DENDROCHRONOLOGICAL STUDIES OF TECHNOGENIC CHANGES IN PINE FORESTS OF THE VORONEZH REGION

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Features of reaction of stands of the grassy-pine type of forest of the Voronezh green zone to technogenic pollution of the environment have been revealed on the basis of dendrochronological analysis. Studies were performed of two sets: 1) a set of trial plots at different distances from a heavy stationary pollution source and 2) a set of plots at different distances from a road. At intensive pollution there has been a great decline in tree radial increment and its cyclic recurrence has been disturbed, especially in the last 20 years.

technogenic pollution; pine forests; dendrochronological analysis; radial increment; growth dynamics

INTRODUCTION

Consequences of pollution of the ecological environment, which were revealed as a negative tendency in the past two decades, turned to be a factual problem which now requires a priority attention, especially in the economically developed regions. Anthropogenic factors have a determining effect on the condition and biosphere productivity and first of all on forest ecosystems. Technogenic pollution plays a very big role in terms of the scale and of risks imposed on forest ecosystems. To determine the extent of these effects, dendrochronological method is widely used (Lovelius, 1979; Tzubanov, 1986; Kort, 1986; Rieger, 1986; Stravinskene, 1987; Alexejev, 1990; Graybill, 1991; Darchovskij, 1990; Matvejev, 1994; Smith, 1985; Tarankov, Matvejev, 1993, 1994, etc.). Growth increment of separate trees and stands is the most universal and generalizing attribute of their condition. The size of growth increment and fluctuation regime of the research interval provide valuable information about functional processes of stands in the zone under active anthropogenic influences.

MATERIAL AND METHODS

For evaluation of the impact of air pollution with industrial effluents on radial increment of pines (*Pinus silvestris*), numerous trial plots (0.2–0.25 ha) were established at different distances from the source of pollution in artificial pure (monospecific) pine forests of the second age class (20–40 years, 35 years precisely) of grassy-pine type (pine with grasses according to Sukachev). For detailed characteristics of the plots, see Matvejev (1994).

In the south-east part of Voronezh, there is a high concentration of enterprises and industries such as, e.g. power station, rubber synthesising industries, quarries, tyre plant, polluting heavily the surrounding environment. Not far from these industries there are artificial pine forest stands of the Novousman forests. Trial plot No. 12 is located very close to the source of pollution, about 2 km east from the boundaries of the industrial zone (in direction of the prevailing winds). Trial plot No. 13 was established 4 km far from the boundaries in the south-east direction (perpendicular to the direction of the prevailing winds). At a distance of 0.5 km from the aluminium plant there is trial plot No. 14. At a distance of 13 km from the industrial zone in the direction against the prevailing winds there is trial plot No. 15 used as a check plot. In the centre of Voronezh there is the City Park (forest plantation of about 25 ha). This forest plantation suffers from intensive complex effects of anthropogenic factors (continuous, all-year-round leisure-time activities, air pollution by different industrial plants and different means of transport). Trial plot No. 16 is located there. All enterprises contributing to the environmental pollution were active already before the forest plantation, except the aluminum plant opened in 1973.

Dendrochronological analysis was carried out of pure artificial pine forests of the second age class (35 years) with grassy-pine stands exposed to traffic pollution alongside the Voronezh–Rostov road by testing a sample of selected trees from trial plot No. 17 (located alongside the road) and No. 7 (50 m far from the road). Plot No. 15 was used as the check one.

For dendrochronological analysis 10 trees were selected on every plot. One core sample was taken from each one. This sampling method ensures a maximum 10% relative standard error of mean width of the year-ring (with a 30% coefficient of variation) (Matvejev, 1994). Sample trees with stems of a good quality with regular year increment, without injuries, belonging to classes 2 and 3 according to Kraft were chosen. Samples were taken by borer from the west side of stems with respect to the direction of the prevailing winds in the region of Voronezh. General trends in radial year increment are easier to determine by using one sample from one tree which eliminates the influence of factors affecting individual trees (Bitvinskas, 1974).

For the year width measurement stereomicroscope MBS-9 with micrometer scale was used. The accuracy was 0.05 mm. Average values were determined for each plot from 10 sample trees, smoothed by the method of sliding averages for an 11-years period (Bitvinskas, 1974). To eliminate the age effect and to enable data correlation the method of relative indexes was used (Rudakov, 1951; Bitvinskas, 1974; Moltshanov, 1976).

A graphic method was used to compare the obtained data correlating periodicity, dynamics, fluctuation of amplitude, minimum and maximum radial increment values (Matvejev, 1994).

Statistical significance of radial increment decrease was calculated by using the formula:

$$t = (x_1 - x_2) \cdot (m_1^2 + m_2^2)^{-1/2}$$

where: x_1, x_2 – sampling averages

m_1, m_2 – standard errors

If $t > 3$, the difference is significant, confirmed and the studied effect is supposed to cause the observed phenomenon. If $t = 2$, the error probability is 5% (Dvoreckij, 1971). The average radial increments of *Pinus silvestris* on the trial plots of the last 10 years were compared with the check values for individual years.

RESULTS AND DISCUSSION

The graphic analysis of radial increment of *Pinus silvestris* documented regular fluctuations of amplitude (extent) and periodicity in the check stand (plot No. 15). Periodicity fluctuations of a little more chaotic tendency were observed at a distance of 4 km from the industrial zone (plot No. 13) with amplitude increasing with the stand age. Periodicity fluctuations became totally chaotic and amplitude increased considerably with age at a distance of 2 km from the pollution source (plot No. 12). Concerning plot No. 14, 0.5 km far from the aluminium plant working from late 1973, periodicity remained stable but amplitude increased considerably from 1974 with an increment reduction observed from 1978. In the City Park (plot No. 16) a continuous reduction of increment was observed during the life of pines. Periodicity still occurred but fluctuations were irregular and very frequent.

A decrease in radial increment of forest trees as well as stands was documented by many other authors (Sabirov, 1987; Tshubanov, 1989; Bartkjavitshus, Agustaytis, 1990, etc.). Other works describe an increase in growth intensity of forest trees under air pollution (Simatshov, 1990). An increase in the amplitude of increment fluctuations in trees exposed to industrial pollution is documented by contributions of A l e x e j e v (1990) and T s h u b a n o v (1989).

An analysis of the extreme values of increment (Tab. I) showed an increase in amplitude fluctuations in *Pinus silvestris* with decreasing distance from the emission source. Absolute values of the year-ring width showed the lowest minimum on plot No. 16 (the City Park) with values increasing with distance from the emission source. The minimum value on plot No. 14 (0.5 km far from the aluminium plant) was registered in 1974 next to the opening of the plant. The minimum absolute values of late wood width increased in the order: plot No. 12 (2 km far from the industrial zone), plot No. 13 (4 km far from the industrial zone) and plot No. 15 (check plot), i.e. with distance from the source of pollution. The maximum absolute values are not relevant as they were always registered in the first year's rings (early growth), thus reflecting the age of trees.

The minimum values of relative indexes of the whole year-rings showed also an increase with distance from the pollution source. The highest increment was indicated by relative indexes on plot No. 16 (the City Park), probably due to a decrease in absolute increment in the studied period. The same situation appeared in late wood. More polluted plots showed higher values of increment corresponding to the maximum values of relative indexes of year-rings (excluding plot No. 16). Thus the results document both a decrease

I. Extreme values of radial increment of *Pinus silvestris* under pollution effects

Plot No.	Absolute values (mm)		Relative indexes (%)			
	year	maximum/ /minimum	year	maximum	year	minimum
12	1973	0.99	1982	147	1973	53
	1973	0.23	1981	137	1973	39
13	1984	1.17	1982	148	1984	61
	1984	0.29	1981	141	1984	50
14	1974	1.20	1978	153	1974	56
	1972	0.35	1967	138	1972	53
15	1987	1.33	1982	137	1969	65
	1985	0.37	1983	151	1985	56
16	1984	0.78	1974	137	1984	60
	1984	0.74	1978	134	1984	63

Above – whole year-ring width, below – late wood width for particular plots

in the minimum values and an increase in amplitude with decreasing distance from the emission source.

As for the maximum values of relative indexes for late wood, the lowest value was obtained for plot No. 16 under the heaviest anthropogenic load while the maximum one appeared on check plot No. 15. This means that the maximum values of relative indexes of late wood did not increase with decreasing distance from the source but decreased in comparison to the whole year-ring dynamics. The minimum values of relative indexes of late wood also decreased with decreasing distance from the pollution source; this meant that late wood width decreased with decreasing distance from the stationary pollution source.

A visual analysis of graphs of radial increment in stands near the road did not reveal a disturbance of radial increment periodicity but a considerable increase in amplitude. This is quite clear when analysing the extreme values of radial increment (Tab. II). As the absolute values both of the whole year-ring and late wood widths show, the minimum values decreased with decreasing distance from the road. Relative indexes show that the maximum values of the year-ring width increased and the minimum ones decreased in such direction. There is a very big difference in the maximum values of relative indexes of individual plots. The results document a remarkable increase in fluctuation amplitude towards the road.

The highest maximum of late wood as well as the whole year-ring width (relative indexes) was observed near the road but the minimum values for late wood (relative indexes) showed the opposite tendency with the lowest minimum of increment near the road. Like the situation on plot No. 16 (the City Park), this reflects the phenomenon of a long-time reduction of late wood increment caused by traffic pollution.

For evaluation of quantitative changes in growth increment of *Pinus silvestris* under the effects of atmospheric pollution, the average radial increment was analysed in absolute units (mm) for the last 20 and 10 years (Tab. III). The whole ring increment for the past 20 years was minimum in the forest of the City Park (plot No. 16) and 2 km away from the city boundaries (plot No. 12). A higher growth increment of annual rings appeared on plot No. 13 (4 km far from the industrial zone) due to a relatively small intensity of atmospheric pollution and on plot No. 14 (0.5 km far from the aluminum plant) with a little delayed beginning of pollution (1974). The initial short-term increase in growth increment under the effects of air pollution was observed also by other researchers (A l e x e j e v , 1990). During the last decade, the influence of technogenic pollution on reduction of growth increment was more remarkable. The deepest depression was observed especially in the forest of the City Park (plot No. 16) where the difference between the radial increment values and the check ones was statistically significant (t = 3.87 > 3).

A comparative analysis of radial increment dynamics in stands near the road showed a sharp increase in fluctuation amplitude of growth increment towards the road and a disturbance of cycle recurrence. The mean radial increment of annual rings (mm) for the last 20 and 10 years increased from the source of pollution (the road) towards the check plot. During the last decade average increment decreased on all trial plots with a growing intensity towards the road (Tab. IV).

Statistical differences between the radial increment values alongside the road and the check ones are at a level of 97%, or have a probability significance (t = 2.18 > 2). It is obvious that in the remaining cases the fall in radial

II. Extreme values of radial increment of *Pinus silvestris* under traffic pollution

Plot No.	Absolute values (mm)		Relative indexes (%)			
	year	minimum	year	maximum	year	minimum
17	1987	1.01	1978	197	1976	58
	1968	0.28	1983	163	1968	62
7	1968	1.07	1978	163	1984	64
	1969	0.33	1973	149	1969	58
15	1987	1.33	1982	137	1969	65
	1985	0.37	1983	151	1985	56

Above – whole year-ring width, below – late wood width for particular plots

III. Average radial increment of *Pinus silvestris* at different distances from the stationary pollution source

Parameter		Plot No.				
		12	13	14	15 (check)	16
Distance from industrial zone	(km)	2.0	4.0	0.5	13.0	city
Average increment of 20 years	(mm)	1.96	2.19	2.14	2.13	1.83
	(%)	92	103	101	100	86
Average increment of 10 years	(mm)	1.95	1.98	2.09	2.1	1.2
	(%)	93	94	99	100	58
Std. error (10 years)	(m)	0.118	0.126	0.142	0.169	0.160
t-statistics (10 years)	(t)	0.73	0.58	0.06	–	3.87

IV. Average radial increment of *Pinus silvestris* at different distances from the road

Parameter		Plot No.		
		17	7	15
Distance from the road	(m)	0	50	check
Average increment of 20 years	(mm)	1.91	2.03	2.13
	(%)	90	95	100
Average increment of 10 years	(mm)	1.53	1.91	2.10
	(%)	73	91	100
Std. error (10 years)	(m)	0.202	0.089	0.169
t-statistics (10 years)	(t)	2.18	1.03	–

increment has not reached a critical level yet as confirmed by the statistical analytical method.

CONCLUSIONS

- On sites exposed to intensive technogenic pollution a steady but significant fall in radial increment in the stands (plots No. 16 and 17) occurred. During the last decades (with longer lasting technogenic effects) the intensity of fall in growth increment on polluted trial plots increased.
- With decreasing distance from the source of pollution there was a sharp, dramatic fall in the mean absolute increase in the stands, an increase in fluctuation amplitude and a disturbance of cycle recurrence increment. Late wood annual ring decreased which indicates a lower wood quality and resistance of the ecosystem as a whole.
- Statistically significant differences in radial increment values in the stands were observed between the check ones (plot No. 15) and those of the most polluted forests of the City Park (plot No. 16). Differences between the radial increment values on plots alongside the road (plot No. 17) and check plot No. 15 were determined with a 97% probability significance.

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Dendroindikace technogenních změn v borových porostech voroněžské oblasti.

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V práci jsou uvedeny výsledky aplikace dendrochronologických metod při studiu reakce borových porostů typu travnatých borů (podle Sukačeva) na antropogenní znečištění v příměstských lesích Voroněže. Výzkum byl prováděn ve dvou souborech ploch: 1) soubor ploch v různých vzdálenostech od silného lokálního zdroje průmyslového znečištění, 2) soubor ploch v různé vzdálenosti od silně frekventované silnice. Reprezentativním způsobem byly na jednotlivých plochách odebrány vývrty a aplikovány standardní metody dendrochronologické analýzy. Výsledky jsou uvedeny v tab. I a II.

Z analýzy výsledků vyplývá:

- Na stanovištích se silným vlivem technogenního znečištění je pozorován stálý a významný pokles radiálního přírůstu borovice (plochy č. 16, 17). Během posledních desetiletí spolu s růstem imisního zatížení roste i intenzita poklesu tloušťkového přírůstu.
- S klesající vzdáleností od zdroje znečištění je doložen výrazný pokles průměrného přírůstu, nárůst amplitudy přírůstů a narušení cykličnosti přírůstu. Dále se snižuje podíl letního dřeva, což indikuje sníženou kvalitu dřeva a rezistence ekosystému jako celku.
- Statisticky významné rozdíly byly potvrzeny mezi kontrolní plochou (č. 15) a nejvíce zatíženou plochou městského parku (plocha č. 16). Rozdíly v radiálním přírůstu plochy u silnice (plocha č. 17) a plochy kontrolní (č. 15) byly významné na 97% hladině spolehlivosti.

antropogenní znečištění; borové lesy; dendrochronologická analýza; radiální přírůst; růstová dynamika

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