

Monitoring the impact of sulphur with the Austrian Bioindicator Grid

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“Capsule”: *With the help of the Austrian Bioindicator Grid, the annual and regional development of the impact of sulphur could be assessed all over the country.*

Abstract

In Austria, the impact of sulphur has been assessed since 1985 with the help of the Austrian Bioindicator Grid on 760 sample plots with *Picea abies* as the main tree species (90%). The annual sampling allows a precise evaluation of the temporal and regional development of the impact of sulphur on the basis of legal standards. Despite the reduction of SO₂ emissions in Austria, the legal standard is still exceeded on 8% of the plots. These plots are mainly located near large Austrian emitters, but also in areas affected by transboundary sulphur emissions from neighbouring countries. The present paper describes how the Bioindicator Grid can be applied for the control of legal requirements to enact effective clean air measures in Austria and take supportive measures that reduce the impact of sulphur from emitters in neighbouring countries.

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1. Introduction

Forest ecosystems in Europe are particularly influenced by stress factors. This has led to intensive research activities with regard to cause–effect relationships (Krupa and Arndt, 1990; Blank and Lütz, 1990; Michaelis, 1997). In Austria, where forests cover 47% of the territory with a high share of mountain forests, forest ecosystem research has also been intensified (Bolhar-Nordenkamp, 1989; Smidt et al., 1994, 1996, 2002; Herman et al., 1998, 2001). Mountain forests, which represent a large amount of the forest area, play an important role in protecting settlements and infrastructure for nearly half of the population of Austria.

In the early 1980s, the Federal Office and Research Centre for Forests established monitoring networks (Austrian Forest Inventory, Forest Damage Monitoring System, Forest Soil Monitoring System; Neumann and

Themessl, 1995; Schieler et al., 1995). Both forest decline research and monitoring activities contribute to a better understanding of the condition of forests and produce a reliable database to provide a basis for advising policy makers on effective clean air measures. In the course of the monitoring activities, the Austrian Bioindicator Grid was established to assess the impact of sulphur on an Austria-wide scale.

Plant analyses have been used in Austria for the bioindication of sulphur impact for more than 100 years (Portele, 1891; Rusnov, 1910, 1917). In SO₂-polluted areas it was possible to relate forest damage to specific emitters (Dässler, 1991). The Federal Office and Research Centre for Forests has carried out intensive air pollution research to identify areas suffering from sulphur impact in Austria. The collected data have been entered into a comprehensive database (Stefan, 1975, 1982). Thus, it was possible to lay down legal standards for the sulphur content of needles and leaves which are unique for Europe (Federal Law Gazette, 1984).

The Austrian Bioindicator Grid started in 1983 with the aim of investigating the environmental situation of forests

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regarding sulphur impact and nutrition status (N, P, K, Ca, Mg; micronutrients Fe, Mn, Zn; Stefan, 1992, 1995). F, Cl, Pb, Cd as well as ^{137}Cs and ^{90}Sr are also analysed in the neighbourhood of emitters (Fürst, 1992; Irlweck et al., 1999). Annual sampling, which is unique for Europe, and the density of the network give evidence of the time-related and regional development. The data are available on the Internet (<http://fbva.forvie.ac.at/600/1491.html>).

On the European level, the sulphur content of needles and leaves is also analysed in the Level I (crown assessment, forest soil condition survey, chemical contents of needles and leaves; approx. 1400 sites) and Level II networks (additional to Level I: forest growth, deposition, meteorology, soil solution, vegetation, remote sensing/aerial photography; approx. 860 sites), respectively (UN-ECE, 1994, 1998). Thirty-nine countries are involved. Three classes of sulphur content have been established and are related to the Austrian legal standards (Stefan et al., 1997, 2000).

In Austria, the emission rates of SO_2 have been reduced since the beginning of the 1980s. In 1980, 400,000 tons of SO_2 were emitted; in 2000, the emitted amount was 41,000 tons (Gangl et al., 2002). The reduction of the SO_2 -emissions has led to a significant decrease of the SO_2 concentrations (-0.7 to $-2.0 \mu\text{g SO}_2 \text{ m}^{-3} \text{ year}^{-1}$, annual mean values below $20 \mu\text{g m}^{-3} \text{ SO}_2$) and sulphur deposition ($-0.38 \text{ kg S ha}^{-1} \text{ year}^{-1}$) in forested areas (Smidt et al., 1999). Whereas in Austria the reduction between 1980 and 1993 amounted to 82%, in the neighbouring countries of Austria the reduction was lower (23–61%; Berge et al., 1995). Thus, the positive effect of the reduction of SO_2 -emissions in Austria has been counterbalanced by increases especially near the Slovenian and Hungarian borders.

The sulphur input modelled by the EMEP-measuring grid (www.emep.int) was $15.2 \text{ kg S ha}^{-1} \text{ year}^{-1}$ for 1985 and $8.2 \text{ kg S ha}^{-1} \text{ year}^{-1}$ for 1998, respectively. Sulphur input measured on the 20 Austrian Level II plots ranged from 2 to $15 \text{ kg S ha}^{-1} \text{ year}^{-1}$ for the period 1996–2001 (Smidt, 2002). In Austria Critical Loads for sulphur are exceeded on acidic parent material, which is represented on about one fifth of the forested area (Mutsch and Smidt, 1994).

The results outline the necessity to survey the current sulphur impact situation in order to achieve the following goals:

1. Description of the environmental status regarding the impact of sulphur for the entire forested area of Austria taking into consideration time-related variations and identification of “hot spots”.
2. Controlling legal requirements to enact clean air measures.
3. Provision of a reliable database to support measures for the reduction of a transboundary sulphur impact from neighbouring countries.

The present paper describes the design of the Austrian Bioindicator Grid and gives examples of the earlier mentioned major goals.

2. Material and methods

The Austrian Bioindicator Grid was set up in 1983, and the plots were arranged at a distance of 16 km. This “basic grid” was coupled to the already existing Bavarian grid. The grid was intensified in 1985 (“high density grid”) where required by specific topographic conditions and in congested areas in order to give evidence of small-scale air pollution impacts. In the present report, the results that are discussed stem from the high density grid (760 sample plots, 90% *Picea abies*, 10% *Pinus sylvestris*) surveyed annually between 1985 and 2000. Fig. 1 shows the location of the sample plots and the special monitoring grids Lenzing and Šoštanj.

2.1. Sampling and analysis

According to the Forest Law (Federal Law Gazette, 1984), plant material was collected once a year in autumn from two permanently marked sample trees of each of the sample plots.

Sulphur concentrations of spruce and pine needles of the current and previous years were analysed with a LECO SC432 (Fürst, 1987). The quality assurance was achieved with certified reference material (Beech Leaves, CRM 100 and Spruce Needles, CRM 101; Institute for Reference Materials and Measurements of the European Communities).

2.2. Legal standards

Sulphur concentrations were evaluated using the legal standards for *Picea abies*, which are also applicable to *Pinus sylvestris* (Stefan and Fürst, 1998). An excess of 1100 ppm S in the current needles and 1400 ppm S in the needles of the previous year gives evidence of an unacceptable impact of sulphur (Stefan, 1992).

2.3. Statistical methods

The development of the sulphur impact for the entire forested area of Austria, the SO_2 and H_2S emissions of the Cellulose Fibre Plant Lenzing, and the sulphur content of the needles in the special monitoring grids Lenzing and Šoštanj were validated with statistical methods. The annual development as well as 4-year mean values were tested. The programme packages GENSTAT® and STATISTICA® were applied.

The Gaussian distribution of the data sets was tested according to Cramere and Von Mises (Table 1; Aitchinson, 1986).

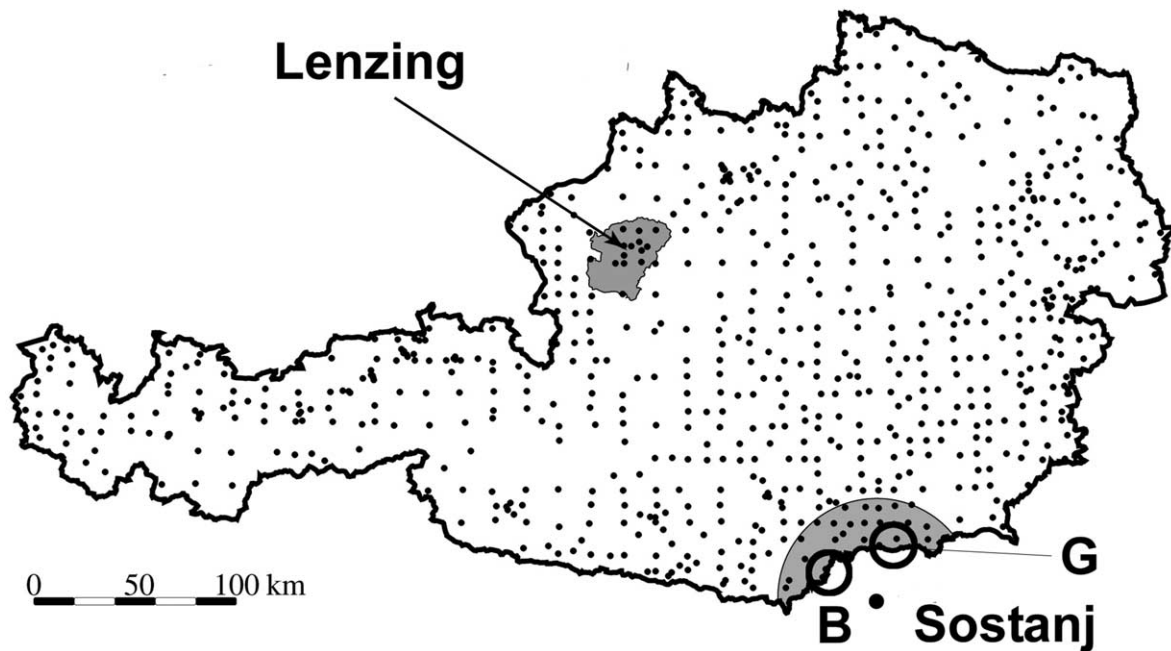


Fig. 1. Sample plots of the Austrian Bioindicator Grid (“high density grid”, $n = 760$), special monitoring grids Lenzing/Upper Austria ($n = 13$) and Šoštanj/Slovenia ($n = 24$) and location of two SO_2 -measuring stations in Carinthia (B: Bleiburg, 480 m a.s.l.; G: St. Georgen, 540 m a.s.l.).

As only two data sets were normally distributed, statistical tests were applied which allowed also calculations with data sets not normally distributed:

- Trend test according to Wallis and Moore (Sachs, 1997) on the basis of individual years.
- H -test according to Kruskal and Wallis (Sachs, 1997) for “non-constant trends” for determining differences between four-annual mean values.
- U -test according to Mann and Whitney (Sachs, 1997) for the comparison of the first and last four measuring years, when significant differences of four-annual mean values were found using the H -test.

3. Results and discussion

The following paragraphs outline the sulphur impact and its development from 1985 to 2000 for the forest areas of Austria. Furthermore, the sulphur impact caused by the emissions of an Austrian and a Slovenian emitter is evaluated.

3.1. Description of the sulphur impact situation and trends

Figs. 2 and 3 compare the sulphur impact on the basis of the evaluation of the excess of legal standards from 1985 to 1988 and from 1997 to 2000, respectively. The regional differences and the decrease of sulphur impact are evident, especially in the northern part of Austria, which is influenced by emissions of the Czech Republic

Table 1

Normal distribution test according to Cramere and Mises (n : years)

| | |
|--|----------------------------|
| Percentage share of instances of exceeding the legal standard in the entire area of Austria | 0.058 n.s. ($n = 16$) |
| SO_2 -emissions (t years^{-1}), Cellulose Fibre Plant Lenzing/Upper Austria | 0.236 ** ($n = 17$) |
| H_2S -emissions (t years^{-1}), Cellulose Fibre Plant Lenzing/Upper Austria | 0.967 ** ($n = 17$) |
| S-content (ppm S), special monitoring grid Cellulose Fibre Plant Lenzing/Upper Austria | 0.148 * ($n = 16$) |
| Percentage share of instances of exceeding the legal standard, special monitoring grid Šoštanj /Slovenia | 0.062 n.s. ($n = 16$) |

* $P \leq 0.05$.

** $P \leq 0.01$.

and Slovakia. No improvement was found in the vicinity of large emitters and near the national border to Slovenia. These findings still suggest an excess of the legal standard on 8% of the plots in 2000 (Fig. 4).

The statistical evaluation showed a slight decrease of the percentage of the exceeding legal standards since the period 1989–1992 from 23.09 to 15.10% on the basis of the 4-year mean values. The trend was not significant. The statistical evaluation of the individual years did not prove any change of the share of the instances of exceeding the standards either (Table 2).

Air pollution stress at higher altitudes is of particular importance in a mountainous country like Austria. Therefore, the percentage shares of plots where the legal standard for the current year needles was exceeded were determined in seven ranges of altitude. The results are

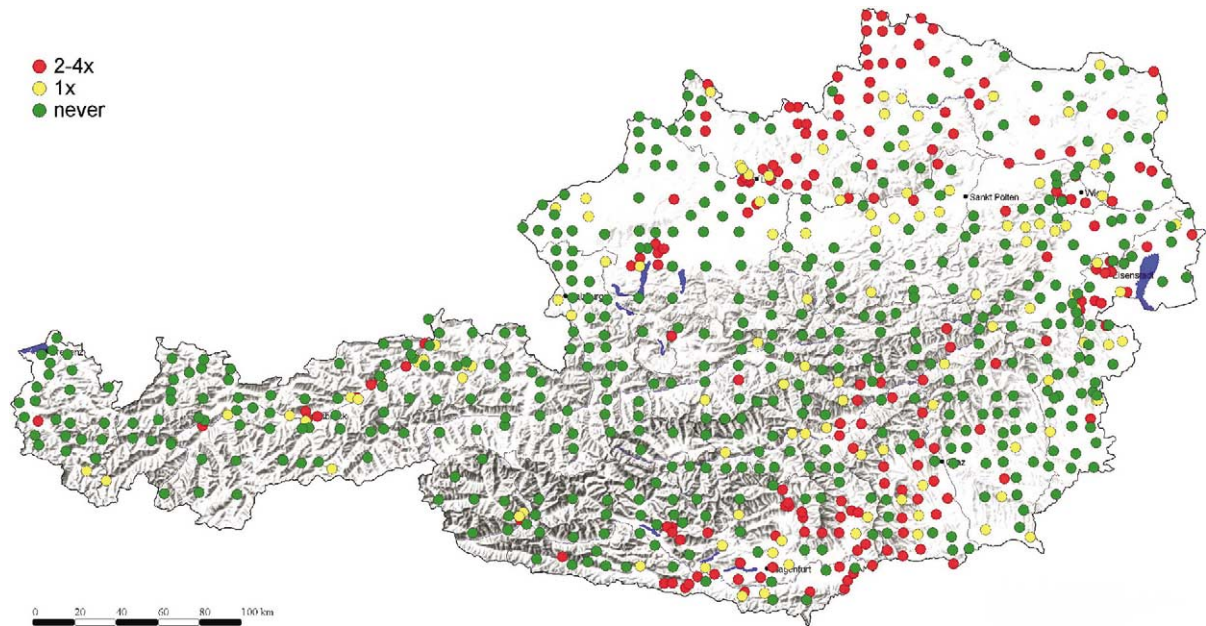


Fig. 2. Austrian Bioindicator Grid 1985–1988: green plots: no exceeding of the legal standard in current year or previous year needles; yellow plots: 1 instance of exceeding, red plots: more than 1 instance of exceeding during this 4-year period.

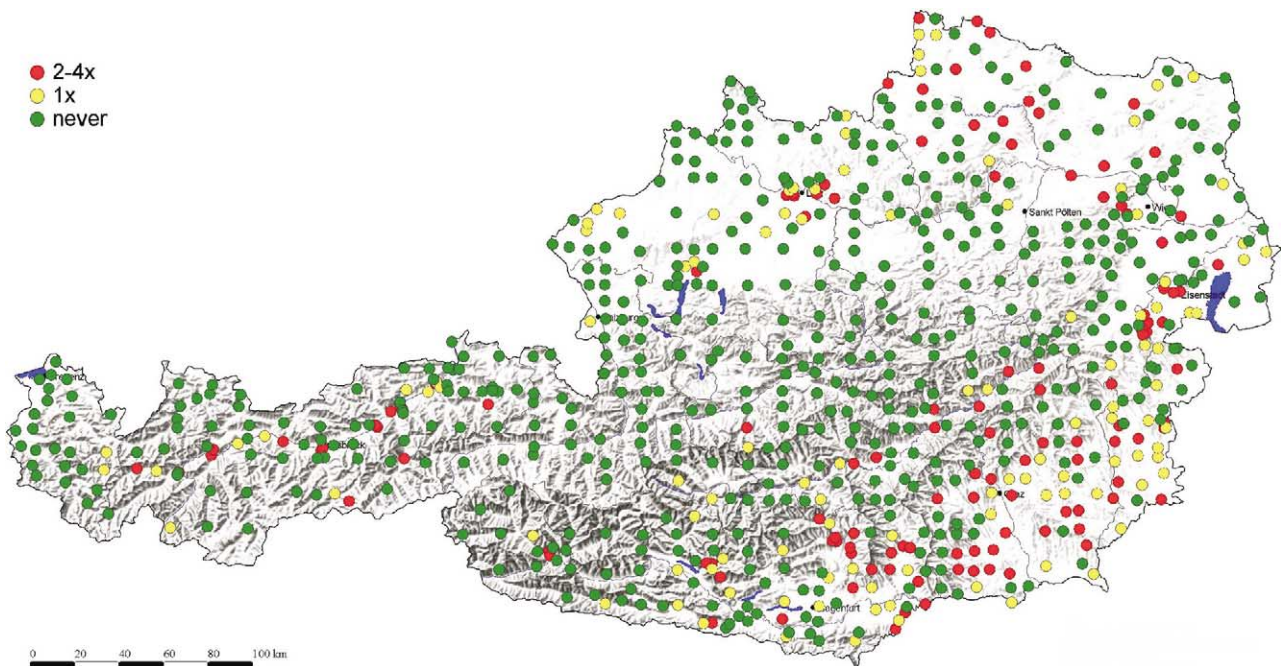


Fig. 3. Austrian Bioindicator Grid 1997–2000: green plots: no exceeding of the legal standard in current year or previous year needles; yellow plots: 1 instance of exceeding, red plots: more than 1 instance of exceeding during this 4-year period.

described in Table 3. Sulphur pollution was concentrated in the three altitude ranges below 800 m a.s.l., but even at altitudes above 1400 m a.s.l. some sample plots proved to be heavily stressed. From 1985/1988 to 1997/2000, the 4-year annual mean numbers of instances of exceeding the standard were reduced up to a third from 400 up to 1200 m a.s.l. Below 400 m a.s.l. the impact was constant. Especially above 1400 m a.s.l., however, the instances of exceeding the standard increased.

The sulphur content of the needles is not only related to the total input, but also depends on the climatic conditions during the vegetation period. As demonstrated in Fig. 4, remarkably low percentages of plots with instances of exceeding the legal standards were determined for 1992 and 2000. These years were characterised by extremely dry summers, which reduced the uptake of SO_2 because of stomatal closure (Wehrmann, 1961; Schmidt, 1985; Stefan and Gabler, 1998). These

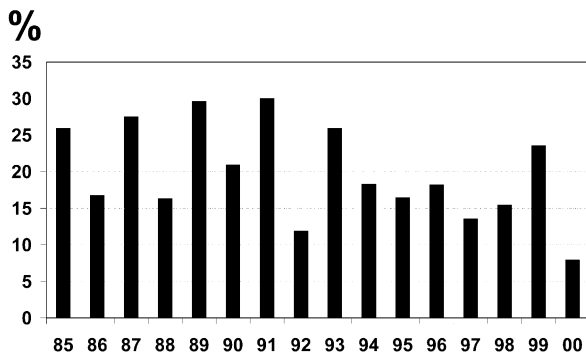


Fig. 4. Austrian Bioindicator Grid: percentage of plots where legal standards were exceeded in the years 1985–2000.

exceptional years prove that discontinuous investigations may lead to misinterpretation of the impact situation. The probability of an underestimation of the sulphur impact can be assumed when results from only a few years are available.

3.2. Controlling of legal requirements

In 1985, the Lenzing AG, the world leader in manufacturing and marketing of man-made cellulose fibres for textile and non-textile applications, was one of the industrial hot spots in Austria. The statistical tests resulted in a significant decrease of the SO_2 emissions. The reduction of the H_2S emissions showed significant differences only using the U -test (Fig. 5).

Table 2
Statistical evaluation of exceeding the legal standards ($n = 16$ years)

| | Years | Mean percentage of instances of excess | z -value | H -value | U -value |
|---|-----------|--|------------------|--------------------|------------------|
| Percentage share of instances of exceeding the legal standard | 1985–1988 | 21.61 | 1.36 n.s. | 3.63 n.s. | 2.00 n.s. |
| | 1989–1992 | 23.09 | | | |
| | 1993–1996 | 19.70 | Wallis and Moore | Kruskal and Wallis | Mann and Whitney |
| | 1997–2000 | 15.10 | | | |

Table 3
Percentages of instances of exceeding the legal standard in needle year 1 during the investigation periods 1985/88 and 1997/2000

| Metres above sea level | Number of analyses | Percentage of instances of excess 1985–1988 | Percentage of instances of excess 1997–2000 |
|------------------------|--------------------|---|---|
| > 1400 | 240 | 1.7 | 3.8 |
| –1400 | 184 | 4.9 | 4.3 |
| –1200 | 328 | 10.4 | 7.9 |
| –1000 | 408 | 13.7 | 10.5 |
| –800 | 532 | 29.5 | 21.2 |
| –600 | 712 | 31.0 | 20.9 |
| < 400 | 636 | 26.6 | 26.1 |

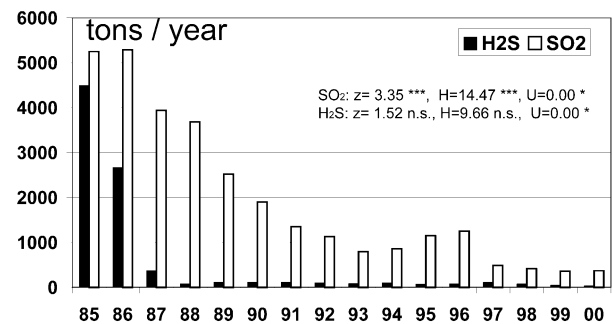


Fig. 5. Cellulose fibre plant lenzing (Upper Austria): emission data 1985–2000 (t year^{-1}) and statistical evaluation.

In 1985, these emissions caused the maximum S content in the needles of all plots of the bioindicator grid. Even the mean value of the special monitoring grid Lenzing exceeded the legal standards.

The evaluation of mean and maximum values of the sulphur content of the special monitoring grid Lenzing showed no significant trend, but on the basis of the 4-year means, these trends were significant (Fig. 6).

3.3. Controlling of the transboundary impact

The Slovenian power plant Šoštanj is located 30 km south of the border of Austria (Fig. 1). It started operation in 1956 and was expanded during the following decades. It is fuelled by a sulphur-rich brown coal. In 1991, the SO_2 emissions were 90,000 t, which equals 90% of the total Austrian output. The negative effects on forests were reported not only for Austrian forests but also for Slovenian forests (Kalan, 1991; Simončič, 2001).

Since the beginning of the Yugoslavian war in the early 1990s, the power plant produced most of the electricity because the existing nuclear power plant in Krsko was closed for safety reasons. In 1994, the related plots of the Bioindicator Grid within the special monitoring grid showed the highest number of instances of excess values since 1985 (Fig. 7). Therefore, in April 1995, the first desulphurisation co-financed by the Austrian

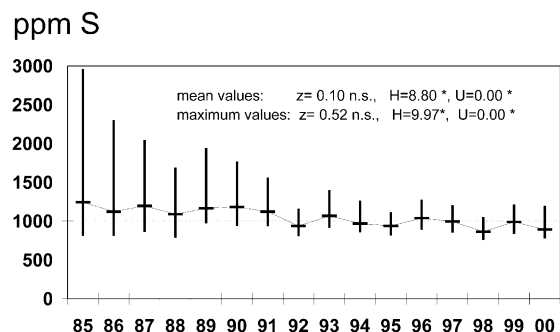


Fig. 6. Special monitoring grid Lenzing (Upper Austria): S content in the current year needles 1985–2000 and statistical evaluation.

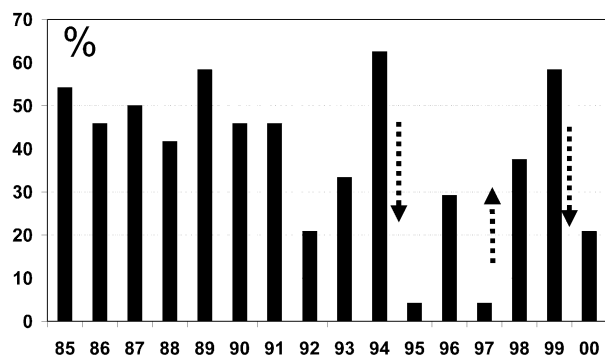


Fig. 7. Special monitoring grid Šoštanj (Slovenia): Percentage of plots influenced by sulphur impact ($n=24$). ↓ reduction of SO_2 emissions of the power plant, ↑ increase of energy production.

government was installed in the two biggest blocks (275 and 345 MW). This resulted in a reduction of the SO_2 emissions by 30%. Subsequently, the amount of excess values decreased markedly. Since 1998, the energy production has increased substantially, which, in turn, has caused instances of exceeding the limiting values in the surrounding area. In 2000/2001, additional desulphurisation equipment was installed. Today the power plant consists of five blocks, with a total output of 755 MW, and produces about one third of the total electricity of Slovenia.

The effects of the reduction of SO_2 -emissions by the power plant Šoštanj could also be seen in SO_2 -measurements on the Austrian side near the Slovenian border (Fig. 1): the number of instances of exceeding the Austrian legal standard for SO_2 varied depending on the reduction measures taken (Amt der Kärntner Landesregierung, 2002; Fig. 8).

The relation between the SO_2 -emissions of the power plant Šoštanj and the sulphur impact could also be shown for more distant areas: With the help of modelling trajectories from June to August 2000 it was possible to

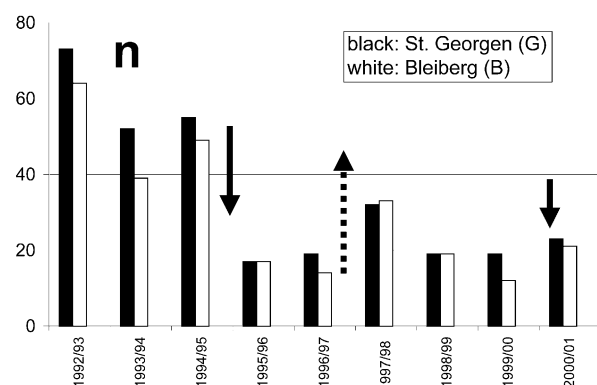


Fig. 8. Number of instances of exceeding the legal standard for SO_2 (half hour mean values) at the monitoring stations St. Georgen (G) and Bleiberg (B). Half hour mean value: $150 \mu\text{g SO}_2 \text{ m}^{-3}$, from November to March and $70 \mu\text{g SO}_2 \text{ m}^{-3}$; from April to October; Federal Law Gazette, 1984). ↓ reduction of SO_2 emissions of the power plant, ↑ increase of energy production.

prove that SO_2 that was transported as far as to the Central Alps at a distance of more than 120 km stemmed from the same emitter (Kaiser et al., 2002).

4. Conclusions

The systematic arrangement of the plots within a dense net as well as the annual sampling offer the possibility to survey the status and the development of the sulphur impact on Austrian forests. Based on the Austrian legal standard, the sulphur impact can be evaluated.

Therefore, the grid is suitable for:

1. Defining areas influenced by emitters.
2. Assessing compliance with legal standards for sulphur impact.
3. Using the database for legal regulations when new plants are built or existing emitters are expanded.
4. Initiating measures for the protection of forests in case of transboundary impacts.

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