Ekológia (Bratislava) Vol. 23, No. 4, p. 438–445, 2004

SCOTS PINE (*Pinus sylvestris* L.) RADIAL GROWTH IN THE VICINITY OF THE NITROGEN FERTILIZERS PLANT "ACHEMA" IN LITHUANIA

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Abstract

Stravinskiene V.: Scots pine (*Pinus sylvestris* L.) radial growth in the vicinity of the nitrogen fertilizers plant "Achema" in Lithuania. Ekológia (Bratislava), Vol. 23, No. 4, 438–445, 2004.

Results of Scots pine (*Pinus sylvestris* L.) growth in the vicinity of long-term air pollution source of Jonava nitrogen fertilizers plant "Achema" are presented. The objective of investigation was the analysis of changes in annual radial increment of Scots pine forests growing in the zones of intensive (3–12 km) and moderate (13–24 km) pollution during different periods (fertilization, depression and recovery) of tree reaction to air pollution. It was ascertained that during the fertilization period a small amount of nitrogen emissions affected tree growth positively: annual radial increment in both the zones of pollution was similar to the control forests or higher. Negative effect of pollutants on pine forests started in 1974–1979. The greatest damages to forests were caused in 1979-1983, when the amounts of emissions with prevailing sulphur dioxide were the highest (34–40 thou. tons annually). During the depression period annual radial increment of pine forests growing in the zone of intensive pollution comprised only 60–65%, compared to the control pine forests. The most severely damaged 60-year-old pine stands lost 2.66 m^3/ha of wood per year on the average. In 1986–1988 changes in pine annual radial increment stabilized at the level of 1980–1982, while in 1990–2003 a tendency of pine forests recovery and increasing radial increment is observed.

Key words: air pollution, Scots pine, increment loss

Introduction

Air pollution is ascribed to predisposing and tree condition worsening factors (Manion, Lachance, 1992). Some authors point out, that air pollution impact on forests appears only under very high concentrations of pollutants and is revealed only locally (Kandler, 1992; Landmann, Bonneau, 1995). Under polluted air almost ceases the growth of conifers is limited. Ever more researchers think, that the decrease of tree radial increment, forest damage

and decline are caused by the deposition of dry pollutants (Schulze, 1989; Lindberg et al., 1990).

Conifer trees are especially sensitive to environmental pollution impact. Therefore they are the perfect indicators of environmental condition.

As far as tree-rings (annual radial increment of trees) accumulate information on phenomena taking place in the environment (Eckstein, 1989) and serve as natural monitors (Schweingruber, 1989, 1996), information provided by them allows to objectively evaluate all changes taking place in the environment and indicate the effect of long-term air pollution to forest decline. As an anatomical indicator of tree condition, annual radial increment of trees can be used. The dynamics of annual radial increment is reliant not only on biological characteristics of tree species, but also by the main climatic parameters: air temperature and the amount of precipitation (Eckstein, 1989; Lovelius, 1997; Stravinskiene, 2002, etc.)

The main task of this research is to estimate changes in radial increment of Scots pine (*Pinus sylvestris* L.) growing in the environment of long-term industrial pollution.

Material and methods

The investigation was carried out in the vicinity of the biggest polluters in Lithuania, i.e. the plant of mineral fertilizers "Achema" situated in Jonava district in the central part of Lithuania. "Achema" was run in 1965 and was gradually expanded until 1978, when total annual emissions reached the maximum amount – almost 40 thou. tons. Scots pine (*Pinus sylvestris* L.) forests prevail in this region. Pine forest stands, growing in *Pinetum vacciniosum* and *Pinetum vaccinio-myrtillosum* forest types 3–12 and 13–24 km away from the pollution source were chosen as the object of this research. 20 sample plots were singled out in homogeneous stands or ones with a small (up to 20%) admixture of other species in Scots pine forests of 0.7–0.9 stocking level in 6 forest districts (Azuolyne, Jonava, Liepiai, Santaka, Vepriai and Upninkai) of Jonava forest enterprise. Control plots were chosen in analogous according to all biometric parameters Scots pine stands growing in forest ecosystem without local air pollution.

Tree-ring samples (boreholes) were taken with a special borer. 660 wood samples were taken and 45000 annual radial increment measurements were conducted. For annual radial increment measurement and assessment, LINTAB tree ring measurement system and TSAP set of programs were used. Measurement accuracy (± 0.01 mm) was chosen depending on the aim of study. Primary tree ring measurement data is recorded on a diskette to facilitate further processing of the information by mathematical statistics and dendrochronological analysis methods according to special TSAP programs, usable for dating, synchronization, compiling of chronologies, etc. For the dating of annual rings and tree increment synchronization, methodics used worldwide for dendrochronological studies was applied, on the basis of which a set of TSAP programs was worked out (TSAP by FRANK RINN and SIEGWARD JAKEL, Heidelberg, Germany).

The control stand method was used to estimate radial increment, losses in the zones of local pollution impact, when climatic conditions are similar to all stands. It was conditionally agreed, that background pollution level is the same on the whole Lithuanian territory. Having chosen for local pollution control a stand growing in a relatively clean place, increment differences reflect only the impact of local pollution on trees. It is necessary to evaluate, if radial increment of the control stand since the start of growth was not higher than that of studied stands, if their dynamics and the range of fluctuations were similar until the onset of local pollution.

Annual radial increment losses or additional increment (%) were calculated by comparing radial increment data of control and investigated stands by the formula:

$$Z_n = \frac{Z_k - Z_L}{Z_k} \cdot 100, \quad (1)$$

where Z_n – losses of annual radial increment (additional increment – when the increment of sample stand is higher than that of control stand)
Z_k – increment of control stand
Z_t – increment of investigated stand (Stravinskiene, 2002).

Results and discussion

Structure and dynamics of Jonava "Achema" emissions

CO, SO_2, NO_2, NH_3 and mineral dust prevail in the emission stream from Jonava mineral fertilizers plant "Achema". Since 1971 the amounts and concentrations of emitted pollutants were gradually increasing. The biggest compound stream of annual emissions was in 1979–1981 – every year even 34–40 thou. tons of pollutants were emitted into the atmosphere.

Sulphur and nitrogen compounds comprise an essential part of overall emissions. In the zone of intensive pollution sulphates amounted 100 kg/ha, while in the moderate pollution zone – 87 kg/ha, 2.5 and 2.2 times exceeding background concentrations. Nitrate emissions in the zone of intensive pollution 5.9 times, while in the moderate pollution zone 4.8 times exceeded background concentrations. As it can be seen from Fig. 1, since 1982 emissions started decreasing and until 1988 their amount was reduced even 8 times.

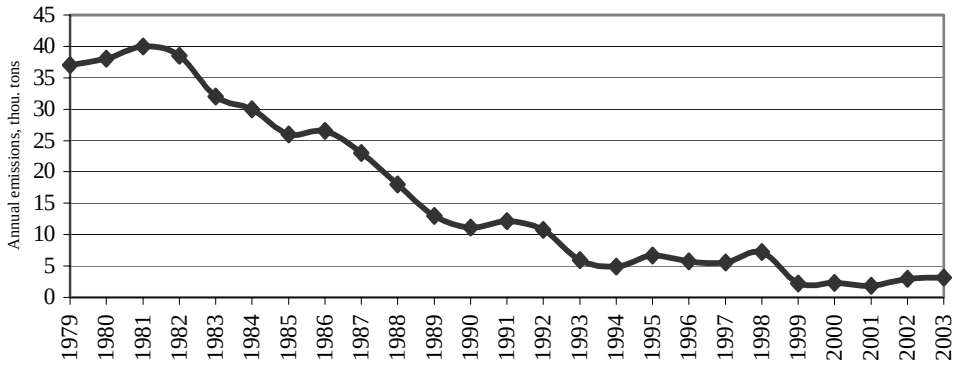

Fig. 1. Total annual emissions of Jonava nitrogen fertilizers plant "Achema" in 1979–2003.

A very essential reduction of emissions to air has started since 1993. In 1997 overall emissions from "Achema" plant comprised only 5.5 thou. tons. However, some increase in total annual emissions (up to 7.5 thou. tons) was recorded in 1998 (Armolaitis, 2002). In recent years (1999-2003) annual emissions comprised 2.1-3.4 thou. tons, i.e. several times less than in 1980–1982.

Many authors (Schulze, 1989; Lindberg et al., 1990; Kandler, 1992; Landmann, Bonneau, 1995, etc.) have proved that high concentrations of sulphur dioxide are harmful to plants, causes necrosis, gradual degradation and decline.

Annual radial tree increment changes in the impact zone of industrial pollution

As it was estimated (Stravinskiene, 2002; Juknys et al., 2002) the greatest influence on annual tree ring formation in Lithuania has air temperature during the period of active vegetation (may-august), as well as the amount of precipitation in summer mounts. The growth of annual radial increment is caused by temperature higher than mean annual and the amount of precipitation lower than mean annual, but a lower temperature and a higher precipitation act as the growth limiting factors and induce a decrease of annual radial increment.

Until the onset of pollution (in 1965) the fluctuations of annual radial increment in pine stands were close to Solar activity 11 and 12-year cycles, which in their turn lead to climatic background variation (Fig. 2).

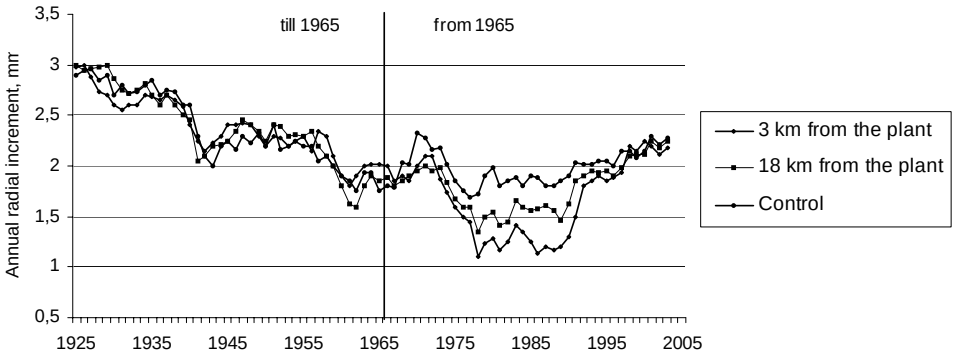

Fig. 2. Dynamics of Scots pine radial growth nearby the source of pollution (3 km from the plant), at more distant (18 km from the plant) and control stands.

Increment maximums (in 1945–1950, 1958–1959, 1965) coincided with favorable for growth warm periods, while minimums (1940–1943, 1956–1957) were relevant to low air temperature at the beginning of vegetation periods, when precipitation amount was close to norm, as well as in cold and rainy vegetation periods.

Since 1965, when "Achema" plant started to produce fertilizers, small amounts of nitrogen emissions had a positive impact on tree growth. This period was called as fertilization period. Therefore, in the first five-year period following the start of fertilization, annual radial increment of pine trees in the zones of intensive (3–12 km) and moderate (13–24

km) pollution were similar, i.e. close to the control, or insignificantly higher. The duration of fertilization period for Scots pine stands growing at different distances from the pollution source was different – from 6–7 years for pine forests growing nearby (3–4 km) the source of pollution up to 4–5 years for the most distant (20–21 km) forests. An additional tree increment (as compared to the control) during the period of growth promotion (fertilization) comprised approximately 15–20% (P = 0.95).

Several years later the impact of increased amount of emissions became negative and caused Scots pine growth depression. At the beginning of another five-year period a decrease in radial increment is observed, depending on the distance from pollution source and the age of stands. In the zone of intensive pollution Scots pine radial increment in 1973–1977 comprised 83–90%, while that in the zone of average pollution – 87–91% from the control radial increment (Stravinskiene, 1995, 2002).

A rapid decrease of annual increment was observed since 1979, when environmental pollution essentially increased: in the zone of intensive pollution nearby the plant annual radial increment of Scots pine reached only 60–70% from the increment of control stands in that year. The dynamics of pine radial increment until the beginning of pollution in 1965 and since 1965 is presented in Fig. 2. The data of radial growth illustrate the losses of annual radial increment during the depression period of pine forests nearby the plant and at the most distant sites comparing to the data of control stands.

Unfavorable climatic conditions have reinforced the negative impact of pollutants, which after the exclusively cold winter of 1978–1979 – an additional unfavorable external factor – caused weakening of Scots pine trees and their degradation. It was an extra unfavorable environmental factor, which speeded up and intensified growth depression, followed by a sharp worsening of the condition and growth of all stands growing in the impact zone of "Achema" plant. In 1983–1984, annual radial increment of Scots pine in the zone of intensive pollution made up only 75–83%, while in the moderate pollution zone radial increment of trees comprised 82–88% from the control.

The duration of depression period in closest to the plant and most damaged stands lasted for 10–12 years, while in the most distant and less damaged forest stands it took only 4–8 years. Average losses of pine annual radial increment during the depression period comprised 40–45% for the less distant and most damaged stands and 15–25% for the most distant ones.

In 1986–1988, in the result as a result of a considerable decrease of environmental pollution, increment loss became stable. It was not decreasing any more, though in 1988–1989 climatic conditions were not favorable (cold and rainy vegetation periods) for increment formation.

Recovery of damaged stands in the surroundings of "Achema" was indicated since 1990, when environmental pollution was reduced. In 1990–1999 annual radial increment was restored; increment losses was on the level of the first five-year period (1968–1972) pollution, named as fertilization period.

Pine volume increment losses in the vicinity of local pollution source

Mean increment losses over 38 years of local industrial pollution in the zone of intensive contamination in 60–70-year old Scots pine stands comprised 2.46 m^3/ha. The greatest loss of volume increment was registered in the 3rd and 4th five-year periods of industrial pollution, when the plant of nitrogen fertilizers "Achema" was heavily polluting the environment (Fig. 3).

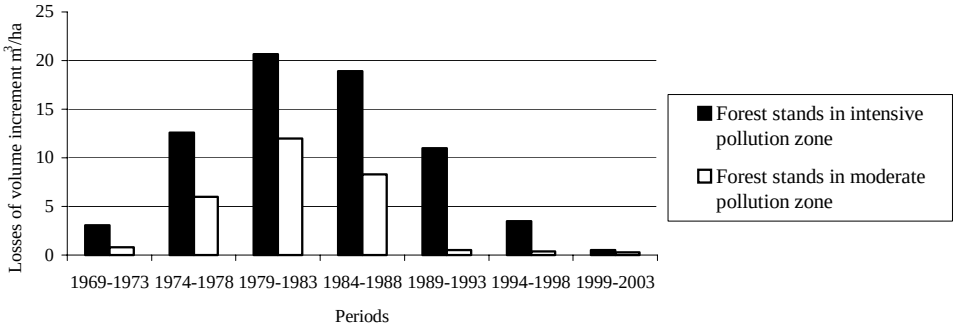

Fig. 3. Losses of Scots pine (*Pinus sylvestris* L.) volume increment in different zones of industrial pollution.

Volume increment losses of wood production in Scots pine forests growing nearby the pollution source in five-year periods are distributed as follows: 1969–1973 – 3.06; in 1974–1978 – 12.6; in 1979–1984 - 20.64 m^3/ha. While in 1984–1988 these forests suffered 18.92 m^3/ha wood production losses. The losses of wood production volume in 1989–1993 decreased slightly (11 m^3/ha), in 1994–1998 – moderately (3.5 m^3/ha) and in 1999–2003 – strongly (0.5 m^3/ha).

Volume increment losses are considerably less at the most distant Scots pine sample forests as compared to forests growing nearby the source of pollution.

Conclusions

Having analysed the radial growth of Scots pine (*Pinus sylvestris* L.) in sample plots affected by local pollution of "Achema" plant, it was ascertained:

1. Until the onset (in 1965) of pollution annual tree radial increment fluctuations in pine forests are close to 11 and 22-year Solar activity cycles – increment maximums coincide with favorable for growth warm periods, while minimums – with low air temperature at the beginning of vegetation periods, when precipitation is close to the norm, as well as with cold and rainy vegetation periods.

2. During the first five-year pollution period a small amount of nitrogen emissions had a positive impact on tree growth: annual radial increment of Scots pine in the zones of intensive (3–12 km) and moderate (13–24 km) industrial pollution was similar to the control or even 15–20% higher (comparing to the control).
3. Permanent negative effect of pollutants on radial growth of pine forests in vicinity of the plant of nitrogen fertilizers "Achema" started in 1974–1978. The greatest damages to pine forests were caused in 1979–1983, when in the zone of intensive pollution annual radial increment of Scots pine comprised only 60–70%, compared to the control. During this period the amounts of emissions with prevailing sulphur dioxide were the highest (34–40 thou. tons annually).
4. Duration of the depression period in the closest to the plant and most damaged stands lasted for 10–12 years, while in the most distant and the least damaged forest stands it took only 4–8 years.
5. The stabilization of radial growth decrease and the beginning of recovery of damaged stands was indicated in 1989–1993, when annual amount of the plant emissions and environmental pollution was considerably reduced.

Translated by the author

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Received 23. 4. 2004

Stravinskiene V.: **Radiálny rast u borovice lesnej** (*Pinus silvestris* L.) **v blízkosti závodu na výrobu dusíkatých hnojív "Achema" v Litve.**

V práci prezentujeme výsledky rastu borovice lesnej (*Pinus silvestris* L.) v blízkosti závodu na výrobu dusíkatých hnojív "Achema", ktorá je zdrojom dlhodobého znečistenia ovzdušia. Predmetom výskumu bola analýza zmien v ročnom radiálnom prírastku u borovice lesnej v zóne intenzívneho (3-12 km) a mierneho (13-24 km) znečistenia v rôznych obdobiach (hnojenie, depresia a regenerácia) reakcie stromu na znečistenie ovzdušia. Potvrdilo sa, že počas hnojenia malé množstvo dusíkatých emisií pozitívne ovplyvnilo rast stromu: ročný radiálny prírastok v oboch zónach znečistenia bol podobný alebo vyšší ako u kontrolných lesoch. Negatívny vplyv pollutantov na borovicu lesnú začal v rokoch 1974-1979. Najväčšie zničenie lesov bolo v rokoch 1979-1983, keď množstvo emisií s prevahou kysličníka sírnatého bolo najvyššie (34-40 tisíc ton ročne). Počas depresie ročný radiálny prírastok u borovice lesnej v zóne intenzívneho znečistenia dosiahol iba 60-65% s porovnaní s kontrolnými lesmi. Najviac poškodené 60-ročné borovicové porasty priemerne ročne stratili 2.66 m^3/ha dreva. V rokoch 1986-1988 zmeny v ročnom radiálnom prírastku sa stabilizoval na úrovni rokov 1980-1982, kým v rokoch 1990-2003 sme zaznamenali tendenciu obnovy borovicových lesov a rast radiálneho prírastku.