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The Threat of Nitrogen Deposition to Austrian Forest Ecosystems

By

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Summary

SMIDT ST. & HERMAN F. 2005. The threat of nitrogen deposition to Austrian forest ecosystems. - Phyton (Horn, Austria) 45 (3): (385)-(393).

Nitrogen oxides (NOx), ammonia (NH_3) and the secondary compounds nitrate and ammonium are of long-term relevance to the health, composition and stability of forest ecosystems. The emissions of NOx in Austria decreased slightly from 1980 to 1999 from 246 to 190 Gg p.a., but afterwards they increased due to the constantly growing traffic volume. In 2002, the NOx emissions reached 204 Gg, 54 % of which resulted from road traffic. NH_3 emissions remained almost constant between 1980 and 2002 with 53 Gg p.a., and they result entirely from agricultural activities.

At most of the stations in forested areas the annual mean values of NOx decreased. However, the NOx limit of 30 $\mu g\ m^{-3}$ has still been exceeded at individual plots. Nitrogen depositions amounted to up to 30 kg N $ha^{-1}\ a^{-1}$ in the open field. The occult deposition (fog) contributed essentially to the total deposition in higher elevations. The nitrogen input exceeded Critical Loads at the measuring plots. Modelling of the Critical Loads for the Northern Tyrolean Limestone Alps made it possible to display sensitive areas: The slopes of the valleys are particularly at risk through nitrogen input.

Introduction

The deposition of nitrogen oxides (NOx = NO + NO_2), ammonia (NH_3), nitrate (NO_3^-) and ammonium (NH_4^+) are a threat to forest ecosystems (ORTLOFF & SCHLÄPFER 1996). The gaseous compounds NOx and NH_3 affect plants directly: NOx forms aggressive radicals in plant cells which attack enzymes and membranes and therefore inhibit photosynthetic activity (HIPPELI & ELSTNER 1996). NH_3 re-

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duces photosynthetic activity and plant growth by inhibiting chlorophyll synthesis (KRUPA 2003). The impact of excessive doses of these gases leads to visible injuries in the vicinity of emittors (VAN HAUT 1975, DÄSSLER 1991). Secondary products of NOx are ozone and NO_3-N; those of NH_3 is NH_4-N; NO_3-N and NH_4-N act as acidifying agents in less buffered soils. As a consequence, excess nitrogen input causes imbalances of nutrients and changes of ground vegetation (e.g. overgrowth with *Calamagrostis*; GLATZEL 1990, BOBBINK & al. 1995). In nitrogen-saturated stands, leaching of nitrate into the subsoil may contaminate the groundwater.

In Austria the annual emissions of nitrogen oxides and ammonia have been recorded since 1980 by the Austrian Federal Environment Agency (Umweltbundesamt). Table 1 describes the emissions for 1980 and 2002 and indicates the main emittors.

Table 1. Emissions of NOx and NH_3 in Austria 1980 and 2002 (Gg = 1000 tons; Umweltbundesamt 2004).

Compound	1980	2002	Main emittors (% of the total emissions 2002)
NOx	246.11	204.47	motorcars (54 %)
NH_3	51.57	53.00	agriculture (96 %)

The emissions of NOx decreased from 1980 to 1997 but increased since 1999 due to the increasing automobile traffic. The emissions of NH_3 remained approximately constant from 1980 to 2000 (Fig. 1).

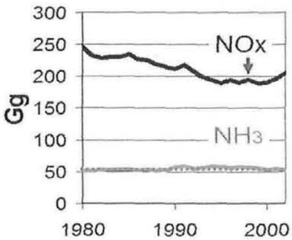

Fig. 1. Emissions of NOx and NH_3 in Austria (Gg p.a.; Umweltbundesamt 2002)

Laws, Legal Standards and Guidelines

Laws and legal standards

To protect the vegetation, the NOx standard of the Austrian Air Pollution Control Act (Federal Law Gazette BGBl. 298/2001; annual mean 30 µg m^{-3}, based on the World Health Organisation 2000 and the EU regulation 1999/30/EC, respectively) has been set up. A daily mean exists only for NO_2 (80 µg m^{-3}) as a goal for 2010. The Second Directive on Air Pollution Damaging to Forests (Federal Law

Gazette BGBl. 199/1984) designed to protect forest vegetation includes NH_3-limits: 300 µg m^{-3} for the half hour mean and 100 µg m^{-3} for the 24-h mean during the vegetation period.

Guidelines

Critical Loads for N input were established by the World Health Organisation 2000. They depend, among other things, on the parent material and texture, nitrification rate and ecosystem and forest stock, respectively. They range from 7 to 30 kg N ha^{-1} a^{-1}.

Data Base

- Austrian Air Quality Measuring Network: NOx data from stations located near forests (SPANGL 2005) have been available since 1990 (interconnected data of the Austrian Federal Environment Agency).
- Deposition Networks: Since the early 80ies samplings of wet depositions have been carried out near forests (LIMBECK & al. 1998). Since 1996, open field and throughfall depositions have been measured continuously at 20 Level II plots of the European ICP Forests Programme (SMIDT 2004a).
- Intensive Investigation Plots: In the framework of the forest ecosystem research of the BFW in the Ziller Valley (1985-1990; SMIDT & HERMAN 1992) and in the Achen Valley (since 1990; SMIDT & al. 1995, 1996), *inter alia*, depositions were measured (HERMAN & al. 1998, HERMAN & SMIDT 1994, 1996). In this context the total nitrogen input (wet + dry and occult depositions) was investigated, too (KALINA & al. 2002). From 1998 onwards, the nitrogen pools and fluxes have been measured and modelled at the intensive investigation plot in the Achen valley; thereby the nitrogen status, the budget including internal fluxes in the above-ground and below-ground compartments, turnover processes in the soil, saturation and the impact of the nitrogen status on the groundwater quality have been investigated (SMIDT & al. 2002).
- Modelling: Critical Loads for nitrogen were modelled for the area of the North Tyrolean Limestone Alps (KNOFLACHER & LOIBL 1998).

Results and Discussion

Nitrogen oxide concentrations

Figure 2 shows, that the NOx limit of 30 µg m^{-3} was exceeded in Austrian forests up to an altitude of more than 1000 m a.s.l., even after 2000. The mean concentrations decreased markedly with altitude.

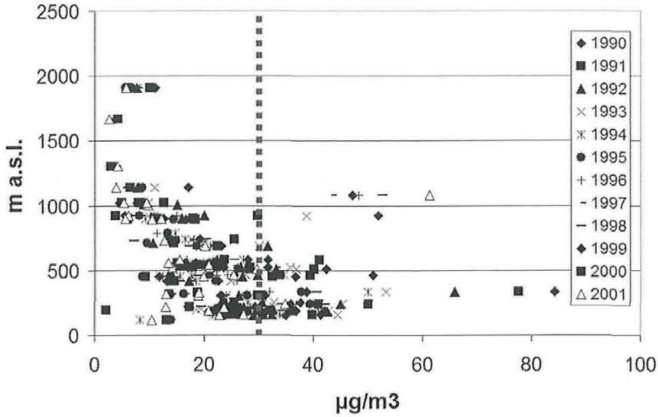

Fig. 2. Annual mean values of NOx in forested areas of Austria depending on elevation above sea level (42 stations).

Table 2. Trends of annual mean values of NOx in forested areas 1990-2001 (Smidt 2004b), n.s. p< 0.05; * p < 0.05, **: p < 0.01; ***: p < 0.001.

Station		Annual mean of the first measuring year (µg m^{-3})	Annual mean of the last measuring year (µg m^{-3})	Mean annual deviation (µg m^{-3}), significance
Innsbruck Nordkette (Tyrol), 1910 m	remote	11	6	-0.34 ***
Lenzing (Upper Austria), 510 m	polluted	42	30	-1.39 **
Steyregg (Upper Austria), 335 m	polluted	84	39	-5.60 ***
Tulbinger Kogel (Lower Austria), 415 m	agglomerationinfluenced by the vicinity of the greater Vienna area	23	14	-0.82 n.s.
Wiesmath (Lower Austria), 738 m	rural	13	26	+1.14 ***
Wolkersdorf (Lower Austria), 190 m	rural	42	21	-1.75 n.s.
Zwentendorf (Lower Austria), 200 m	rural	33	23	-1.11 n.s.

In the Ziller valley and in the Achen valley it was shown that local sources and the traffic contributed to a high degree to the NOx concentrations. Due to the inversions in Alpine valleys, NOx accumulates in the morning hours up to about

300 meters above the valley bottom especially during the winter months. This increases the stress for the valley slopes.

Table 2 shows trends of annual mean values of NOx for selected stations. These were high and significant especially in industrialised areas (Lenzing, Steyregg, Upper Austria) with extremely high concentrations at the beginning of the measuring period and low (but also highly significant) for the remote site Innsbruck-Nordkette.

Ammonia concentrations were measured in the Ziller Valley and in the Achen Valley (Tyrol) only with the help of passive samplers at particular plots within measuring campaigns (therefore, an evaluation considering the legal standards is not possible). Compared to background concentrations which are below 1 $\mu g\ m^{-3}$ (KRUPA 2003), the concentrations exceeded this level. In the Ziller valley, which is influenced by agriculture, the 6-hour mean values (three plots, 600 - 1560 m a.s.l.) ranged from 0.2 to 4 $\mu g\ m^{-3}$, the 24-hour means from 0.1 to 3 $\mu g\ m^{-3}$ (GREGORI & PUXBAUM 1991). In the Achen valley, at five plots (930 - 1758 m a.s.l.) 2-week means amounted 0.1 to 7.5 $\mu g\ m^{-3}$ (STOPPER 1996).

Nitrogen deposition

In areas of high nitrogen deposition (especially regions in Upper Austria, Salzburg and Tyrol) Critical Loads for nitrogen were exceeded by wet depositions. Thus, there exists a risk of eutrophication in these areas. Within the Level II deposition network, deposition rates up to 21 kg N $ha^{-1}\ a^{-1}$ (open field) and 29 kg N $ha^{-1}\ a^{-1}$ (throughfall) occurred. In the wet-only sampling network annual deposition rates up to 37 kg N $ha^{-1}\ a^{-1}$ were measured; the highest values were found in the Inn valley and in areas directly influenced by major local emittors (Steyregg, Upper Austria). Table 3 records the trends of wet-only depositions in Austria (SMIDT 2004b).

In Achenkirch/Tyrol the wet, dry and occult depositions were measured at four plots (920 m, 930 m, 1280 m, 1758 m a.s.l.) in 1-year measuring campaigns. More than 50 % of the total deposition (18 - 30 kg N $ha^{-1}\ a^{-1}$) were deposited by wet deposition. The amount of occult deposition (fog) was low at the valley bottom and high at the mountain plots (Table 4, KALINA & al. 2002).

Assessment of the eutrophication risk

Results from experiments with varying nitrogen input (WRIGHT & TIETEMA 1995, TIETEMA & al. 1998) indicate that enhanced nitrogen input can influence the turnover processes in the soil and lead to enhanced NO_3 concentrations in the groundwater (HAGEDORN 1999). The nitrogen input at the intensive investigation plot in the Achen valley exceeded the Critical Loads (KALINA & al. 1998, 2002, SMIDT & al. 2002). The good correlation of $\delta^{15}N$ nitrate in the precipitation and in the surface water and the poor correlation between precipitation and soil water suggest that the main source of nitrate in soil water is microbial activity such as nitrification reactions and not so much nitrate input by deposition. This conclusion was supported by the $\delta^{18}O$ nitrate measurements (HABERHAUER & al. 2002, HÄRTEL-RIGLER & al. 2002).

Table 3. Trends of the wet nitrogen (NO_3^- and NH_4^+) deposition (kg ha^{-1} a^{-1}) at selected stations in forested areas and at the Sonnblick with more than 8 measuring years. Significance: n.s. $p< 0.05$; * $p < 0.05$, **: $p < 0.01$; ***: $p < 0.001$.

		Annual mean of the first measuring year (kg N ha^{-1} a^{-1})	Annual mean of the last measuring year (kg N ha^{-1} a^{-1})	$NO_3N + NH_4N$ (kg ha^{-1} a^{-1})
Achenkirch (Tyrol), 920 m	remote	9.3 (1992)	8.2 (2000)	n.s.
Almsee (Upper Austria), 591 m	remote	21.1 (1987)	12.3 (2000)	-0.58 *
Bisamberg (Vienna), 310 m	influenced by the greater Vienna area	5.3 (1990)	3.6 (1998)	-0.29 *
Haunsberg (Salzburg), 730 m	remote	15.9 (1984)	8.1 (1998)	-0.39 **
Innervillgraten (Tyrol), 1730 m	remote	6.5 (1985)	5.2 (1998)	n.s.
Kremsmünster (Upper Austria), 384 m	remote	12.9 (1984)	12.8 (2000)	n.s.
Kufstein (Tyrol), 680 m	polluted	17.5 (1984)	11.7 (1998)	n.s.
Litschau (Lower Austria), 560 m	rural	10.5 (1990)	6.1 (1998)	n.s.
Lunz (Lower Austria), 618 m	remote	11.3 (1990)	11.8 (1998)	n.s.
Nasswald (Lower Austria), 1530 m	remote	7.1 (1988)	9.1 (1998)	-0.41 *
Ostrong (Lower Austria), 570 m	rural	7.9 (1991)	5.6 (1998)	n.s.
Reutte (Tyrol), 930 m	polluted	8.9 (1984)	8.9 (1998)	-0.21 *
Schöneben (Upper Austria), 920 m	rural	13.8 (1984)	13.5 (2000)	n.s.
Sonnblick (Salzburg), 3105 m	background	7.8 (1988)	6.3 (1998)	n.s.
Steyregg (Upper Austria), 335 m	polluted	40.8 (1984)	20.6 (2000)	-1.46 ***
Werfenweng (Salzburg), 940 m	rural	8.6 (1984)	6.2 (1998)	n.s.

Modelling critical loads

An approach for the spatial estimation of Critical Loads in the complex terrain of the North Tyrolean Limestone Alps was performed by KNOFLACHER & LOIBL 1998 with the help of a steady state mass balance model including soil structure and chemistry, forest composition and growth dynamics, water balance of stands, precipitation, nitrogen deposition as well as a digitised geological map, a digital elevation model, a precipitation model and a soil depth model. The Critical Loads of eutrophication in the limestone areas ranged from 4 to 31 kg N ha^{-1} a^{-1} with a medium value of 18 kg N ha^{-1} a^{-1}. The slopes of the Ziller and Inn valleys are particularly at risk through nitrogen input (Fig. 3).

Table 4. Total nitrogen deposition and the percentages of occult deposition at measuring sites in the Achen valley (Tyrol).

Site Measuring campaign	Total (kg N ha^{-1} a^{-1})	% occult N-deposition
Christlumkopf, 1758 m		
10/1995 - 9/1996	29	18
10/1997 - 9/1998	31	14
Christlumalm, 1280 m		
10/1995 - 9/1996	20	17
Talboden, 930m		
10/1995 - 9/1996	28	1
Mühleggerköpfl, 920 m		
10/1997 - 9/1998	18	1

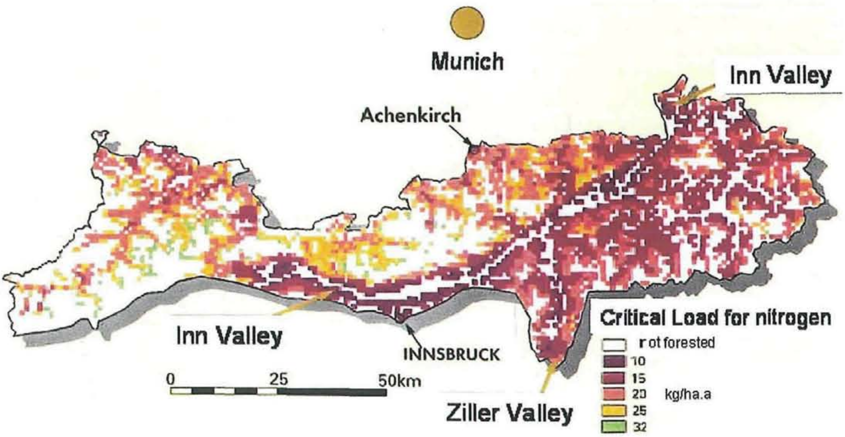

Fig. 3. Critical Loads in the area of the North Tyrolean Limestone Alps.

Conclusions

- The input of "reactive" nitrogen compounds (NOx, NH_3, NO_3-N, NH_4-N) is a threat to Austrian forest ecosystems which are sensitive against eutrophication.
- The actual NOx concentrations are still a problem in the vicinity of emittors and highways as precursors of eutrophying and acidifying nitrogen depositions and of ozone. At individual plots, the legal NOx standard is still exceeded.
- In Austria strong reductions of NOx emissions are necessary in order to achieve the goals of the European Union concerning the reduction of emissions (NOx: minus 48 % comparing 2001 and 2010). This would be the

precondition for adhering to the NOx limit and meeting the NO_2 goal for 2010 in forested areas directly influenced by emittors. The amount of the necessary reduction of the NH_3 emissions is 5 %.

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