LIMITATIONS TO RADIAL GROWTH OF TREES ON INDUSTRIAL TIMBERLINE

Urszula Bugdal and Jadwiga Sienkiewicz

Forest Research Institute

3 Wery Kostrzewy Str., Warsaw, Poland

SUMMARY

Industrial contamination leads to modifications of the environmental abiotic conditions on a geochemical scale,and, as a result, to the formation of new ecosystems. Using the emission of a zinc and lead smelter as an example, the generation is indicated of an industrial borderline of trees and forest. The state of the pine forest vegetation has been studied along with the radial growth of pines. Substantial changes have been found in the pine wood structure on the industrial timberline, these changes manifesting themselves in the diminution of the number and size of tracheids, as compared with the non-contaminated control region.

1 Introduction

In the regions where intensive industrial pollution of the environment is of a permanent nature, the phenomenon occurs of the withdrawal of forest as a plant formation. Industrial pollution of the environment acts here as a complex system of modifying the abiotic conditions on a geochemical scale. This leads, among other things, to a change in the direction of ecological succession and to the formation of new ecosystems corresponding to the changed conditions of the environment (Wolak 1968, 1969 and 1970).

With the increase in intensity of industrial pollution of the environment, there is a decrease in the height attained by the vegetation, and new vegetation zones are formed, dependent upon the site conditions (Gordon and Gorham 1960 and 1969, Halbwachs and Kisser 1967, Wentzel 1970, Wolak 1969, 1970 and 1971, Huttunen 1975).

The vegetation zones thus formed, are similar to the zones formed naturally on the areas of the northern and the upper timberline. Formation of these new vegetation zones is particularly evident on poor sandy soils, where under natural conditions, the communities of fresh or dry coniferous forest would constitute the final stage of ecological succession. On these poor sandy soils, under durable action of industrial imission, distinct zones of non-forest vegetation are formed, such as zones of grass communities, as well as shrubby form communities of tree species, while the forest is found solely on the areas less exposed to the imission (Wolak 1977).

The above grassy- and shrubby communities are characterized by specific climatic conditions unfavourable to the reestablishment of trees. These climatic conditions distinguish themselves by high daily oscillations of temperature during the vegetation season, excessive insolation at high temperatures and excessive heat radiation at night, as well as heightened evapotranspiration that leads to appreciable water losses from the soil and plants.

Furthermore, under these climatic conditions, there is a tendency for the polluted air to keep near the ground and for the toxic fogs to linger (Dunikowski 1977).

With the rise in height over the ground level, there is an increase in the toxicity of the air pollution as measured by the growth of the sulphurization index (Cimander and Grzybowski 1977).

2 Investigation Results of Environment Pollution

We shall deal now with the effect of the limitations of radial growth of trees upon the industrial timberline in a region badly polluted by emission from a zinc-plant. The zinc-plant emits mostly metallic dust (including heavy metal dust) as well as sulphur- and nitrogen oxides. The emissions

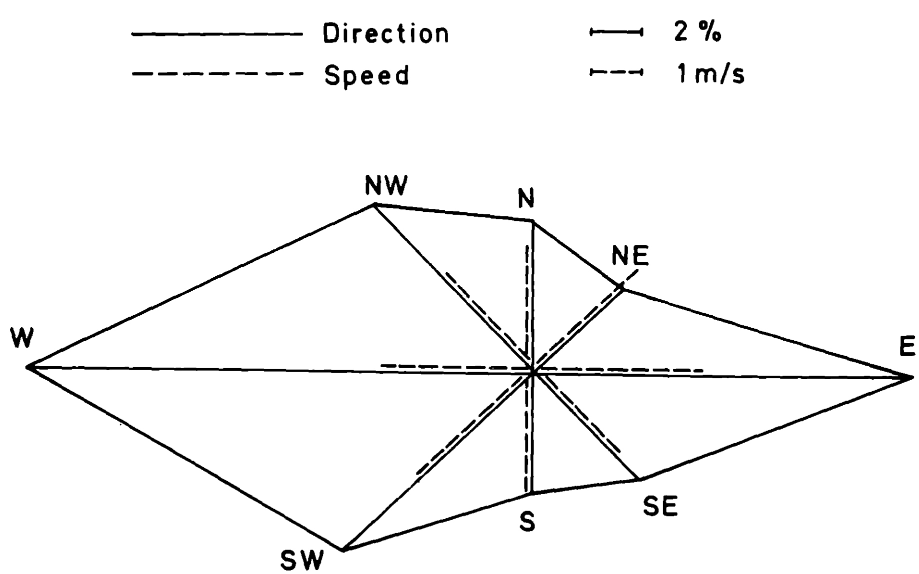

Fig. 1: Distribution of wind direction and speed in the vicinity of zinc-plant.
(Calms = 21.7 %, h_w = 16.0 m above ground level)

are carried by the prevailing western winds onto the neighbouring plant communities. Distribution of the wind direction and speed for the vicinity of the zinc-plant, made on the basis of 10-year observations is depicted in Fig. 1.

On the basis of meteorological and emission data, the ranges have been calculated of gaseous air pollution as converted to SO_2, use being made of the Pasquille expanded equation of diffusion. The results of these calculations are similar to those obtained from the measurements of air pollution by SO_2 (Widera et al. 1980, non published). The calculation results show that at a distance of about 3 km from the source of emission, the imission concentration amounts on the average from 75 to 100 $\mu g\ SO_2/m^3$ per year, while at a distance of 7 to 8 km from the source of emission, in the same direction, the average annual imission concentration oscillates round 50 $\mu g\ SO_2/m^3$.

It should be emphasized that the most recent studies on the effect of the SO_2 imission upon forests, demonstrate that concentrations of about 30 $\mu g\ SO_2/m^3$ per year, on oligotrophic sites, constitute already the limiting values for the existence of forests (Wentzel 1978), and that the air quality standard for the protection of forests recommended by IUFRO is 50 $\mu g\ SO_2/m^3$ per year (IUFRO News 1979).

The studies on the soil and plant pollution in the vicinity of the zinc-plant, have shown that with the joint pollution by heavy metals and SO_2, it is the sulphur that acts more phytotoxically and diminishes the tolerance of plants to the excess of metallic pollution (Swieboda 1970, Krause and Kaiser 1977, Widera et al. 1980, non published).

They have also shown that the dust emission of the zinc-plant brings about considerable alkalization of the upper levels of the soil profile, which acts against the natural podsolization process typical of sandy soils of pine stands (Sozologia i Sozotechnika 1975).

In addition, the alkalization of soil leads, among other things, to a drastic limitation of the number of the forest-floor insects as well as to the structural deformation of their groupings, which disturbs the circulation of matter and the flow of energy in the ecosystem (Leśniak 1977). It must be stressed here that the industrial pollution of the environment has an adverse effect upon soil floras and faunas, which, in combination with the above disturbances, lowers the productivity of the ecosystem (Watson et al. 1974-6).

3 Investigation Results of Vegetation

In the area polluted by the zinc works, the plant communities grow on sandy soils, the only water source whereof is the precipitation (annual average 700 mm). At the distance of about 3 km from the zinc works, there are formed shrubby communities of 40-year-old pines (Pinus silvestris and P. banksiana), and of about 80-year-old pines (P. silvestris), both hindered from growing tall. On the average, the pines attain the height of only 2 to 5 m, the younger trees becoming shrubby, while the older ones obtaining markedly flattened crowns, their side branches "weeping", and crawling on the ground. In the top part of those pines only one generation of needles, usually considerably shortened, can be observed, while in the lower, protected parts there are up to 3 generations of healthy needles. The cones appear very rarely and only on the lower branches (Józefaciukowa 1977).

The pines are attacked by insects that damage the needles and mine the buds, which impairs the habitus of trees and diminishes their photosynthetic ability.

Phytosociological relevés according to the Braun-Blanquet method (Braun-Blanquet 1964) were made as well. Their analysis has shown that the average value of the coverage degree of the layer of trees, is about 25 per cent for the 80-year-old pine and about 40 per cent for the 40-year-old pine at the distance of 3 km from the source of emission, while at the distance of 7 to 8 km from the source of emission the respective values are higher and are: for the 80-year-old pine - 40 per cent, while for the 40-year-old pine - about 70 per cent.

It is noteworthy that at the distance of 7 to 8 km from the source of emission, the plant community preserves the character of a forest, the trees attaining the height from 12 to 15 m, and the needles occurring in 2 to 3 generations though they are shorter and suffer from necrosis.

4 Results of Dendrometric Investigations

At the distance of about 3 km from the source of emission the studies were conducted of the qualitative and quantitative changes in the radial growth of pines. For the studies, above 80-year-old pines were selected from the old pine stand in the zone of intense contamination by industrial emission (from 75 to 100 $\mu g\ SO_2/m^3$ per year).

Timber specimens were sampled from the height of 1.3 m in the early days of April before the cambium activity had started, since this permits the entire radial growth of the last year to be measured.

For comparison, similar pines were studied that grew up on a site comparable to the contaminated one with respect to the soil- and climatic conditions, but situated outside the reach of pollution.

Radial row was measured on each of the 5 samples taken from 5 trees from both the contaminated and the control region. Moreover the share of the late wood in the growth rings in the contaminated samples was compared with that of the control samples. In two samples taken from the height of 5.5 m, the growth rings were measured from cambium to core and the share was calculated of the late wood in the respective growth rings.

Tables 1 and 2 show the average values of the features of the growth rings in trees from the contaminated and the control region. The diminution has been found of the width of the annual radial growth in the contaminated trees. From Table 1 it follows that the radial growth in the contaminated region is on the average 5 times less than in trees from the

Tree Nr.	Total cell number in the ring	Number of late wood cells	Ring width in μm	Per cent share of late wood
	Polluted Region			
1	8	2	235.95	12.12
2	9	4	257.39	18.89
3	6	2	153.01	13.02
4	10	4	296.01	21.74
5	5	1	117.26	12.20
Average	7.6	2.6	211.92	15.79
	Control Region			
1	41	15	1432.86	23.35
2	25	9	900.90	22.38
3	23	9	807.95	25.13
4	19	9	546.26	29.58
5	51	23	1824.68	33.93
Average	31.8	13	1102.53	26.87

Table 1: Some properties of ring width in trees from polluted and control region.

Radial row Nr.	Radial diameter of tracheids in μm early wood	late	Cell wall thickness in tracheids in μm early wood	late
	Polluted Region			
1	31.22	9.3	1.67	2.51
2	39.10	7.86	1.43	2.15
3	29.67	5.72	1.97	2.51
4	34.80	10.37	1.91	2.86
5	21.81	10.01	1.97	2.15
Average	31.81	8.65	1.79	2.44
	Control Region			
1	37.07	12.68	2.59	4.81
2	38.16	12.55	2.77	4.92
3	38.10	12.08	2.56	5.24
4	34.75	11.44	1.86	3.26
5	37.38	15.61	2.85	5.66
Average	37.09	12.87	2.52	4.78

Table 2: Some features of tracheids in 5 radial rows in 5 trees from polluted and control region.

control region. The question arises, what is the reason for the diminution in the growth ring: smaller number of the cells generated or reduction in the size of tracheids?

The above data show that in a region of intense contamination a smaller number of cells is generated in both the early and the late wood, on the average about 5 times smaller (Table 1). The radial diameter of tracheids in the early wood of the contaminated trees oscillates round the average of 31.22 μm. There is a large span between the extreme values of the above diameter, which is on the average about 16 per cent lower in relation to that in the control region.

The radial diameter of tracheids in the early wood of the control trees oscillates inconsiderably round the average of 37.09 μm.

In the late wood of the contaminated trees the drop in radial diameter of tracheids attains on the average 33 per cent in relation to that in the control region.

Furthermore, the width of the cell wall in the tracheids of both the early and the late wood, is on the average about twice less in relation to that of the control trees (Table 2).

From the analysis of the share of the late wood in the structure of annual rings (Table 1) it follows that the change in their structure in the contaminated region results, among other things, from a twice smaller share of tracheids of the late wood in relation to the control trees.

The analysis of the per cent share of the late wood in the structure of rings from cambium to core in the samples taken at the height of 5.5 m is represented in Fig. 2. The per cent share of the late wood in the structure of rings in the control trees, grows in the first 5 years from the value below 10 per cent up to the value of about 20 - 40 per cent, and in the following years is contained within the same values. Whereas, in the contaminated region, after the initial growth of the per cent share of the late wood in the structure of rings up to 55 per cent, there is a gradual drop to below 20 per cent.

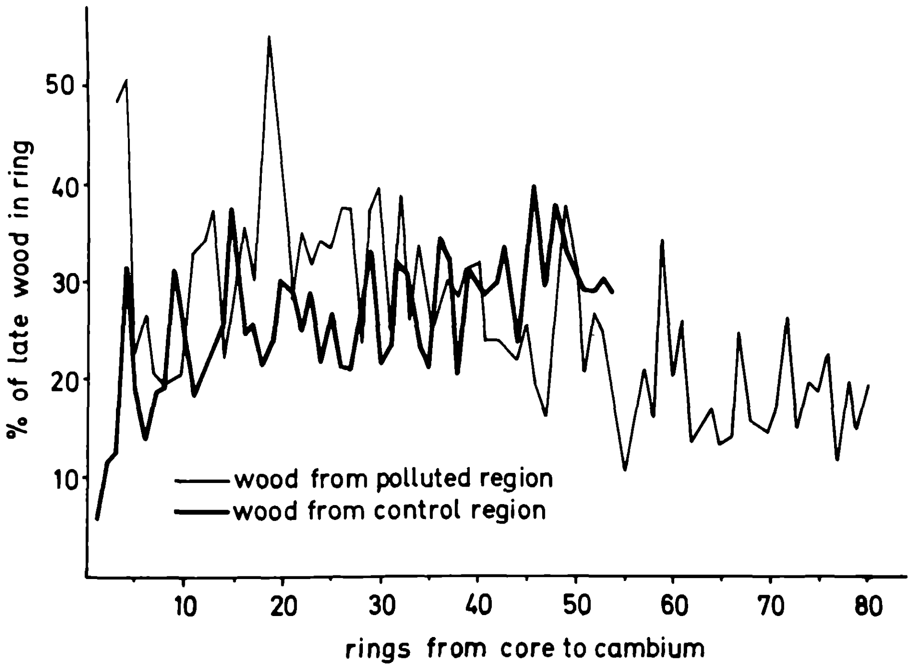

Fig. 2: Percent share of late wood in successive rings at the height of 5.5 m.

5 Conclusions

Summing up the dendrometric results, it can be stated that:

1. The contaminated trees show a drop in the radial growth.
2. The drop in the growth is accompanied by changes in the structure of annual rings in the form of smaller number of tracheids both in the early and in the late wood.
3. There is a tendency towards a diminution of the radial diameter of the tracheids in the early wood by 16 per cent and in the late wood by 33 per cent in relation to the control trees.
4. In the contaminated region, the thickness of the cell wall of tracheids in both the early and the late wood, decreases twice.

5. In the contaminated region the per cent share of the late wood in the structure of rings decreases gradually from about 50 per cent to about 20 per cent.
6. In the contaminated region the size of tracheids in the early wood varies, unlike the size of tracheids in the early wood from the control region.

From the above, the following general conclusions can be drawn:

- a drop in the content of late wood, as well as disturbances in its structure, result in marked deterioration of the mechanical properties of timber, since the weight and strength of the latter depend mainly upon the share of late wood.
- on the industrial timberline there occurs the same phenomenon of the narrowing of growth rings, which can be observed on the northern and the upper range ends of the pine.

LITERATURE CITED

Braun-Blanquet, J., 1964: Pflanzensoziologie. 3 Aufl. Wien, New York.

Cimander, B.and Grzybowski,K., 1977: Studies on the relationship between increase in air pollution toxicity and elevation above ground. Forest Research Institute Report, Warsaw.

Dunikowski, S., 1977: Meteorological studies. In: Relationship between increase in air pollution toxicity and elevation above ground. Forest Research Institute Report, Warsaw.

Gordon, A. and Gorham, E., 1960: The influence of smelter fumes upon the chemical composition of lake waters near Sudbury, Ontario, and upon the surrounding vegetation. Can. Journ. of Bot., 38,477 - 487.

Gordon, A. and Gorham, E., 1963: Ecological aspects of air pollution from an iron-sintering plant at Wawa, Ontario. Can. Journ. of Bot., 41, 1063 - 1078.

Halbwachs, G. and Kisser, J., 1967: Durch Rauchimmissionen bedingter Zwergwuchs bei Fichte und Birke. Cbl.ges. Forstwesen, 84, 2 - 6.

Huttunen, S., 1975: Studies on forest vegetation in air pollution damage area in Oulu. Acta Univ. Oulensis., Ser.A.Nr. 33.

IUFRO News, 1979: Effective limiting values of pollutant concentration. Suppl. to Nr. 25, 3/1979.

Józefaciukowa, W., 1977: Morphological studies. In: Relationship between increase in air pollution toxicity and elevation above ground. Forest Research Institute Report, Warsaw.

Krause, G. and Heiser, H., 1977: Plant response to heavy metals and sulphur dioxide. Envir. Poll. Nr. 12.

Leśniak, A., 1977: Studies on terrestial entomofauna of the sod and shrubby tiers of industriogeneous vegetation. In: Relationship between increase in air pollution toxicity and elevation above ground. Forest Research Institute Report, Warsaw.

Pierelygin, L., 1956: Structure of wood. PWRiL, Warszawa, in Polish.

Sozologia i Sozotechnika, 1975: Influence of zinc works upon accumulation of trace elements in soil. Zeszyt 6, Kraków, in Polish.

Swieboda, M., 1977: Content of Zn, S and Pb in soil and in the needles of pine stands within the reach of emission from Boleslaw Zinc Works near Olkusz. Acta Agr. et Silv. 17, 127 - 151, in Polish.

Watson, A.P., et al., 1974 - 1976: Impact of lead-mining complex on the forest floor litter arthropod fauna in the New Lead Belt Region of Southeast Missouri. ORNL/ NSF/EATC, 30.

Wentzel, K., 1978: Immissionsgrenzwerte für den Wald. Forstwesen, Nr. 5.

Widera, S., et al., 1980: Impact of Boleslaw Zinc Works upon environment. Forest Research Institute Report. Warszawa, in Polish.

Wolak, J., 1968: Industrioclimax and forest. Sylwan, Nr. 5, Warszawa, in Polish.

Wolak, J., 1969: Industrioclimax - a new concept in theory of succession. Ekol. Pol. 15 Nr. 1, in Polish.

Wolak, J. 1970: Formation of new ecological systems under the influence of industrial emission. Sylwan Nr. 8/9, in Polish.

Wolak, J., 1971: Studies on the industrioclimax in Poland. Method for the identification and evaluation of air pollutant injuries to forest. XV IUFRO Congress, Wien.

Wolak, J., 1977: Relationship between increase in air pollution toxicity and elevation above ground. Forest Research Institute Report, Warsaw.