Possible Changes in the Pace of Scots Pine (*Pinus sylvestris* L.) Radial Increment in City Forests and Parks

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Abstract

Air pollution determined threats for trees growing in cities will change due to warming climate and increasing air pollution after the end of Ignalina nuclear power plant exploitation. The aim of this research was to evaluate the pace of radial increment possible changes of Scots pine (*Pinus sylvestris* L.) in future scenarios of warming climate and increasing SO_2 and NO_2 concentration in city atmosphere. Wood samples were collected from 80–90 year old sample pines, growing in parks and forest parks in Vilnius and Kaunas cities, for the analysis of annual radial increment reaction to environmental changes. Multiple regression models (describing 53–66 % of variability of actual dendroscales with probability of 95 %) for predicting pine radial increment were created. If recent cautious climate warming prognosis will be true, the pace of pine radial increment possible changes in cities will be rather slow in the coming 30 years: from +0.001 to +0.004 mm per year. The pace of pine radial increment possible changes in future scenario of increasing SO_2 and NO_2 concentration in city atmosphere will be slow: from -0.002 till -0.006 mm per year and pine radial increment in 2020 will decrease (by 0.03–0.05 mm) in major part of sample plots despite the positive impact of warming climate.

Key words: Scots pine, radial increment, warming climate, SO_2 and NO_2 concentration.

Introduction

Tree growth and productivity are basic forest ecosystem indicators reflecting general forest state and stability, which are dependent on the quality of the surrounding environment (Juknys et al. 2002). City green areas receive local and background air pollution impact, thus city trees are more vulnerable, degrade and fall faster than trees in natural ecosystems (Stravinskienė 2002). The condition of trees in Lithuania is influenced mostly by high concentration of acidifying pollutants (SO_2 and NO_2) in the atmosphere (Augustaitis 2003).

The width of annual tree rings (radial increment) depend on climate and anthropogenic factors, thus this indicator reflects the impact of total present and past ecological factors and is convenient for assessment of environmental state (Bitvinskas 1989, Lovelius 1997, Stravinskienė 2002). Reduction of the radial increment was characteristic of trees in northern latitude forests since 1950, later increase (since 1981) (Linderholm et al. 2002, Todaro et al. 2007). It is considered, that this phenomenon was mostly influenced by warming climate, increasing amount of available nitrogen in soils and increasing carbon dioxide concentration in the atmosphere (Nojd and Hari 2001), also air pollution reduction (Ozolinčius 1998, Juknys et al. 2002).

In future air pollution determined threats for forest condition will change due to warming climate and increasing air pollution after the end of Ignalina nuclear power plant exploitation (Bukantis et al. 2003, Denafas et al. 2004, Paoletti et al. 2007). Considerable climate warming will determine the increase of vegetation period, but at the same time warmer winters will increase appearance of new tree diseases and pests (Rimkus 2007). Thus evaluation of plant reaction towards multiple interacting factors limiting growth and future prognosis is a relevant research topic. The aim of this research was to evaluate the pace of pine radial increment possible changes in future scenarios of warming climate and increasing sulphur and nitrogen dioxide concentration in city atmosphere.

Materials and methods

Research object, sample plots, analysis methods

80–90 year old Scots pine (*Pinus sylvestris* L.) sample trees, growing in parks and forest parks in Vilnius and Kaunas cities, were chosen as the objects of investigation. This tree species was chosen because it is the most widespread tree species in parks and forest parks; also it is sensitive to environmental changes. 9 sample plots (Table 1) were selected on sites of normal humidity sandy loam (Nb habitat) and clay loam (Nc habitat) soils.

Wood samples were selected for the analysis of pine annual radial increment reaction to environmental changes. According to methodological recommen-

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

Sample plot	Pine age, years	Varietal composition	Stocking level	Volume m^3/ha	Site type	Number of sample trees
In Kaunas city parks and forest parks						
Kleboniškis	80	6P4S	0.6	150	*Nb*	24
Lampėdžiai	90	10P	0.6	220	*Nc*	24
Palemonas	90	10P	0.7	220	*Nb*	24
Romainiai	80	10P+A	0.6	140	*Nb*	24
In Vilnius city parks and forest parks						
Aukštagiris	85	8P2B	0.8	340	*Nb*	24
Lazdynėliai	80	10P+O	0.8	340	*Nc*	24
Plytinė	80	10P	0.8	300	*Nc*	24
Santariškės	90	10P+M	0.7	240	*Nb*	24
Turniškės	85	10P+B	0.8	320	*Nc*	24

dations (Stravinskienė 1994), wood samples were taken from each sample tree by Pressler‘s borer at 1.3 m (breast) from root collar in east–west direction. Dry wood samples were soaked for 2–4 hours before measurements. The radial increment was measured by tree-ring measuring system LINTAB and computer program WinTSAP 0.30. The accuracy of measurements was ±0.01 mm.

In order to reach the aim of the research, multiple regression models for predicting pine radial increment were created. Climate parameters in multiple regression models were mean month’s temperature (°C) and amount of precipitation (mm) data (1892–2006) from Kaunas and Vilnius meteorological stations archives. The component of harmonic variation was included in models because cyclic variation of nature processes (repeated solar activity cycles, droughts, very cold, dry or humid periods) increase the equivalence of model radial increment sequences (dendroscales) to actual dendroscales. According to methodological recommendations of other studies (Juknys and Venclovienė 1998, Juknys 2004), regression functions included from one to three 8–23 year period cyclic constituents. Models included multiplier – negative exponential function, which parameters were calculated by least square method, in order to reflect radial increment reduction trend due to the impact of tree age (Fritts 1976, Juknys 2004).

Climate dynamics and future prognosis

1961–1990 period in Lithuania was 0.1–0.3°C warmer than 3 previous decades, except the southern part, where temperature dropped by 0.1°C (Bukantis and Rimkutė 1996). Mean annual amount of precipitation increaced by 20.53 mm in western part of Lithuania and decreased by 20.57 mm in the remaining part of the territory in comparison with 1931–1960 period (Bukantis and Rimkutė 1997). Climate simulation models, using different emission scenarios, predict global temperature rise of 1.4–5.8°C in 1990–2100 (Rimkus 2007).

In order to evaluate the pace of pine radial increment changes in case of warming climate in future, prognosis were calculated by two scenarios: S1 – when climate parameters in 3 coming 11 year solar cycles were the same as in the last 22 year solar cycle, S2 – when S1 climate parameters were increased (decreased in case of September precipitation amount). It was assumed that in coming three 11 year solar activity cycles after 2007, the pace of climatic parameters changes per year in S2 will be: T_{Feb}= +0.10 (°C), T_{Mar}= +0.07 (°C), P_{Feb}= +0.25 (mm), P_{Sep}= -0.15 (mm), P_{pssSep}= -0.15 (mm).

NO_2 and SO_2 concentration dynamics and future prognosis

Emission of acidifying gasses was reduced significantly in many member states of European Union: emission of these gasses was reduced by 43 % in old member states and 58 % in new member states in 1990–2002 (Anon. 2005). Air pollution by sulphur (SO_2) and nitrogen (NO_2) dioxides is 30–50 % greater in cities than in relatively clean Lithuanian districts (Perkauskas et al. 1997). NO_2 and SO_2 concentration dynamics in 1990–2006 in Kaunas and Vilnius cities is presented in Figure 1 (*Lietuvos aplinkos…* 2000, *Oro kokybė...* 2006, *Kauno miesto...* 2005).

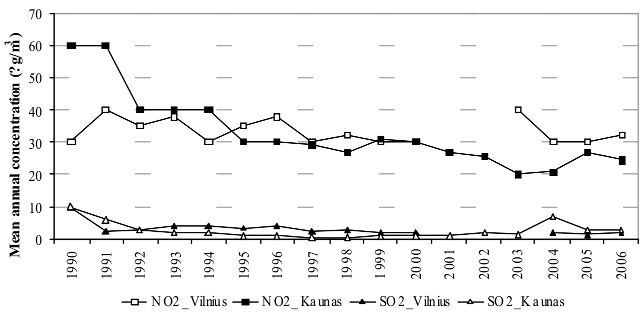

Figure 1. The dynamics of sulphur and nitrogen dioxide concentration (μg/m^3) in the atmosphere of Vilnius and Kaunas cities

When exploitation of Ignalina nuclear power plant (INPP) second block will be finished, SO_2 emission from other Lithuanian power plants will increase from 30 to 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 et al. 2004).

In order to evaluate the pace of pine radial increment changes in case of increasing SO_2 and NO_2 concentration in cities, prognosis were calculated by two scenarios: S3 – when the exploitation of the second block of INPP will be extended till 2020 and concentration of pollutants will be stable (as in 2006–2007 level), S4 – when the exploitation of second block of

Ignalina nuclear power plant (INPP) will be completed in the end of 2009 and concentration of pollutants will start slowly increasing. It was assumed that in S4 scenario SO2 concentration should increase 2–3 times in cities in 2010–2020 (from 2.5 μg/m³ in Kaunas and 2.0 μg/m³ in Vilnius to 5.0 μg/m³ and 5.6 μg/m³ respectively) and NO2 concentration should slightly increase up to 1.2 times (from 24 μg/m³ in Kaunas and 30 μg/m³ in Vilnius till 30 μg/m³ and 35 μg/m³ respectively). Climate parameters in S3 and S4 were not changed (as in S1).

Results

Results showed that multiple regression models were appropriate (determination coefficient R^2>0.5 and p<0.05) for predicting pine radial increment in major part of sample plots in future warming climate and increasing pollution scenarios despite rather short data sequences of pollutants concentration (1990–2006). However, multiple regression models were not suitable (determination coefficient R^2<0.3 and p>0.05) for pine radial increment prognosis in Kleboniškis, Palemonas and Santariškės sample plots in future scenario of increasing SO_2 and NO_2 concentration. As comparison of the pace of pine radial increment possible changes in S2 and S4 scenarios was important in this research, thus Kleboniškis, Palemonas and Santariškės sample plots were not included in further discussion of results and conclusions were based on appropriate models. Actual (Sample_plot) and model (Sample_plot_M) pine dendroscales, calculated prognosis according scenarios S1 (Sample_plot_S1) and S2 (Sample_plot_S2) are presented in Figures 2 and 3.

Multiple regression models, used for predicting pine radial increment in case of warming climate (Table 2), included 2–4 climate parameters, 1–3 cyclic components and multiplier – age trend exponential function. Models described 53–61 % of variability of actual dendroscales with probability of 95 %.

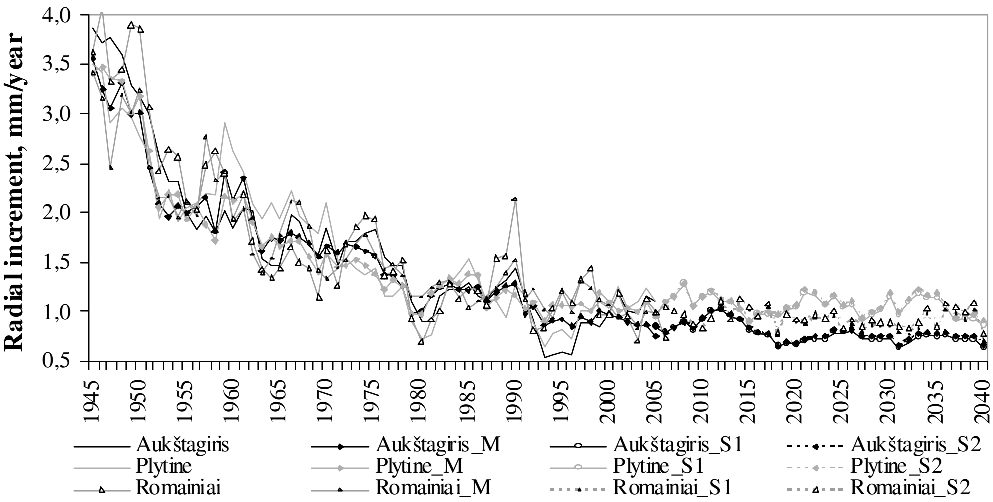

Figure 2. Actual and model (M) radial increment dynamics and prognosis according to S1 and S2 in Aukštagiris, Plytinė and Romainiai sample plots (ΔS2-S1=+0.001 – +0.002 mm/per year)

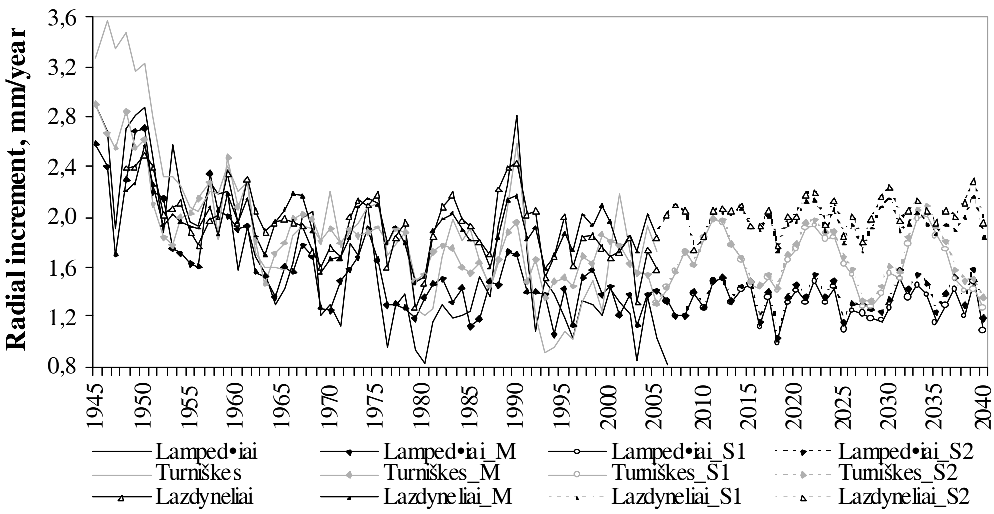

Figure 3. Actual and model (M) radial increment dynamics and prognosis according to S1 and S2 in Lampėdžiai, Turniškės and Lazdynėliai sample plots (ΔS2-S1=+0.003 – +0.004 mm/per year)

Table 2. Multiple regression models used for pine radial increment prognosis S1 and S2

Model dendroscale	Multiple regression equation; determination coefficient R^2 (p<0.05)
Aukštagiris_M	$y = (0.55 + 3.73e^{-0.04t})(1.10 + 0.02T_{Mar} - 0.001P_{pssSep} + 0.08\sin\frac{2\pi t}{12} - 0.05\sin\frac{2\pi t}{21} + 0.05\sin\frac{2\pi t}{22})$; R^2=0.57
Plytinė_M	$y = (0.97 + 3.92e^{-0.06t})(0.96 + 0.01T_{Feb} + 0.03T_{Mar} + 0.002P_{Feb} - 0.001P_{pssSep} - 0.09\sin\frac{2\pi t}{12} - 0.05\cos\frac{2\pi t}{21})$; R^2=0.53
Romainiai_M	$y = (0.79 + 4.59e^{-0.04t})(1.00 + 0.01T_{Feb} + 0.02T_{Mar} - 0.001P_{Sep} + 0.08\sin\frac{2\pi t}{8} - 0.08\cos\frac{2\pi t}{10})$; R^2=0.57
Lampėdžiai_M	$y = (0.79 + 4.59e^{-0.04t})(1.00 + 0.01T_{Feb} + 0.02T_{Mar} - 0.001P_{Sep} + 0.08\sin\frac{2\pi t}{8})$; R^2=0.56
Turniškės_M	$y = (1.47 + 2.91e^{-0.04t})(1.12 + 0.02T_{Mar} - 0.001P_{pssSep} + 0.07\cos\frac{2\pi t}{11} - 0.06\sin\frac{2\pi t}{11} - 0.09\sin\frac{2\pi t}{12})$; R^2=0.54
Lazdynėliai_M	$y = (1.82 + 0.63e^{-0.09t})(1.03 + 0.02T_{Mar} + 0.002P_{Feb} - 0.001P_{pssSep} + 0.06\sin\frac{2\pi t}{8} - 0.05\cos\frac{2\pi t}{11} + 0.03\sin\frac{2\pi t}{22})$; R^2=0.61

Results showed that the pace of radial increment changes in case of warming climate (S2 in comparison with S1) would be rather slow (from +0.001 to +0.004 mm per one year). In future three 11 year solar cycles (till 2040) pine radial increment in case of warming climate would increase in all sample plots: it would increase by +0.03 mm in Aukštagiris sample plot, +0.04 mm – in Plytinė, +0.07 mm – in Romainiai, +0.08 mm – in Turniškės, +0.10 – in Lampėdžiai and +0.13 – in Lazdynėliai.

Actual (*Sample_plot*) and model (*Sample_plot_M*) pine dendroscales, calculated prognosis according to scenarios S3 (*Sample_plot_S3*) and S4 (*Sample_plot_S4*) are presented in Figures 4 and 5.

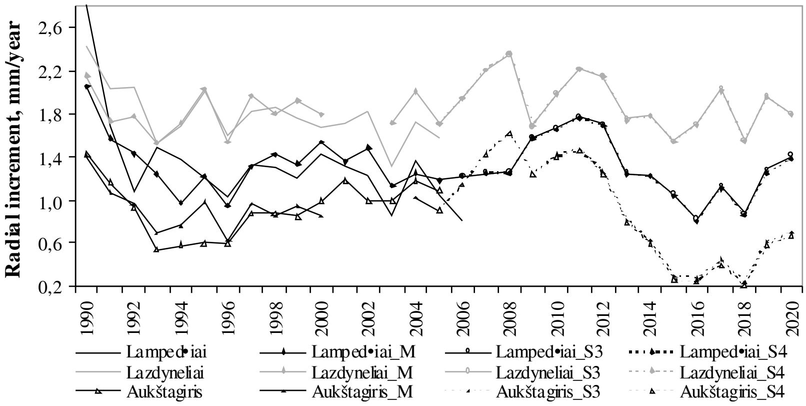

Figure 4. Actual and model (M) radial increment dynamics and prognosis according to scenarios S3 and S4 in Lampėdžiai, Lazdynėliai and Aukštagiris sample plots (ΔS4-S3= -0.002 – -0.004 mm/per year)

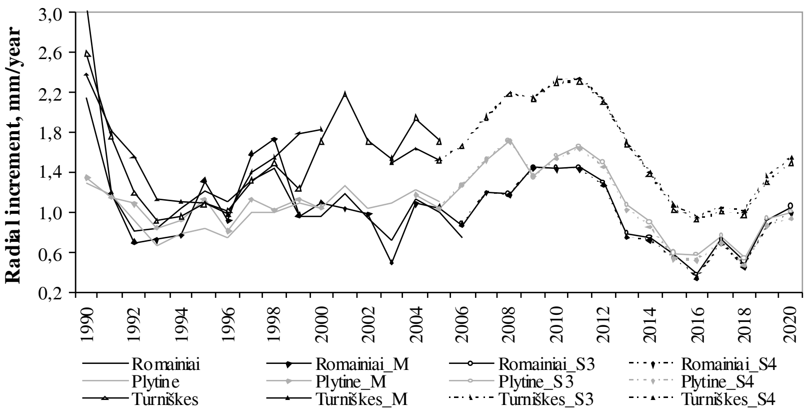

Figure 5. Actual and model (M) radial increment dynamics and prognosis accordingto scenarios S3 and S4 in Romainiai, Plytinė and Turniškės sample plots (ΔS4-S3= -0.005 – -0.006 mm/per year)

Multiple regression models used for predicting pine radial increment dynamics according to S3 and S4 are described in Table 3. These models included 1 climate parameter, 2 cyclic components, SO_2 or NO_2 concentration component and multiplier – age trend exponential function. These models described 56–66 % of variability of actual dendroscales with probability of 95 %. Slightly higher model determination coefficients than the ones used in case of changing climate were determined by smaller length of data sequences (longer SO_2 and NO_2 concentration data sequences were not available). When both SO_2 and NO_2 concentration components were included in models, determination coefficient became statistically insignificant p>0.05, probably due to inter-correlation and short length of data sequences of these components.

Table 3. Multiple regression models used for pine radial increment prognosis S3 and S4

Model dendroscale	Multiple regression model; determination coefficient R^2 (p<0.05)
Aukštagiris_M	$y = (0.55 + 3.73e^{-0.04t})(1.19 + 0.08T_{Mar} - 0.36\sin\frac{2\pi t}{12} - 0.53\cos\frac{2\pi t}{21} - 0.02SO_2)$; R^2=0.56
Plytinė_M	$y = (0.97 + 3.92e^{-0.06t})(1.17 + 0.06T_{Mar} - 0.26\sin\frac{2\pi t}{12} - 0.35\cos\frac{2\pi t}{21} - 0.02SO_2)$; R^2=0.64
Romainiai_M	$y = (0.79 + 4.59e^{-0.04t})(0.83 + 0.04T_{Feb} - 0.28\sin\frac{2\pi t}{12} + 0.31\cos\frac{2\pi t}{23} - 0.01NO_2)$; R^2=0.50
Lampėdžiai_M	$y = (0.79 + 4.59e^{-0.04t})(0.98 + 0.03T_{Feb} - 0.14\sin\frac{2\pi t}{11} - 0.16\cos\frac{2\pi t}{21} - 0.004NO_2)$; R^2=0.55
Turniškės_M	$y = (1.47 + 2.91e^{-0.04t})(1.35 + 0.02T_{Mar} - 0.23\sin\frac{2\pi t}{11} - 0.28\cos\frac{2\pi t}{21} - 0.008NO_2)$; R^2=0.66
Lazdynėliai_M	$y = (1.82 + 0.63e^{-0.09t})(1.09 + 0.05T_{Mar} - 0.15\cos\frac{2\pi t}{11} + 0.13\sin\frac{2\pi t}{22} - 0.002NO_2)$; R^2=0.57

Results showed that the pace of radial increment changes in case of increasing acidifying pollutants (SO_2 and NO_2) concentration (S4 in comparison with S3) would be slow (from -0.002 till -0.006 mm per one year) but slightly faster than in the case of warming climate. In case of increasing SO_2 and NO_2 concentration till 2020 pine radial increment would decrease in all sample plots: it would decrease by -0.02 – in Lazdynėliai sample plot, -0.04 – in Lampėdžiai and Aukštagiris, -0.06 mm – in Romainiai and Turniškės, -0.07 mm – in Plytinė.

Table 4 illustrates the comparison of the pace of possible radial increment changes determined by warming climate and increasing SO_2 and NO_2 concentration in cities.

Results of radial increment changes, predicted by multiple regression models, showed that after the end of Ignalina nuclear power plant exploitation, with the increasing SO_2 and NO_2 concentration in city atmosphere, the pine radial increment in 2020 would decrease (by 0.03–0.05 mm) in major part of sample plots despite the positive impact of warming climate.

Discussion

Prognoses of recent climate change models are cautious: the pace of air temperature increase will be no more than 0.05 – 0.10°C in a decade (Rimkus 1999). Forecast for a hundred years predicts greatest changes in winter (depending on the development scenario, air temperature will rise 4–8°C) and smallest – in summer (1.5–3.5°C) (Rimkus et al. 2007). Amount of precipitation will increase in winter (depending on the development scenario, precipitation will increase 5–60 mm in a hundred years) and spring (5–38 mm), meanwhile amount of precipitation will decrease in summer (till -0.31 mm per year) and autumn (Rimkus et al. 2007).

Results of this research suggest that warming climate will have weak positive influence on pine growth and increasing concentration of acidifying pollutants – weak negative influence in Lithuanian cities, which does not contradict the findings of many other studies (Nojd and Hari 2001, Linderholm et al. 2002, Todaro et al. 2007, Juknys et al. 2002). However, there are some contradictory findings. Results of a study of mature (up to 160 years) pine trees response

Table 4. Predicted pine radial increment changes in 2020, determined by warming climate (Δ=S2-S1) and increasing acidifying pollutants concentration (Δ=S4-S3)

Sample plot	Change Δ (S2-S1), mm	Change Δ (S4-S3), mm	Total change Δ
Aukštagiris	+0.01	-0.04	-0.03
Plytinė	+0.02	-0.07	-0.05
Turniškės	+0.03	-0.06	-0.03
Lazdynėliai	+0.05	-0.02	+0.03
Lampėdžiai	+0.04	-0.04	0.00
Romainiai	+0.03	-0.06	-0.03

towards CO_2 enrichment and temperature elevation (3–5^{o}C above ambient) in experimental ecosystem in Norway showed that these factors did not significantly influence the tree radial increment and these findings contradicted many short-term studies, done with seedlings or young plants (Rasmussen et al. 2002).

There is a probability of inaccuracy in predicted pine radial increment possible changes. Results of this research are based mostly on mathematical modelling, which can not include all factors influencing pine growth in studied sample plots. Future prognosis of various factors used in models for different scenarios were based on findings and suggestions of other researchers, which also creates a probability of errors in models used for predicting pine growth. However, the pace of pine growth possible changes due to warming climate and increasing air pollution was calculated using the same method and results of this research may be relevant for evaluating possible environmental conditions in cities in future.

Global emission scenarios predict, that the concentration of greenhouse gasses in the atmosphere will increase, even if all measures for emission reduction will be undertaken (Intergovernmental Panel... 2001, Jacobson 1999, Ramanathan 1998). Carbon dioxide (3–4 % per year) and monoxide (0.5 % per year), methane (1–2 % per year), nitrogen oxides (0.3 % per year) emission will increase due to better technologies in industry and fuel consumption. Energy consumption will be 20–40 % greater in 2020 in comparison with 2000, but still 20–40 % less than in 1990 (Nacionalinė energetikos... 2002). In a few coming decades global emission of sulphates will increase, but from 2030 reduction will start and changes in nitrogen oxides concentration will be insignificant (Bukantis 2007).

Future SO_2 and NO_2 concentration dynamics prognosis after 2020 are vague. If Ignalina nuclear power plant is closed in 2009, probably the increase of acidifying pollutants concentration should slow down in coming 20–30 years and stabilize (Denafas et al. 2004). Greater changes in SO_2 and NO_2 concentration in Kaunas and Vilnius cities due to changes in European region are unlikely, as future predictions forecast the reduction of global sulphate emission from 2030 and no significant changes in nitrogen oxides emission. Probably at some point (around 2030) the pace of pine radial increment possible changes determined by climate warming and acidifying pollutants concentration (SO_2 and NO_2) will unify and it is likely that later climate warming will have major impact.

Conclusions

1. Multiple regression models, which described 53–66% of variability of actual dendroscales with probability of 95%, were suitable for pine radial increment prognosis according future scenarios (S1–S4) of warming climate and increasing sulphur and nitrogen dioxide concentration in major part of sample plots.

2. If recent cautious climate warming prognosis will be true, the pace of radial increment possible changes (S2 scenario in comparison with S1) of pines, growing in forest parks and parks in Kaunas and Vilnius cities, will be rather slow in the coming 30 years: from +0.001 to +0.004 mm per one year.

3. Comparison of multiple regression model predictions showed that the pace of pine radial increment possible changes in future scenario of increasing acidifying pollutants (SO_2 and NO_2) concentration in city atmosphere after the end of Ignalina nuclear power plant exploitation (S4 in comparison with S3) will be slow: from -0.002 to -0.006 mm per one year.

4. Pace of radial increment changes in case of increasing SO_2 and NO_2 concentration would be slightly faster than in future scenario of warming climate, thus after the end of INPP exploitation in 2009, pine radial increment in 2020 will decrease (by 0.03–0.05 mm) in major part of sample plots despite the positive impact of warming climate.

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СКОРОСТЬ ВОЗМОЖНЫХ ИЗМЕНЕНИЙ РАДИАЛЬНОГО ПРИРОСТА СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.) В ГОРОДСКИХ ЛЕСАХ И ПАРКАХ

А. ШИМАТОНИТЕ

Резюме

Загрязнение воздуха определяет угрозы деревьям, растущим в городах, вызывают изменения из-за потепления климата и увеличения загрязнения воздуха после окончания эксплуатации атомной электростанции Игналины. Цель этого исследования была оценить скорость возможных будущих изменений радиального прироста сосны обыкновенной (*Pinus sylvestris* L.) из-за потепления климата и увеличения концентраций подкисляющих загрязнителей (диоксида серы и азота) в атмосфере городов. Для анализа реакции годичного радиального прироста сосны на экологические изменения, образцы древесины были собраны из учетных деревьев 80–90-летних сосен, растущих в парках и лесопарках городов Каунаса и Вильнюса. Были созданы математические модели (отражающие 53–66% изменчивости фактического радиального прироста с вероятностью 95%) для прогноза радиального прироста сосны. Если осторожный прогноз потепления климата будет верный, в течении 30 лет скорость возможных будущих изменений радиального прироста сосны в городских парках будет довольно медленной: ежегодно от +0,001 до +0,004 мм. Скорость возможных будущих изменений радиального прироста сосны в будущем сценарии увеличения концентраций диоксидов серы и азота в атмосфере городов будет медленной: от -0,002 до -0,006 мм через год и радиальный прирост сосны в 2020 году уменьшится (на 0,03–0,05 мм) в большинстве случаев, несмотря на положительное воздействие потепления климата.

Ключевые слова: сосна обыкновенная, радиальный прирост, потепление климата, концентрация диоксидов серы и азота