.000**	***t*=2.43 *p*=0.02**	***t*=-4.40 *p*<0.000**

Dynamics of the radial increment ratio corresponds to dynamics of acidifying pollutants concentration in cities. Unfavourable climatic conditions (such as extremely cold 1979/1980 winter) weakened tree resistance towards the increasing air pollution in cities and sharpened the reduction in radial increment at certain periods (such as in 1981–1995).

3.2. Pine radial increment correlation with nitrogen and sulphur dioxide concentration

Mean correlation coefficients (*r*) between nitrogen and (Fig. 5) sulphur (Fig. 6) dioxide concentration and radial increment of various age pines (from all sample plots) indicated that the reduction in NO_2 and SO_2 concentration in the atmosphere could determine increase in radial increment of pines growing in cities in 1990–2006.

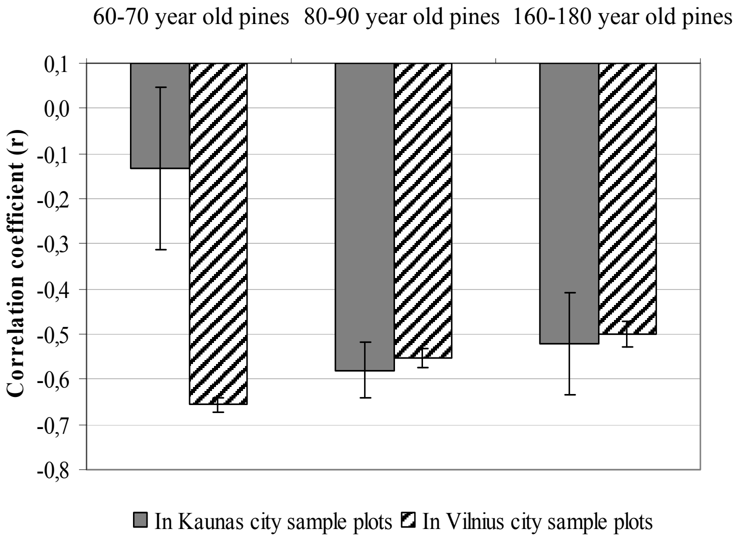

Fig. 5. *Correlation coefficients NO_2 concentration*

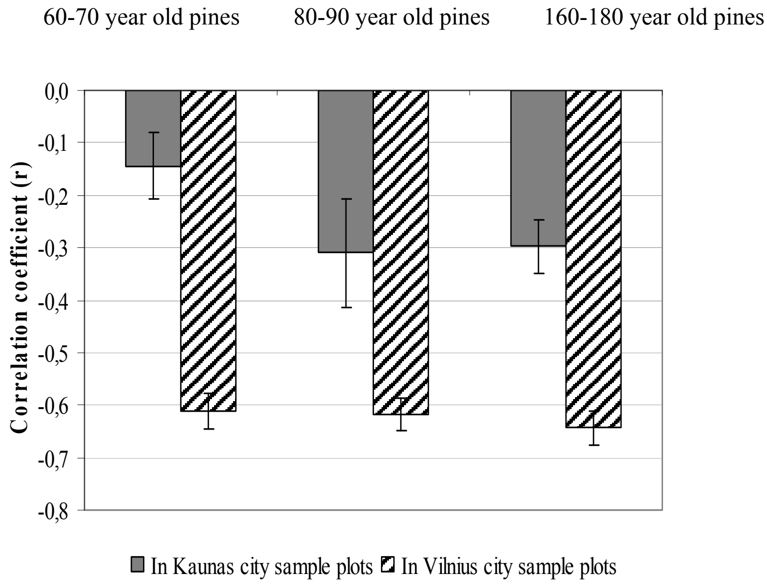

Fig. 6. *Correlation coefficients SO_2 concentration*

When only statistically significant ($p<0.05$) correlation coefficient values were considered, a strong statistically significant relation was estimated between pine radial increment and NO_2 concentration in Vilnius and Kaunas cities (mean r was equal to– -0.61 and -0.62, respectively), also SO_2 – in Vilnius city (r=-0.65). The relation between pine radial increment and SO_2 concentration in Kaunas city was statistically insignificant ($p>0.05$) in a majority of sample plots. Strength of the statistically significant relation between the pine radial increment ratio and acidifying pollutant concentration did not depend on the tree age (mean $r_{(NO2)}$ of 60–70 year old pines was equal to -0.56 in Kaunas city and -0.66 in Vilnius city; that of 80–90 year old pines – -0.63 and -0.58, respectively; of 160–180 year old pines – -0.63 and -0.56, respectively; mean $r_{(SO2)}$ of 60–70 year old pines was -0.63 in Vilnius city; of 80–90 year old pines – -0.66 and -0.50 in Kaunas city; of 160–180 year old pines – -0.64).

3.3. Models of complex impact

The actual (*Sample_plot*) and model (*Sample_plot_m*) radial increment ratio of pines in some sample plots (where determination coefficient R^2 was the highest and $p<0.05$) in Kaunas and Vilnius cities are presented in Figs. 7 - 8.

Prognosis (for 10 years) of the radial increment ratio was calculated according to multiple regression models according to two scenarios:

– Scenario 1, when the exploitation of the second block of the Ignalina nuclear power plant (INPP) will be completed at the end of 2009 and the concentration of pollutants will start slowly increasing;

– Scenario 2, when the exploitation of the second block of INPP will be extended till 2020 and the concentration of pollutants will be stable (as at the 2006–2007 level).

As the rate of the climate change in a few last decades has been rather slow (Rimkus 1999, Rimkus 2007), it is assumed that in the nearest future fluctuation of climatic parameters will remain similar to the last 11 year solar activity cycle (1997–2007). After the end of INPP second block exploitation, SO_2 emission from the other Lithuanian power plants will increase from 30 till 52.3 kilo tons (kt) per year and will reach 83.3 kt in 2020, NO_x – from 3.8 till 6.7–10.0 kt (Denafas 2004). Thus, in a case of scenario 1 SO_2 concentration in cities should increase 2–3 times since 2010 (from 2–2.5 μg/m^3) till 2020 (till 5–5.6 μg/m^3), NO_2 concentration should slightly increase up to 1.2 times (from 24–30 μg/m^3 till 29–35 μg/m^3).

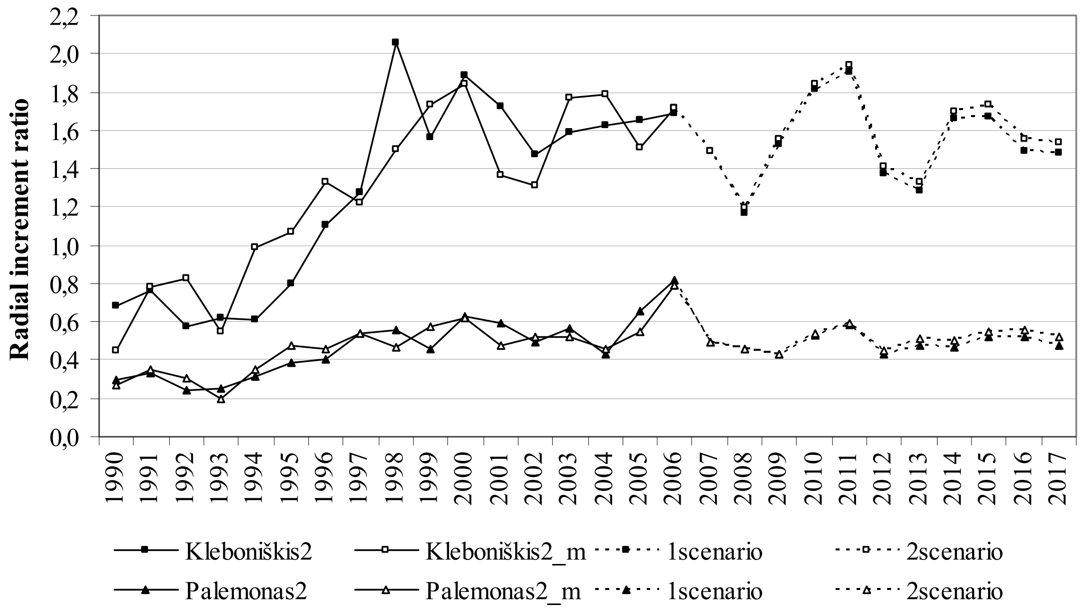

Fig. 7. Actual and model radial increment ratio of pines in Kleboniškis2 and Palemonas2 sample plots

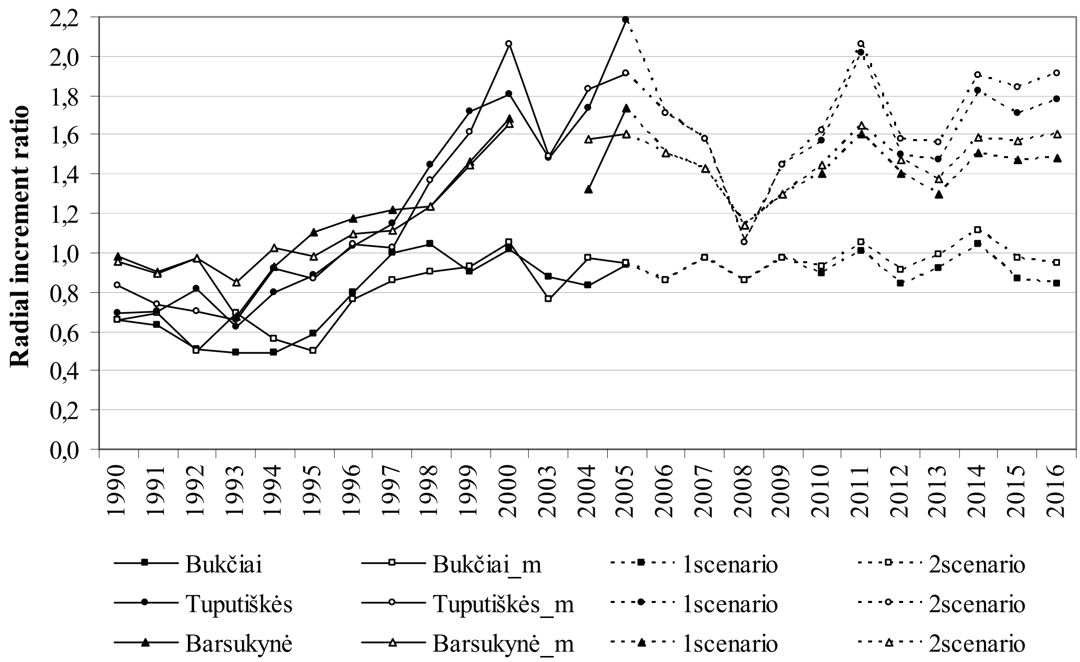

Fig. 8. Actual and model radial increment ratio of pines in Barsukynė, Bukčiai and Tuputiškės sample plots

Model sequences of the radial increment ratio (Figs.7-8) were calculated by linear multiple regression equations presented in Table 3. Where: *y* – expected radial increment ratio of particular sample plot pines and pines growing in the relatively clean environment, *Pr* – mean month's amount of precipitation (mm), *pss* – passed year, NO_2 and SO_2 – mean annual nitrogen dioxide and sulphur dioxide concentration (μg/m^3) in the atmosphere in Kaunas or Vilnius city.

It was noticed (Fig. 7) that in coming 10 years at the gradual SO_2 concentration increase by 2.2 μg/m^3 in Kaunas city, in a case of scenario 1 compared with scenario 2, the radial increment ratio would decrease by 0.04. With an increase in NO_2 concentration by 4.0 μg/m$^{3.}$ the radial increment ratio would decrease by 0.06. These changes being not great, nevertheless, it is clear that an increase in the acidifying pollutant concentration by a few micrograms in the city environment would determine a traceable decrease in pine radial increment in cities in comparison with the relatively clean environment.

The results have shown (Fig. 8) that in future in a scenario 1 case with the gradual NO_2 concentration increase by 3.0 μg/m^3 and SO_2 increase by 3.2 μg/m^3 in Vilnius city compared with scenario 2, the radial increment ratio would decrease by 0.11–0.13. These changes would be slightly larger than in Kaunas city because Vilnius city is in the direction of dominating west and southwest winds from Elektrėnai, where a significant air pollution increase is predicted after 2010 due to the contribution of Lithuanian power plant.

Table 3. Multiple regression models used for pine radial increment prognosis

Model dendroscale	Determination coefficient R^2 (p<0.05)	Multiple regression equation	Standardized coefficients (p<0.05)
Kleboniškis2_m	R^2=0.69	$y = 2.66 - 0.01 \mathrm{Pr}_{Sep} - 0.01 \mathrm{Pr}_{pssSep} - 0.02 NO_2$	$\beta(Pr_{Sep})$=-0.61 $\beta(Pr_{pssSep})$=-0.44 $\beta(NO_2)$=-0.37
Palemonas2_m	R^2=0.66	$y = 0.52 + 0.004\ \mathrm{Pr}_{Jun} - 0.002\ \mathrm{Pr}_{Sep} - 0.003\ \mathrm{Pr}_{pssSep} - 0.02 SO_2$	$\beta(Pr_{Jun})$=0.43 $\beta(Pr_{Sep})$=-0.42 $\beta(Pr_{pssSep})$=-0.66 $\beta(SO_2)$=-0.39
Barsukynė_m	R^2=0.70	$y = 2.58 - 0.005\ \mathrm{Pr}_{Sep} - 0.004\ \mathrm{Pr}_{pssSep} - 0.02 NO_2 - 0.02 SO_2$	$\beta(Pr_{Sep})$=-0.69 $\beta(Pr_{pssSep})$=-0.50 $\beta(NO_2)$=-0.34 $\beta(SO_2)$=-0.21
Bukčiai_m	R^2=0.68	$y = 2.32 - 0.004\ \mathrm{Pr}_{Mar} - 0.003\ \mathrm{Pr}_{Sep} - 0.04 NO_2$	$\beta(Pr_{Mar})$=-0.53 $\beta(Pr_{Sep})$=-0.53 $\beta(NO_2)$=-0.70
Turniškės_m	R^2=0.72	$y = 3.76 - 0.01 \mathrm{Pr}_{Sep} - 0.006\ \mathrm{Pr}_{pssSep} - 0.04 NO_2$	$\beta(Kr_{Rugs})$=-0.84 $\beta(Kr_{prRugs})$=-0.42 $\beta(NO_2)$=-0.34

Complex climatic factors and air pollution models described 66–72% of pine annual radial increment variation. In the period of 1990–2006 the influence of nitrogen dioxide and sulphur dioxide concentration on pine radial increment was less than that from climatic factors. According to standardized coefficients (β) of multiple regression models, climatic factors determined a greater part of the complex impact (74–88%) on the pine radial growth (mean coefficients β of the present year and previous year September precipitation amount were equal to -0.62 and -0.51, respectively, p<0.05). Though the concentration of acidifying pollutants (mean statistically significant p<0.05 coefficients β of NO_2 and SO_2 were equal to -0.35 and -0.30, respectively) determined 12–26 % of the complex impact on pine radial increment dynamics, model prognosis has shown that an increase in NO_2 and SO_2 concentration by a few micrograms would determine the reduction in radial increment of pines growing in Kaunas and Vilnius cities in comparison with pines in the relatively clean environment.

4. Conclusions

Dynamics of radial increment of Scots pine (*Pinus sylvestris* L.) growing in Kaunas and Vilnius cities corresponds to that of the acidifying pollutants concentration in the atmosphere: a significant decrease in radial increment since 1960 (decrease especially sharpened in 1980–1995) and an increase after 1996 were detected in comparison with radial increment in the relatively clean environment.

Decrease in the nitrogen dioxide and sulphur dioxide concentration in the urban atmosphere could determine an increase in pine radial increment in 1990–2006: strong statistically significant relation was estimated between pine radial increment and NO_2 concentration in Vilnius and Kaunas cities (mean correlation coefficient r was equal to -0.61 and -0.62, respectively, p<0.05) and SO_2 concentration in Vilnius city (r=-0.65, p<0.05). Relation between pine radial increment and SO_2 concentration in Kaunas city was statistically insignificant (p>0.05) in most sample plots.

The complex of climatic and acidifying pollutants concentration factors described 66–72 % of pine radial increment variation. The possible influence of climatic factors determined 74–88 % and acidifying pollutants concentration – 12–26 % of the complex impact. The prognosis calculated by multiple regression models showed that an increase in NO_2 and SO_2 concentration by a few micrograms in the city environment would determine traceable decrease in pine radial increment in comparison with the relatively clean environment.

References

Augustaitis A. 2003. Impact of regional pollution load on tree condition and interpretation of assessment methods. *Ecologia (Bratislava)*, Vol. 22(1), p.p. 37-41.

Beckett K. P., Freer-Smith P. H., Taylor G. 1998. Urban woodlands: their role in reducing the effects of particulate pollution. *Environmental Pollution*, Vol. 99, p.p. 347-360.

Bolund P., Hunhammar S. 1999. Ecosystem services in urban areas. *Ecological Economics*. Vol. 29, p.p. 293-301.

Chakre O. J. 2006. Choice of Eco-friendly Trees in Urban Environment to Mitigate Airborne Particulate Pollution. *Journal of Human Ecology*, Vol. 20 (2), p.p.135-138.

Chapelka A. H., Freer-Smith P. H. 1995. Predisposition of trees by air pollutant to low temperatures and moisture stress. *Environmental Pollution*, Vol. 87, p.p. 105-117.

Čekanavičius V., Murauskas G. 2002. *Statistika ir jos taikymai. II dalis*. Vilnius: TEV, 272 p.

Denafas G., Sitnikovas D., Vaikšnorienė R. 2004. Lietuvos elektros energetikos infrastruktūros pokyčių įtaka aplinkos oro taršai. *Energetika*, Nr. 1, p.p. 34-40.

Hirano T., Morimoto K. 1999. Growth reduction of the Japanese black pine corresponding to an air pollution episode. *Environmental Pollution*, Vol. 106, p.p. 5-12.

Innes J. I. 1993. *Forest health: its assessment and status*. Oxon, CAB International, 677 p.

Jankauskaitė M. 2002. Urbanizuotos aplinkos gamtinio savivalos potencialo vertinimo metodologiniai aspektai. *Geografijos metraštis*, Nr. 35, p.p 274-293.

Juknys R. 2004. Tree-Ring Analysis for Environmental Monitoring and Assessment of Anthropogenic Changes. In: *Environmental Monitoring* (Editor G. B. Wiersma). London, CRC Press, p.p. 347-369.

Nihlgard B. 1997. Forest decline and environmental stress. In: Brune D., Chapman D. V., Gwyne M. D., Pacyna J. M. (eds.), *The Global Environment: Science, Technology and Management*, p.p. 422-440.

Oro kokybė aglomeracijose ir zonoje. 2006. Vilnius, Aplinkos apsaugos agentūra. 45 p.

Ozolinčius R. 1998. Miestų medžiai ir miškai. *Mūsų girios*, Nr. 4, p. 12-13.

Ozolinčius R., Stakėnas V. 1998. Medžių lajų defoliacija Lietuvoje ir jos dinamika. *Miškininkystė*, Nr. 1(41), p.p. 81-92.

Perkauskas D., Mikelinskienė A. 1998. Evaluation of SO_2 and NO_2 concentration levels in Vilnius (Lithuania) using passive diffusion samplers. *Environmental Pollution*, Vol. 102(1), p.p. 249-252.

Perkauskas D., Mikelinskienė A., Giedraitis B., Milukaitė A., Juozefaitė V. 1997. Evaluation of SO_2 and NO_2 concentration levels in Lithuania using passive diffusional samplers. *Proceedings of Twenty-Second NATO/CCMS international technical meeting on air pollution modeling and its applications*, Clermont-Ferrand, France, June 2-6, p.p. 529-530.

Riepšas E. 1981. *Miškas ir žmogaus poilsis*. Vilnius: Mokslas, p.p. 39-54.

Rimkus E. 1999. Klimato kaita: modeliai, prognozės, faktai. *Geografijos metraštis*, Nr. 32, p.p. 16-25.

Rimkus E., Kažys J., Junevičiūtė J., Stonevičius E. 2007. Lietuvos klimato pokyčių XXI a. prognozė. *Geografija*, Nr. 43(2), p.p. 37-47.

Ruseckas J. 2002. *Miško ir drėgmės sąveika*. Kaunas: Lututė, 200 p.

Stravinskienė V. 1994. *Medžių gręžnių paėmimas ir radialinio prieaugio matavimas, atliekant dendrochronologinius ir dendroindikacinius tyrimus*. Metodinės rekomendacijos. Kaunas-Girionys: Lietuvos miškų institutas. 24 p.

Stravinskienė V., Erlickytė R. 2003. Klimato veiksnių poveikis paprastosios pušies (*Pinus sylvestris* L.) augimui AB „Akmenės cementas“ aplinkoje. *Ekologija*, Nr. 3, p.p. 34-39.

Šešelgis K. 1991. *Aplinkos apsauga*, Vilnius, 211 p.

Dr. Asta Šimatonytė, junior researcher at Vytautas Magnus University, Kaunas Botanical Garden.
Main research areas: bioindication and dendrochronological study methods application for the evaluation of urban environment quality.
Address: Ž. E. Žilibero str. 6,
Kaunas LT-46324, Lithuania
Tel. : +370 7 390 033; +370 686 82567
E-mail: a.simatonyte@gmf.vdu.lt

Dr. Jonė Venclovienė, associated professor at Vytautas Magnus University, Faculty of Natural Sciences, Department of Environmental Sciences.
Main research areas: application of statistical data analysis methods in environmental sciences.
Address: Vileikos str. 8
Kaunas LT-44404, Lithuania
Tel./Fax.: +370 7 327 904
E-mail: j.vencloviene@gmf.vdu.lt

Sieros ir azoto dioksidų koncentracijos įtaka miestuose augančios paprastosios pušies (*Pinus sylvestris* L.) radialiojo prieaugio dinamikai

Asta Šimatonytė, Jonė Venclovienė
Vytauto Didžiojo universitetas

(gauta 2008 m. vasario mėn.; atiduota spaudai 2009 m. birželio mėn.)

Medžiai, augantys miestų ir miškų parkuose yra veikiami ilgalaikės didesnės oro taršos nei augantys sąlygiškai švarioje aplinkoje. Miškų ir miestų parkai atlieka daugelį reikšmingų funkcijų, todėl yra svarbu ištirti medžių atsaką į aplinką rūgštinančių teršalų (SO_2 ir NO_2) koncentracijos pokyčius. Tyrimo objektais buvo pasirinkti paprastosios pušies (*Pinus sylvestris* L.) apskaitos medžiai, augantys Kauno ir Vilniaus miestų želdiniuose. Medienos gręžiniai buvo surinkti iš 330 apskaitos pušų 15-oje tyrimo plotelių Kauno mieste ir iš 480 apskaitos pušų 20-yje tyrimo plotelių Vilniaus mieste. Siekiant pašalinti amžiaus įtaką medžių radialiajam prieaugiui nepanaikinant neigiamo antropogeninės taršos poveikio, miestuose augančių pušų radialiojo prieaugio dendroskalės buvo pakeistos į radialiojo prieaugio santykio sekas. NO_2 ir SO_2 koncentracijos ore sumažėjimas galėjo lemti pušų radialiojo prieaugio padidėjimą 1990–2006 m.: reikšmingas ryšys nustatytas tarp radialiojo prieaugio ir NO_2 koncentracijos Vilniaus ir Kauno miestų ore (vidutinis koreliacijos koeficientas r buvo lygus atitinkamai (–0,61 ir –0,62; $p < 0,05$), taip pat tarp railiojo prieaugio ir SO_2 koncentracijos Vilniaus miesto ore ($r = –0,65$; $p < 0,05$). 1990–2006 m. klimato veiksniai lėmė didesnį kompleksinį poveikį pušų radialiajam prieaugiui (74–88 %), palyginti su aplinką rūgštinančių teršalų koncentracija (12–26 % kompleksinio poveikio).