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Stress on the Northern Tyrolean Limestone Alps by the Depositions of Pollutants

By

S. SMIDT[1)], F. MUTSCH[2)], M.H. KNOFLACHER[3)], K. STEFAN[1)] & F. HERMAN[1)]

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Summary

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Anthropogenous stresses to the forest ecosystems of the Northern Tyrolean Limestone Alps are caused by local emittors and long-range transport. Apart from the gaseous pollutants SO_2, NO_x and ozone, the proton, nitrogen and heavy metal depositions are particularly harmful.

Investigation results from all over Austrian surveys (Austrian Bio-Indicator Grid, Austrian Forest Soil Monitoring System), air monitoring data from the Federal Province of the Tyrol, model calculations, and surveys from the Achenkirch area were used to describe the stress imposed by pollutants. The monitoring data were evaluated by using effect-related limiting values and/or Critical Loads.

The evaluation of air monitoring data from the Northern Tyrolean Limestone Alps showed that pollution patterns vary greatly depending on altitude. In valleys, the effect-related limiting values for SO_2 and NO_2 are exceeded in agglomerations; at higher locations, ozone is a potential risk factor, particularly for sensitive species. In the needles of Norway spruce, which has been used as a bioindicator species, sulphur depositions were proved up to altitudes of 1200 m. Attention should also be paid to the heavy metal depositions caused by anthropogenous emittors. They accumulate in the upper soil layers, increase with altitude and are important because they can influence soil-biological processes. Whereas the acid inputs in the Northern Tyrolean Limestone Alps are usually well buffered by the soil, excessive nitrogen inputs may cause negative effects on forest ecosystems.

[1)] Institute of Air Pollution Research and Forest Chemistry of the Federal Forest Research Centre, Seckendorff-Gudent-Weg 8, A-1131 Vienna, Austria.

[2)] Institute of Forest Ecology of the Federal Forest Research Centre, Seckendorff-Gudent-Weg 8, A-1131 Vienna, Austria.

[3)] Seibersdorf Research Centre, A-2444 Seibersdorf, Austria.

Introduction

Alpine forest ecosystems are subjected to numerous stresses, of which the deposition of air pollutants is particularly important. It includes dry (gases, dusts), wet (pollutants contained in rain, snow, etc.), and occult depositions (fog). To protect forest ecosystems from the deposition of pollutants, legal standards and limiting values as well as reference and target values were introduced, which, however, do not consider organic components and synergistic effects (Table 1). While gases are mostly directly effective through needles and leaves, gravitational depositions are of importance mainly in respect of proton, sulphur, and nitrogen depositions (UN-ECE 1991); their influence on needles and leaves or on other surface parts of plants is for instance through the leaching of nutrient elements. Nitrate, sulphate, and ammonium depositions can lead to an acidification of the soil; nitrogen depositions can cause nutrient imbalances and a eutrophication of the soil.

In the present report the stress on the Northern Tyrolean Limestone Alps (growth areas 2.1 and 4.1 according to KILIAN & al. 1994) is to be evaluated through integrated interpretation of the results of numerous large-scale surveys and special investigations. The result of the evaluation is to serve as a basis of selective protective measures.

The Northern Tyrolean Limestone Alps cover about half of the area of Northern Tyrol. Parts of the Inn Valley and its side valleys suffer from high pollution stress through traffic, domestic heating, and industrial enterprises (OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1991). In the course of the past ten years SO_2 emissions have been greatly reduced and the concentrations of atmospheric pollutants has considerably decreased (SMIDT & GABLER 1994a, UMWELTBUNDESAMT 1994a; cf. Table 2), but far-distance transportation still allows large amounts of sulphur components to be imported. Unlike SO_2, NO_x emissions have decreased only slightly in Austria during recent years.

The stress air pollutants impose on the vegetation depends on site, exposure, and altitude above sea level, on the orographic and meteorological conditions of the valleys, and on the local emission situation (KAISER 1994, 1995). While mean SO_2 concentrations usually decrease slightly and NO_2 concentrations above the valley floor decrease significantly with altitude, ozone concentrations increase considerably with altitude (HERMAN & STEFAN 1992, SMIDT 1994a,b). Air pollutants and combinations are consequently a threat to the forest vegetation of the entire Alpine area.

The proton, nitrogen, sulphur, and heavy metal inputs through wet gravitational deposition are additional potential threats to the phyllosphere and the rhizosphere. Apart from their concentrations (which usually decrease with increasing altitude), also the amounts are crucial. They depend on the amounts of precipitation, which again increase with altitude. The major part of the pollutants so deposited is imported through far-distance transport.

Volatile organic compounds represent another group of agents able to affect plants (SMIDT 1994c). They are mainly produced by the traffic, particularly in the Inn Valley (OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1991).

Material and Method

The pollution stress of the Northern Tyrolean Limestone Alps was described on the basis of all-Austrian surveys, permanent records of air pollutants, special investigations at selected plots, and model calculations of crucial inputs. The air pollution records were evaluated by using effect-related limiting values and air quality criteria.

All-Austrian surveys by the Federal Forest Research Centre: Both the impacts of SO_2 pollution and their temporal and spatial distribution were determined with the help of data from the Austrian Bio-Indicator Grid (BIN, "Grid 83" and "Grid 85") with the major species, spruce (STEFAN 1994). The results from the Austrian Forest Soil Monitoring System (MUTSCH 1992) indicated airborne depositions, particularly through the heavy metal content of the soils; the determined soil parameters were also used to evaluate the threat through proton depositions.

Data from the Office of the Provincial Government of the Tyrol: Data from numerous permanently registrating air quality measuring stations (SO_2, O_3, NO_x, dust, CO; OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1990-1993) were available for assessing the air pollution situation. Investigation results from the Tyrolean "Transit Study", which aims at the assessment of the threat through transit traffic (OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1991), were also available. The deposition data from three WADOS stations (Kufstein, Reutte, Achenkirch) and one stand metering station (Achenkirch) of the Tyrolean Limestone Alps were published (OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1989, TECHNICAL UNIVERSITY VIENNA 1994).

Special investigations in the area of Achenkirch: Investigations of the air and of depositions were carried out in the area of Achenkirch in the framework of the "Ecosystematic Studies in the Limestone Alps - Achenkirch Altitude Profile" by the Federal Forest Research Centre (SMIDT & HERMAN 1994, BERGER 1995). The SO_2, NO_x and ozone records (SMIDT & GABLER 1994b), the pesticide concentrations of the rain water (LORBEER & al. 1994), and data regarding the chlorinated hydrocarbons content of the air (SCHRÖDER 1994) were also available.

Model calculations of the Critical Loads: The Critical Loads (UN-ECE 1988) for acidification and eutrophication through nitrogen were calculated using several forest soil maps (KNOFLACHER & PIECHL 1992, KNOFLACHER & LOIBL 1993); the depositions were calculated by the evaluation and surface-related interpolation of the measuring results (KOVAR & al. 1991). The sensitivity of receptors to certain pollutant agents was first determined in plots of 150 x 150 km and then compared to the nitrogen depositions. The model evaluation rendered possible the assessment of the ion concentration of the soil water, taking into consideration ion deposition, weathering, leaching, and the amount taken up by the vegetation (UN-ECE 1991). The model approaches to the calculation of the Critical Loads are described in a simplified manner and in most cases are based on the assumption that soil layers are homogenous and agents uniformly distributed and transported in the soil.

Criteria of assessment (Table 1)

Concentrations of air pollutants were assessed using effect- related air pollution limiting values and Critical Levels (according to WHO 1995 "the concentrations of pollutants in the atmosphere above which direct adverse effects on receptors such as plants, ecosystems or materials, may occur according to present knowledge"). Further, it was possible to characterize the area by comparing its data with those of other areas.

Air pollutant depositions were assessed using the Critical Loads for proton, sulphur, and nitrogen depositions. According to UN-ECE 1988 and WHO 1995, Critical Load means "a

Table 1.1. Effect-related limiting values for gaseous air pollutants (μg/m^3).

Compound	1/2 h (months)	8 h (months)	24 h (months)	Period (months)	Year	References
SO_2	70 (IV-X) 150 (XI-III)	-	XI-III: 50 IV-X: 150	- -	-	2nd Regulation Against Air Pollutants Affecting Forests (1984)
SO_2	-	-	-	I-XII/X-III 20 1) 15 2)	10$^{2a)}$	WHO 1995
SO_2	75 (IV-X) 150 (XI-III)	-	50 (IV-X) XI-III: 100	-	25	IUFRO 1975/78
NO_2	200 (I-XII)	-	80 (I-XII)	-	30	AUSTRIAN ACADEMY OF SCIENCES 1987
$NO+NO_2$	-	-	-	-	30$^{3)}$	WHO 1995
O_3	300 (I-XII)	I-XII: 60	-	IV-X: 60 (9.00-16.00)	-	AUSTRIAN ACADEMY OF SCIENCES 1989
O_3	Dose: 10ppm.h (1h mean values > 40ppb = 80μg/m^3, e.g. April - September);					UN-ECE 1994 WHO 1995

1) Forests and natural vegetation
2) Forests and natural vegetation (effective temperature sum < 1000 °C days > +5 °C)
2a) Lichens
3) NO and NO_2 added in ppb and expressed as NO_2 in μg/m^3

Table 1.2. Critical Loads for H. S and N Input (kg/ha.a).

Acidity (S: equivalent S input)	< 0.2-0.5	quartzine, granite	(S: < 3-8)	UN-ECE 1988
	0.5-1.0	greywacke, gabbro, schist	(S: 8-16)	
	1.0-2.0	gabbro, basalt	(S: 16-32)	
	> 2	carbonate	(S: > 32)	
		parent material	texture	WHO 1995
	< 0.25	acidic	coarse	
	0.25-0.50	acidic	coarse-medium	
		intermediate	coarse	
		basic	coarse	
	0.5-1.0	acidic	medium, medium-fine	
		intermediate	coarse-medium, medium	
		basic	coarse-medium	
	1.0-1.5	intermediate	medium-fine	
		basic	medium	
	< 1.5	intermediate	fine	
		basic	medium-fine	
N	10-12 / > 20	coniferous forests 1)		UN-ECE 1988
	< 15	deciduous forests 2)		
	10-15	coniferous forests (acidic, managed) 3)		WHO 1995
	20-50	coniferous forests (acidic, managed) 4)		
	15-20	deciduous forests (acidic, managed) 5)		
	15-20	calcareous forests) 6)		

1) Nutrient imbalances depending on the Mg and Ca concentrations and on the nitrification rate of the soil; shifting of species of the herbaceous layer and of shrubs depending on the uptake by the trees and the base saturation of the soil.
2) Shifting of species of the herbaceous layer and of shrubs to nitrophilic species.
3) Tree health; nutrient imbalance, low nitrification rate.
4) Tree health; nutrient imbalance, moderate - high nitrification rate.
5) Tree health; nutrient imbalance, shoot-root ratio; changes in ground flora.
6) Changes in ground flora.

Acidic: Sand (stone), gravel, granite, quartzine, gneiss.
Intermediate: Gronodiorite, loess, fluvial and marine sediments.
Basic: Gabbro, basalt, dolomite, volcanic deposits.

Table 1.3. Reference values describing the input of pollutants in spruce needles and spruce bark.

	Spruce needles (%S)			References
	Needle year 1	Needle year 2		
S total (%) class 1 class 2 class 3 class 4	 < 0.081 0.081 - 0.110 0.111 - 0.150 > 0.150	 < 0.101 0.101 - 0.140 0.141 - 0.190 > 0.190		2nd Regulation Against Air Pollutants Affecting Forests (1984)
Overall classification 1 2 3 4	Sum of classifications 2 3 and 4 5 and 6 7 and 8	 Impact of SO_2 not possible Impact of SO_2 possible Impact of SO_2 Severe impact of SO_2		STEFAN 1991
Pb (mg/kg)	4	-		KNABE 1984
	Spruce bark (mg/kg)			
Pb	> 32			HERMAN 1991
Cd	> 0.80			HERMAN 1991

Table 1.4. Reference values describing the Pb and Cd content in agricultural soils.

	Pb (mg/kg)	Cd (mg/kg)	References
Assumed stress Rererence value for stress	50 100	0.5 1.0	ÖNORM L 1075
Guidance data tolerable	0.1 - 20 100	0.1 - 1 3	KLOKE 1980, 1981

Table 1.5. Reference values describing the mean annual concentrations of gaseous pollutants (HAHN 1991).

Compound	Remote areas	Rural areas	Congested areas
SO_2 (µg/m^3)	0.5 - 10	4 - 20	10 - 90
NO_2 (µg/m^3)	3 - 10	10 - 55	30 - 105
O_3 (µg/m^3)	70 - 130	30 - 100	15 - 60

Table 1.6. Reference values for Pb content (mg/kg) in spruce needles.

*) Without specific emittors **) Polluted by local emittors

Remote areas	Rural areas	Urban areas	Reference
< 0.80	0.80 - 1.10 *) 1.11 - 1.70 **)	> 1.70	HERMAN 1994

quantitative estimate of an exposure, in the form of deposition, to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge".

Pollutant content of spruce needles: The assessment of the total sulphur content was based on the limiting values set in the 2nd Regulation Against Pollutants Affecting Forests (Austrian Federal Law Gazette no. 199/1984, STEFAN 1994). The overall classification is the sum of the classifications of needle years 1 and 2 (Table 1.3; STEFAN 1991). The results of the assessment provide additional information about air pollution by lead in that area; it is possible to distinguish between differently stressed areas (HERMAN 1994a). According to HERMAN 1991 also the content of lead and cadmium in spruce bark are indicators of air pollution impacts.

Results

Concentrations of gaseous air pollutants (1990-1993; Fig. 1)

Sulphur dioxide: Thanks to the considerable reduction of emissions since the early eighties (UMWELTBUNDESAMT 1994a) the mean SO_2 concentrations (annual averages) have decreased significantly and the valley floors are now only slightly more severely stressed than the high-altitude areas located at greater distances from the emittors (cf. annual mean values in Fig. 1). Not even at the urban monitoring stations would the annual means be higher than 20 $\mu g/m^3$ (HERMAN & STEFAN 1992). Like everywhere in Austria, the IUFRO limiting value for annual means of 25 $\mu g/m^3$ has not been exceeded since 1989; the limiting values for half-hour and daily mean values laid down in the 2nd Regulation Against Air Pollution Affecting Forests (Austrian Federal Law Gazette no. 199/1994) were exceeded at some urban stations (OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1990-1993). The maximum daily and half-hour means clearly decreased with altitude.

Nitrogen dioxide: The annual NO_2 means varied between 10 and 90 $\mu g/m^3$, with the values determined in the valleys or at relatively low altitudes being considerably higher than those measured at high-altitude plots (Fig. 1b). The maximum daily and half-hour means, too, proved to decrease significantly with altitude. The fact that mean values were so much lower at high-altitude plots was found to be due to the relatively high concentrations at the low-altitude places which are to a high degree a consequence of the motor traffic. Between 1990 and 1993 the maximum annual mean of 30 $\mu g/m^3$ of the AUSTRIAN ACADEMY OF SCIENCES 1987 was exceeded in Hall, Kufstein, Innsbruck, and Wörgl. The effect-related NO_x limiting values of the WHO 1995, which are more rigorous and consider also the NO concentrations, were found to be exceeded even more frequently. In the areas between 1000 m and 1400 m, where approximately 50 % of the Austrian forests stock, no NO_2 exceedances have been determined under the present criteria of assessment of the AUSTRIAN ACADEMY OF SCIENCES 1987; close to the timber line, the concentrations were even lower.

Ozone: The annual ozone means varied between 30 and 90 $\mu g/m^3$, with values increasing up to the timber line (Fig. 1c). As regards very sensitive plants, even vegetation period means (which are higher than annual means) of 60 µg/m^3 constitute a threat, annual means below that value are potential risks, particularly in areas located above 1000 m. Unlike this, the maximum half-hour mean value established by the AUSTRIAN ACADEMY OF SCIENCES 1989 (300 µg/m^3) was hardly ever exceeded; the 1-hr maximum (150 µg/m^3) was exceeded only slightly; the 8-hrs mean and the vegetation period mean (60 µg/m^3) were, however, exceeded at a very high rate (SMIDT 1994a). Vegetation period means and daily peak values increased considerably with altitude; the maximum half-hour means were almost the same at all altitudinal levels.

Apart from the above-mentioned effect-related air pollution limiting values, also the temporary Critical Level of the UN-ECE 1994 ("AOT40") can be used to assess possible impacts. This Critical Level is calculated by summing up the amounts of the 1-hr means which exceed 40 ppb (80 µg/m^3). For forest plants, the evaluation proved that, at Alpine stations, the critical dose of 10 ppm.h for six months of maximum plant sensitivity was reached already in May and that, between April and September a multiple of the upper limit was reached. At Austrian-based stations, the AOT40 values increased more than the vegetation period means did (Fig. 2; SMIDT 1994a).

Depositions of air pollutants

Nitrogen inputs: Between 1985 and 1993 the N inputs through wet field depositions determined in the Northern Tyrolean Limestone Alps amounted to 5-20 kg/ha.a annually (SMIDT 1994d, TECHNICAL UNIVERSITY VIENNA 1994). The monitoring results from individual Alpine altitude profiles indicated different changes with altitude: In the Loisachtal/Bavaria and in the Zillertal/Tyrol, the results from the monitoring period 1985-1988 did not show any uniform increase or decrease with altitude; the results from the altitude profiles Koralpe/Carinthia and Bad Reichenhall/Bavaria, however, proved a decrease of N inputs with altitude (SMIDT & MUTSCH 1993). (The inputs were found to change uniformly with altitude where the decreasing concentrations in precipitation with altitude, or

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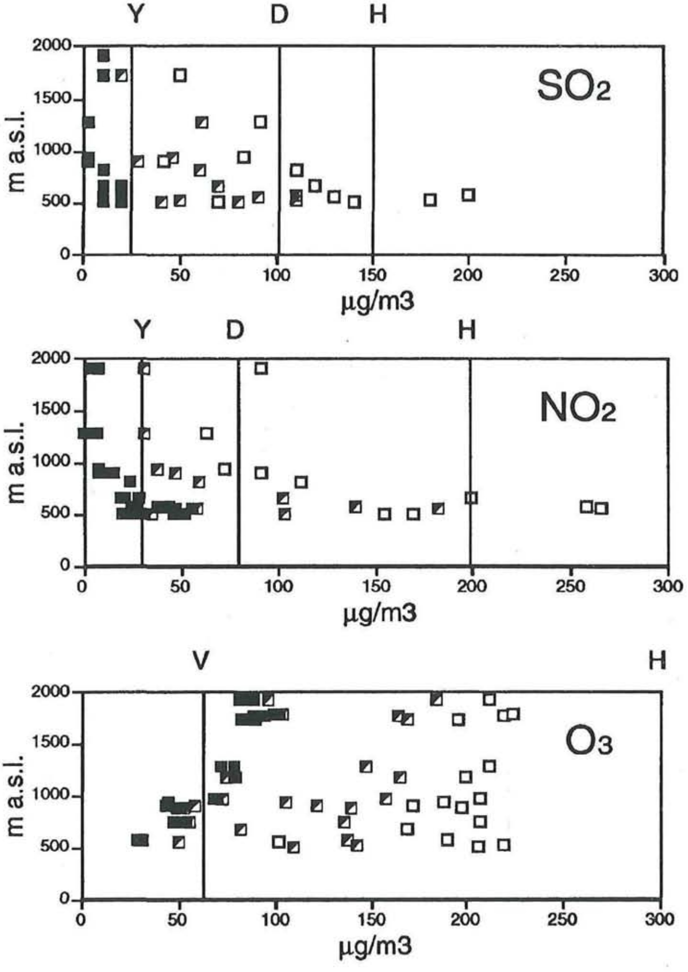
Fig.1. Annual mean values, maximum daily mean values and half-hour mean values in the Northern Tyrolean Limestone Alps (1990-1993)

Critical Level / Limiting value:

■	Annual mean values	Y	Annual mean value
◩	maximum daily mean values	D	Daily mean value
□	Maximum half-hour mean values *)	H	Half hour mean value
		V	Vegetation period mean value

*) The absolute SO_2 half hour maximum of 660 µg/m^3 was registered in Brixlegg (Inn Valley, Station Innweg).



altitude above valley floor, were compensated by the increasing amounts of precipitation.) In the area of Achenkirch, nitrogen inputs of 5-12 kg/ha.a were recorded in the field (SMIDT 1994d) and 12 kg/ha.a in throughfall (BERGER 1995). Compared to results from Germany, these inputs were low (Table 2). With reference to these results, the nitrogen inputs in the throughfall were found to have slightly increased in Germany (r=0.32), while they had slightly decreased in the Tyrol (r=0.02; Fig. 3).

Sulphur inputs: In the Tyrol, the sulphur inputs in the field amounted up to 15 kg/ha.a and so were somewhat lower than the N inputs. For the area of Achenkirch, the inputs determined in the field were < 7 kg/ha.a (SMIDT 1994d); those in the throughfall were < 8 kg/ha.a (BERGER 1995). These inputs, too, were low compared to results from Germany (cf. Table 2). Between 1984 and 1993 the

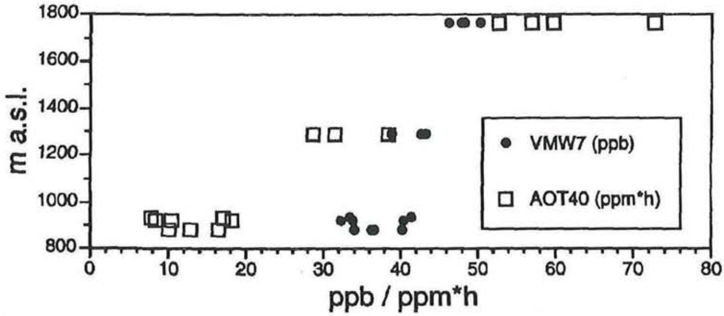


Fig. 2. Ozone - annual means and vegetation period means (μg/m^3) and AOT40 values (ppm.h) from the Northern Tyrolean Limestone Alps (1991 - 1994; records projected to 100 % data availability, data availability > 75 %).

average sulphur inputs decreased both at the 22 German throughfall plots (r=0.91) and at the 3 field stations based in Austria (r=0.69).

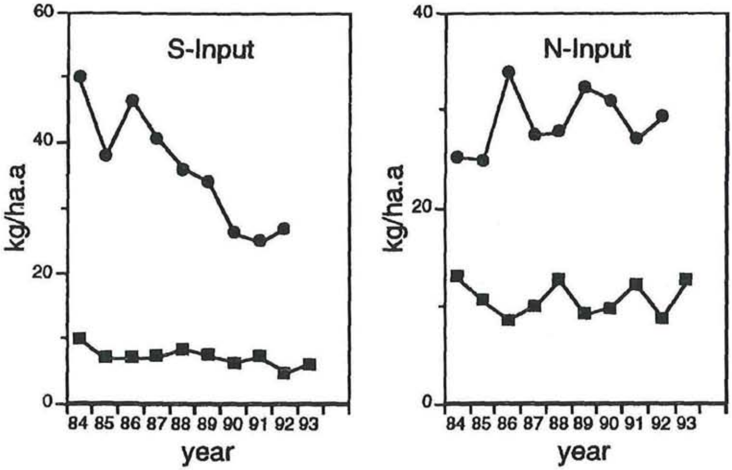


Fig. 3. Development of mean SO4-S and N inputs (NH_4^- + NO_3^-) in Austria and Germany.

● Germany, 22 stations (registrating of canopy drip); according to VOLZ 1995

□ Tyrol, 3 stations (wet-only sampling in the field); VIENNA TECHNICAL UNIVERSITY 1995.

Table 2. Inputs of elements in forest stands and in the field (values rounded; kg/ha.a).

	Germany (n=22, 1984-1993; VOLZ 1995)	Bavaria (n=9, 1984-1992; KENNEL 1994)	Tyro1995 (n=1, 1984-1987; OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1989	Tyrol (n=3); OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1995	Alpine altitude profiles (n=5), 1985-1988), SMIDT & MUTSCH 1993
	Throughfall (Spruce) Overall mean	Throughfall (Spruce) Variation	Throughfall (Spruce) Mean value	Field investigations Variation	Field investigations Variation
N	30	12-56	10	7-17	7 - 17,5
S	28	7-60	17	4-13	7 - 15
H	0.6	0.4-3.3	0.2	0.1-0.6	0.05 - 0.32

Proton inputs: At Alpine altitude profiles, the proton field inputs reached up to 0.5 kg/ha.a; their amounts did not correlate with altitude (SMIDT & MUTSCH 1993). In Achenkirch, too, the proton inputs determined in the field reached up to 0.5 kg/ha.a (SMIDT 1994); those determined in the throughfall varied between 0.2 and 0.3 kg/ha.a (BERGER 1995). The inputs, notably those of the throughfall, corresponded to the lower measurements made in Germany (cf. Table 2).

Model calculations for H, S, and N inputs: According to the UN-ECE 1988 and the UMWELTBUNDESAMT 1993 proton inputs exceeding 2 kg/ha.a can be considered Critical Loads for the Northern Tyrolean Limestone Alps. Accordingly, the direct proton input from wet field deposition falls by far below the Critical Load, but also the inputs from dry deposition of SO_2, NO_2, and NH_4^+, and the unknown amount from occult deposition (deposition by fog) have to be taken into account. As it is not possible to determine the occult deposition when collecting the gravitational deposition, the values determined with the help of WADOS samplers are minimum total inputs. According to KOVAR & al. 1991 the sulphur and nitrogen inputs (sulphur inputs: up to 30 kg/ha.a) found in the Northern Tyrolean Limestone Alps are relatively high compared to other Austrian areas (Fig. 4a and 4b). With the help of the basic data for the calculation of Critical Loads for acidification, the N models were used for a first appraisal of the Critical Loads for nitrogen. According to KNOFLACHER & LOIBL 1993 the results indicate that the Critical Loads for nitrogen are very low in the Alpine area (between 5 and 10 kg/ha.a; lower values were not considered for the uncertainty of the data; Fig. 5). In the Achenkirch project area, inputs varied between 5 and 15 kg/ha.a, which would mean that (with reference to the total deposition) the Critical Loads for nitrogen are exceeded.

Inputs of herbicides: In recent years, direct and indirect effects of volatile organic components were frequently discussed in connection with forest damage (SMIDT 1994b). Especially herbicides or components which, in the course of the photooxidative conversion, begin to act as herbicides, chlorinated C_1 and C_2 hydrocarbons are considered important stress factors to forest ecosystems. These persistent components are transported over long distances and can be deposited also by wet deposition (LORBEER & al. 1994). For the area of Achenkirch as well as for other stations in Austria, the extrapolated inputs amounted to approx. 0.3 g/ha.a for atrazine, 0.7 g/ha.a for alachlor, 2.8 g/ha.a for γ-HCH, and approx. 3.5 g/ha.a for trichloroacetic acid (SMIDT & al. 1995b). These inputs represent about 1/1000 of the amounts deposited in the course of one single application of pesticides; they are spread over wide areas, but do not constitute a threat to the forests.

Fig. 4. Nitrogen inputs according to KOVAR & al. 1991
(a) NH_4-N inputs; (b) NO_3-N inputs.
Fig. 5. Critical Loads for nitrogen inputs (KNOFLACHER & LOIBL 1993).
Fig. 8. Overall classification of the sulphur contents of spruce (GK; Bio-Indicator Grid), 1985-1992.

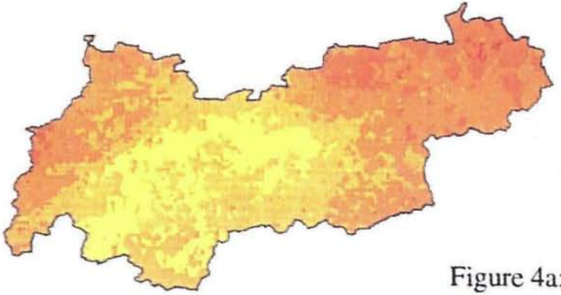
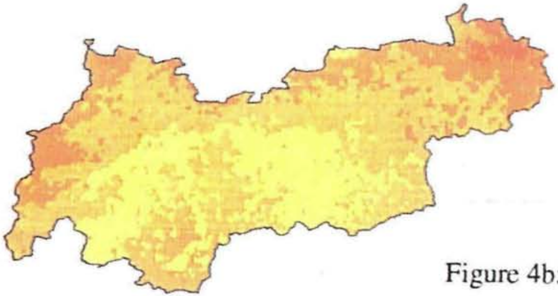


Figure 4a: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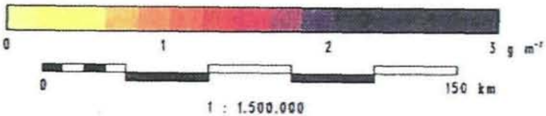

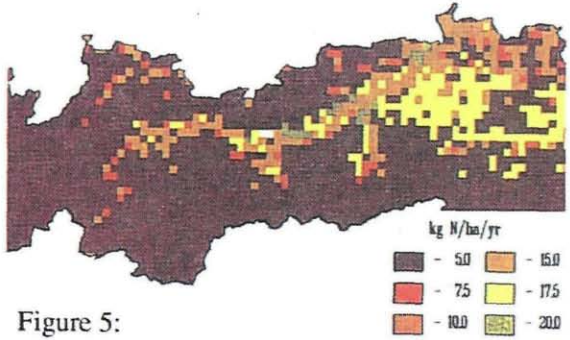

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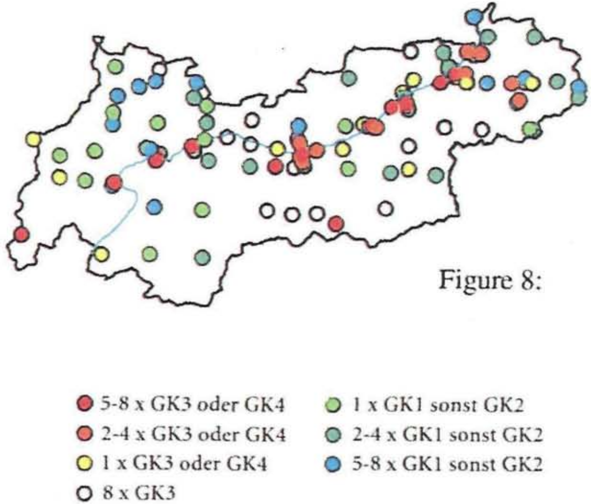

Figure 8:

Results of the Austrian Forest Soil Monitoring System: The sample plots located in the Northern Tyrolean Limestone Alps are mainly carbonate-influenced and therefore not problematic in respect of proton inputs; only in the southernmost part of that growth zone some sample plots showed results (pH, base saturation, cation exchange capacity, and heavy metal content) which indicated a potential threat through acidity and which fell below the reference values established by MUTSCH & SMIDT 1994 or were within the critical range (Fig. 6).

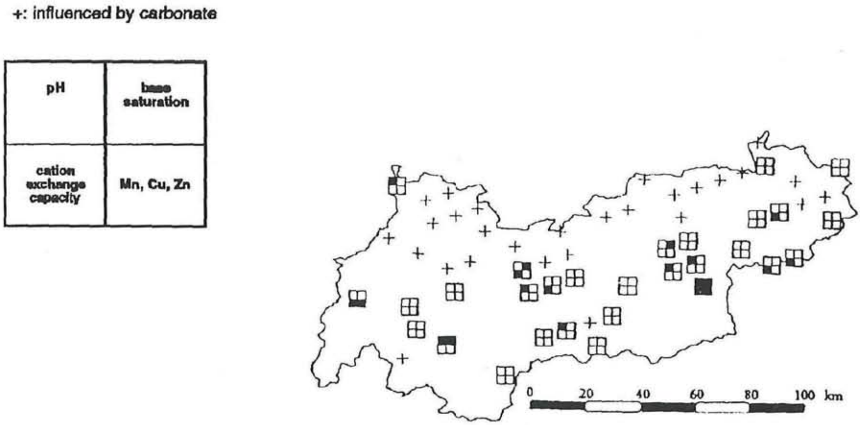

Fig. 6. Records remaining below the references values for pH values, base saturation, cation exchange capacity, and trace element content.

If results fall below the references values for pH (4.2), base saturation (18 %), cation exchange capacity (100 µmol/g), and Mn, Cu and Zn concentration (200, 14 and 40 mg/kg, respectively), integrated over all depth levels of the mineral soil (0-10, 10-20, 20-30, 30-50 cm), this indicates a threat through acid inputs (black squares). MUTSCH & SMIDT 1994.

Heavy metal content of the soil

The results of the Austrian Forest Soil Monitoring System showed that in Austria the lead and cadmium values increase significantly with altitude and exposure. The Alps therefore represent an important sink of heavy metals transported from distant parts of Central and Northwestern Europe (main direction of the wind). Compared to the subsoil, these heavy metals proved to have considerably accumulated in the topsoil (MUTSCH 1992 and 1995). Also the differences in the absolute content of topsoil (0-10 cm) and subsoil (30-50 cm) increased with altitude. (Unlike lead, copper, chromium, and nickel do not accumulate in the topsoil.) All over Austria, the accumulations in the topsoil as compared to the subsoil ranged between -218 and +209 mg/kg for lead (n = 141; only 7 values below 0); the lead content of the topsoil was on average by 32.4 mg/kg higher than that of the subsoil. The decrease of the lead and cadmium content from topsoil to subsoil and the resulting difference may be an indicator of air pollution and/or of the severity of air pollution.

In the Northern Tyrolean Limestone Alps the lead content of the soil was between 50 and 120 mg/kg; the cadmium content ranged between 0.5 and 3 mg/kg. Unlike the all-Austrian result, it was not possible to prove an altitude-related increase of the lead inputs on north-exposed plots in Achenkirch (Schulterberg; MUTSCH 1995; Fig. 7) because, for a statistical evaluation, the number of plots is too low compared to the all-Austrian data record and, with such limited data record, the absolute altitude above sea level does not precisely enough account for the actual criterion, namely the exposure to the weather (main direction of the wind, wind-ward side, relative altitude above sea level). It is assumed that no altitudinal dependance was found for the Schulterberg (Achenkirch) because the latter has no prominent foothills, which means that the entire north-exposed slope is relatively uniformly exposed to weather events and, consequently, also to air pollution.

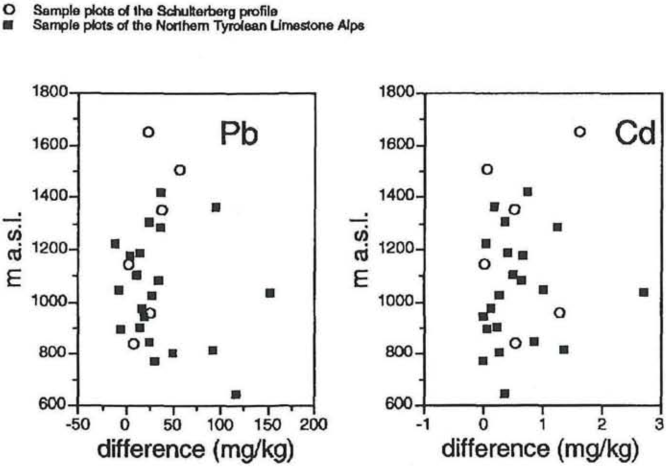

Fig. 7. Differences between the Pb and Cd contents of the depth levels of 0-10 cm and 20-30 cm.

○ Sample plots of the Schulterberg profile
■ Sample plots of the Northern Tyrolean Limestone Alps

Based on reference values (Austrian Industrial Standard, ÖNORM L1079/1993) and on the guidance data (KLOKE 1980, 1981) for agricultural soils, exceedances were found for lead and cadmium (Table 1). Cadmium is present in much lower concentrations than lead, but it is easily taken up by plants. According to data from expert literature, it cannot be excluded that mycorrhicae and/or other microorganisms living in the soil are affected (HERMAN 1994a); in the Northern Tyrolean Limestone Alps, there are, however, no concrete indications to the influence of soil-biological processes as a result of heavy metal input.

Pollutant content of needles and barks of spruce

Sulphur content of spruce needles: 66 of the 135 Tyrolean BIN plots are located in the Northern Tyrolean Limestone Alps. Fig. 8 (page 261) shows that between 1985 and 1992 the overall classifications 3 and 4, which indicate that forests are under the impact, or severe impact, of air pollution, occured most frequently in the Inn Valley and in the area close to St. Johann. The annual sulphur means of the BIN sample trees (needle year 1) from the Northern Tyrolean Limestone Alps ranged between 0.077 and 0.102 % (STEFAN 1994); no significant changes occurred within the investigation period (Fig. 9). But the reduction of the SO_2 emissions in Austria is not evident from the mean S content of spruce needles.

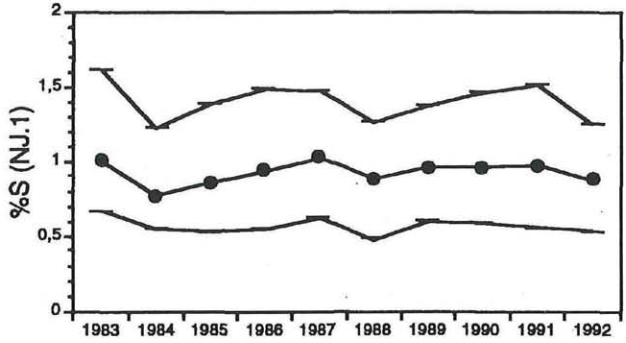

Fig. 9. Development of the total sulphur content of needle year 1 (NJ.1; mean values and ranges of values in the Northern Tyrolean Limestone Alps from 1983-1992; n=66).

When using the total mean values it is not possible to distinguish between the sum of the areas with, without, or with severe impact. This is why the results from the individual years were classified in one of the overall classifications 1, 3 or 4. As can be seen from Table 3, there was no great difference in the percentages of the two grids in respect of the overall classifications 1 and 3 + 4. Remarkable differences were, however, proved for the annual changes in air pollution impacts: In 1984 and 1985, for instance, more than half of the sample plots ranged in the overall classification group 1; during the entire investigation period similarly good results were never observed again. In 1992, about 30 % of the sample plots ranged in that class, which, however, does not mean that the stress situation improved because in 1993 not one single plot was in that classification group. Taking Grid 83, severe air pollution impacts were determined especially in 1987; in 1988 and 1992 the situation improved considerably, but, in analogy to the above comment, deteriorated again in 1993. One cannot conclude from these evaluations that the SO_2 air pollution situation improved between 1983 and 1993.

The total sulphur concentrations of needle year 1 between 1983 and 1992 are provided in Fig. 10. They clearly show a decrease with altitude as well as exceeded limiting values at altitudes of up to about 1200 m a.s.l.
Another way to point out the inter-relation between the sulphur content of spruce needles and altitude is to present the percentage of the respective concentrations for the different overall classifications. Fig. 11a shows that almost 67 % of the BIN sample trees stocking at altitudes $\leq$ 600 m were at least once in the course of the observation period in one of the overall classification groups 3 or 4; at locations < 800 m the percentage was even higher, but it was < 30 % for altitudes between 800 and 1000 m. It is interesting that up to 1200 m concentrations increased again, while from 1200 m upwards, not a single case of

Table 3. Shares of sample plots from Grid 83 and Grid 85 which, during the periods of 1983-1993 and of 1985-1993, respectively, were in the overall classification (Ov. Class) class 1 and 3/4, respectively.

Year	Grid 83 (n=49) Ov. Class 1	Grid 85 (n=66) Ov. Class 1	Grid 83 (n=49) Ov. Class 3 or 4	Grid 85 (n=66) Ov. Class 3 or 4
1983	8.2	-	18.4	-
1984	63.3	-	2.0	-
1985	46.9	40.9	12.2	10.6
1986	24.5	24.2	14.3	12.1
1987	6.1	7.6	26.5	31.8
1988	22.4	24.2	6.1	6.1
1989	16.3	16.7	14.3	13.6
1990	12.2	15.2	20.4	21.2
1991	8.2	9.1	20.4	21.2
1992	28.6	28.8	2.0	3.0
1993	-	3.0	18.4	16.6

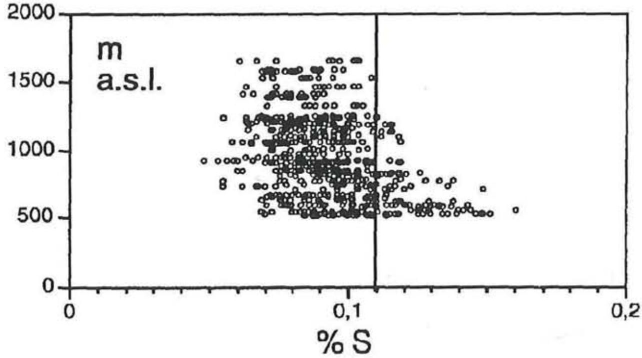

Fig. 10. Total sulphur content of individual sample plots, depending on altitude (needle year 1, 1983-1992).

0,11 % S: Limit value according to the 2nd Regulation Against Pollutants Affecting Forests (needle year 1)

overall classification 3 or 4 was observed any more. Also the percentage of the trees which were once or several times in overall classification 1 and otherwise only in 2, increased with the altitudinal level (Fig. 11b).

Lead concentrations in spruce needles: As regards the lead concentrations of the needles, Achenkirch is a clean-air area; as opposed to this, the Zillertal, another Alpine valley belonging to the Northern Tyrolean Limestone Alps, showed for several years concentrations which were as high as in rural or even in congested areas (HERMAN 1992).

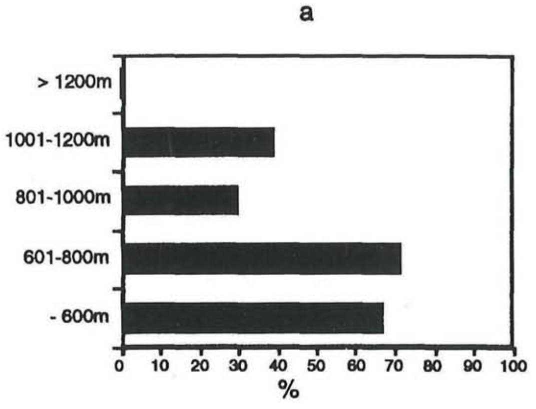

Fig. 11a: Percentage of the plots of the individual altitudinal levels with at least one limiting value exceeded (overall classification 3/4; 1985-1993; n=66).

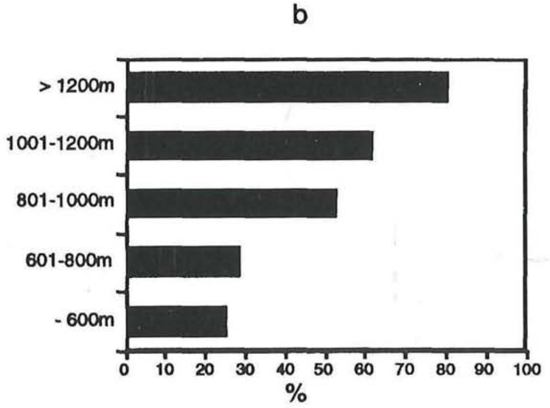

Fig. 11b. Percentage of the plots of the individual altitudinal levels with no limiting values exceeded (at least once in overall classification 1, otherwise in 2; 1985-1993; n=66).

Lead and cadmium concentrations of spruce bark: In the Northern Tyrolean Limestone Alps, the spruce stems of the BIN trees sampled in 1987 showed lead concentrations of 1.1 to 67.6 mg/kg. The highest amounts were determined in the areas of Kufstein and Innsbruck, as they are severely stressed by the traffic. According to the evaluation system by HERMAN 1991 these concentrations indicated impacts of air pollution through lead. The inter-relation of traffic and lead concentrations was evident also from the results of the Transit Study, where samples collected at sites characterized by an extremely high traffic volume in the Wipptal showed extremely high lead concentrations (HERMAN 1991, OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1991). On the other hand, the example of the Lechtal side valleys proved that sites located at a great distance to traffic are hardly stressed at all. At the Achenkirch altitude profiles, the lead concentrations indicated a possible impact of air pollution (HERMAN 1994b). What was striking in Achenkirch was that, compared to the valley floor, the lead and cadmium concentrations of the high-subalpine plot (1686 m) were high, which corresponded to the results of the needle analyses (HERMAN 1992). The cadmium concentrations of the bark of BIN trees ranged between 0.05 and 3.28 mg/kg and in many cases indicated the impact of air pollution. Unlike lead, the cadmium concentrations of the area of Innsbruck were not higher than those of the other sites. As opposed to this, some accumulation was found in side valley having a low traffic volume. In the area of Achenkirch the cadmium concentrations of the barks ranged up to 1.8 mg/kg, with the highest concentrations being determined at the highest locations, as was the case with lead. At those high locations, the cadmium concentrations indicated the impact of air pollution.

Chlorinated hydrocarbon and trichloroacetic acid (TCA) analyses of spruce needles were carried out for the area of Achenkirch only; the results indicated "ubiquitarian" distribution. The volatile components, which do not accumulate in the needles, were found in amounts of approximately 1 µg/kg; TCA is, however, accumulated (concentrations of 1 - 7 µg/kg; PLÜMACHER & SCHRÖDER 1994). No adverse effects of these concentrations are mentioned in literature.

Discussion

Concentrations of gaseous air pollutants

In the course of the observation period the valley floors of the Inn Valley and of some of its lateral valleys were found to be stressed by NO_2 and, to a lower degree, by SO_2. Effect-related limiting values were exceeded only now and then in congested areas. Due to the orographic particularities of the Alpine valleys and the resulting unfavourable conditions of spreading pollutant concentrations are, however, relatively high when the weather does not allow much exchange. (The inversion layer is mostly located at about 200 m above the valley floor.)

The reduction of the SO_2 emissions during recent years has not influenced the mean sulphur content of spruce needles. This is due to the fact that the sulphur content of the soil, to which depositions were added for many decades, decreases only rather slowly; in addition, local emissions still exist and must be taken into consideration. Lichen maps worked out for the area of the Northern Tyrolean Limestone Alps illustrated also that especially the valleys, but sometimes even high-altitude locations, are subject to stress through acid pollutant depositions (OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1991, HOFMANN 1992a, b). That acid trace constituents are transported to the sensitive area of the mountain sides at altitudes above the inversion layer is possible because of anabatic winds, the latter being evident also from the BIN results. Thanks to the low concentrations it can be excluded that SO_2, as an individual component, constitutes a threat to high-altitude forests of that growth area. The conversion products, however, notably the proton concentrations of wet precipitation, contribute to the stress of a large area. Also NO_2 is by itself not a direct threat to forest ecosystems of the Northern Tyrolean Limestone Alps located above 1000 m, but its conversion products play an important part in the photolytic cycle and in the formation of ozone. Furthermore, deposited gaseous nitrogen compounds add to the acidification of the soil and to the nitrogen input.

Unlike SO_2 and NO_2 concentrations, those of ozone increased considerably towards the timber line. Based on effect-related air pollution limiting values and ozone doses, very sensitive plants are to a high degree threatened by ozone. Plants which are less sensitive to ozone are not immediately threatened, but, notably at high altitudes, under permanent stress. When evaluating the threat to forest ecosystems on the basis of the species composition and the sensitivity of the individual species one has to take into consideration that forest ecosystems with the major species spruce in fact cannot be threatened because of the low sensitivity of this species to ozone. However, more sensitive species of mixed forests, such as common beech, make up an essential part of Alpine forest ecosystems: According to the surveys of the Austrian Forest Inventory spruce is the major species of the Northern Tyrolean Limestone Alps with 72 % in production forests and 65 % in protection forests with commercial yield; but its share is only about 39 % in protection forests without commercial yield (SCHADAUER 1995). In protection forests with commercial yield, the share of beech is approximately 14 %; in protection forests without commercial yield about 5 % (in these areas, "other broadleaved trees" are found on 6 % of the area; dwarf pine covers almost the same percentage of floor space as spruce). According to REICH 1987 the leaves of deciduous trees are considerably more sensitive than the needles of the conifers, which allows the conclusion that ozone is a stress factor especially in respect of the protection forests. Also herbacious plants, which equally contribute to the stability of the soil, are to be classified as sensitive to ozone.

Depositions of air pollutants

At high altitudes, there are air pollutants from far-distant transport in addition to those produced locally (depositions). All over Austria, the amounts of imported pollutants are much higher than the depositions produced in our own country (the sulphur imports are nearly 13 times, the nitrogen imports nearly three times as high as the depositions of the respective elements produced in Austria; UMWELTBUNDESAMT 1994a; cf. Table 4).

Nitrogen inputs: According to GLATZEL 1990 forest ecosystems need 7 kg of N/ha annually for the production of biomass over a period of 100 years. In the Northern Tyrolean Limestone Alps the nitrogen inputs of up to 20 kg/ha.a determined from the wet field depositions exceed the Critical Loads for sensitive sites. Actually, the total input is even higher because the dry and occult depositions were not been determined for the investigation area, but would have to be taken into account.

Table 4. Import, export, and intrinsic deposition of sulphur and nitrogen compounds (tons) in Austria, 1992 (UMWELTBUNDESAMT 1994b).

	Import	Export	Intrinsic deposition
Sulphur	121,500	16,100	9,500
N, reduced	49,800	26,500	39,700
N, oxidized	67,800	27,400	3,200
N, total	117,600	53,900	42,900

into account. Using the criteria of Critical Loads, there is no acute threat to forest ecosystems; only nutrient imbalances and species shifts in the herb and bush layer may occur. However, the Alps are in general sensitive to nitrogen inputs into the soil because Alpine forest ecosystems are adapted to soils poor in nitrogen. Additional input may lead to increased growth, but can also cause nutrient imbalances and reduce stability.

The critical inputs in the Northern Tyrolean Limestone Alps were assessed using empirical models. However, for the above-mentioned reasons, they can be regarded only a first approximation aiming at the evaluation of the nitrogen inputs. Their informational value depends on whether the essential processes are described in sufficient detail, which data are available at which spatial and temporal pattern, and how precise they are. As regards the models on the eutrophicating effect of nitrogen, it is not yet clear which changes are actually of relevance to forest ecosystems. As the release and utilization of agents in forests involve more than just one process simultaneously, it may come to different combined effects, depending on the respective site conditions. Apart from the processes taking place in the soil solution, which are considered in the model, also changes in short-term conversion cycles (e.g. disintegration of the litter) can lead to changes of the nutrient spectrum available to plants if they occur over several vegetation periods. Models are particularly problematic as the effects were monitored over large areas (several 1000 m^2), while receptor systems were relatively small (several km^2). Depending on the selected receptor systems, the definition of critical impacts, and the evaluation of the individual results, this can lead to different results.

Proton inputs: The Northern Tyrolean Limestone Alps are carbonate-influenced and therefore in most cases not endangered by proton inputs, except for non-carbonate influenced (small) sites. However, acid depositions may cause corrosions of the cuticula on the surface of leaves and consequently cause nutrient leaching and infections even before they reach the soil.

In the Northern Tyrolean Limestone Alps the Critical Loads for proton inputs (HETTELINGH & al. 1991) were only slightly exceeded, which means that they will probably not cause unfavourable changes. However, in analogy to the model calculations of the UN-ECE for Switzerland the total input would have to be estimated at a considerably higher amount. The reason for is that these models consider the trace gases SO_2, NO_2, and NH_4^+, which after hydrolization and deposition in the soil also release protons, and that they are based on several different assumptions (e.g. that neither denitrification or net N_2 production nor ammonium leaching take place in the soil). The inputs referred to above are therefore rather a minimum estimate of the actual inputs. According to WINKLER & PAHL 1993 occult deposition can represent a considerable portion of the annual precipitation: In a 40-year old fir forest in the Schwarzwald (a wooded mountain range in the south-west of Germany), at 1024 m a.s.l., it ranged between 23 % and 43 %; depending on the respective ion, the concentrations were 6 to 12 times higher than in rain. The annual input through fog can even exceed that through rain (PAHL, pers. comm.). However, there are still lacking data about fog depositions in the Alpine area. First results from the area of Achenkirch indicated extremely high S and N peak concentrations (e.g. up to 160 mg NH_4^+/l and up to 303 mg NO_3^-/l; KALINA & al. 1995). Along an elevational gradient in the State of New York (600 - 1275 m) the percentages of sulphur and nitrogen deposited by fog increased considerably from 600 to 1275 m, reaching up to 61 % (S) and 66 % (N), respectively (at 1275 m; MILLER & al. 1993).

According to model calculations, the total proton inputs in Switzerland in 1990 ranged between 1.5 and 4.5 kg/ha.a (FEDERAL OFFICE OF ENVIRONMENT, FORESTS AND LANDSCAPE 1994). The future effects of such proton inputs depend to a high degree on the characteristics of the relevant ecosystem. The high structural and ecological diversity of Alpine zones might create small critical areas where limits are exceeded at a critical rate able to cause problematic secondary damage in the long run (e.g. increase of erosion).

Volatile organic components of anthropogenic origin are found everywhere, even in clean-air areas; using the amounts of chlorinated hydrocarbons determined in air and needles, this was confirmed also for the Achenkirch investigation area (SCHRÖDER 1994). According to the present state of our knowledge, the determined inputs of pesticides can be classified as being unrisky, as there are at present no concrete indications that volatile organic components, taken up via the foliage or the soil, might be a direct or acute threat to Alpine forest ecosystems. Their indirect effects are assumed to be of greater importance than the direct ones.

Heavy metal content of precipitation: In the area of Achenkirch, the lead and cadmium inputs to forest ecosystems through field depositions amounted on average to 0.012 kg Pb/ha.a and 0.001 kg Cd/ha.a, respectively (SMIDT & RENDL 1992). These results were low compared to the concentrations determined in field depositions of various other forest stations from all over Europe (0.7 kg Pb/ha.a and 0.026 kg Cd/ha.a (VEREIN DEUTSCHER INGENIEURE 1983); in Austria annual inputs of up to 0.15 kg Pb/ha.a (peak values around Vienna) were determined.

Heavy metal content of the soil: Cadmium and, in particular, lead are little mobile in carbonate-influenced soils. As there are no limiting values for forest soils at the moment, it is not possible to make any detailed statements regarding the actual threat heavy metals mean to forest soils. Though the tolerable total concentrations for agricultural soils (100- > mg/kg for Pb and 1 - 3 mg/kg for Cd) are not applicable to forest soils, they can serve as approximate reference values. In the Northern Tyrolean Limestone Alps, these values are exceeded and therefore present a potential threat to soil-biological processes, particularly in respect of a possible accumulation. The inputs till now of lead ranged between 10 and 100 kg/ha, those of cadmium between 0.1 and 1 kg/ha.

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Autor(en)/Author(s): Smidt Stefan, Mutsch Franz, Knoflacher M. H., Stefan Klaus, Herman F.

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