Air Pollution and Forest Health Studies along a South-North Transect in Poland[1]

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Abstract

*Air pollution, bulk deposition and throughfall, soil characteristics, needle chemistry, and forest injury were studied on six permanent plots from the south (Brenna and Salmopol in the Beskidy Mountains) to the north (Gac, the Baltic Sea coastal area) in Poland. The concentrations of sulfur dioxide and nitrogen dioxide were the highest at the Katowice location and the lowest at Gac. Annual mean concentrations of sulfur dioxide at the Brenna, Salmopol, Katowice, and Puszczykowo sites, have exceeded the critical level of 20 $\mu g\ m^{-3}$ proposed by United Nations- Economical Committee for Europe (UN-ECE) bodies, and the Polish national standard (32 $\mu g\ m^{-3}$ for the whole country, and 11 $\mu g\ m^{-3}$ for special protected areas, e.g. National Parks). Nitrogen dioxide concentration has neither exceeded the UN-ECE nor the Polish national standards for the whole country (30 and 50 $\mu g\ m^{-3}$, respectively). Bulk deposition from all locations was acidic. The pH of throughfall in spruce stands was lower than the bulk deposition by about 0.5 of a unit. A larger decrease of pH has been found occasionally. Concentration of all elements measured was higher in throughfall as compared to bulk deposition. However, the differences in concentration of elements between bulk deposition and throughfall varied. The differences were from three to five times for sulfates, but for nitrogen compounds, such as nitrates and ammonium, differences were smaller or did not exist at all. The soil pH of all plots ranged from 2.9 to 3.6 (H_2O) in the organic layer. The highest concentrations of lead and zinc were found in the organic layer of the sites in southern Poland. The greatest needle loss (crown transparency) was found at the highest elevation site (Salmopol) for Norway spruce (*Picea abies*) and in the most polluted site (Katowice) for Scots pine (*Pinus sylvestris*). The smallest crown transparency of spruce was found for the Gac location. Discoloration of needles was the highest at Gac, followed by Katowice and Salmopol. Insects contributed to the observed higher crown transparency on plots at Brenna and needle discoloration at Gac.*

Introduction

Sulfur dioxide (SO_2) air pollution acting directly or indirectly has been one of the major causes for poor forest health status and forest decline in Poland (Ashmore and others 1990, Forschungsbeirat Waldschaeden/Luftverunreinigungen 1989, Godzik 1984, Godzik and Sienkiewicz 1990, Narodowy Program 1988, Koth-Jahr and Kollner 1993, Paluch 1968). According to model calculations, a gradient of both concentrations and depositions of sulfur compounds was found from the south to the north of Poland (Narodowy Program 1988) (*fig.1*). The reason of such uneven distribution was mostly emission from sources located in the south of Poland, the Czech Republic, and Germany (former German Democratic Republic). Results of forest injury inventories in Poland have followed a similar pattern. The most severe injuries (class three) were noted in southern Poland along the border with the Czech Republic. Severe injury was also observed on a local scale in other parts of the country (Godzik and others 1996, GUS 1995, Malachowska and Wawrzoniak 1995). Although emission of air pollutants in recent years has decreased, the pattern of its distribution has remained similar.

The total area of forest in Poland is 873,200 hectares, comprising 27.9 percent of the total area of the country (GUS 1995). Scots pine (*Pinus sylvestris*) cover about 70 percent of the total forest area. Norway spruce (*Picea abies*) cover about 6 percent of the forest (GUS 1995).

On the basis of data concerning the gradient of sulfur dioxide concentration in Poland, six permanent plots in coniferous forests have been established. Climatic

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differences are represented by plots at different locations above the sea level (asl) in the Brenna region and at the Baltic Sea coast. Differentiation of air pollution level is represented along the line from the south to the north of Poland *(fig. 1)*.

This paper reports a study of the concentrations of sulfur dioxide and nitrogen dioxide in the air, deposition of air pollutants and mineral nutrients, and their relationship to forest stand parameters, such as needles and soil characteristics, on six permanent plots in Poland.

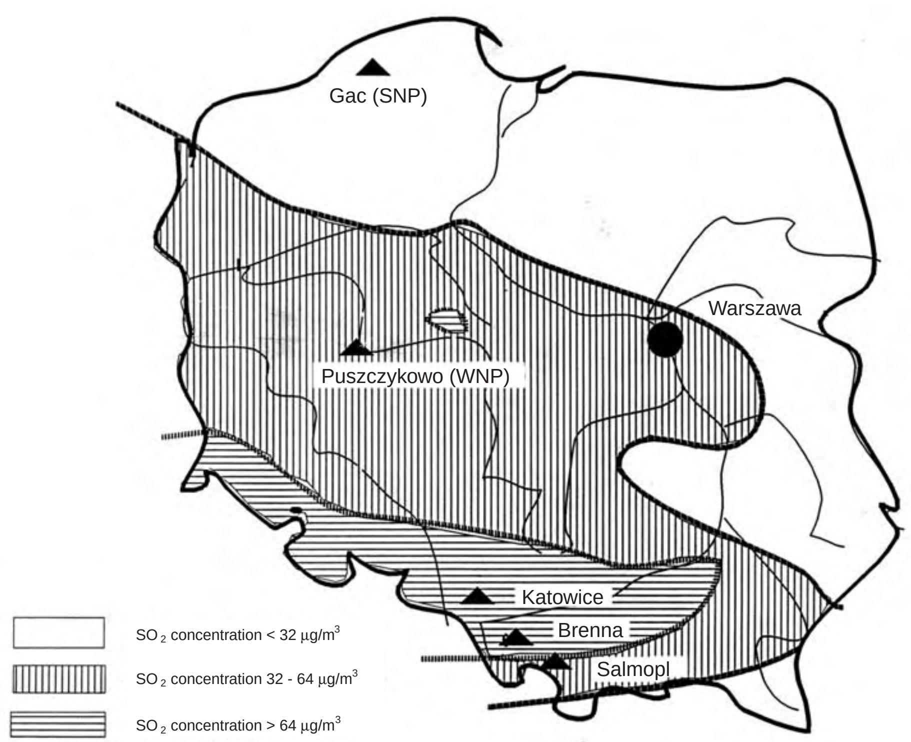


Figure 1 — Locations of six forest permanent plots in Poland with isolines showing SO_2 annual mean concentration in the air. SNP = Slowinski National Park; WNP = Wielkopolski National Park.

Site Description, Material, and Methods

Permanent forest plots were established in southern Poland (two plots in the Brenna area and one plot in the Katowice region), central Poland (Puszczykowo — Wielkopolski National Park (WNP)), and two plots in northern Poland (Gac — Slowinski National Park (SNP) — at the Baltic Sea coast) *(fig.1)*. The size of the plots was 50 by 50 m. All plots met standards required by the measurement program for sites for Integrated Monitoring for Forest Ecosystems within the Long Range Transboundary Air Pollution (LTRAP) UN-ECE protocol (Environmental Data Centre 1989).

The two plots in the Brenna area, the Beskidy Mountains, were located at 1,000 m asl (Salmopol) and 650 m asl (Brenna). The main tree species in those sites were Norway spruce with additions of white fir *(Abies alba)* or beech trees *(Fagus sylvatica)*. The plot in the Katowice region was basically a Scots pine stand with admixture of broad leaf species in the lower layer. This region was the most polluted and has been influenced by air pollution for more than a century. The only tree species at the Puszczykowo plot was Scots pine. In Gac, at the Baltic Sea coast, two plots were established in spruce and pine stands. On every plot 15 throughfall collectors were randomly distributed. In an open area, collectors for bulk precipitation were placed. Ceramic vacuum cup lysimeters were installed at 25 and 50 cm depth on each of plots in a regular net. All samples were collected and analyzed monthly.

Ions were determined with ion chromatograph DX-100 with column AS4A.[3] Metallic cations were determined with atomic absorption spectroscope Varian Spectra AA 300. Concentration of NH_4 was determined by using the Nessler method (Hermanowicz and others 1976). Soil samples were collected from each horizon and analyzed separately. For the chemical soil analysis, standard methods recommended by the Soil Service Laboratories were applied (Litynski and others 1976).

Needles for chemical analysis were taken in late October. Forest class injury was assessed based on degree of crown transparency and discoloration from methods recommended by the UN-ECE ICP Forest working group. Concentrations of sulfur dioxide and nitrogen dioxide in Brenna, Salmopol, Katowice, and Puszczykowo were determined as 24-hour means. Sulfur dioxide was absorbed in H_2O_2, producing sulfates that were determined with ion chromatography. Nitrogen dioxide was determined by methods recommended by EMEP: absorbed on a sintered glass filter impregnated with KI-$NaAsO_2$ mixture, and colorimetrically determined by using sulfonamide and N-(1-Naphtyl)ethylenediamine dichloride (NEDA) reagents (Environmental Data Centre 1989). Data for the Baltic coast area is from the national base network for air pollution measurements (PIOS 1995).

Results and Discussion

Air Pollution

Differences in concentration of sulfur dioxide and nitrogen dioxide were not found between two elevations in the Beskidy Mountains *(fig. 2)*. The data show that monthly and yearly mean concentrations of sulfur dioxide were higher than for the Rhine-Westphalen area in 1987 (Koeth-Jahr and Koellner 1993); and the values for nitrogen dioxide were lower than in the same area of Germany (Koeth-Jahr and Koellner 1993). For the Schwarzwald area, the values did not exceed 29 µg m^{-3}, and for the growing season were lower by 50 percent (Forschungsbeirat Waldschaeden/ Luftverunreinigungen 1989). The concentration pattern of sulfur dioxide on the plots showed similar differences between winter and summer. The mean values were rather high, given that sulfur dioxide is not the only air pollutant hazardous for trees. Concentrations of this air pollutant are lower than proposed by the International Union of Forest Research Organizations (IUFRO) for not extreme environmental conditions (50 µg m^{-3}). However, except for the Gac area, values of sulfur dioxide were in the range or higher than proposed as critical levels by the UN-ECE convention on Long Range Transboundary Air Pollution (20 µg m_{-3} and 30 µg m^{-3} for SO_2 and NO_2, respectively; Ashmore and Wilson 1994). Concentration of sulfur

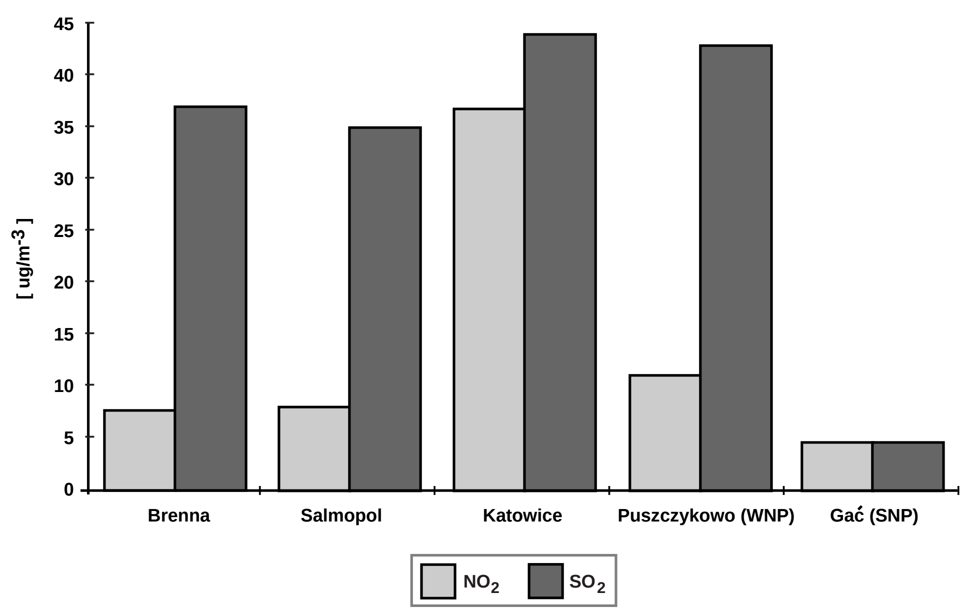


Figure 2 — Annual mean concentration of SO_2 and NO_2 (µg m^{-3}) in the air over permanent plots.

[3] Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

dioxide has exceeded or was very close to the Polish national standard (32 µg m^{-3} as yearly mean value) for the whole country. For the WNP, as a "special protected area," the standard is 11 µg m^{-3}. Concentration of sulfur dioxide was found to be several times higher.

The most probable direct effects on the forests caused by air pollutants (only SO_2) were the sites in the Katowice area, and to a lesser extent in the WNP. Direct effects of nitrogen dioxide seems to be less probable. For the plots located in the Beskidy Mountains, ozone should be considered as a possible factor contributing to the forest health status (Godzik, this volume).

Deposition

As expected from the model calculations (Narodowy Program 1988), the bulk deposition concentrations of most elements were higher in the polluted locations: Katowice and Puszczykowo (WNP) (see Staszewski 1996 for results of all six locations). The most interesting data for loads of sulfur and nitrogen are the differences between pine and spruce stands at the Gac site *(table 1)*. This difference may be the result of species-specific characteristics and/or number of trees for the same area. No similar comparison could be made for the southern Poland stands. Higher loads of sulfur and nitrogen for the spruce stands in Brenna and Salmopol compared to the Katowice area can be explained by rainfall that is almost two times higher in the Brenna region. If spruce stands were compared, loads for spruce in the Katowice region would likely be even higher. We may also consider that the extent of the earlier and more severe deterioration of spruce stands compared to pine stands in the Silesia Industrial Region could be attributed to differences in loads (Godzik and Harabin 1968). Amount (load) of sulfur and nitrogen deposited to all forest ecosystems under study exceeded, except SNP sites, the critical loads recommended by the UN-ECE.

***Table 1** — Annual loads of sulfur and nitrogen calculated for bulk deposition and throughfall (kg ha^{-1} a^{-1}).[1]*

Location and species	Sulfur	Nitrogen
Salmopol: spruce		
Bulk deposition	15.1	26.6
Throughfall	36.3	30.3
Brenna: spruce		
Bulk deposition	13.6	17.2
Throughfall	41.0	28.0
Katowice: pine		
Bulk deposition	12.7	10.4
Throughfall	27.3	13.0
WNP: pine		
Bulk deposition	13.1	13.7
Throughfall	27.8	15.5
SNP		
Bulk deposition	8.4	8.8
Throughfall(pine)	10.0	8.0
Throughfall(spruce)	17.0	12.5

[1] The values are a sum of data from separate sampling periods (sampling intervals). During the whole sampling period, concentration of elements in throughfall was always higher if compared to the same sampling time for the bulk deposition.

Soil Characteristics

Soils of all but one location (spruce site in Gac) were of the podzolic type and of low pH (Godzik and others 1994). Soil profiles represented typical handbook descriptions of distributions of genetic horizons. Low amounts of calcium and magnesium that are mostly responsible for the soil pH were found. In all soils potassium content was higher than calcium. The highest concentrations of lead and cadmium were found in the organic soil layer. The concentration of lead in samples from southern Poland exceeded the concentration recognized as "normal" for soils of this region.

Soil investigation data showed that soils on all but one plot were comparable. Thus, this data shows that climate and air pollution were the major variables in our studies. Differences in forest injury class at plots under investigation could not be explained by differences in soil properties. This conclusion is based on the comparison of soil data from two plots in the Brenna area for spruce, and Katowice-WNP for pine. Investigations performed earlier for the Izerskie-Beskidy Mountains showed similar conclusions (Godzik and Szdzuj 1994).

Needle Chemistry

The highest concentration of sulfur in needles of spruce has been found for the coastal area (Gac), followed by that found in the Salmopol and Brenna needles *(fig. 3)*. The highest injury class has been assessed at the Salmopol location, and the least at the coastal area (SNP). Further investigations are needed to explain the highest concentration of sulfur in spruce needles from the Gac location, where the air pollution was the lowest. One possible explanation is the difference in soil properties at this site, as compared to the locations at Brenna and Salmopol. The influence of the nearby Baltic Sea seems to be less likely when looking for the results for sulfur concentration in pine needles. For the pine stands, the sulfur content of needles is higher in forests of higher injury class: Katowice had the highest pine needle injury, followed by WNP and SNP.

Forest Injury

The highest mean defoliation (crown transparency) in spruce stands was found in Salmopol, followed by Brenna and the Gac (SNP) *(fig. 4)*. At the Salmopol location, 100 percent of trees were in injury classes 2 and 3. At the Brenna and Gac locations 60 and 30 percent, respectively, were in these classes. Only trees at the Brenna location were found with no injury. At the Brenna and Gac locations, insect injuries were noted.

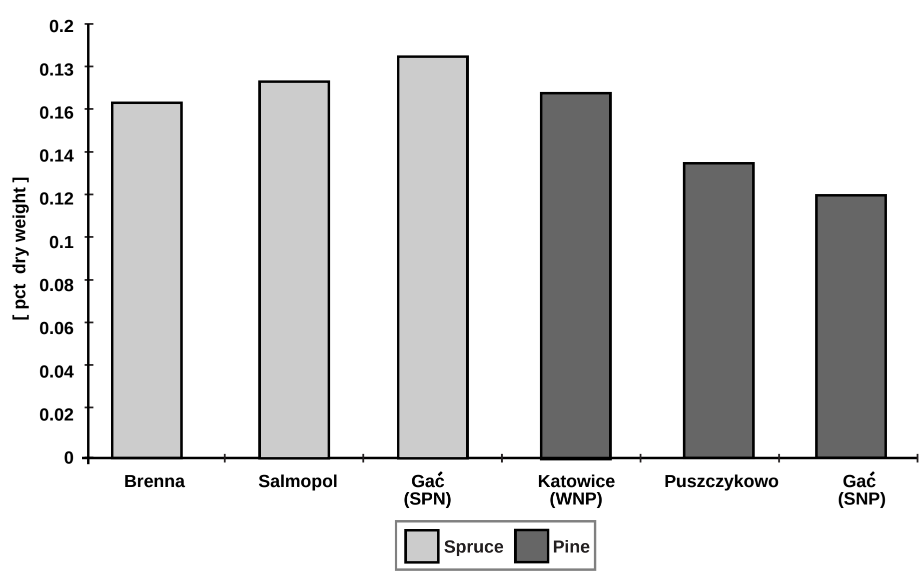
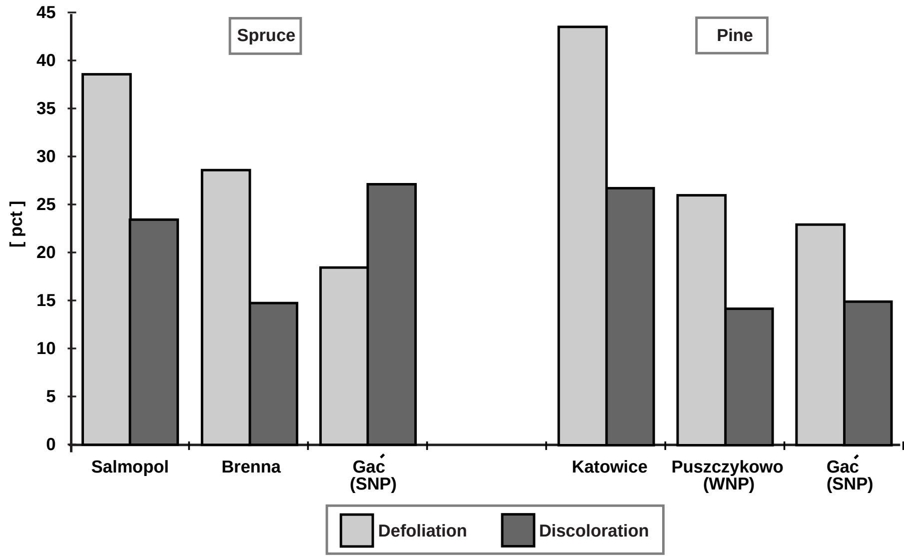


Figure 3 — Content of sulfur (percent dry weight) in 1-year-old spruce and pine needles.

Figure 4 — Mean values (percentage) of defoliation and discoloration of pine and spruce stands on permanent plots.



Most severe defoliation of pine trees has been found at the Katowice plot, where 80 percent of trees were in the injury class 3. The numbers for the WNP and SNP plots are 20 and 25 percent, respectively.

Mean values for discoloration of spruce trees are the highest for the Gac, followed by Salmopol and Brenna (*fig. 4*). However, at the Salmopol plot 35 percent of trees are in the discoloration classes 2 and 3. For the two remaining plots the numbers are 10 percent for Gac and 5 percent for Brenna. No discoloration was found on 35 percent of trees at the Brenna plot, followed by Gac with 25 percent, and Salmopol with 5 percent.

The highest mean discoloration of pine trees was found at the Katowice plot. No difference in discoloration was found between the WNP and SNP locations (*fig. 4*). All trees at the Katowice plot are in the discoloration class 1 (60 percent) and 2 (40 percent). For the WNP plots they are 30 percent and 10 percent; and 55 percent and 0 percent for the SNP plots — class 1 and 2, respectively. Similar patterns of sulfur concentration in pine needles have been found. Because soil properties at all plots did not differ distinctly, the discoloration differences may be more related to concentration of sulfur dioxide and load of sulfur deposited to these ecosystems.

Conclusions

Concentrations of sulfur dioxide were the highest in the Katowice region, followed by the Wielkopolski National Park (WNP), the Brenna (Beskidy Mountains) and Gac (Slowinski National Park) locations. Concentrations of nitrogen dioxide followed a similar pattern. Load of sulfur and nitrogen to the forest floor differs depending on localization and tree species. Higher loads were measured on spruce stands as compared to the pine (Gac). Higher loads have been found for spruce stands in Salmopol and Brenna when compared to pine stands in the Katowice region (where concentration of air pollutants is higher). The result is caused by rainfall that is almost two times higher in the Beskidy location. However, other factors may be involved as well.

Forest soils at all sites were acidic. Except for the soil at the spruce stand at Gac, they were also of similar physico-chemical characteristics. The highest levels of lead and cadmium were found in an organic layer and in sites in the southern part of the country.

No clear relationships were found between air pollution — concentration and load — and forest health on plots under investigation. However, injury of spruce and pine trees were higher at locations where air pollution levels were also higher. The comparison of results from Brenna and Salmopol suggests that climatic parameters are an important factor in forest injury. However, a lack of measurements resulted in the inability to assess the possible contribution of ozone to the more severe forest injury at the higher elevations.

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