Phyton (Horn, Austria) Special issue: "Achenkirch II"	Vol. 36	Fasc. 4	[271]-[294]	1. 7. 1996

Description of the Northern Tyrolean Limestone Alps and Assessment of Risks - Synopsis

By

S. SMIDT[1)] & F. HERMAN[1)]

Key words: Forest ecosystem investigations, rhizosphere, Northern Tyrolean Limestone Alps, risk assessment.

Summary

SMIDT S. & HERMAN F. 1996. Description of the Northern Tyrolean Limestone Alps and assessment of risks.- Synopsis.- Phyton (Horn, Austria) 36 (4): 271 - 294.

The following paper offers a brief overview of the results from the project "Ecosystematic Studies in the Limestone Alps - Achenkirch Altitude Profiles". The contributions include descriptions of the Northern Tyrolean Limestone Alps and the assessment of risks (mainly of risks due to the input of pollutants or of pasturing). They are based on investigations carried out in the area of Achenkirch and on all-Austrian monitoring surveys. The studies refer to the rhizosphere.

Depositions of SO_2 and NO_x are significant in valley bottoms only, while the ozone input increases with altitude. Proton inputs do not seriously affect the carbonate-influenced soils, but long-term effective pollutants, such as nitrogen and heavy metals, may constitute risks. Other important stress factors are harvesting, game and forest pasturing; this applies especially to protection forests.

Introduction

Forest ecosystems are exposed to a number of natural and anthropogenic, site-related stress patterns. Extreme climatic conditions that increase with altitude, anthropogenic stress factors (mainly tourism, game management, forest pasturing, and pollutant depositions), and several biotic factors (e.g. insects and fungi) are among the most important ones. The stress pattern influences the degree of crown thinning. According to the 10-year crown condition inventory approximately 40 % of the stands aged over 60 years are affected in the Tyrol. The development is particularly alarming in the protection forests of the Northern Tyrolean Limestone

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

Alps, where the portions of affected trees increased from 46 % to 62 % between 1984 and 1987 and amounted to 54 % in 1993 (OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1995).

The heavy stress of the forest ecosystems, which are of vital importance especially because of their protective function, requires extensive knowledge allowing us to take effective steps both at the forestry and at the political level. Although forest ecosystem research has been intensified in recent years, our knowledge and understanding of the interrelation and dynamics of forest damage have remained incomplete. The problem has to be studied on a very broad scientific basis. Interdisciplinary investigation approaches and integrated data interpretation are to provide results which can be used in the practice. Results focusing on the "phyllosphere" are already available (HERMAN & SMIDT 1994, SMIDT & al. 1994): The investigation area was evaluated by using limiting values, guidelines, and target values as well as biomonitors. The results proved that it is possible to assess the stress of forest trees by means of biochemical and physiological parameters.

The present volume provides an overview of the results from forest ecoregions 2.1 and 4.1 (according to KILIAN & al. 1994), of which the Northern Tyrolean Limestone Alps are a part. The contributions include descriptions of the areas and risk assessments (mainly of risks caused by pollutant depositions or grazing). They are based on the investigations carried out in the area of Achenkirch and on all-Austrian monitoring surveys. The investigations refer to the rhizosphere.

Results and Discussion

The research approach was elaborated and presented by HERMAN & SMIDT 1995a. The individual contributions of the present volume are organized as follows:

- Contributions describing the Northern Tyrolean Limestone Alps;
- Contributions regarding the risk assessment of the Northern Tyrolean Limestone Alps, based on investigations in the area of Achenkirch;
- Contributions regarding risk assessment in the Northern Tyrolean Limestone Alps, based on data from all-Austrian monitoring surveys, survey networks and model approaches.

In addition to the Federal Forest Research Centre, Vienna, which coordinated the individual projects, numerous Austrian and German organizations and institutes have participated in the sub-projects. In the following sections the results of the individual contributions and the respective page numbers from this special volume are provided.

Contributions Describing the Northern Tyrolean Limestone Alps

Genetic characterization of spruce (BREITENBACH-DORFER, p. 23-32)

To be able to survive, organisms must adapt themselves to environmental changes. If their ability to survive is genetically determined, selective adaption processes take place. The genetic characteristics of spruce permit conclusions regarding the adaptability of that species at different altitudes.

In the framework of a pilot investigation in the Limestone Alps autochthonous and nature-conforming spruce stands were genetically analyzed. The analyses confirmed high genetic multiplicity, characterized by the number of genetic variants. The populations studied in the investigation area of Achenkirch differed only little in respect of the allele frequencies. The number of polymorphic gene loci and the total number of alleles decreased with increasing altitude; the adaptability of the stand was, however, not reduced. The mean diversity, a standard for the adaptability, was slightly lower here than it was in other investigated spruce populations of the alpine region. This permits the conclusion that the adaptability of stands at the timber line is not lower than that of stands growing at lower altitudes. As opposed to this, the genetic differentiation of subpopulations was very low compared to results from areas outside Austria (random samples from the entire European spruce habitat). However, the results of the analyses corresponded with those from investigations of other autochthonous spruce populations of Austria (GEBUREK 1994).

The assumption that, as a result of the climatic conditions, stands growing at the timber line might be well adapted, but have a poor adaptability, could not be confirmed for the stands at the timberline that were investigated in Achenkirch. If one uses the hypothetic gametic multilocus diversity as a basis for the evaluation of the adaptability, the stand at medium altitude (1220 m) is slightly less adaptable than the other two stands. The mean diversity did not prove to be influenced by the altitude; it was slightly lower than that of Italian spruce populations and autochthonous Swiss stands (MÜLLER-STARCK 1994).

Supply of soils with nutrients (MUTSCH, p. 55-64)

The status of the soil contributes essentially to the status and stability of forest ecoystems. Chemical soil analyses permit conclusions about their nutrient status as well as about pollutant depositions, particularly of heavy metals.

The soils were classified according to the relevant site characteristics and types of soil (ENGLISCH 1992) and by using chemical parameters. Nutrient status and heavy metal content were compared to the respective values of other carbonate-influenced forest soils, and then evaluated. Compared to the carbonate-influenced soils of the Austrian forests analyzed in the course of the Austrian Forest Soil Monitoring System (FEDERAL FOREST RESEARCH CENTRE 1992), the pH values and carbonate concentrations determined at the uppermost depth levels of the

Achenkirch area were significantly below average. However, as substantial acidification can more or less be ruled out on carbonate-influenced soils, the low pH values were nevertheless not judged as being unfavourable. The soil-chemical results alone provide a favourable classification of the Achenkirch investigation area among Austria's carbonate-influenced forest sites.

Forest communities (ENGLISCH & STARLINGER, p. 33-54)

Apart from a detailed documentation of the investigation area based on site mapping, the characterization of the forest communities provides answers to the questions of what degree of naturalness the investigation area is, how representative it is of the Northern Tyrolean Limestone Alps, and to which extent the results are transferable to the area. Indicator plants inform about the supply with, or the deficiency of nutrients.

In the course of the plant-sociological survey nine forest communities of the Achenkirch investigation area were selected, some of them further subdivided. The site survey showed 18 different types of sites, a representative selection of the Limestone Alps.

The effects of long-term non-forestry use, such as litter raking and forest pasturing, and the large, historically proved clearcuttings led to degradation symptoms of varying severity and to the lowering of the natural timber line. The effects of forest pasturing in areas at the timber line caused the mixture of tree species and the canopy density and were similar for the two profiles. Effects of litter raking were mainly observed near living areas. In Alpine spruce-beech-fir forests fir and beech have been strongly reduced due to selective browsing and large-area clear-cuttings, while in subalpine spruce forests grazing does not affect the mixture of tree species very much. However, stand density is significantly reduced in either case. On both profiles the plots located at a great distance from the most densely populated areas and outside the areas that are intensively used for forest pasturing proved to be most nature-conforming. While the parent material of the Christlum profile and the Mühleggerköpfl is dolomite ("Hauptdolomit"), the peak of the Schulterberg is made up of platy limestone ("Plattenkalk"). The different substrate is the reason why soil layers are usually thicker on the Schulterberg, which is also reflected in the higher nitrogen indicator values there. In an all-Austrian comparison the nitrogen values from the Christlum profile and from the uppermost Schulterberg plot correspond to soils of below-average supply. The medium and lower Schulterberg plots are Austrian average. The soil data indicate neither eutrophication nor acidification of the soil. As regards Critical Loads, nitrogen inputs from the points of view of vegetation and soil science do not constitute a risk to the sites of the Christlum profile. On the well supplied Schulterberg plots, however, increased nitrogen input might cause nitrate output into the groundwater. Indicators of poor soils presently do not indicate any shift in the mixture of species.

Diversity and abundance of Basidiomycetes (PEINTNER & MOSER, p. 65-82)

By means of a comparison with results from other regions the mycosociological investigations (diversity and abundance of fungi) provide information about the "physiological condition" of forests.

In the Christlum profile and at the Schulterberg diversity and abundance of basidiomycetes were observed during three vegetative periods. The biodiversity determined there (approx. 300 species), the dynamics of the fruiting bodies and the periodicity of basidiomycetes indicate that the area of the Schulterberg, in particular the northern profile, is rich in species. As vegetation differed widely, the poor diversity of the Christlum profile was not comparable to the high diversity of the Schulterberg; nevertheless it is an indicator of a disturbed ecosystem. Proceedings on their "present state", future changes of the fungal communities, e.g. by the influence of pollutants or by changes in land use, were to be determined. Their exact recording seem urgent as almost one third of all fungal species are menaced by environmental changes and figure on the new list of threatened (higher) fungi. Most seriously menaced are the mycorrhizal fungi, which live in symbiosis with trees, and fungi specialized on very specific environments.

Soil-biological parameters (RANGGER & INSAM, p. 83-94)

Soil-biological parameters play an important part in the nutrient cycle of forest ecosystems. The microbial biomass is also an important nutrient pool which can buffer intermittent, short-term rises in the nutrient supply. The increase of microbial activity which is possible in soils disposing of limited amounts of nutrients may cause an undesirable loss of organic matter. Also, the microflora of the soil significantly infuences the nutrient cycles by the decomposition of litter and so contributes to the vitality of forest stands; reduced activity indicates impairment, e.g. by pollutant deposition or degradation. Especially in montane and subalpine forest ecosystems which have very thin humus layers it is therefore important that sufficient importance is attached to decomposing processes, in particular to ammonification and nitrifiction.

The microbial activities and biomasses determined with the help of parameters and the investigated ecophysiological parameters (basal respiration, N-mineralization rate and metabolic quotient) characterize the Christlum profile and the sample plots of the Schulterberg as relatively unaffected, nature-conforming sites not subject to any particular stress.

The investigation of the soil-biological parameters of three soil layers along the Christlum profile showed a significantly increased microbial activity and biomass for the layer between 0 and 10 cm of the sample plot at 1240 m a.s.l. The result was primarily explained by the high litter input which is caused by the larger share of deciduous trees of that plot. The characteristic ecophysiological values of the metabolic quotient and the $C_{mic/}C_{org}$-proportion were not affected as the local site factors prevailed over the climatic ones. Altogether, the soil-biological parameters were not influenced by the altitude above sea level.

Investigation of the state of mycorrhizae and fine roots; qualitative and quantitative description of mycorrhizal fungi (GÖBL & THURNER, p. 95-108, KREUZINGER & al., p. 109-118).

With a view to the stabilization of stands, ectotrophic mycorrhizae are of special importance to the nutrient supply of forest trees particularly on poorer soils. Their number is a criterion in the qualitative assessment of sites. Mycorrhizae and fine roots are sensitive to environmental changes caused by pollutant depositions, mechanical stress, or dryness. They are therefore suited for the characterization and/or evaluation of sites. As to the spread of young plants, mycels of so-called "first-stage" fungi are also of importance, especially in protection forests.

As the protection forests of the Northern Limestone Alps include wide afforestation sites of sometimes limited nutrient supply, the identification of the mycorrhizal fungal species is equally of great importance.

The description of the density of the fine roots, the vitality of the fine roots and mycorrhizae, and the number of mycorrhiza types proved that the three sample plots of the Christlum profile were not negatively affected. Rather, the type of soil and the form of humus might influence growth and vitality of the fine roots and mycorrhizae. Compared to the plots at 1060 m and 1420 m a.s.l., the one at 1240 m was much better rooted and had a high fine root dry mass. This may, among other things, be due to the fact that the plot had been fenced. As to mycorrhizae, no abnormal changes which might have indicated the instability of the ecosystem were observed. First investigations regarding the accumulation of nutrients and pollutants in mycorrhizae showed significant increases of all elements analyzed in the course of the vegetative period. As the phenotypic stages of leaf unfolding of beech correspond to the developmental stages of mycorrhizae, it was possible to identify and quantify that soil-biological parameter with the help of a quick and simple method.

To elaborate a method for the soil-biological identification and quantification of mycorrhizae is important because, at least during their early stages of development, biological methods do not permit a certain determination of the fungi. At present, mycorrhizal fungi are still determined morphologically, by examining the fruitbodies and the immediate contact zones of the plant and the fungus, or by using selective nutrient media. Compared to other methods, such as the determination of metabolic (enzyme) activities, molecular biological methods have the advantage that they determine a cell component which is static and independent of the surrounding conditions. The PCR method permits the identification and quantification of mycorrhizal fungi by means of the glycerine aldehyde-3-phosphate dehydrogenase (gpd) gene.

Contributions Regarding the Risk Assessment of the Northern Tyrolean Limestone Alps, Based on Investigations of the Area of Achenkirch

Landuse potential analysis (OTTITSCH, p. 119-130)

Landuse potential analyses, based on the Forest Function Plan and other local information, provide information about the major forest functions, the required silvicultural measures, the stress caused by tourism, forest pasture and other risk factors threatening forest ecosystems, and about landuse conflicts.

A landuse potential analysis for the area of Achenkirch proved that the release of forests from pasturing is of prime importance where grazing endangers the protective function. Such release was already successfully effected in the framework of a protection forest regeneration project carried out during the past two years. About half of the area which is to maintain a protective function requires regeneration measures so as to restore sufficient stability over the medium term.

When evaluating the landuse potential analysis, the main functions of the forest according to the Forest Function Plan, the silvicultural requirements (regeneration, care), topographical risks, damage due to game, damage caused by grazing, the recreational effect, and touristic activities were described for an area of 7500 ha and with a view to the threat to the forest ecosystem. A landuse potential and conflict analysis of the investigation area showed that current landuse conflicts are due to the simultaneous demand for different high-intensity landuses. Among the six investigated uses (hunting, timber-production, conservation, recreation, disaster control, and grazing), forest pasturing on areas with a protective function as well as the intense touristic infrastructure and the resulting disturbance of the game represent local landuse conflicts.

Canopy drip and litter fall (BERGER & KATZENSTEINER, p. 131-144)

Depositions influence the nutrient balance of forest sites. The amounts of wet field depositions and canopy drip indicate the actual concentrations and inputs that enter the forest soil. The difference between the amounts of throughfall and field deposition indicates the "filtering capacity" of forest stands. (For a complete assessment, the inputs effected by dry and occult deposition would also have to be considered.) Investigations of the soil water provide information about the output; and investigations of the litter fall improve the knowledge of nutrient cycles within ecosystems.

Compared to all-Austrian values, the canopy drip of two monitoring plots (1050 m and 1400 m) proved that the latter were only slightly affected by pollutant inputs.

Under the canopy the Ca, Mg, and K inputs as well as the cation sum were in some cases even markedly higher than they were at the field station located in the valley; the Na, Cl, H, and NO_3-N inputs as well as the anion sums were approximately equally high; the NH_4-N and the sulphate-S values were, however, lower. The nitrogen concentrations of the soil water were low. Under the canopy, the N inputs amounted to 12-13 kg/ha.a, at the bulk stations of the Christlum profile (930 - 1758 m) to 4.8 - 11.7 kg/ha.a (1991-1993). As for very sensitive sites the Critical Loads for nitrogen begin at 5 kg/ha.a, it is possible that forest ecosystems are affected. According to the needle analyses, nitrogen is, however, a limitating factor in the area of investigation. Taking the criteria for Critical Loads, no immediate danger to forest ecosystems is to be expected, but only nutrient imbalances and shifts in the species of the herb and shrub layers could be the consequence. The Northern Tyrolean Limestone Alps are to be considered sensitive to nitrogen inputs into the soil because their forest ecosystems are adjusted to soils poor in nitrogen; additional inputs may therefore lead to increased growth, but may also cause nutrient imbalances and, consequently, reduced stability.

The inputs of sulphate-S amounted to 8 kg/ha.a, a value which can be a risk only on sites which are extremely sensitive to H^+. The proton inputs varied on both sites between 0.2 and 0.3 kg/ha.a. According to the Austrian Forest Soil Monitoring System the area is carbonate-influenced, which means that the Critical Loads for the soils are not exceeded (but does not exclude that the surface parts of the plants are affected, e.g. by increased leaching). The leaching of nutrients from the canopy by protons in wet precipitation was between 16 % and 73 %; in the rooting area the repeated uptake of K, Ca, and Mg may lead to the acidification of the immediate rhizosphere.

Pesticides in precipitation (SMIDT & al., p. 245-270)

Depositions of volatile organic compounds may have harmful effects on plants. Many of their components are spread over wide areas and seem to be present everywhere. Particularly interesting are the components which are used as, or have the effect of, herbicides. They are spread in the form of pesticides or, like trichloroacetic acid, may develop in the course of the photochemical conversion of C_2-hydrochlorocarbons, and effect the physiology of the plants (e.g. the activity of the detoxification enzyme glutathione-S-transferase).

The amounts deposited by gravitational deposition were only about 1/1000 of the amounts that are spread per hectar of agriculturally used land. The forest vegetation is therefore probably not in danger. However, the fact that agents which have meanwhile been prohibited in Austria (such as atrazine or gamma) can still be detected proves the wide spread of those agents and their long retention time, which, in the case of slow degradability, may lead to accumulation in the soil and to the contamination of the groundwater.

Heavy metal content of the soils (MUTSCH, p. 145-154)

In the soil, heavy metals act as trace elements. Too low concentrations can easily cause deficiency symptoms. Increased concentrations, particularly of heavy metals which are not indispensible to plants (e.g. lead, cadmium), may have toxic effects even if not taken up by the roots because they may affect the mycorrhization (and consequently the uptake of nutrients) and the degradation of litter.

The lead and cadmium content of the soil increased significantly with altitude (MUTSCH 1992). As there are no limiting or guiding values for the evaluation of forest soils, the guiding values for the assessment of the heavy metal contents of soils for agriculture and gardening (AUSTRIAN INSTITUTE OF STANDARDIZATION 1993) and the guiding data for the acceptable total content of arable land (KLOKE 1980) were used. It turned out that on more than half of the sample plots these evaluation criteria for lead and cadmium were exceeded. Compared to the subsoil, also the topsoil showed a remarkable accumulation of these two heavy metals, an accumulation (differences regarding the absolute values of topsoil (0 - 10 cm) and subsoil (30 - 50 cm) which increased with altitude. The accumulation of heavy metals constitutes a potential risk and a further additive stressor to forest ecosystems, particularly in the Alps. As a weather divide with above-average amounts of precipitation (which, on the northern fringe of the Alps, can be more than 2000 mm per year) these forest ecosystems are a particularly effective sink of air pollutants which have been transported over long distances (MUTSCH 1992). Also in Styria, at exposed sites, lead and cadmium were found in amounts which indicate stress (SOBOTIK, pers. comm.). The lead and cadmium values determined in the area of Achenkirch, particularly in the topsoil, were slightly above the all-Austrian average and could be used as air pollution indicators. According to MUTSCH (pers. comm.) 10 to 100 kg of lead/ha and 0.1 to 1 kg of cadmium have been deposited so far, values which are apparent from the quotients of the total heavy metal content and the mobile share (the smaller the quotient, the higher the air pollutant share). It is striking that the increases in the lead and cadmium content of the soil with altitude, which were determined in connection with the Austrian Forest Soil Monitoring System, could not be confirmed when sampling a northerly-exposed stemming slope of the Schulterberg although ZECHMEISTER 1995 found lead values far above the Austrian average for mosses of the same investigation area and additionally the lead and cadmium content of the bark and needle samples investigated by HERMAN 1994a proved to correlate with altitude. The highest concentrations were determined for the upper parts of the subalpine area.

Heavy metal contents of fungi (PEINTNER & MOSER, p. 155-162)

Fungi accumulate heavy metals and therefore function as indicators of heavy metal depositions and heavy metal contents of the topsoil. The heavy metal content of basidiomycete fruiting bodies is suited to indicate the degree of environmental stress caused by anthropogenic pollutants.

In the Schulterberg investigation area, frequently occurring basidiomycete species were examined for their cadmium, copper, lead, and zinc content. Various species belonging to the genus of *Cortinarius* are suited mainly to indicate cadmium, zinc and copper in the upper soil. However, the accumulation behaviour is still to be checked for its constance on sites of different ranges of concentration.

Lead is taken up primarily in the stems of the fungi, where it is accumulated 2- to 8fold relative to the extractable soil content. The lead concentrations of the collected fruiting bodies were very high as compared to the data from other European countries (median: 10 µg/g dry weight = dw), which indicates heavy stress. The cadmium content ranged high for an Alpine area (median: 4.8 µg/g dw); the element is accumulated 10- to 35fold in the caps. The zinc content ranged between 2 and 385 µg/g dw and is to be considered normal; zinc is accumulated 15- to 20fold in the caps of the fruiting bodies. The copper content was only between 1 and 121 µg/g dw, which is very low, although the element is accumulated 700fold in the cap.

As takeup and accumulation differ greatly depending on the respective species, and as also local conditions must be accounted for, one should consider more general species-related characteristics when using fungi as bioindicators to assess stress situations. Generally it can, however, be assumed that the very high lead concentrations of the fruiting bodies indicate a severe lead stress of the area. Also the cadmium values are relatively high compared to other Alpine areas.

Fungi are not only of methodical interest, they are also a popular food. As neither in Austria nor in Germany there are statutory limits to the lead and cadmium content of wild fungi, the Austrian guiding values for culture mushrooms were used. As the lead and cadmium values of all investigated fruiting bodies were higher than those guiding values, people are advised not to eat too many wild fungi.

Cytogenetic bioindication (MÜLLER & BERMADINGER-STABENTHEINER, p. 163-176)

The impact of stress on forest trees results, among other things, in higher percentages of damaged chromosomes in fine roots. The determination of those percentages provides therefore additional information about the impact of stress on particular sites; and, as the method responds quickly, impairments of the vitality can be determined already at a time when external symptoms (e.g. crown thinning) or increased pollutant accumulation cannot yet be detected in needles or leaves.

The cytogenetic method proved to be promising and suitable for the practice. At the Achenkirch altitude profiles it was observed that at altitudes between 1000 m and 1400 m the plants were stress-influenced, the result being a higher aberration rate and striking particularities of certain sample plots: At 1140 m a.s.l. (Christlum profile) the situation had deteriorated significantly during the three years of investigation (1991 - 1993). Which influences were responsible for the higher aberration rates or whether they were due to a natural phenomenon independent of pollutants, is not clear yet.

Influences of pasturing (SOBOTIK & POPPELBAUM, p. 177-192; GÖBL, p. 193-204; INSAM & al., p. 205-216)

On steep alpine slopes or at the climatic border of forests which fulfill a significant protective function, landuse changes may be of great importance. If land is intensively used for grazing, the results are soil compaction, a lower volume of pore space, and, consequently, increased topsoil runoff and regeneration problems (ZAUPER 1993, FEDERAL MINISTRY OF AGRICULTURE AND FORESTRY 1994, OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1995); forest pasturing also causes damage due to browsing, debarking and trampling.

The investigations showed in what complex a way the subject of "Forest pasture in the mountains" is to be treated and with which preciseness the results must be interpreted together with the respective orographic and climatic conditions. In the course of the present project vegetational, root-ecological and soil-biological investigations were carried out to prove that grazing constitutes a stress on the soil.

Altogether, taking into consideration the intensity of pasturing as well as the geomorphological conditions, the following results can be summarized:

No or only minimum influence of pasturing:

- the number of species (but shifting of species);
- the soil-biological parameters (microbial biomass, metabolic quotient, C_{mic}/C_{org} ratio, basal respiration).

Influences of pasturing:

- microbial substrate utilization.

Reduction of:

- the heights of the vegetation cover;
- the fine root masses;
- the length of the root hairs;
- the humus cover;
- the vitality of mycorrhizae and fine roots;
- *the production of spruce seedlings;*
- the feeding value.

Increase of:

- soil stability;
- the amount of fodder;
- the fibrous root mass;
- soil compaction;
- the pH value of the soil.

Contributions on the Assessment of Risks Regarding the Northern Tyrolean Limestone Alps, Using All-Austrian Monitoring Surveys, Grids and Model Approaches

Assessment of damaging factors, based on the investigations of the Austrian Forest Inventory (SCHADAUER, p. 217-230)

With the help of several parameters investigated in the framework of the Austrian Forest Inventory concrete information is available about risks regarding the Northern Tyrolean Limestone Alps, especially about mechanical damage and the regeneration situation of protection forests.

68 % of the Northern Tyrolean Limestone Alps are wooded. About 50 % of the wooded area grow at altitudes between 1000 and 1400 m a.s.l.; above and below, the percentage of forested area is much lower. The protective function of the forests of this area, of which 80 % are located at altitudes above 1000 m, is of special importance.

Damage due to debarking was observed on approx. 15 % of the wooded area, which is clearly below the Austrian average. Also the evaluation according to the Forest Function Plan indicates that browsing damage is only of minor importance in the Northern Tyrolean Limestone Alps.

Damage caused by harvesting or rockfall plays a much more important role than browsing damage does in the Northern Tyrolean Limestone Alps. In commercial protection forests only 28 % of the forested area is without any damage; on 33 % of the area more than one third of the stems are affected. In protection forests, 85 % of that damage class is caused by rockfall, which, accordingly, is the main reason of stem damage, while only 15 % is due to timber harvesting. The very high percentage of damage caused by rockfall is characteristic of the Austrian Limestone Alps and can be explained by their high relief energy. Moreover, the difficult conditions for forestry and public road-building projects, which frequently require blasting, increase the number of rockfall events.

Regeneration: Although about 50 % of the area covered by protection forests would need regeneration, it has been provided on only 15 %. On the remaining 35 % of the area, no regeneration has been effected. Nevertheless, the regeneration situation of the protection forests of the Northern Tyrolean Limestone Alps is still slightly more favourable than it is in other parts of Austria. In the protection forests of the Northern Tyrolean Limestone Alps, natural regeneration prevails at a rate of 85 % over artificial regeneration.

According to the assessment criteria of the Austrian Forest Inventory it will be possible on half of the area that the protection forests maintain their protective function for the next 20 years even if no tending measures are carried out; on 33 % of the area, however, the protective function will probably be impaired. On the remaining 14 %, regeneration measures are urgently required, with special importance to be attached to the support of natural regeneration (although in the protection forest of the Northern Tyrolean Limestone Alps natural regeneration preponderates with 85 % over artificial regeneration). The damage caused by browsing and grazing should be reduced, which implies a re-consideration of the use of forests for hunting, and which requires a solution of the problem of conflicting landuses of forests and pastures (e.g. by means of cash payments, by the separation of forests and pastures, or by the transfer of pasture rights).

Assessment of the impacts of air pollution by SO_2 by means of needle-analytical investigations carried out in the frame of the bio-indicator grid (sulphur analyses) (STEFAN & HERMAN, p. 231-244)

As bio-accumulators, bio-indicators are suited to evidence the impacts of air pollution caused by SO_2. In the course of the bio-indicator grid mainly spruce needles are analyzed; the impact of the air pollution is assessed by means of the respective total sulphur content and, as a basis, the limiting values of the Second Regulation Against Forest Damaging Air Pollutants (Federal Law Gazette 199/1984).

Despite the marked reduction of SO_2 emissions, which were observed all over Austria, the overall mean of the sulphur analyses of the spruce needles (entire sample material collected on the sample plots between 1983 and 1992) did not indicate a reduction of the air pollution impact. Especially at the low-altitude locations of the Inn Valley limiting values proved to be exceeded; impacts of air pollution by SO_2 were, however, detectable up to altitudes of 1200 m. This is, on the one hand, due to the slow decrease of the sulphur content of the soil, which was deposited during several decades, and, on the other, to local air pollution stress.

Assessment of the nutrient status of trees by means of investigations from the bio-indicator grid (STEFAN & HERMAN, p.231-244)

The nutrient content of spruce needles as well as various nutrient quotients can be used to characterize the nutrient status of the sample trees. Nutrient deficiency is seen in connection with air pollution impacts, e.g. as a result of nutrient leaching from needles or leaves.

The needle analyses were evaluated according to the types of deficiency and indicated a deterioration of the nutrient status between 1983 and 1992. It is supposed that this unfavourable development is mainly due to weather-related factors (much lower amounts of precipitation and during summertime temperatures above the long-term average). The altitudinal levels around 1100 m were insufficiently supplied in the entire Limestone Alps and in the Achenkirch investigation area. An evaluation of the other nutrient elements also showed that this altitudinal level was the one which suffered most from nutrient deficiencies. As compared 1985/86, when only about one quarter of the plots had suffered from nitrogen deficiencies, and taking the average of the past two invesigation years, the number of plots affected by such deficiencies has more than doubled.

Assessment of air pollution stress by means of long-term records (SMIDT & al., p. 245-270)

Air pollution impact is a severe threat to forest ecosystems and, by means of limiting and values and standards, can be used to elaborate risk prognoses. The concentrations of gaseous components as well as dry and wet depositions have to be taken into consideration.

Sulphur dioxide and nitrogen dioxide: As a result of the remarkable reduction of SO_2, which has been observed all over Austria since the beginning of the 80's, the concentrations decreased significantly. In recent years, the SO_2 limiting values ("2nd Regulation Against Air Pollution Affecting Forests", Federal Law Gazette 199/1984) were exceeded only a couple of times, at monitoring stations placed in congested areas. As opposed to SO_2, the NO_x emissions decreased only very little in Austria. In the Tyrol, the NO_2 air pollution limiting values of the AUSTRIAN ACADEMY OF SCIENCES 1987 were exceeded at urban monitoring stations only, but much more frequently than the limiting values for SO_2. Between 1000 m and 1400 m (where, according to the investigations of the Austrian Forest Inventory, 50 % of the forests of the Northern Tyrolean Limestone Alps are stocking) all NO_2 values proved to be below the standards; close to the timber line the concentrations were even lower.

Ozone: An evaluation of the ozone content according to the criteria of the AUSTRIAN ACADEMY OF SCIENCES 1989 and the temporary Critical Levels of the UN-ECE 1994 for forest plants ("AOT 40") proved that the sensitive forest vegetation should be highly endangered by that air pollutant. A comparison of the annual ozone means from Alpine monitoring stations of recent years showed that the maximum vegetation period mean of 30 ppb (which corresponds to an annual mean of 10 - 25 ppb) is exceeded at all medium- and high-altitude monitoring stations (from about 1000 m to the timber line) and that it increases with altitude. In Austria, this altitudinal level is of special importance because of its protective function.

While spruce is considered not very sensitive to ozone, it is well possible that ozone presents a danger to dwarf pine and to beech or other deciduous trees. Table 1 provides some information about the risks to which the most common tree species are exposed; the assessment may produce different results depending on whether the sensitivity of needles and leaves or the impairment of the photosynthesis are used as the basis of assessment.

Table 1. Ozone sensitivity of the major Austrian tree species with regard to the sensitivity of foliage and the impact on photosynthesis (simplified).

Tree species	Austria: Stocked area (Growing stock)	Sensitivity of foliage	Impact on photosynthesis	References
Conifers	*77.3 %* *(82.4 %)*		*less sensitive*	REICH 1987
Picea abies	61.8 % (60.9 %)	 less sensitive	less sensitive	WIESER & HAVRANEK 1993 VDI 1987; LANDOLT & LÜTHY-KRAUSE 1991
Larix decidua	5.0 % (6.9 %)	very sensitive	 less sensitive	VDI 1987 HAVRANEK & WIESER 1993
Abies alba	2.7 % (4.7 %)	less sensitive	less sensitive sensitive	GROSS 1987, SENSER et al. 1987; LANDOLT & LÜTHY-KRAUSE 1991 ARNDT & KAUFMANN 1985
Pinus sylvestris	6.4 % #)	intermediate *) sensitive		VDI 1987 LANDOLT & LÜTHY-KRAUSE 1991
Pinus cembra		sensitive **)		SIMONS 1993
Deciduous trees	*22.7 %* *(17.6 %)*		*intermediate *)*	REICH 1987
Fagus silvatica	9.8 % (9.1 %)	less sensitive (very) sensitive **)	 intermediate*) sensitive less sensitive	VDI 1987 REICH 1987 KRAUSE & PRINZ 1989 GUDERIAN et al. 1990 ARNDT & KAUFMANN 1985
Acer platanoides			sensitive **)	KRAUSE & PRINZ 1989
Betula pendula			sensitive	MATYSSEK et al. 1990
Quercus robur			sensitive **)	KRAUSE & PRINZ 1989

*) Compared to herbaceous plants and conifers (deciduous trees resp.).
**) Young trees.
\# Total share of pine: 7.7 % (9.8 %).

Evaluation of the proton inputs: According to MUTSCH & SMIDT 1994 who evaluated the soil data from the Austrian Soil Monitoring System (pH-value, base saturation, cation exchange capacity and copper, zinc and manganese contents), the "carbonate-influenced" Northern Tyrolean Limestone Alps are less sensitive to proton input. Also Model calculations showed only minor exceedances of the Critical Loads for protons (UN-ECE 1988) for the area of the Northern Tyrolean Limestone Alps and will not cause any unfavourable changes in the soils of the Limestone Alps. However, in analogy to the model calculations of the UN-ECE for Switzerland, and taking into consideration the trace gases SO_2, NO_2 and NH_4, which after their hydrolyzing and deposition in the soil also release protons there, and several assumptions (e.g. that neither the denitrification or the production of net N_2 nor ammonium leaching take place in the soil), total inputs would be much higher. According to the model calculations proton inputs ranged between 1.5 and 4.5 kg/ha.a in Switzerland in 1990 (FEDERAL OFFICE OF ENVIRONMENT, FORESTS AND LANDSCAPE 1994).

In connection with the scientific search for the reasons of the new-type forest damage more importance is being attached to the nitrogen depositions. Their (potentially) negative effects can be summed up as follows:

- Increased nitrogen depositions influence the composition of plant communities (cf. Critical Loads of the UN-ECE 1988), especially of those adjusted to sites poor in nitrogen.
- As a result of the direct release of protons, namely of ammonium, nitrogen depositions lead to acidification through nitrification of the soil. One of the consequences is increased mobilisation of heavy metals, which, in turn, may have a negative effect on soil microbes and mycorrhizae. Further, larger amounts of calcium, magnesium and potassium are leached from the soil. Acid depositions, especially nitrogen depositions, are also considered important factors in the decreasing number of fungal species and the lack of fungal fruiting bodies (KUBICEK 1995).
- High nitrogen doses may increase the sensitivity to frost, dryness and pathogenes (BOBBINK & al. 1992).
- Unbalanced nitrogen depositions lead to unbalanced nutrient supply (GLATZEL 1988).
- Forest ecosystems containing too much nitrogen export their surplus nitrogen as nitrate into the seepage water and pollute the groundwater; also, more N is released in the form of gaseous compounds (N_2, NO_x, and N_2O) (ISERMANN & ISERMANN 1995).
- In most forested areas the supply with nitrogen exceeds the demand. During a period of 100 years 7 kg N/ha.a are accumulated annually (GLATZEL 1990).
- There is no connection between the N content of the needles and the permanent increment produced by the needles during their lifetime. Apparently the production of biomass is very little increased by nitrogen depositions from respiration (HEPP & HILDEBRANDT 1993).

As the anthropogenic N input has greatly increased in the course of the century, it is assumed that most ecosystems are in the phase of nitrogen accumulation or even in that of nitrogen saturation (HADWIGER - FANGMEIER & al. 1992). All over Europe the inputs were determined and their impacts on most different terrestrial and aquatic ecosystems were assessed. Critical Loads were defined in accordance with the present state-of-the-art; they start at 5 kg/ha.a and, depending on the site conditions, vary between 5 and 20 kg/ha.a. In Austria, nitrogen inputs through wet deposition fall in that category. In the Tyrol, and in the entire alpine region, 5 - 20 kg N/ha.a annually are deposited by wet deposition (KOVAR & PUXBAUM 1991, OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1995), with slight increases for congested areas since 1984/85 and slight decreases for clean air areas. According to GLATZEL 1990 the inputs are high enough to have serious consequences for the forest soils and their nutrient dynamics. In addition, nitrogen inputs can be up to six times higher under the canopy, depending on the tree species (DVWK 1988); and also dry and occult depositions add to the amounts deposited (GREGORI 1992, WINKLER & PAHL 1993, KALINA & al. 1995).

Synopsis of the Risks to the Growth Areas 2.1 and 4.1 Considering the Available Data From Field Investigations

Based on the results of the interdisciplinary investigations undertaken so far the risk factors have been compiled in Table 2 (BOLHAR-NORDENKAMPF 1989, OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1991, HERMAN & SMIDT 1994, 1995a).

Table 2. Stress factors, criteria of assessment, results of the field investigations, and effects on the forest ecosystems of the Northern Tyrolean Limestone Alps (forest ecoregions 2.1 and 4.1).

*) The references refer to papers which were not published in the framework of the present volume and which are of importance to the said growth areas.

Stress factors	Suitable criteria of assessment	Results of the field investigations *)	Effects on forest ecosystems *)
Climate		Reduction of the amounts of precipitation; simultaneously, increase of temperatures as compared to long-term average.	Poorer supply with nutrient elements
Climate		Dry years	Increase of the mass of fibrous roots of herbaceous plants and therefore competition for plants whose roots grow close to the surface of the soil, e.g. spruce.
Climate	Stress indices for temperature, photochilling, radiation, and vapor saturation deficit (BOLHAR- NORDENKAMPF & LECHNER 1989).	General increase of the climate stress with altitude a.s.l.	Reduction of the photosynthetic capacity (BOLHAR-NORDENKAMPF & GÖTZL 1992).
Sulphur dioxide	Effect-related limiting value (Federal Law Gazette 199/1984; 2nd Regulation Against Air Pollution Affecting Forests).	Limiting values exceeded in agglomerations; relatively high long-term averages on valley bottoms (esp. Inn Valley) air pollution impacts of SO_2 up to approx. 1200 m a.s.l.	Contribution to acid depositions; influence on the spectrum of lichen species (HOFMANN 1992, 1994) and on cuticular wax structures (BERMADINGER-STABENTHEINER 1994a, TRIMBACHER & al. 1995).
Nitrogen oxides	Effect-related limiting values for NO_2 (NO_2 air quality criteria of the AUSTRIAN ACADEMY OF SCIENCES 1987 and WHO 1995).	In agglomerations, all limiting values exceeded on the valley bottom; decrease with altitude above valley.	Influence on the spectrum of lichen species (HOFMANN 1992, 1994).
Stress factors	Suitable criteria of assessment	Results of the field investigations *)	Effects on forest ecosystems *)

tab. cont. p. 289

Ozone	Effect-related limiting values, air quality criteria of the AUSTRIAN ACADEMY OF SCIENCES 1989, the UN-ECE 1994, and the WHO 1995).	8-hour mean, vegetation period mean and AOT40 very frequently exceeded; ozone concentrations increasing with altitude a.s.l. (SMIDT & GABLER 1994).	Stress to sensltive tree species (beech, pine); influence on the anti-oxidative system of spruce (BERMADINGER-STABENTHEINER 1994b); impaired photosynthesis together with photo-chilling effects (BOLHAR-NORDENKAMPF & GÖTZL 1992).
Nitrogen inputs	Critical loads of the UN-ECE 1988, WHO 1995	Critical loads exceeded: 5-20 kg N/ha.a (in the field), 12-13 kg N/ha.a (through fall).	On well supplied soils nitrates are exported into the groundwater; nutrient imbalances.
Pb and Cd inputs	Soil: AUSTRIAN INSTITUTE OF STANDARDIZATION 1993, KLOKE 1980, 1981 Needles: KNABE 1984, ARNDT & al. 1987, HERMAN 1994b Bark: HERMAN 1991	Increasing with altitude (ZECHMEISTER 1995, MUTSCH 1992), interpreted as anthropogenic inputs.	Effects on the food chain.
Insufficient nutrient supply (needles and leaves)	Content of major nutrients of the needles (GUSSONE 1964) and nutrient quotients (HÜTTL 1986).	Generally poor supply with N and, in many cases, also with many other nutrient element, esp. at altitudes of about 1100 m.	
Forest pasture	Formation of root hairs; vitality classes of fine roots and mycorrhizae.	Decrease in the vitality of fine roots and mycorrhizae; perturbed volume of natural regeneration.	Soil compaction, change in the mixture of different tree species at the timber line; reduced stability of protection forests; conflicting uses; increased formation of humus and acidification; reduced density of stocking.
Damage caused by harvesting and rockfall	Criteria of the Austrian Forest Inventory (FEDERAL FOREST RESEARCH CENTRE 1994).	In protection forests high percentage (85 %) of damage caused by rockfall.	
Stress factors	Suitable criteria of assessment	Results of the field investigations *)	Effects on forest ecosystems *)

tab. cont. p. 290

Wildlife; tourism	Criteria of the Austrian Forest Inventory (FEDERAL FOREST RESEARCH CENTRE 1994).	Conflicts of use between wildlife management and tourism and the protective function of the forests.	Extensive damage due to rubbing, browsing, and bark peeling (SCHWANNINGER 1995); loss of fir and beech in Alpine spruce- fir-beech forests; reduction of the density of stocking.

Results

The major functions of the forests, particularly its protective function, must be maintained by a number of combined measures aimed at reducing stress. The demands have been expressed many times (KROTT 1994, OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1995, HERMAN & SMIDT 1995b, FEDERAL OFFICE OF NATURE CONSERVATION 1995) and will be summed up, supported by results from field investigations. Numerous investigations proved that it is necessary to precisely record local stress patterns, while at the same time interpreting them together with basic data from the respective areas. References refer to papers which are not included in the present volume. (Results of this volume are not separately quoted.)

- Reduction of nitrogen emissions.
  Reason: Exceedance of Critical Loads and influence on the species composition, consequences for the nutrient balance, leaching of nitrate.
- Reduction of sulphur dioxide emissions.
  Reason: Exceedance of effect-related limiting values and negative effect on sensitive parts of the forest ecosystem.
- Reduction of the emission of ozone precursors (nitrogen oxides, hydrocarbons).
  Reason: Exceedance of Critical Levels for ozone in the entire Alpine region. Impairment of plant-physiological processes.
- Reduction of the heavy metal emissions.
  Reason: Results from the Forest Soil Monitoring System and from mycosociological and vegetational investigations.
- Reduction of the transit traffic (OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1991, HERMAN 1991, 1994a).
  Reason: Need to reduce precursors of oxidants and heavy metal emissions.
- Easing of the forest pasture problem (for instance by cash compensation of forest pasturing rights, conversion into wood supply rights, separation of forests and pastures, compensation in the form of land; SICKL 1992)
  Reason: Negative effects on individual vegetational, root-ecological and soil-biological parameters.

- Support of natural regeneration to maintain the protective function, mainly by reducing the stress caused by browsing and forest pasturing (DONAUBAUER 1979, 1981).

  Reason: Results from the Austrian Forest Inventory, from soil-biological and root-ecological investigations.
- Use of genetically adapted provenances for high-altitude afforestations (DONAUBAUER 1982).

  Reason: Greatly increased threat to species which are not site-conforming.
- Prevention of excessive game stocks in order to disentangle land use conflicts. Reason: Results of the Achenkirch landuse potential analysis and the Austrian Forest Inventory.

Acknowledgements

The authors would like to thank Mag. M. FREUND for the translation work.

References

ARNDT U. & KAUFMANN M. 1985. Wirkungen von Ozon auf die apparente Photosynthese von Tanne und Buche.- Allg. Forstztg. 1/2: 19-20.

---, NOBEL W. & SCHWEIZER B. 1987. Bioindikatoren. Möglichkeiten, Grenzen und neue Erkenntnisse.- Verlag E. Ulmer, Stuttgart.

AUSTRIAN ACADEMY OF SCIENCES 1987. Luftqualitätskriterien Stickstoffdioxid.- Bundesministerium für Umwelt, Jugend und Familie.

--- 1989. Luftqualitätskriterien Ozon.- Bundesministerium für Umwelt, Jugend und Familie.

AUSTRIAN INSTITUTE OF STANDARDIZATION 1993. Austrian Standard (ÖNORM L1075). Anorganische Schadelemente in landwirtschaftlich und gärtnerisch genutzten Böden. Ausgewählte Richtwerte.- Wien.

BERMADINGER-STABENTHEINER E. 1994a. Epikutikularwachse von Fichtennadeln an den Höhenprofilen Achenkirch.- FBVA-Berichte (Federal Forest Research Centre, ed.) 67: 117-120.

--- 1994b. Stress-physiological investigations on spruce trees (*Picea abies* [L.] Karst.) from the "Achenkirch Altitude Profiles".- Phyton (Horn, Austria) 34 (3): 97-112.

BOBBINK R., BOXMAN D., FREMSTAD E., HEIL G., HOUDIJK A. & ROELOFS J. 1992. Critical Loads of nitrogen.- Background document to the workshop. Lökeberg (Sweden), April 6-10, 1992.

BOLHAR-NORDENKAMPF H. (ed.) 1989. Streßphysiologische Ökosystemforschung Höhenprofil Zillertal.- Phyton (Horn, Austria) 29 (3).

--- & LECHNER E. 1989. Synopse streßbedingter Modifikationen der Anatomie und Physiologie von Nadeln als Frühdiagnose einer Disposition zur Schadensentwicklung bei Fichte.- Phyton (Horn, Austria) 29 (3): 255-301.

--- & GÖTZL 1992. Chlorophyllfluoreszenz als Indikator der mit der Seehöhe zunehmenden Streßbelastung von Fichtennadeln.- FBVA-Berichte (Federal Forest Research Centre, ed.) 67: 119-132.

DONAUBAUER E. 1979. Standortsgerechte Wildbewirtschaftung.- Agrarwirtschaftl. Inst., Schriftenreihe 30: 9-22.

--- 1981. Überlegungen zur jagdlichen Raumordnung für das Schalenwild in Österreich.- Z. Jagdwiss. 26 (3): 172-178.

--- 1982. Forstschutzprobleme im Zusammenhang mit der Aufforstung.- Forstverein für Oberösterreich und Salzburg, 15-17.

DVWK (Deutscher Verband für Wasserwirtschaft und Kulturbau) 1988. DVWK-Regeln 122.- Verlag P. Parey Hamburg, Berlin.

ENGLISCH M. 1992. Standörtliche Grundlagen im Bereich der Höhenprofile Achenkirch.- FBVA-Berichte (Federal Forest Research Centre, ed.) 70: 13-18.

FEDERAL FOREST RESEARCH CENTRE (ed.) 1992. Österreichische Waldboden-Zustandsinventur. Mitteilungen der Forstlichen Bundesversuchsanstalt 168/1 und 168/2.

--- (ed.) 1994. Instruktion für die Feldarbeit der Österreichischen Waldinventur 1992-1996.- Wien.

FEDERAL MINISTRY OF AGRICULTURE AND FORESTRY 1994. Österreichischer Waldbericht 1993.

FEDERAL OFFICE OF ENVIRONMENT, FORESTS AND LANDSCAPE 1994. Critical Loads of acidity for forest soils and Alpine lakes.- Environmental Series no. 234.

FEDERAL OFFICE OF NATURE CONSERVATION 1995. Klimaänderungen und Naturschutz.- Angewandte Landschaftsökologie, Vol. 4.

GEBUREK T. 1994. Kriterien zur Erhaltung forstlicher Genressourcen.- FBVA-Berichte (Federal Forest Research Centre, ed.) 81: 85-96.

GLATZEL G. 1988. Waldbodenzustand und Waldbodensanierung. Forschungsinitiative gegen das Waldsterben, Report 1988, 102-116.- Bundesministerium für Wissenschaft und Forschung Wien.

--- 1990. The nitrogen status of Austrian forest ecosystems as influenced by atmospheric deposition, biomass harvesting and lateral organomass exchange.- Plant and Soil 128: 67-74.

GREGORI M. 1992. Höhenabhängigkeit der trockenen Deposition von Stickstoff- und Schwefelverbindungen sowie Ozon in einem Alpental.- Doctoral Thesis, Technical University of Vienna.

GROSS K. 1987. Gaswechselmessungen an jungen Fichten und Tannen während Begasung mit Ozon und SO_2 im Kleinphytotron.- Allg. Forst- & Jagdztg. 158: 31-36.

GUDERIAN R., KLUMPP G. & KLUMPP A. 1990. Reaktionen von Baumarten auf Luftschadstoffe unter kontrollierten Bedingungen. In: ULRICH B. (ed.), Int. Congr. on Forest Decline Research. Lectures Volume, Friedrichshafen, 445-478.

GUSSONE H.A. 1964. Faustzahlen für die Düngung im Walde.- Bayer. Landw. Verl. München, Basel, Wien.

HADWIGER-FANGMEIER A., FANGMEIER A., JÄGER H.J. 1992. Ammoniak in der bodennahen Atmosphäre - Emission, Immission und Auswirkungen auf terrestrische Ökosysteme. Forschungsberichte zum Forschungsprogramm des Landes Nordrhein-Westfalen "Luftverunreinigungen und Waldschäden", Nr. 28.

HAVRANEK W. & WIESER G. 1993. Zur Ozontoleranz der europäischen Lärche.- Forstw. CBl. 112: 56-64.

HEPP R. & HILDEBRAND E.E. 1993. Stoffdeposition in Waldbeständen Baden-Würtembergs.- Allg. Forstzeitschr. 22: 1139-1142.

HERMAN F. 1991. Schwermetallgehalte von Fichtenborken als Indikator für anthropogene Luftverunreinigungen.- VDI-Berichte 901: 375-389.

--- 1994a. Nutrient content of spruce needles and content of pollutants in spruce needle and bark from the Achenkirch investigation area.- Phyton (Horn, Austria) 34 (3): 85-96.

--- 1994b. Schwermetallgehalte von Fichtennadeln als Kriterium zur Beschreibung der Umweltsituation.- Doctoral Thesis, University of Agriculture, Vienna.

--- & SMIDT S. (eds.) 1994. Ökosystemare Studien im Kalkalpin. Höhenprofile Achenkirch.- FBVA-Berichte (Federal Forest Research Centre, ed.) 78.

--- & --- 1995a. Einleitung und Zielsetzungen.- FBVA-Berichte (Federal Forest Research Centre, ed.) 87: 9-18.

--- & --- 1995b. Integrated research approach to the evaluation of the danger of airborne pollutants to forest ecosystems.- 10th World Clean Air Congress, Espoo May 28 - June 2, Proceedings Vol. 3, 424ff.

HOFMANN P. 1992. Immissionsbezogene Flechtenkartierung im Zillertal.- FBVA-Berichte (Federal Forest Research Centre, ed.) 67: 133-138.

--- 1994. Pollutant-related mapping of lichens in the area of Achenkirch.- Phyton (Horn, Austria) 34 (3): 71-84.

HÜTTL R.F. 1986. "Neuartige" Waldschäden und Nährelementversorgung von Fichtenbeständen (*Picea abies* L. [Karst.]) in Südwestdeutschland.- Freiburger Bodenkundl. Abh. 16.

ISERMANN K. & ISERMANN R. 1995. Die Landwirtschaft als einer der Hauptverursacher der neuartigen Waldschäden.- Allg. Forstzeitschr. 5: 268-276.

KALINA M., ZAMBO E. & PUXBAUM H. 1995. Okkulte Deposition in Achenkirch - 1. Interim Report.- Institute of Analytical Chemistry, Technical University Vienna.

KILIAN W., MÜLLER F. & STARLINGER F. 1994. Die forstlichen Wuchsgebiete Österreichs.- FBVA-Berichte (Federal Forest Research Centre, ed.) 82.

KLOKE A. 1980. Richtwerte 1980. Orientierungsdaten für tolerierbare Gesamtgehalte einiger Elemente in Kulturböden.- Mitt. VDLUFA, 9-11.

--- 1981. Sollen Richtwerte für tolerierbare Schwermetallgehalte in landwirtschaftlich-gärtnerisch genutzten Böden auch für Forstböden gelten?- Mitt. Forstl. Bundes-Vers.anst. Wien 137/II: 141-146.

KNABE W. 1984. Merkblatt zur Entnahme von Blatt- und Nadelproben für chemische Analysen.- Allg. Forstzeitschr. 847-848.

KOVAR A. & PUXBAUM H. 1991. Nasse Deposition im Ostalpenraum.- Technische Universität Wien, Institut für Analytische Chemie, Berichte 14/91.

KRAUSE G.H.M. & PRINZ B. 1989. Experimentelle Untersuchungen der LIS zur Aufklärung möglicher Ursachen der neuartigen Waldschäden.- LIS-Report 80, Landesanstalt für Immissionsschutz Nordrhein-Westfalen, Essen.

KROTT M. 1994. Strategien für intelligenten Waldschutz.- Forstarchiv 65: 19-23.

KUBICEK C.P. 1995. Identifizierung und Quantifizierung von Mykorrhizapilzen anhand spezifischer PCR-amplifizierter DNA-Sequenzen.- Final Report GZ 56.810/39-VA2/91 (Bundesministerium für Land- und Forstwirtschaft).

LANDOLT W. & LÜTHY-KRAUSE B. 1991. Wirkungen umweltrelevanter Ozonkonzentrationen auf verschiedene Pflanzen.- Luftschadstoffe und Wald 5: 127-134. Verlag der Fachvereine Zürich.

MATYSSEK R., KELLER T. & GÜNTHARDT-GOERG M. 1990. Ozonwirkungen auf den verschiedenen Organisationsebenen in Holzpflanzen.- Schweiz. Z. Forstwes. 141 (8): 631-651.

MÜLLER-STARCK G. 1994. Die genetische Variation der Fichte in Graubünden, eine Pilotstudie.- Bündnerwald 4/9: 15-20.

MUTSCH F. 1992. Schwermetalle.- Mitteilungen der Forstlichen Bundesversuchsanstalt 168/II: 145-192.

--- & SMIDT S. 1994. Durch Protoneneintrag gefährdete Waldgebiete in Österreich.- CBl. f. d. ges. Forstwes. 111 (1): 57-66.

OFFICE OF THE PROVINCIAL GOVERNMENT OF THE TYROL 1991. Auswirkungen des Straßenverkehrs auf die Umwelt.- Bericht an den Tiroler Landtag.

--- 1995. Zustand der Tiroler Wälder 1994.- Bericht an den Tiroler Landtag.

REICH P.B. 1987. Quantifying plant response to ozone. A unifying theory.- Tree Physiol. 3: 63-91.

SCHWANNINGER C. 1995. Wie gut verjüngt sich Tirols Wald.- Österr. Forstztg. 10: 24-36.

SENSER M. et al. 1987. Wirkungen extremer Ozonkonzentrationen auf Koniferen.- Allg. Forstztg. 27/28/29: 709-714.

SICKL A.M. 1992. Die Waldweide - ein agrar- und forstpolitisches Problem.- Österr. Forstztg. 5: 42.

SIMONS S. 1993. Biochemische Effekte und Symptomentwicklungen bei Buchen und Nadelgehölzen unter realen und proportional erhöhten Ozonkonzentrationen.- Doctoral Thesis, Ludwig Maximilians Universität Munich.

SMIDT S. & GABLER K. 1994. SO_2, NO_x and ozone records along the "Achenkirch Altitude Profiles". Phyton (Horn, Austria) 34 (3): 33-43.

---, HERMAN F., GUTTENBERGER H. & GRILL D. (eds.) 1994. Studies of ecosystems in the Limestone Alps.- Phyton (Horn, Austria) 34 (3).

TRIMBACHER C., ECKMÜLLNER O. & WEISS P. 1995. Die Wachsqualität von Fichtennadeln österreichischer Hintergrundstationen.- Umweltbundesamt, Monographien, vol. 57.

UN-ECE 1988. Critical Loads Workshop, 19. - 24. 3. 1988, Skokloster, Schweden.

--- 1994. Critical Levels for ozone. A UN-ECE Workshop Report (FUHRER J. & ACHERMANN B., eds), Schriftenreihe der FAC Liebefeld Nr. 17.

VEREIN DEUTSCHER INGENIEURE (VDI) 1987. VDI-Richtlinie 2310, Blatt 6.

WIESER G. & HAVRANEK W. 1993: Ozone uptake in the sun and shade crown of spruce - quantifying the physiological effects of ozone exposure.- Trees 7: 227-232.

WINKLER P. & PAHL S. 1993. Eintrag von Spurenstoffen durch Nebel auf Wälder.- In: Stoffeinträge aus der Atmosphäre und Waldbodenbelastung in den Ländern von ARGE ALP und ALPEN ADRIA.- Proceedings, GSF-Bericht 39/93, 126-134.

WHO 1995. Updating and revision of the air quality guidelines for Europe.- Les Diablerets, Switzerland, 21-23 Sept. 1994.

ZAUPER A. 1993. Auswirkungen der Beweidung auf die Bodenbeschaffenheit in der montanen und subalpinen Waldstufe der nördlichen Kalkalpen, dargestellt an Beispielen aus dem Bereich nördlich des Achensees.- Doctoral Thesis University Erlangen, Nürnberg.

ZECHMEISTER H. 1995. Correlation between altitude and heavy metal deposition in the Alps.- Environmental Pollution 89: 73-80.