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Air pollution effects on 15 European and Siberian Scots pine (*Pinus sylvestris* L.) provenances growing in a 75-year-old experiment*

Abstract

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Results are presented of dendrometric and viability evaluations of trees in a provenance experiment established in 1912, in which there are 15 Scots pine provenances represented, from Poland in the west to central Siberia in the east, and from Arkhangelsk in the north to Turkey in the south. The experiment is localized 3 km from the Nitrogen Works in Puławy which emit substancial quantities of SO_2, NH_3, NO_x and dusts of saltpeter and urea. It was established that in the years 1981 - - 1986 the number of trees declined by 20 - 57% for individual provenances and the standing volume generally declined by 22%. The most damaged crowns were observed on trees originating from Tobolsk (Ural) and Kars (Turkey) and least on those from Kiev, Jenisiejsk and Arkhangelsk. In view of the small distance from the emitter and the associated with it high concentrations of pollutants, the substancial differences between populations which were still visible during the last measurement in 1981 are now gradually disappearing.

Additional key words: genotype × environment interaction, susceptibility, environmental pollution, populations.

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INTRODUCTION

During the last several decades on various occasions studies were undertaken aimed at establishing the individual, progeny and population variability of trees in sensitivity to industrial air pollution. The influence of toxic gases on various Scots pine populations has been studied both in laboratory conditions (Schütt et al. 1970, Demeritt

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1977) and in the field (Huttunen 1978, Huttunen, Törmälehto 1982, Oleksyn 1983, Oleksyn, Białobok 1986). It needs to be stressed that a common feature of the majority of the studies conducted so far was that the studies were performed on juvenile material.

In view of the fact that the oldest and at the same time one of the largest provenance experiments with *P. sylvestris* in Poland, located in Forest Range Ruda near Puławy, is since 1966 under the influence of pollution emitted from the Nitrogen Works located 3 km from the site, an attempt was made to evaluate the influence of this pollution on growth of individual populations (Oleksyn 1983). The results of dendrochronological studies conducted have shown that there is a relatively small decline in volume increment on pines of northern provenances from the former regions (gubernias) of the pre-revolutionary Russia such as Olonec, Arkhangelsk, Vologda and Kurland compared to pines from the central part of the range of the species.

It was the aim of the studies presented in the present publication to evaluate the damage to trees by industrial pollution and to determine other changes which took place in the experiment presented above over the 5 years since the last measurement made in 1981 (Oleksyn, Giertych 1984).

DESCRIPTION OF THE EXPERIMENTAL AREA

The experimental area with various provenances of *Pinus sylvestris* L. has been established in 1912 by S. Z. Kurdiani in compt. 25 of the present experimental Forest Range Ruda in the Institute of Cultivation

Table 1

Provenances of Scots pine used in the experiment of S. Z. Kurdiani in Forest Range Ruda near Puławy

Plot no.	Region	Forest Range	Coordinates[1] N	E
1 - 2	Lublin		51°24′	22°03′
3	Kars	Songalugskoe and Boržomskoe	40°30′	42°00′
4	Arkhangelsk	Verkoleskoe and Lasskoe	63°50′	45°10′
5	Kharkov	Majackoe and Kent's estate	50°00′	36°20′
6	Olonec	Karganopolskoe and Podomskoe	61°30′	39°00′
7	Voronež	Hrenovskoe	51°06′	40°17′
8	Vologda	Georgievskoe	59°43′	36°52′
9	Jenisiejsk	Jenisejskoe (Konsko-Jenisejskoe)	58°00′	62°00′
10	Novgorod	Tihvinskoe	59°37′	33°33′
11	Tobolsk	Turinskoe and/or Jauturovskoe	58°00′	63°42′
12	Volyniya	Luckoe	50°45′	25°18′
13	Ufa	Šajtanovskoe	55°00′	52°00′
14	Kiev	Dymarskoe	50°50′	30°17′
15	Tver	Viesiegonskoe	58°38′	37°13′
16	Kurland	Rucavskoe	56°07′	21°08′

[1] The data concern geographic coordinates of individual ranges in which seed was collected for the experiment as given by Fomin (1940). Some of them are only approximate.

and Fertilisation (IUNG) in Puławy (51°24' N, 22°03' E). Information about discovery of the experiment, its detailed description and scientific purpose to which it was directed we have presented in earlier publications (Oleksyn, Giertych 1982, 1984, Oleksyn 1985). Thus only the basic information about the experiment is given here.

For the establishment of the experiment seed of *P. sylvestris* were used which represented 15 populations of the species from the European part of the former Russian Empire and from Siberia. Data on the origin of the seed is given in Table 1.

The planting site is at 140 m elevation, slightly sloping in the northwesterly direction. The soils here are sandy, originating from shallow sands on gravel (Tomaszewski 1928). The mean annual sum of precipitation for Puławy in the period 1920 - 1980 was 571 mm and the mean monthly temperature for the same period varied from −3.8°C in January to 18.5°C in July.

ATMOSPHERIC POLLUTION IN THE VICINITY OF THE PUŁAWY NITROGEN WORKS

The Nitrogen Works were localized 3 km northwest from the experimental area (fig. 1). Operations started in June 1966 after the sector "Azoty I" producing urea was opened. In November of the following year "Azoty II" started operation producing nitric acid and ammonium nitrate. The degree of air pollution with toxic substances emitted from these works in different years shown in Table 2, was taken from Trojanowski (1983). It needs to be stressed that besides emissions resulting from the normal production process there occur also uncontrolled emissions, associated with equipment failures. In such instances toxic substances are emitted into the atmosphere the concentrations of which several times over exceed the annual average values.

The first symptoms of plant injuries caused by the emitted pollutants have been observed in the spring of 1967 (Jakubczak et al. 1969). They occurred also with substancial intensity in the region adjacent to the settling pond for industrial sewage and ashes from the heat and power generating plant. The complete dying of pine stands in that same year already affected an area of several dosen hectars (Puszkar 1979). Since that time the zone of death expanded several times attaining in 1978 an area of about 1200 ha (Puszkar 1980, after Trojanowski 1983). It extends primarily in the easterly direction, which is associated with the prevailing winds in the region (Tab. 3, fig. 1).

Sierpiński (1972) was of the opinion, that the very fast rate of dying of stands in the vicinity of the Nitrogen Works is associated with the exceptionally high, though short lasting, concentrations of pollutants reaching the forests as a consequence of uncontrolled emissions during equipment failures.

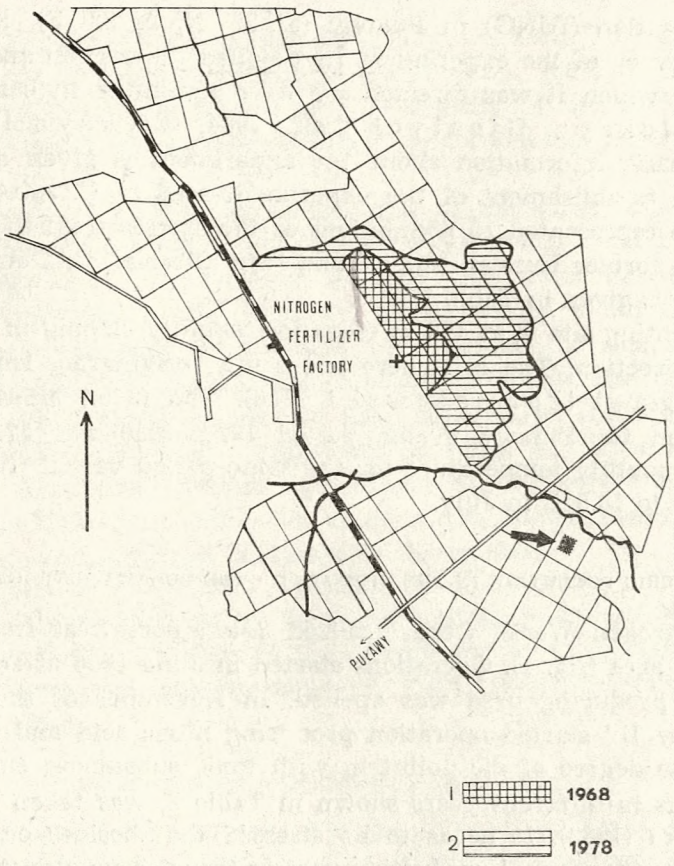

Fig. 1. Zone of complete deforestation in the vicinity of Puławy Nitrogen Works in the years 1968 (1) and 1978 (2) (after Trojanowski 1983, somewhat changed). The arrow indicates location of the provenance experiment and + the plant producing ammonium nitrate

The magnitude of the zone of injury to plants is also associated to a large extent with the height of the emitting chimneys. In the case of the toxic nitrogen compounds the emissions occur from relatively low emittors: 6 chimneys 47 m tall emit ammonium nitrate, and 5 chimneys 30 m tall emit gaseous ammonia (Trojanowski 1983). A part of the nitrogen compounds reaches the atmosphere also from the surface of tanks with industrial sewage. This results in the formation of particularily high concentrations of atmospheric and soil pollution near the Nitrogen Works itself (Fig. 2). According to Adamczyk-Winiarska (1980) within a radius of 2.5 km from the emitor the permissible norm of NH_3 in the air has been exceeded in 30% of the 20 minute measurements made (the norm for Poland is 0.4 mg m^{-3}). In the case of NO_x the norm (0.6 mg m^{-3}) has been exceeded by 10% 1 km from the Works.

Table 2

Pollution emission from Nitrogen Works in Puławy in thousands of tons per year (data from the Nitrogen Works after Trojanowski 1983)

Type of emission	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
NH_3	15.7	22.6	18.5	16.3	10.6	10.9	12.0	11.6	11.8	11.2	9.8	9.2
N_2O_5	3.6	4.6	3.5	3.9	3.8	3.7	3.7	3.9	4.6	5.3	5.7	5.9
Saltpeter dust	3.5	3.5	3.7	3.9	3.9	2.5	2.6	3.1	3.2	3.3	3.4	3.2
Urea dust	1.6	1.4	1.5	1.5	1.5	1.8	1.9	2.2	2.4	2.2	1.9	1.6
SO_2	24.5	28.0	15.4	34.0	23.0	12.0	10.7	10.3	13.1	13.0	12.7	11.8
Smoke-box dust	4.5	5.0	4.8	5.0	5.8	8.0	5.6	5.5	5.7	5.7	5.9	5.4

Table 3

Wind directions for the meteorological station in Osina from data for the years 1958 - 1967 (after Adamczyk-Winiarska 1980)

Direction to	S	SW	W	NW	N	NE	E	SE
%	6.3	7.0	10.2	15.9	13.3	15.3	20.8	11.2

Sulphur dioxide is emitted from a chimney 160 m tall. This on the one hand results in a lowering of SO_2 level in the vicinity of the Nitrogen Works themselves, but on the other it transports the pollutant over substancial distances attaining up to 120 km (Fig. 2). The concentration of SO_2 within a radius of 2.5 km from the emittor as evaluated in 20 minute measurements was 0.2 mg m^{-3} (Adamczyk-Winiarska 1980).

METHODS OF MEASUREMENT

In the spring of 1986 on each plot diameters of all trees were measured to the nearest 1 cm at 1.3 m from the ground, and the height of 10 trees was measured to the nearest 0.5 m in each of the experimental variants. The data obtained in this manner served for the calculation of standing volumes. Also the number of trees was counted and the volume removed as dead trees in the years 1981 - 1986.

In different variants of the experiment, the viability of all trees was estimated individually. For the purpose a five point scale was used in which 5 indicated trees without symptoms of injury by industrial pollution with a well developed crown and foliage of several years on the tree, and 1 indicated dying trees.

The mean annual volume increment over the last 5 year has been calculated from the formula:

$$\bar{i} = \frac{V_{1986} + V_d - V_{1981}}{5}$$

were:

$\bar{i}$ — the average annual volume increment over the years 1981 - 1986 in m^3 ha^{-1},

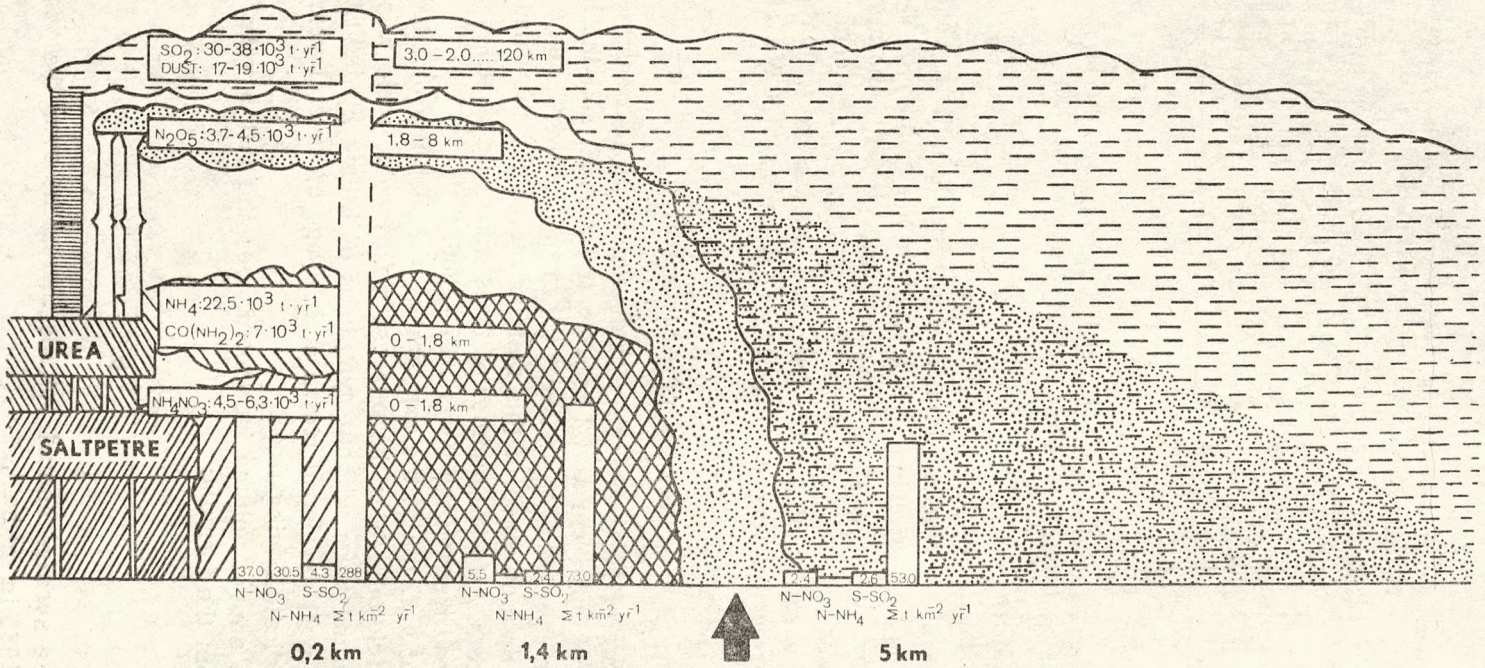

Fig. 2. Range and magnitude of pollution emitted from the Puławy Nitrogen Works in the years 1967 - 1974 (from Puszkar 1979). The arrow indicates location of the experimental area

Table 4

Results of measurements of Scots pine (*Pinus sylvestris* L.) in the provenance experiment from 1912 located since 1966 in the zone of pollution from the Puławy Nitrogen Works

Provenances (former regions)	Trees/ha		Trees lost 1981 - 86	Diameter cm		Height m		Volume m^3/ha		Change in vol. 1981 - 86	Dead vol. removed 1981 - 86	Tree viability 1 = low 5 = high	Vol. increment 1981 - 86
	1981*	1986	%	1981*	1986	1981*	1986	1981*	1986	%	m^3/ha		m^3/ha
Volyniya	718	464	35	26.5	28.7	23.9	24.4	437.7	353.8	−19	154.8	2.49	14.2
Kiev	498	336	33	25.3	27.5	24.5	25.7	287.4	240.4	−16	93.5	2.81	9.3
Kurland	586	371	37	23.5	25.9	23.7	23.9	284.5	235.1	−17	104.4	2.70	11.0
Lublin	586	315	46	24.8	27.3	21.8	21.9	283.1	184.3	−35	130.9	2.54	6.4
Voronež	409	314	23	26.5	29.1	23.5	25.9	243.3	260.0	7	56.5	2.48	14.6
Olonets	264	171	35	30.2	31.2	22.3	24.4	205.2	155.2	−24	72.3	2.41	4.5
Kharkov	308	193	37	27.3	28.6	23.6	24.3	195.2	143.7	−26	72.9	2.76	4.3
Arkhangelsk	242	193	20	30.9	32.2	22.8	23.4	188.1	170.7	− 9	38.1	2.88	4.1
Novgorod	176	107	39	31.0	31.7	23.5	23.9	154.5	101.2	−34	60.6	2.65	1.5
Vologda	183	100	45	32.2	33.5	21.9	23.9	150.0	98.9	−34	68.0	2.56	3.4
Kars	198	86	57	27.3	30.5	23.7	22.8	130.6	72.0	−45	73.9	2.20	3.1
Ufa	227	107	53	24.6	30.0	21.5	23.5	122.3	83.0	−32	64.6	2.59	5.1
Jenisiejsk	139	107	23	31.6	34.4	23.0	23.9	125.3	114.1	− 9	28.8	2.93	3.5
Tver	198	129	35	23.3	26.5	22.2	22.3	88.7	80.2	−10	30.9	2.60	4.5
Tobolsk	110	57	48	30.5	32.4	22.0	22.4	87.1	57.6	−34	42.0	1.92	2.5
Mean	323	203	38	27.7	30.0	22.9	23.8	198.9	156.7	−22	72.8	2.57	6.1

* Oleksyn, Giertych 1984

Fig. 3. A shoot of Scots pine from Voronež with only one year's growth of needles persisting

Fig. 4. A dying tree of provenance Kars

Fig. 5. A plus tree of provenance Volyniya

V_{1986} — standing volume in 1986 in $m^3\ ha^{-1}$,

V_d — volume of dead wood removed in the years 1981 - 1986 in $m^3 ha^{-1}$,

V_{1981} — standing volume in 1981 in $m^3\ ha^{-1}$.

In view of the fact that the experiment was established without replicates, it was not possible to use statistical verification in analysing the results obtained.

RESULTS AND DISCUSSION

Results of measurements of individual provenances have been listed in Table 4. In the period of 5 years which passed since the last measurements were made on this area, in all populations a substancial number of dying trees was noted. The largest number of trees died from provenances Kars (57%), Ufa (53%) and Tobolsk (46%). Much less than average for the whole area, 38%, has been found in provenances Arkhangelsk (20%), Voronež (23%) and Jenisiejsk (23%). The number of trees per ha was in all provenances 31 - 91% lower than expected from volume tables (Szymkiewicz 1971).

The drastic decline in the number of trees in individual populations has found a reflection in the standing volume, which in 1986 was on the average 21.2% lower than in 1981. Over the same period the greatest losses of volume were noted in provenances Kars (45%), Lublin (35%), Novgorod, Vologda and Tobolsk (each 34%). Only in the case of provenance Voronež no decline in volume was observed over the last five years but in fact a small 7% increase.

In the case of the mean annual volume increment over the years 1981 - 1986 in which the magnitude of dead volume removed is included, higher than average increments were observed in provenances Voronež, Volyniya, Kurland, Kiev and Lublin. The lowest increments were found in Novgorod, Tobolsk and Kars. This data confirm our earlier results concerning the productivity and plasticity of the above mentioned provenances growing in other areas of European USRR (Giertych, Oleksyn 1981).

The degree of tree viability, evaluated on the basis of a visual estimate of their crowns using a 5-point scale has shown relatively small differences. The average values of the estimate varied from 2.93 for provenance Jenisiejsk to 1.92 for provenance Tobolsk. Practically all trees from this area have had only one-year needles on them (Fig. 3). Also the needles in the upper part of the crown have had necrotic symptoms and were discoloured as a consequence of the action of air pollutants. The crowns of the majority of trees were substancially sparse. This concerns both the little productive and far removed from pla-

ce origin populations such as Kars (Fig. 4) and Tobolsk and those most productive in the experiment such as Volynija (Fig. 5).

The data presented in Table 4 indicate that at the present time the stand is in a state of disintegration. At this stage the differences between populations reported earlier on the degree of sensitivity to pollution from dendrochronological studies (Oleksyn 1983) tend to disappear. In view of the fact that the magnitude of emissions of toxic substances from the Nitrogen Works in individual years do not show any declining tendencies (Table 2), one should expect that in the nearest decade the deforested zone which so far expect that in the nearest decade the deforested zone which so far extended east of the Works (Fig. 1) will start covering also regions in the south.

The results presented in this study unfortunately indicate that in view of the dominant role of pollution as the limiting factor, the experiment with Scots pine in Forest Range Ruda cannot be further utilized for the purposes for which it was planted 75 years ago. This is a loss to science, the more so that it is the most westerly location of the experimental series of pre-revolutionary provenance experiments on the species established in Russia on the initiative of V. D. Ogievskij in 1910 - 1916 (Giertych, Oleksyn 1981).

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Wpływ zanieczyszczeń powietrza na 15 europejskich i syberyjskich proweniencji sosny zwyczajnej (*Pinus sylvestris* L.) rosnących w 75-letnim doświadczeniu

Streszczenie

Przedstawiono wyniki pomiarów dendrometrycznych oraz ocenę stopnia żywotności drzew wykonaną w założonym w 1912 roku doświadczeniu proweniencyjnym, w którym reprezentowanych jest 15 populacji *Pinus sylvestris*, od Polski na zachodzie do środkowej Syberii na wschodzie i od Archangielska na północy do Turcji na południu. Doświadczenie to zlokalizowane jest 3 km od Zakładów Azotowych w Puławach emitujących znaczne ilości SO_2, NH_3, NO_x oraz pyłów saletry i mocznika.

Stwierdzono, że w latach 1981 - 1986 zmniejszyła się o 20 - 57% liczba drzew w poszczególnych proweniencjach i spadł średnio o 22% zapas masy. Najbardziej uszkodzone korony miały drzewa pochodzące z Tobolska (Ural) oraz Karsu (Turcja), a najmniej z Kijowa, Jenisiejska i Archangielska. Ze względu na małą odległość od emitora i związane z tym wysokie stężenia zanieczyszczeń, widoczne jeszcze w czasie poprzedniego pomiaru w 1981 roku znaczne różnice międzypopulacyjne w stopniu wrażliwości ulegają stopniowemu zatarciu.

Влияние загрязнения воздуха на 15 европейских и сибирских провененций сосны обыкновенной (*Pinus sylvestris* L.) растущих в 75-летнем опыте*

Резюме

Представлены результаты таксационных измерений и оценка степени повреждения деревьев выполненные в заложенных в 1912 году географических культурах, в которых представлено 15 популяций *Pinus sylvestris* от Польши на западе до центральной Сибири на востоке и от Архангельска на севере до Турции на юге. Эти культуры находятся на расстоянии 3 км от завода по производству азотных удобрений в Пулавы, загрязняющего воздух значительными количествами SO_2, NH_3, NO_x и пылью селитры и мочевины.

Установлено, что в 1981 - 1986 гг. на 20 - 57% уменьшилось количество деревьев в отдельных вариантах опыта и в среднем на 22% уменьшился запас. Наиболее поврежденным кроны были у деревьев представлющих провененции Собольск (Урал) и Карс (Турция) а менее всего с киева, Енисейска и Архангельска. Всвязи с небольшим расстоянием от источника загрязнений и связанными с этим значительными концентрациями загрязнений, видимые еще во время предыдущих измерений в 1981 году значительные разницы между отдельными популяциями в степени восприимчивости постепенно сглаживаются.

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