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ÚVOD

Ve dnech 15.–18. září 1997 se v Kovářské v Krušných horách konal mezinárodní workshop *Krušné hory – The Ore Mountains 1997: Experiences and New Problems*.

Workshop organizovali pracovníci útvaru ekologie lesa Výzkumného ústavu lesního hospodářství a myslivosti v Jílovišti-Strnadech ve spolupráci s odborníky z Univerzity v Essenu. Uspořádání workshopu bylo vyvoláno potřebou reagovat na novou situaci ve zdravotním stavu lesů Krušných hor. Jak je všeobecně známo, po příznivém vývoji lesních porostů na počátku devadesátých let došlo v zimním období 1995/1996 k velkoplošnému poškození smrkových porostů a na jaře 1997 k výraznému poškození březových porostů – to vše se stalo při výrazně nižší úrovni emisí, než byla ve druhé polovině osmdesátých let. Úkolem workshopu bylo zhodnotit současnou situaci a vytyčit potřebné směry výzkumu, které by vedly k objasnění příčin těchto škod a k zabránění jejich dalšího opakování. Konference se zúčastnili odborníci z České republiky, Spolkové republiky Německa, Slovinska a Finska, kteří se v rámci exkurze (přípravene v spolupráci s OI LČR Teplice) a úvodních referátů seznámili se současnou situací a během pracovního jednání dospěli k následujícím závěrům:

Závěry z konference Krušné hory – The Ore Mountains 1997: Experiences and New Problems:

Účastníci, kteří se podrobně seznámili během exkurze a referátů přednesených na konferenci se současným stavem lesních ekosystémů ve východním Krušnohoří, předkládají své stanovisko:

1. Přestože významně klesá imisní zatížení Krušných hor oxidem siřičitým, zůstávají nadále vysoce ohroženou oblastí. Důkazem toho je poškození smrkových a březových porostů v letech 1995–1997. Je pravděpodobné, že toto ohrožení bude trvat ještě několik desetiletí.

2. Současné poškození náhradních březových porostů je výsledkem dlouhodobého komplexního působení biotických a abiotických faktorů, přičemž imisní zatížení má stále významnou úlohu. Teplotní zvraty v průbě-

hu zimy 1996/1997 a na počátku vegetačního období byly počátečním spouštěčím faktorem zhoršení zdravotního stavu březových porostů. Nastupující zima ukáže, zda má poškození březových porostů reverzibilní charakter.

3. Za této situace by lesní hospodářství mělo mít veškerou podporu a volnost ve výběru nejvhodnějších pěstebních postupů včetně volby vhodných druhů dřevin.

4. Za velmi důležité považujeme zajistit průběžný monitoring všech stresových faktorů a reakce dřevin a zpřístupnit existující databáze, jejichž podklady jsou nezbytné pro toto sledování.

5. Pro řešení situace je nutná podpora intenzivního výzkumu v dlouhodobější – minimálně pětileté – perspektivě a plnohodnotné využití starších výsledků výzkumu, které se týkají daného problému.

6. Jako vysoce aktuální se jeví podrobná analýza stanovištních podmínek ve vztahu k poškození břízy, která je základní dřevinou náhradních porostů a jejíž zastoupení je v postižené oblasti 50%.

7. Vzhledem k tomu, že zatížení Krušných hor depozicemi je stále obrovské, je velmi důležité zintenzivnit a rozšířit výzkum otázek spojených s koloběhem látek, výživou dřevin, se sledováním depozice a nebezpečím intoxikace dřevin rizikovými prvky.

8. Jedním z možných zdrojů financování těchto aktivit je důsledné vymáhání náhrad za poškození lesních porostů od průmyslových podniků, jejichž emise Krušné hory poškozují. To je jeden z úkolů státní správy.

9. Význam poškození Krušných hor se neomezuje jen na bezprostřední území České republiky a Saska, ale má širší středoevropské dimenze. Je proto žádoucí hledat podporu k řešení složité situace také v rámci existujících mezinárodních projektů.

10. Je povinností lesního hospodářství zajistit odpovídající informovanost veřejnosti. Situaci by se měl zabývat i zákonodárny sbor České republiky.

Příspěvky přednesené na semináři otiskujeme v č. 4 a 5/1999.

INTRODUCTION

In September 15 to 18, 1997 an international workshop *The Ore Mountains 1997: Experiences and New Problems* was held in Kovářská, the Ore Mts.

The workshop was organized by the Forestry and Game Management Research Institute in Jíloviště-Strnady, Dept. of Forest Ecology, in cooperation with the Essen University. The workshop was called by the urgent need to react in the new situation of the health state of forest stands within the Ore Mts. region. It is gene-

rally known that after a positive development of the forest state in early nineties, vast devastation of the spruce stands occurred in winter 1995/1996, followed with serious damages of birch stands in spring 1997 – all this under the conditions of significantly lower emission load, to compare with the state in the second half of eighties. The aim of the workshop was to evaluate the present situation and to propose the directions of the research focused to explain the causes of damages, and

to prevent similar situations in future. In the seminar there were experts from Germany, Slovenia, Finland, and the Czech Republic. The situation was explained and practically demonstrated in introductory presentations, and during the excursion, prepared in cooperation with the Forests of CR, Teplice. The situation was widely discussed during the session with the following conclusions:

Conclusions from the workshop *Krušné hory – The Ore Mountains 1997: Experiences and New Problems:*

The participants informed in detail on the problem both during the excursion and on the base of different presentations, have prepared following statements:

1. In spite of significant lowering of the sulphur dioxide load within the Ore Mts. region, the forests are still highly threatened. It was underlined by the recent damages of spruce stands and birch during the period of 1995 to 1997. It can be expected that such a danger will continue for several future years.

2. Current damage of the birch stands is a result of long-term complex effect of main stress factors, the air pollution load is still of importance. The temperature changes during the winter period of 1996/1997 and at the beginning of vegetation period were probably the factor starting the deterioration of the health state of birch stands. The next winter will show whether the character of damage is reversible.

3. Considering this situation, the forest management should have all the possible support and free choice of the most suitable silvicultural measures, including choice of tree species.

4. Continuous monitoring of all the stress factors and corresponding reactions of the tree species is of importance, and also free access to the data-base giving the source materials necessary.

5. To cope with the situation, an intensive support of the research in long-term – minimum of 5 years – perspective and full use of older research results on the topic are basic.

6. The analysis of site conditions and possible relations to the damages on birch became recently extremely important, consider as birch is the basic tree species of the transitory stands, representing 50% of trees there.

7. Considering the depositions load is still extremely high in the Ore Mts. more intensive research focused on problems of substances circulation, tree nutrition, monitoring of deposition, and possible risk of intoxication of the tree species by dangerous elements is needed.

8. Compensations for the damages to forests stands paid by the industrial enterprises polluting the region of Ore Mts. can be one of possible financial sources. This would be the task of the Forest Administration.

9. The air pollution from the Ore Mts. basin is not affecting only the Czech Republic and Saxony, it has a broader, central-European dimension. The existing international projects should also support the solution of this uneasy situation.

10. The forest management should inform the public about this alarming situation. Also the government and other official bodies of the Czech Republic should be concerned with the problem.

Papers presented to the workshop will be published in issues No. 4 and 5/1999.

DEVELOPMENT AND CAUSES OF FOREST DAMAGE IN THE ORE MTS.

VÝVOJ A PŘÍČINY POŠKOZENÍ LESŮ V KRUŠNÝCH HORÁCH

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ABSTRACT: Fifty years since the sharp deterioration of the forest health state in Eastern part of the Ore Mts. is the period long enough to evaluate not only the development of damages but also the results of the effort to improve the unsatisfactory situation. This seems to be necessary also with respect to significant damages of spruce, and even of birch, in 1996 and 1997, observed after comparatively long period without any dramatic deterioration of the forest state. The analysis of the development shows that the region of the Ore Mts. was exposed to the pollution load by sulphur dioxide much before the first significant damages have been observed in 1947, since the second half of the last century. This long-term load and debilitation of the stands were probably the main causes of a sharp deterioration of the state, in the period when the air pollution load was probably not increased dramatically. The level of the air pollution by the emissions from the Ore Mts. basin was probably not exceeding 100,000 tons of sulphur dioxide per year during that time. In contrary, following unsatisfactory development was connected with the rapidly increasing level of the air pollution. Several dramatic episodes could be observed followed by a sharp deterioration of the health state of spruce stands. Forest management so had to solve extraordinary tasks of unprecedented extent. When evaluating further development it is necessary to understand that even after desulphurisation of the power plants within the region, the amount of SO₂ emissions will be still higher than fifty years ago. Also the changes connected with a long-term deposition of acid compounds in soil are increasing. Constant attention paid to this region will be necessary also in the next decades.

air pollution; forest decline; Ore Mts.; Norway spruce; sulphur dioxide

ABSTRAKT: Padesátileté období, které uplynulo od významného prudkého zhoršení zdravotního stavu lesních porostů ve východním Krušnohoří, je dosti dlouhou dobou, aby bylo možné posoudit nejen vývoj poškození, ale i výsledky snah o nápravu nepříznivého stavu. Je to žádoucí i proto, že po delším období, ve kterém se neprojevovalo dramatické zhoršení stavu, v roce 1996 a 1997 byly výrazně poškozeny nejen porosty smruku ztepilého, ale i břízy. Z analýzy vývoje je zřejmé, že krušnohorské lesy byly zatíženy imisemi oxidu siřičitého již daleko dříve, než se projevilo první výrazné poškození v roce 1947, a to již od druhé poloviny minulého století. Toto dlouhodobé zatížení a oslabení porostů bylo zřejmě hlavním důvodem, proč se stav porostů prudce zhoršil v době, kdy zřejmě nedošlo k náhlému výraznému vzestupu imisí. Úroveň znečištění ovzduší v Krušných horách byla v této době dána emisemi, jejichž výše v Podkrušnohoří pravděpodobně nepřesahovala 100 tisíc tun oxidu siřičitého za rok. Další nepříznivý vývoj byl naopak způsoben rychle stoupající úrovní znečištění ovzduší. Došlo k několika dramatickým zvratům, k prudkému zhoršení zdravotního stavu smrkových porostů. Lesní hospodářství tak muselo řešit zcela mimořádné úkoly ve zcela mimořádném rozsahu. Pro posouzení dalšího vývoje je důležité si uvědomit, že i při realizaci programu odsířování emisí severočeských elektráren zde bude stále působit vyšší množství emisí, než bylo před 50 lety. Navíc se zřetelně prohlubují změny, které působí trvalá depozice kyselých složek znečištění ovzduší v půdě. Je proto nezbytné věnovat této oblasti stálou pozornost i v příštích desetiletích.

znečištění ovzduší; chřadnutí lesů; Krušné hory; smrk ztepilý; oxid siřičitý

INTRODUCTION

Forest decline, that began to manifest in the whole Europe in the late 70s and especially in the early 80s, very substantially increased the public interest in the state of forests; at the same time the attention, till that time given to some intensively polluted areas like for instance the Ore Mts. had ever been, was a little weakened.

However, there are lots of reasons to deal with the situation in this area again and more deeply.

Above all here is the fact that it is already 50 years when the dramatic, sudden deterioration of health state of forest stands appeared. This period is long enough for evaluating the development in the certain area as well as the results of efforts to solve the unfavourable aspect of this development. Another reason is the repeated appearance of sudden and significant damage of

stands with Norway spruce and birch in the highly polluted parts of the Ore Mts. That is why the deeper analysis of processes causing such changes of health state of stands is again needed.

The analysis of development and state of the Ore Mts. forests and conditions at which the damage had occurred are very important items in finding of causes of forest decline in general and in explanation of some unclearnesses and casual relations of forest decline.

And at last, the detailed analysis of development under the increase of air pollution level in the whole area can influence the decisions on management the forest in the course of the opposite procedure, i.e. under the gradual decrease of air pollution load, easier. These are the reasons for brief characteristic of principal periods in development of the Ore Mts. forests.

AREA DETERMINATION

The natural forest area No. 1 the Ore Mts. defined by the Institute of Forest Management (Plíva, Žlábek, 1986) is not equivalent in the whole extent to the area where the most significant problems are occurring. It should be remarked that there are very principal differences both in development and in present state and character of load as well as in reaction of forests on this load between the eastern part (to the east from the Klínovec) and the part situated to the West from this highest mountain of the Ore Mts. This fact is sometimes disregarded and consequently leads to wrong conclusions about extent and intensity of air pollution disaster and possibilities of its solution.

The main reason of differences between the two parts is that since 60s the main sources of air pollution in the foothills of the western Ore Mts. remained the power plant in Tisová and the combine processing the brown coal-gasworks in Vřesová. On the contrary, constructions of large sources-mainly great power plants continued in the area of Chomutov, Most and Teplice which are the sources of emissions directly impacting the eastern Ore Mts. both in the past and at present. The difference in emission amount of SO₂ by which both parts are influenced is roughly 1 : 10. Further information deals mainly with development in the eastern part of the Ore Mts.

DEVELOPMENT OF DAMAGE

Some scant data from the beginning of the century and mainly these ones in the Stoklasas' work (1923) prove that already at the end of the last and at the beginning of this century the damage of forest stands was evident both directly in the basin, where the extent of forests was only small, and in the lower part of the Ore Mts. forest massif. Also another information witnesses that the first symptoms of forest damage by air pollution appeared at least to the end of the last century.

These old observations present above all fir dieback, reduction of stand fertility and certain symptoms of spruce stands dieback on exposed sites as a consequence of influence of „smoke gases“ (Nožička, 1963). It is hard to suppose that the emission amount from the industrial resources could cause even such a limited damage when the coal processing of those times is considered and especially the amount burnt directly in the basin. As it can be deduced from the Stoklasas' data, the main cause of air pollution seems to be the coal remnants and oxidation of pyrites and organic sulphur in spoil heaps. Those ground emissions loaded very significantly the air in the valley by very high concentrations of sulphur compounds (hydrogen sulphide and sulphur dioxide). Probably it was the principal cause of difficulties. Occurrence of damage even in the stands at remote sites is connected with geomorphology of this range of the Ore Mts. as well as with specific character of emission dispersion under some conditions.

The amount of sulphur dioxide penetrating into the air by such a way cannot be reliably estimated. When regarding the volume of coal mining and responding amount of tail on heaps, the amount of sulphur dioxide might be of tens of thousands tons per year. That load persisted from the second half of the last century for the number of decades and its influence cannot be underestimated because the prevailing part of emissions remained in the area, in the Podkrušnohoří valley and in the marginal parts of forests in the lower area of the Ore Mts. and the Czech Upland. In those locations the forest damage concentrated.

Till the year 1963 factually no information on the amount of SO₂ emissions exist. There are some information about coal mining. The first coal mines in NW Bohemia came in operation between 1740 and 1780. According to the data about coal exploitation, the increase after 1880 was very rapid.

Period	Amount of exploited coal in million tons
1880-1913	480
1914-1937	370
1938-1945	144
1946-1963	570

As there is no reliable information what was the extent of coal mining before 1880, it is only possible to suppose, that the amount of exploited brown coal in this region amounted 1 billion tons till to the World War II. The amounts of sulphur dioxide emitted only in connection with mining (burning coal on spoils) were therefore of substantial importance. Without considering this fact it would be impossible to explain why in spring 1947 the state of spruce stands in the middle part of the eastern Ore Mts. got worse so dramatically and why the process of dying-off of the Ore Mts. forests proceeded rather fast. In spring 1947 the distinct forest damage appeared on the area of 10,000 ha, on the slopes and the ridge of the Ore Mts. in the vicinity of Nová Ves v Horách, in the space leading into the neck

of deeply cut of the so-called Mariánské valley stretching from Horní Jiřetín to the mountainous range. The enterprise on hydrogenation of brown coal that has been constructed during the World War II could be considered as a greater source of emissions. But it worked only for a short period, in 1944 it was destroyed out of order and after the war it was only slowly and gradually rising from ruins. Its emissions could not be the main cause of the dramatic worsening. Neither of other resources could be a cause of distinctive change in emission, i.e. such a change that could be the stimulus of so sudden change in the state of spruce stands.

Already the first reports on forest damage in spring 1947 (Němec, 1952) pointed out the possibility of influence of very harsh winter 1946/1947 which was the winter of century.

The shortage of data and principal information about situation, that was not completed even with report from Němec, were there reason why it could not be unambiguously and exhaustingly explained what has happened following. We can only offer the exploitation which responds to the situation in other cases when forests in the Ore Mts. were damaged in the similar way.

The starting point is above all the long-term load of forest stands. Terrain configuration enables the emission, even from near above ground sources mixed into warmer air masses, to ascend up the valley and to impact stands below and on the range in the valley neck. The low parts and valley sides are covered with deciduous stands with prevalence of beech and therefore the emission impact did not occur there. The spruce stands, weakened for the long time and latently damaged, could not resist the influence of another stress factor, the harsh winter frosts. But it is also possible that the air masses with very high concentrations of harmful agents were transported into the range parts under the given conditions. In ground layers in the neighbourhood of heaps the concentrations of sulphur dioxide reached absolutely extreme concentrations of tens milligrams on 1 m^{-3} of air due to influence of spontaneous fire. Such high concentrations are damaging the evergreen coniferous species even in the time of dormancy. Regarding all uncertainty when characterizing the conditions of damage occurrence, it is not reliably possible to recognize the mechanism of damage appearance. Nevertheless, the published data, description of damage, of leaf and soil analyses are proving:

- that the area was under the influence of sulphur compounds for the long time because the concentrations of this element were extremely high in the analyzed material;
- that the damage with its outside symptoms responds with its extension and development to the situation known and described in other areas, especially in Saxony, like the damage caused by immission of sulphur dioxide.

So, there is no doubt that the decisive cause was the impact of sulphur dioxide in air pollution. The similar situations and similar symptoms of damage are known to

as from several late episodes where the conditions are much better known. The first episode is important not only because it started the catastrophical development in the forests of the Ore Mts.

It is very important also for the present days that the damage occurred in the time when the total load by emissions of sulphur dioxide did not get over 100.000 tons in the afflicted area; it can be supposed that the load was substantially lower. However, it means that if the emissions of harmful agents do not significantly drop under this amount in the observed area, certain endangering of forests must be taken into consideration. In spite of changes in character of emissions in the Ore Mts. Foothills the ground load is still very high; efforts to reduce emissions are concentrating above all on the big sources.

After the year 1947 the stands did not regenerate. The stands seemed to be exposed to the influence of increasing emissions from various resources built on behalf of post-war restoration of industry and coal mining. It can be documented by the first map delineation of observation results concerning level of damage of spruce stands in the Ore Mts. from 1956.

Classification of damage level in this first survey does not correspond with present criterion and classification, nevertheless it proves unambiguously that in that time the damage was evident on the whole forest area of the eastern Ore Mts. and Děčínský Sněžník including exposed part of the Czech Upland; the damage hit also the stands on the right bank of the Elbe (Zprávy VÚLHM, 1957).

Therefore the information that the unfavourable development of state of the Ore Mts. forests started first after 60s is not reliable.

Since the late 50s there are more reliable data for the characteristic of load in relation to the forest state because in 1959 systematic monitoring of health state of stands on about one hundred monitoring plots was started. Since the half of the 60s we can systematically observe development of concentrations of sulphur dioxide thanks to the cooperation with the Polarographic Institute of the Czechoslovak Academy of Sciences and later with the Czech Hydrometeorological Institute (Materna et al., 1969).

Further development can be characterized best like a gradual deterioration of forest stand oscillating along to descending trend. The present state of spruce stands was influenced by the development of air pollution and weather course in winter months. The importance of air pollution level in winter was proved in various publications (Materna, Kohout, 1963; Materna, 1974; Ryšková, Uhlířová, 1985).

Another crucial point was the year 1977. Very warm weather at the end of winter was the reason of premature awakens of vital activity of wooden species, but in the late March the temperature fell suddenly deeply below the freezing point (in the Ore Mts. to $-13\text{ }^{\circ}\text{C}$). In the eastern Ore Mts. large plots of spruce stands were very heavily damaged and on the ridges the part of them

died. However, the damage intensity did not respond to the differences in the level of temperature decrease but to the level of load. This can be demonstrated for example by the fact that the western Ore Mts. was hit by the same temperature drop but stand damage was only sporadic and of very low level. Also in the eastern Ore Mts. more loaded parts of forests were much more affected.

On the turn of 1978/1979 the whole unfavourable development culminated again in sudden temperature drop that extremely stressed especially coniferous species. That was destructive for forests exposed to a higher air pollution level. Thus the spruce stands in the eastern Ore Mts. were most damaged and prevailing part did not survive. In the less polluted and of western Ore Mts. the worsening of health state occurred too, but without serious consequences.

In the eastern part only very few spruce stands have survived, mostly young stands on the ridges, and the stands of older age classes in the foothills and protected locations, which means that the base for evaluation of state of stands of sensitive tree species and their reaction to load development during the period, when the amount of emissions of sulphur dioxide in the Ore Mts. foothills culminated (i.e. in the late 80s) is very limited. Even in that period from time to time the state of remained spruce stands got worse in some locations in dependence on weather course in winter months; reddening of needles was caused by acute influence of stress factor.

The above mentioned statements seem to be in contradiction with a certain stabilization of spruce stands in the late 80s when the height growth increased in the younger stands as well as the growth of lateral annual shoots, and reduction of degree of defoliation decreased. On trees where former only two age classes of needles survived, one or two other older age classes of needles would be preserved. Also in the older spruce stands, especially in the zone B, i.e. in the less exposed locations, decreased the level of estimated defoliation although the high air pollution level has been still lasting. There were several factors that took part in that development. The more sensitive parts of stands as well as the more sensitive individuals, i.e. more sensitive to the whole complex of air pollution and ecological factors, disappeared; somehow surviving individuals adapted by harmonizing the above-ground and root parts; certain role might played the more favourable course of weather without great extremes as well as certain influence of liming could not be excluded.

If we now summarize and briefly characterize the development, it is obvious that forest destruction in the eastern Ore Mts. was caused by episodes of coincidence of air pollution influence and weather extreme-temperature drops which caused the gradual deterioration of health state of stands corresponding with the increasing concentrations of sulphur dioxide in the air. It is evident from that, that the stand can be weakened even by relatively low air pollution load (similar to that one in 1947).

The second important knowledge from the investigation of development is that also the sensitive tree species can gradually adapt to a certain degree even when the load is high or increasing.

CAUSES

Nowadays the development of knowledge has undoubtedly proved that in the eastern Ore Mts. the direct influence of sulphur dioxide is the decisive process causing the stand damage. But in the initial times there was a certain distrust if sulphur dioxide itself or in a decisive extent is able to cause such a large and intensive stand damage. Those doubts were based on the older data about critical concentrations of sulphur dioxide; it was supposed that the plants were damaged first when concentrations exceeded 1 ppm SO₂ (ca. 2.860 µg.m⁻³). Experiences from the Ruhr basin supported the opinion that also at least fluorine compounds participated in stand damage. The results of great series of analysis in the 50s and 60s did not confirm any more important role of fluorine compounds in the damage of the Ore Mts. stands. Neither direct measurement of fluorine in the air confirmed that the critical limit for that harmful agent in that area (1 µg F.m⁻³ of the air) was exceeded.

Present situation is the same. In spite of this, the influence of fluorine compounds together with the entire complex of emitted substances must not be forgotten. The main source of fluorine compounds in this area is burning of brown coal in power (emission in 10³ t F annually). The long-term trials with low concentrations of sulphur dioxide and with their influence on coniferous species clearly proved that already the concentrations of two orders lower than the limit given by Wislicen, i.e. even the concentrations distinctively lower than the common load in the eastern Ore Mts., influence unfavourably the spruce plants when impacting for the long time (M a t e r n a, 1973).

In the 70s and 80s a rather dense network of stations of SO₂ monitoring stations both in the Czech Hydrometeorological Institute and within forest research was operating in the area. Their long-term work has enabled to evaluate the dependence between the concentration of sulphur dioxide and reaction of spruce stands. It was unambiguously proved that intensity on influence depends not only on the concentration of harmful agent but also on some site conditions – above all wind velocity, in smaller degree on moisture and soil fertility.

The influence of air movement on damage intensity was proved by many observations in the open space as well as experimentally (J i r g l e, 1989). Therefore, for example spruce stands in intensively loaded area in the Ore Mts. foothills survived for very long time and on many localities have survived till now while Norway spruce stands, for example in the exposed area of Měděnec, Horní Halže on the mountain ridge, died at lower load during several years since the time the

power plants in Tušimice and Pruněfov had started to work.

However, it would be wrong to show influence of sulphur dioxide with occasional admixture of fluorine compounds as the only cause of damage. Besides mentioned gases and of course also carbon dioxide, several tens of organic compounds in gaseous form as well as dust containing a lot of harmful substances leave the chimneys of works burning brown coal. The stands are also impacted by deposition of various substances from polluted air in dew, rime, and rain.

Deposition of substances from the polluted air endangers mainly the Ore Mts. soil which is possible to prove by investigation of their chemistry. It involves not only the influence of enormous amounts of sulphur, protons, but also the influence of deposition of hazardous elements having been concentrated in organic horizon – e.g. lead (Materna, 1995). Rather intensive liming in recent years (app. 4 t of lime on 1 ha) and to a certain degree also dusty fallout with a content of elements neutralizing partly the acidity prevent the situation to become so critical as it could be expected. From this point of view the situation in the western Ore Mts. shows to be more unfavourable regarding that no ameliorative operations were done. Therefore here are the more distinctive disorders in stand nutrition on large area and in higher intensity. Because, in spite of continuing high deposition of acidic compounds of polluted air, the liming was stopped even in the eastern Ore Mts., the possibility of further worsening of situation is real.

PRESENT SITUATION

Roughly from the early 80s the unfavourable development of health state of stands had retarded and the situation in some parts of the eastern had gradually stagnated or even improved. After this relatively long period, in spring 1997 very significant damage in spruce stands occurred again. Its character responded to the one appearing in previous decades (1947, 1977, 1979). The detailed analyses revealed again the decisive influence of high air pollution level during winter months' inversion (Lomský et al., 1996).

At present the vegetation cover in the eastern part of Ore Mts. is characterized by the large extent of stand with substitute species that cover large areas in the ridge parts (more than 30 thousand ha): there are mainly stands of birch alder, blue spruce. European larch is also a tree species, which was broadly used not so much for future wood production, but more to cover the soil. In small extent also other tree species have been used. The state of these species growing here, in conditions very different from their optimal ones, cannot be taken for satisfactory. Declining of some stands has already begun earlier (Jirgle, 1984). The damage of birch stands, which occurred suddenly in the course of 1997, can be taken as decline culmination; till now no reason-

able explanation for its appearance exists (Kula, Rybář, 1998). However, the repeated localization of the damage in to the eastern Ore Mts. shows the dependence on the high load of the whole region.

Finally we must mention that the soil surface was drastically deteriorated on a large scale during preparation for planting the trees. This significantly hit the nutrition of planted wooden species and the consequences will be appearing for many decades.

PERSPECTIVE

To assess further development some questions must be answered.

Firstly, there is the question how long will be lasting such a load with sulphur dioxide that can endanger the existence of sensitive species – i.e. Norway spruce, which will again be a decisive part of future stands. In 1996 emissions in Northern Bohemia dropped to roughly 450,000 t, i.e. approximately to 40% of emission amount in the period of culmination. In the 60s such a load of the area caused significant deterioration of the situation and the mass dieback of forests. It is supposed that it will be necessary to reduce emissions to a fraction of present level for eliminating the stand endangering.

Secondly, there is the question of development of health state mainly of substitute stands. The development in the last year has proved the increased sensitivity stands against stress factor in the exposed parts of the area. In connection with permanent high deposition of acidic compounds of polluted air also the changes in nutrition level of blue spruce and other species must be consider as hazardous.

Thirdly, there is the strengthening unfavourable trend in development of soil chemistry with lasting high deposition of substances from polluted air being caused by stopping all ameliorative operations. The conditions for regeneration of more demanding wooden species, the representation of which will be necessary in stands, will be getting worse.

There are and it can be supposed that even in next decades there will be very serious risk for forest management in the Ore Mts. In case the emissions of sulphur dioxide drop below the level of the load from the beginning of the calamity development in 1947, other factors will endanger as a consequence of the long-term high load. There will be necessary, henceforward, extraordinary measures in forest management.

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VÝVOJ A PŘÍČINY POŠKOZENÍ LESŮ V KRUŠNÝCH HORÁCH

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Krušné hory jsou lesnické veřejnosti obecně známy jako území, na kterém byl les zničen intenzivním vlivem znečištěného ovzduší. To plně platí pro východní část přírodní lesní oblasti, les v prostoru západně od Klínovce trpěl podstatně méně. Celý prostor je vystaven vlivu imisí již téměř 150 let a důsledky jejich působení na les zaznamenala celá řada autorů již koncem minulého století. K výraznému posunu v poškození však došlo až v období po druhé světové válce s rychlým rozvojem průmyslu a energetiky zejména v té části Podkrušnohoří, která přiléhá k východní části krušnohorského hřebene.

Vývoj poškození do jisté míry kopíroval stoupající emise oxidu siřičitého i jeho přízemní koncentrace, vyskytlo se však několik epizod, které vyvolaly náhlé výrazné zhoršení zdravotního stavu smrkových porostů.

Jedna z nich stála na počátku intenzivního poškozování v roce 1947, další v letech 1977 a 1979 zničily většinu porostů smrku ztepilého ve východním křídle Krušných hor. Ty bylo nutné nahradit porosty odolnějších dřevin, především břízy a smrku pichlavého.

Postupné snižování emisí v Podkrušnohoří od kulminace v roce 1985 a zejména od počátku devadesátých let vzbudilo naději na poměrně rychlý návrat k normálnímu lesnickému hospodaření. Intenzivní poškození zbytků porostů smrku ztepilého na jaře 1996 a náhradních porostů břízy na velkých plochách v roce 1997 však dokládá, že bude nezbytné ještě velmi výrazně snížit emise škodlivin v přilehlých oblastech, aby bylo možné se v lesích vrátit k normálnímu hospodaření. Dlouhodobým ohrožením stavu lesa jsou půdní změny vyvolané intenzivním působením imisí.

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BULK DEPOSITION AND THROUGHFALL FLUXES IN THE ORE MTS. – DECREASING ATMOSPHERIC DEPOSITION INTO SPRUCE STANDS

SPAD SRÁŽKAMI VOLNÉ PLOCHY A PODKORUNOVÝMI SRÁŽKAMI V KRUŠNÝCH HORÁCH – KLESAJÍCÍ ATMOSFÉRICKÁ DEPOZICE VE SMRKOVÝCH POROSTECH

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ABSTRACT: Bulk deposition and throughfall mass fluxes of sulphur in the heavily polluted Ore Mts. decreased. Air pollution and receptor surfaces are two key parameters responsible for this pattern. High air pollution levels chronically deteriorate receptor surfaces (defoliation) and thus decline in throughfall fluxes documents both improvements in air quality and the continuing destruction of the remaining spruce stands under the ongoing air pollution stress. Five-year average throughfall flux in the mature spruce stand was $38.1 \text{ kg S}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ and $22.1 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ total inorganic nitrogen. Far higher throughfall fluxes ($126 \text{ kg S}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ and $31 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ total inorganic nitrogen) were determined on the site subjected to enhanced cloud deposition.

sulphur; nitrogen; acid rain; throughfall; Ore Mts.; Načetín; Czech Republic; cloud deposition; spruce stands

ABSTRAKT: Celková atmosférická depozice a podkorunová depozice síry v silně znečištěné oblasti Krušných hor klesá. Pokles znečištění atmosféry a ztráta vegetačních povrchů jsou dva hlavní faktory, které vysvětlují tento pokles. Chronicky vysoká hladina znečištění poškozuje listoví (defoliace korun) a pokles v podkorunové depozici je způsoben jak zlepšením kvality ovzduší, tak pokračující destrukcí zbývajících smrkových porostů, které jsou i nadále vystaveny stresu ze znečištění ovzduší. Kromě chronického stresu mají významný vliv i epizodické události, jako byla námraza v zimě 1995/1996, kdy vysoké koncentrace škodlivin způsobily poškození smrkových porostů v celých Krušných horách. Během pětiletého sledování v dospělém smrkovém porostu byla stanovena podkorunová depozice $38,1 \text{ kg S}\cdot\text{ha}^{-1}\cdot\text{rok}^{-1}$ a $22,1 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{rok}^{-1}$ celkového anorganického dusíku. Významně vyšší toky ($126 \text{ kg S}\cdot\text{ha}^{-1}\cdot\text{rok}^{-1}$ a $31 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{rok}^{-1}$ celkového anorganického N) byly zjištěny ve vrcholových partiích na místě, které je vystaveno silné depozici z oblaků a mlhy.

síra; dusík; kyselý déšť; podkorunové srážky; Krušné hory; Načetín; Česká republika; oblačná depozice; smrkové porosty

INTRODUCTION

Vertical deposition (rain, snow) does not dominate atmospheric deposition in extremely polluted areas. High concentrations of gases in ambient atmosphere are favourable for dry deposition of gaseous compounds that are scavenged from atmosphere by receptor surface, such as canopies of trees. Aerosol particles are also captured directly by vegetative surfaces, instead of being washed-out from the atmosphere by precipitation (Fowler et al., 1989).

Throughfall is precipitation (rain or snow) collected below the canopies of trees or shrubs. Precipitation on its passage through canopies (crowns) is affected in its quantity and chemical composition. The volume of precipitation decreases due to interception, e.g., loss of water due to evaporation. Chemical changes stem either from leaching or from wash-off of chemical com-

pounds. All substances determined in throughfall are leached to some extent from plant tissues; the highest leaching is reported for potassium. Dry deposited material (such as sulphur dioxide, or product of its oxidation, sulphate) is being washed-off from the needles by precipitation. The difference between mass flux in throughfall collected below canopies and precipitation measured on the open field is termed net throughfall or net removal. Positive values of net removal indicate source of the given element in canopies; negative term stands for sink in canopies.

The nature of the source can differ, for instance net removal of sulphur is dominated by wash-off of dry deposited material, which was only temporarily stored onto canopies during a dry period (Hultberg, Grennfelt, 1992; Lindberg, Lovett, 1992). For other elements, leaching from needles may compete in importance with wash-off or dominate. Dambriene,

Prevosto (1988, in Durand et al., 1992) assume that for sulphate, hydrogen ion and nitrogen 100% of net removal in a spruce stand is due to wash-off of atmospherically derived compounds, for sodium and chloride 90%, for calcium 80%, for magnesium 50% and for potassium only 5%, e.g., that 95% of potassium flux in net removal is due to leaching from canopies.

Monitoring of throughfall in spruce stands is used for assessment of dry deposition for understanding the reasons for recent forest die-back in Europe (Ivens et al., 1990). Throughfall measurements were performed in the Ore Mts. to assess the current levels of atmospheric deposition in a mature spruce stand. Most of the forest damage in the region was in mature stands (Kubelka et al., 1992), present data should document changes resulting from the shutdown of some emission sources in former East Germany and desulphurisation program in the Czech Republic (more details in Černý, Pačes, 1995).

ORE MTS.

The Ore Mts. lie on the border between the Czech Republic and Germany. The mountain range is composed of metamorphic rocks and follows a SW-NE direction, the top of the mountain range is relatively flat and most of the summit area lies within 700 to 800 m a.s.l. The area was never glaciated.

The climate is slightly cold and wet. Mean annual air temperature at the summit ranges from 4 to 5 °C. July is the warmest month and December and January are the coldest. Annual precipitation in the upper parts of the Ore Mts. averages 1000 mm year⁻¹, which is almost twice that of the adjacent coal basin in the south-east (Böer, Vesecký, 1975).

After World War II the tertiary basin at the base of the Ore Mts. (Krušné hory Mts., Erzgebirge) became the primary energy source for former Czechoslovakia – brown coal (lignite) mining peaked in the mid- 1980s. Brown coal was fired locally which led to extreme gaseous emissions and air pollution levels in this region. Chronically high SO₂ led to spruce dieback in extensive areas of the Ore Mts. (Kubelka et al., 1992), which peaked in the early 1980s. Summary of the post-war environmental development is given in Černý, Pačes (1995).

SAMPLING SITES

Načetín (50°35' N, 13°15' E, 780 m a.s.l.) is mature spruce stand (Norway spruce, *Picea abies*) situated close to the German border (Kienhaide). Forest is managed by the Forestry District Červený Hrádek.

The stand was classified as moderately affected by atmospheric deposition; damage to spruce was classified as medium, e.g., up to 30% of trees heavily damaged. SO₂ concentrations measured at the nearby station Kalek averaged 78 µm⁻³ in the period 1978–1990.

Two spruce stands at the site are under the investigation.

The first, „Original“ site, 102 years old, is located in the forest section 101B10.

The second Načetín site, „aPOS“ site, 58 years old, was instrumented in 1994 in the stand 101B6 for measurements performed within the scope of the international project „aPOS“ – The Influence of Different Air Pollution Levels on the Degree of Forest Soil Acidification and Forest Stability, CIPA-CT93-0100/DG 12 HSMU.

Age of the forest stands given above comes from the forestry records. We have available independent age estimate from the coring of 20 trees at the „Original“ plot and 10 trees at the „aPOS“ plot (Josef Kyncl, unpublished material, 1996). According to these data, the „aPOS“ plot was established in 1930 and the „Original“ plot in 1905, with some additional trees planted in 1940. Correspondingly the age of the „aPOS“ plot is 61 years and the age of the „Original“ plot is 92 (57) years in 1997.

FIELD METHODS

Bulk deposition (BD) was determined in a forest opening. Bulk deposition samples were collected by means of continuous exposure of polyethylene funnels (area of 122 cm²) fitted to PE 1 l bottles. Plastic vessels (area 380 cm²) with PE bags were used for snow collection in winter. Three to four weeks interval of sample collection prior to VIII/1994 was replaced with two-week exposure since then, some irregularities resulted from the either lack or overabundance of precipitation.

Throughfall (TF) samples were collected in a sampling network of 25 samplers spaced in a regular 5 x 5 grid with 10 m spacing between collectors. The identical samplers and the same sampling protocol as for bulk deposition were used.

Five samples forming one row were composed to create one sample representing this row. Each sampling period thus resulted in five chemical analyses and five throughfall quantities representing five rows. Plot averages reported in this paper were calculated from these values (volume weighted average).

At the „Original“ site prior to VIII/1994, samplers were exposed for a period ranging from 9 to 36 days, in average for three weeks. Since VIII/1994 the collection period was four weeks. Some irregularities resulted from the same reasons as in the case of bulk deposition sampling.

At the „aPOS“ plot the same collection vessels (and geometry of the sampler distribution) were used, the collection period was two weeks.

Net Removal (NR) for both sites were calculated (TF minus BD), where positive value of net removal stands for source in canopies, negative value stands for sink in canopies.

All the results throughout this paper are reported for biological years, beginning on November 1 and

ending on October 31 next year; hydrological year 1995 thus starts on 1. XI. 1994 and ends on 30. X. 1995.

LABORATORY METHODS

Water flux was measured by weighing the samplers prior to and following exposure. Conductivity, pH and alkalinity were measured within 48 hours of collection (Radelkis conductivity electrode, Radiometer GK 2401C combined pH electrode and automated Gran titration were used). An aliquot was filtered (0.45 μm) and analyzed in the chemical laboratory of the Czech Geological Survey. Chemical analysis was done using ion chromatography analysis (Cl^- , NO_3^- , SO_4^{2-}), ISE analysis (F^-), spectrophotometry (NH_4^+), cations were determined in acidified aliquots by AAS Perkin Elmer (bulk deposition samples) or ICP spectrometer Perkin Elmer Plasma II (throughfall samples).

RESULTS

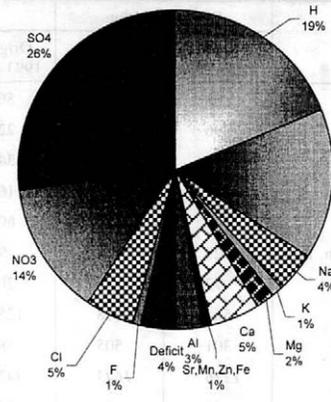
Average ionic composition of bulk deposition (BD), throughfall (TF) and net removal (NR) as measured at Načetín site are shown in Fig. 1. Chemical nature of the solution basically does not change through contact of the incident precipitation with the spruce canopies – acidic solution is dominated by sulphate (26–32%) of the ionic charge, hydrogen (16–19%) and nitrate (10–14%). Proportions of other components do not differ when incident precipitation gets into contact with canopies (4, 3, 5, 1%, respectively for Na^+ , Mg^{2+} , Ca^{2+} , Cl^- and F^-). Although there exists an anion deficit in our samples, it remains constant, and it does not increase under the canopies. This suggests small contribution of organic compounds released from the canopies to the ionic charge of the solution.

Significant changes in per cent contribution to the ionic charge were found for ammonia, potassium and calcium. Ammonia in BD was as important as nitrate (15 vs. 14% for ammonia and nitrate, respectively), but ammonia was consumed in the canopies. Ammonia in TF forms only 8% of the ionic charge, in net removal only 2%. Conversely, calcium and potassium increase their share from 5% (1%) in bulk deposition to 10% (11%) in NR (first value stands for calcium, the one in brackets is for potassium).

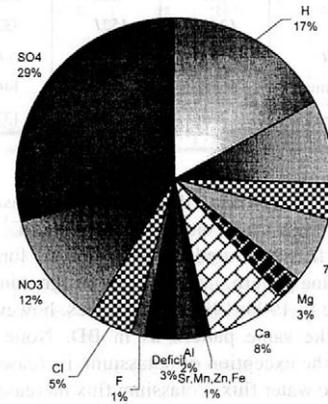
Annual mass fluxes expressed in $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ are reported in Tab. I as bi-annual averages, i.e. for periods 1993–1994 and 1995–1996 (hydrological years).

Water input on open field (BD) in the period 1995–1996 was 28% higher than in 1993–1994. Correspondingly, input of all substances in BD with an exception of fluoride was higher in the 1995–1996. Fluoride BD flux decreased from 31 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ to 26 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$, i.e. by 5 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$. This decrease is marginal in comparison with the increase of other deposition fluxes. The most important increase was associated with nitrogen

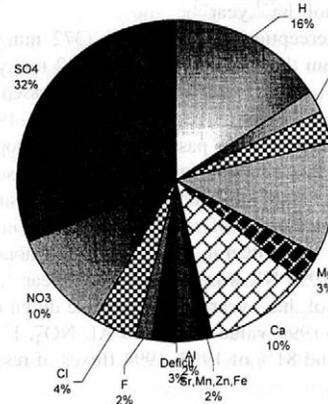
Bulk Precipitation



"Original" site Throughfall



"Original" site Net Removal



1. Ionic charge distribution in bulk deposition, throughfall and net removal, Načetín 1995–1996. The „Original“ site throughfall data are shown. Units are percents of total charge, expressed in moles of charge Γ^{-1}

1. Bulk deposition, throughfall and net removal fluxes at Načetin, Ore Mts. Units are $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ (hydrological years), water flux in mm. Total inorganic nitrogen is ammonia plus nitrate

	Bulk deposition		Throughfall			Net removal		
	Bulk 1993–1994	Bulk 1995–1996	„Original“ 1993–1994	„Original“ 1995–1996	„aPOS“ 1995–1996	„Original“ 1995–1996	„Original“ 1995–1996	„aPOS“ 1995–1996
Water flux	838	1074	595	702	773	-242	-372	-301
Na ⁺	96	136	224	259	267	128	124	131
K ⁺	20	36	345	473	631	325	437	595
Mg ²⁺	47	62	163	185	208	116	122	146
Ca ²⁺	146	165	604	566	686	457	402	521
Σ Sr, Mn, Zn, Fe	29	36	94	94	125	65	58	89
Al ³⁺	72	87	207	168	329	134	81	242
H ⁺	564	618	1256	1225	1930	692	608	1312
NH ₄ ⁺	301	505	585	592	772	284	87	267
Cations	1276	1643	3477	3563	4948	2200	1919	3304
F ⁻	31	26	116	91	106	86	65	80
Cl ⁻	108	161	299	332	384	191	171	223
NO ₃ ⁻	336	451	884	845	948	548	394	497
SO ₄ ²⁻	769	882	2237	2076	3086	1469	1193	2204
Anions	1243	1521	3536	3344	4524	2293	1823	3003
Anion deficit	33	123	-60	219	424	-93	96	301
Total inorganic N	638	956	1469	1437	1720	831	481	764
Σ Na, K, Mg, Ca	309	398	1335	1484	1792	1026	1085	1393

compounds. Ammonia deposition increased by 203 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ and nitrate by 115 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$.

TF water flux measured in the „Original“ forest followed the same pattern, i.e. it was 18% higher in 1995–1996 relative to 1993–1994. Mass fluxes, however, did not follow the same pattern as in BD. None of the fluxes, with the exception of potassium, increased comparably to the water flux. Potassium flux increased from 345 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ to 473 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$. For some compounds, namely fluoride, a decrease in deposition in 1995–1996 relative to 1993–1994 was recorded. Fluoride decreased from 116 to 91 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$, e.g. by 25 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$.

Water interception in 1995–1996 (372 $\text{mm} \cdot \text{year}^{-1}$) increased from the 1993–1994 value (242 $\text{mm} \cdot \text{year}^{-1}$). Interception ratio (TF/BD water flux expressed in per cent) was close, 71 and 65, respectively in 1993–1994 and 1995–1996. Precipitation pass through the canopies resulted in the loss of water, but also in an increase of the mass fluxes of most substances (net release, positive net removal). The amount of released substances in 1995–1996 was far lower than in 1993–1994, most notably for NH₄⁺ (1993–1994 NR was 284 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$, 1995–1996 – 87 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$, i.e. decrease down to 31% of the 1993–1994 value), but also Al, NO₃⁻, F⁻, SO₄²⁻ (60, 72, 76 and 81% of 1993–1994 fluxes of respective compounds).

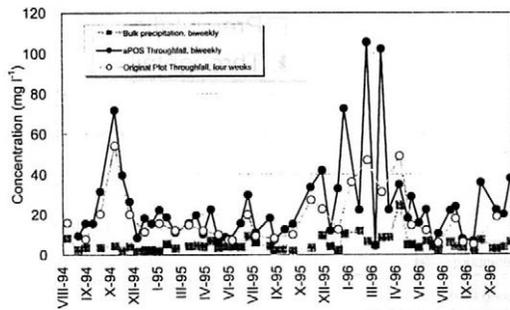
More comprehensible data on inter-annual changes in bulk deposition, throughfall flux and net removal in the „Original“ plot since 1992 are presented in Tab. II for sulphur, nitrogen and hydrogen ion.

Data from the „aPOS“ stand cover only the 1995–1996 period, so assessment of trends is impossible. Water interception in this stand in the 1995–1996 period was close to the „Original“ stand (72%), but mass fluxes in TF and NR were higher in the „aPOS“ stand. The most remarkable difference between the two stands was in the case of ammonia flux: 1995–1996 NR flux at the „aPOS“ plot (267 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$) was three times the value at the „Original“ plot (87 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$), but almost the same as 1993–1994 value at the „Original“ (284 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$). This shows large change in ammonia cycling at the „Original“ site. Sulphur NR in the „aPOS“ stand amounted to 185% of the value encountered at the „Original“ stand (2204 vs. 1193 $\text{mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ for the „aPOS“ and „Original“ sites, respectively).

Results from the „Original“ plot can be compared also with published results from the first observational year (April 1991 to March 1992, Černý, 1993a). Even if the water input in both periods was about the same (671 and 702 mm), TF of most substances decreased in 1995–1996 relative to 1991–1992. For instance, sulphur TF flux decreased from 47.4 $\text{kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ to 33.3 $\text{kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$, total inorganic nitrogen from 23.9 to 20.1 $\text{kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$. Increases were observed for potassium, manganese and zinc (K increased from 14.0 to 18.5 $\text{kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$). In the case of zinc, concentrations all year round are close to the detection limit of the method used, so increase in TF flux might be the result of a sampling artifact. Potassium and manganese, however, originate from the canopies and their enhanced

II. 5-year data on sulphur, nitrogen and hydrogen ion at Načetín „Original“ site. Data for ammonia – N, nitrate – N, total inorganic nitrogen [(NH₄⁺-N) + (NO₃⁻-N)], sulphate-S and hydrogen ion are given both in kg.ha⁻¹.year⁻¹ and in kmol_e.ha⁻¹.year⁻¹, water flux is in mm.year⁻¹

		Water (mm.year ⁻¹)	NH ₄ ⁺ -N (kg.ha ⁻¹ .year ⁻¹) (kmol _e .ha ⁻¹ .year ⁻¹)		NO ₃ ⁻ -N (kg.ha ⁻¹ .year ⁻¹) (kmol _e .ha ⁻¹ .year ⁻¹)		Inorganic N (kg.ha ⁻¹ .year ⁻¹) (kmol _e .ha ⁻¹ .year ⁻¹)		SO ₄ ²⁻ -S (kg.ha ⁻¹ .year ⁻¹) (kmol _e .ha ⁻¹ .year ⁻¹)		H ⁺ (kmol _e .ha ⁻¹ .year ⁻¹)
Bulk	1992	887.52	5.78	0.41	4.86	0.35	10.63	0.76	13.17	0.82	0.46
	1993	754.53	4.29	0.31	4.26	0.30	8.55	0.61	10.80	0.67	0.44
	1994	920.90	4.15	0.30	5.16	0.37	9.31	0.66	13.84	0.86	0.69
	1995	1291.74	6.95	0.50	6.61	0.47	13.55	0.97	15.24	0.95	0.68
	1996	856.65	7.19	0.51	6.03	0.43	13.22	0.94	13.05	0.81	0.55
Throughfall	1992	824.18	12.17	0.87	17.04	1.22	29.21	2.09	52.14	3.25	1.89
	1993	578.73	9.13	0.65	12.44	0.89	21.56	1.54	38.07	2.37	1.25
	1994	612.04	7.26	0.52	12.32	0.88	19.58	1.40	33.66	2.10	1.26
	1995	765.37	7.69	0.55	11.05	0.79	18.74	1.34	31.34	1.95	1.22
	1996	638.13	8.90	0.64	12.62	0.90	21.51	1.54	35.21	2.20	1.23
Net removal	1992	-63.34	6.40	0.46	12.18	0.87	18.58	1.33	38.97	2.43	1.43
	1993	-175.81	4.83	0.34	8.18	0.58	13.01	0.93	27.27	1.70	0.81
	1994	-308.86	3.11	0.22	7.16	0.51	10.28	0.73	19.82	1.24	0.57
	1995	-526.37	0.74	0.05	4.44	0.32	5.18	0.37	16.10	1.00	0.54
	1996	-218.52	1.71	0.12	6.59	0.47	8.30	0.59	22.15	1.38	0.68



2. Sulphate concentrations in throughfall as measured at two adjacent plots at Načetín. Both „aPOS“ (solid circles) and „Original“ (open circles) data are volume weighted averages calculated from five composite samples (see Methods section). Bulk precipitation concentrations (squares) are shown for comparison. Units: mg.l⁻¹

leaching rates can mark increased deterioration of the canopies.

Fig. 2 illustrates time series of sulphate concentrations in TF as encountered at Načetín sites, „aPOS“ and „Original“. High concentrations encountered on the „aPOS“ plot in winter 1995/1996 were associated with the formation of rime [see Tab. III, where the highest observed TF concentration („Extreme“) is compared with the two-year volume weighted average concentration of TF]. Extremely high concentrations were associated with small water amounts. Consequently, ex-

treme nature of the event was registered only in the „aPOS“ plot samples, collected biweekly. The „Original“ plot samples represent four week periods and high concentrations encountered in the rime episode were inadvertently offset by further less mineralized precipitation events during the collection period. Higher sampling frequency (2-weeks) was decisively superior to 4-week sampling scheme when assessing the extreme conditions to which spruce needles were exposed is of interest.

Finally, the results from Načetín are compared in Fig. 3 with the results from Lower Saxony (Lux, 1995), Jezeří (Růžička, 1991) and number of other European and North American sites (references are given in the caption to Fig. 3).

DISCUSSION

Sulphur BD was stable over the five year period (1992–1996, Tab. II) averaging 13.2 kg S.ha⁻¹.year⁻¹. TF flux in the same period averaged 38.08 kg S.ha⁻¹.year⁻¹. Four years of observation exhibited a rapid decline in TF flux; this trend was however reversed in 1996 when TF flux was 35.2 kg S.ha⁻¹.year⁻¹. Although higher than in preceding years, this value is less than half of the value of 77 kg S.ha⁻¹.year⁻¹ reported by Raben (this volume) for spruce at the Olbernhau research site in Germany, ca. 10 km from the Načetín site. NR decreased in the first four years from

III. Extreme chemical composition of throughfall (mostly rime) collected in the period 13. II. 1996–29. II. 1996 (denoted as „Extreme“) compared to the volume weighted average composition of throughfall at Načetín „aPOS“ plot (denoted as „Mean“, all sample collections from the period 8. VIII. 1994–26. XI. 1996)

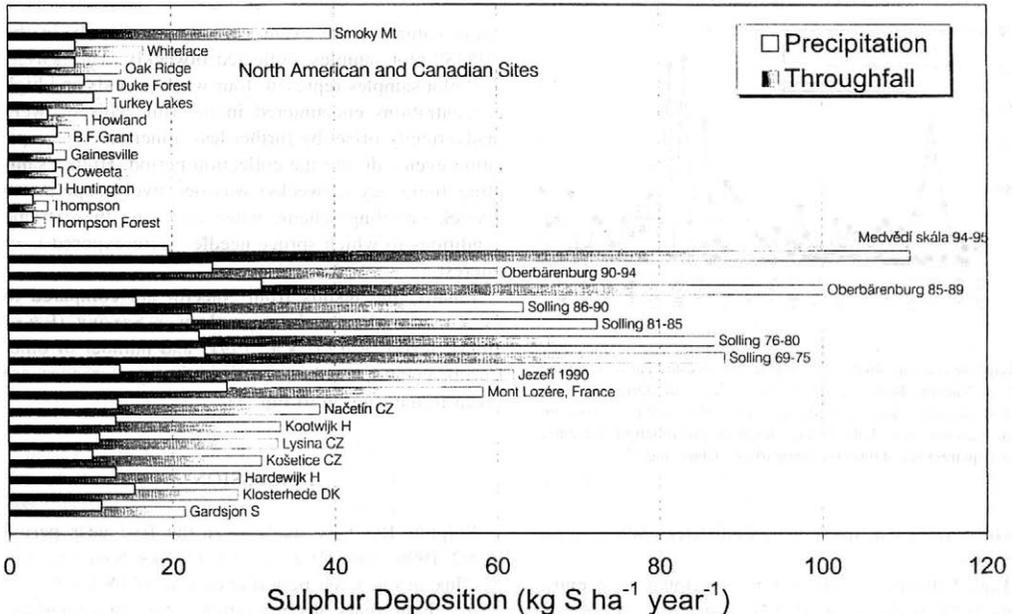
Compound	Units	Extreme	Mean
Na ⁺	(mg.l ⁻¹)	1.87	0.83
K ⁺	(mg.l ⁻¹)	13.91	3.26
NH ₄ ⁺ -A	(mg.l ⁻¹)	9.42	1.40
Mg ²⁺	(mg.l ⁻¹)	1.22	0.35
Ca ²⁺	(mg.l ⁻¹)	6.22	1.94
Sr ²⁺	(μg.l ⁻¹)	32	8
Mn ²⁺	(μg.l ⁻¹)	591	178
Zn ²⁺	(μg.l ⁻¹)	705	67
Fe ³⁺	(μg.l ⁻¹)	861	157
Al ³⁺	(μg.l ⁻¹)	1922	414
F ⁻	(mg.l ⁻¹)	1.81	0.27
Cl ⁻	(mg.l ⁻¹)	4.33	1.83
NO ₃ ⁻ -N	(mg.l ⁻¹)	8.27	1.78
Inorganic N	(mg.l ⁻¹)	17.68	3.18
SO ₄ ²⁻ -S	(mg.l ⁻¹)	35.23	6.57
SiO ₂	(mg.l ⁻¹)	0.42	0.35
H ⁺	(μmol.l ⁻¹)	1440	253
pH	(units)	2.84	3.60

39.0 kg.ha⁻¹.year⁻¹ (in 1992) to 16.1 kg S.ha⁻¹.year⁻¹ (in 1995), but this trend was also reversed into slight increase to 22.2 kg S.ha⁻¹.year⁻¹ in 1996.

Nitrogen compounds deposition increased in bulk deposition, but decreased in throughfall and net removal. Nitrogen deposition in BD in period 1995–1996 was 25% higher than in 1992. Conversely, NR was 28% and 45% of the 1992 NR flux (in 1995 and 1996, respectively). Nitrogen TF flux at Načetín was (as well as the one for sulphur) less than half of the value measured by Rabeň (this volume) (21.5 and 47 kg N.ha⁻¹.year⁻¹ at Načetín and Olbernhau, respectively).

Comparison of two two-year periods (Tab. I), i.e. hydrological years 1993–1994 and 1995–1996, reveals that in spite of the increased BD input of water and all substances (except fluoride) in the 1995–1996 period, throughfall and net removal at Načetín site decreased in the same time period. In addition, „aPOS“ throughfall fluxes exceed those reported from the „Original“ plot.

The only element in TF for which mass flux increased was potassium. Its increase in the 1995–1996 period includes major release after the severe foliar injury from winter 1995/1996, when combination of low temperatures and rime with high concentration of chemicals such as fluoride, sulphate and nitrate (see Tab. III, „Extreme“) destroyed needles in the stand, resulting in large defoliation and increase in the litterfall.



3. Comparison of sulphate bulk deposition and throughfall fluxes with literature data. Sources of data: Gardsjon – Hultberg, Grennfelt, 1992; Klosterhede DK – Rasmussen, 1990; Hardewijk H – Rasmussen, 1990; Košetice CZ – Pačt, 1992; Lysina CZ – Hruška, Krám, 1992; Kootwijk H – Rasmussen, 1990; Načetín CZ, 1992–1996 – this paper; Mont Lozère, France – Durand et al., 1992; Jezeff 1990 – Růžička, 1991; Solling 69–75 – Matzner, Meiwes, 1994; Solling 76–80 – Matzner, Meiwes, 1994; Solling 81–85 – Matzner, Meiwes, 1994; Solling 86–90 – Matzner, Meiwes, 1994; Oberbärenburg 85–89 – Lux, 1995; Oberbärenburg 90–94 – Lux, 1995; Medvědí skála 94–95 – Havel et al., 1996; all American and Canadian sites – Lindberg, Lovett, 1992. Units are kg S.ha⁻¹.year⁻¹

Throughfall fluxes at Načetín are rather low, considering the pollution climate of the site and its proximity to the sources of both gaseous and particle pollution. There are many sites outside the Ore Mts. region with far lower air pollution levels (e.g. Solling) or in the Ore Mts. region, but in the better state of the forest (e.g. Oberbärenburg, Olbernhau) which report far higher throughfall rates than Načetín (see Fig. 3).

Part of the difference may be due to local exposure of the stand under the study. Importance of local exposure of the stands is clearly demonstrated in Fig. 3 by Medvědí skála throughfall of 126 kg S.ha⁻¹.year⁻¹ recorded in 1994 (Havel et al., 1996). High flux of sulphur (and other compounds) at this site is due to the combination of two factors promoting horizontal deposition to the stand: young dense forest is located on a windy mountain top (862 m a.s.l.). TF flux of other compounds was high as well (31.0 kg total inorganic nitrogen ha⁻¹.year⁻¹ and 9.0 kg F.ha⁻¹.year⁻¹).

At the Načetín „Original“ site TF of sulphur over the 1992–1996 period averaged 38.1 kg S.ha⁻¹.year⁻¹ (range 31–52 kg S.ha⁻¹.year⁻¹; 65%). Hydrogen ion TF flux was 1.37 (1.2–1.9 kmol H⁺.ha⁻¹.year⁻¹; 59%) and total inorganic nitrogen flux 22.1 (19–29 kg N.ha⁻¹.year⁻¹; 50%). Percentages shown in the brackets are the proportion of net removal to throughfall flux. Assuming that net removal for above listed compounds equals to dry deposition, these percentages show the relative importance of dry deposition to total deposition.

At Načetín, far higher TF values were collected in the same spruce stand as reported in this paper („Original“) using three troughs situated under the most vigorous tree (Černý, 1993b). Sulphur throughfall flux under this single tree in the period April 1991 to March 1992 was 114 kg S.ha⁻¹.year⁻¹, hydrogen ion 3.9 kmol H⁺.ha⁻¹.year⁻¹, and total nitrogen flux 52.9 kg N.ha⁻¹.year⁻¹. These values from troughs are in good agreement with values reported from Lower Saxony (Lux, 1995; Raben, this volume), but at the same time exceed the values collected in the sampling network of 25 funnels, such as reported in this paper by more than a factor of 2.

It was previously shown (Černý, 1993b) that a large difference exists between results collected at the same site using troughs and a network of twenty-five samplers. Damaged forests are inhomogeneous and consist both of heavily damaged trees (with reduced canopy and decreased potential for collection of dry deposition) and of relatively healthy trees, still capable of effective scavenging of pollutants. Therefore, large differences may be encountered at the same site just through using differently placed collectors or changing the sampling design. At Načetín we have however obtained quite different results using the same sampling design (net removal of sulphur was 2204 and 1193 mol_c.ha⁻¹.year⁻¹ for the „aPOS“ and „Original“ site, respectively, in the same period). This difference has to be purely a result of the different properties of the „aPOS“ and „Original“ sites, as exposure to air pollu-

tion at the two sites is the same (the plots are 200 m apart on a gently sloping terrain). The most prominent difference between the stand is higher deterioration of the „Original“ site, resulting also in decreased values of the Leaf Area Index („aPOS“ – 5.37, „Original“ – 3.56; averages of five measuring campaigns after Pokorný, Opluštilová, this volume).

Vanishing crowns are therefore considered the most decisive factor for the observed low throughfall fluxes even in polluted environment. Remarkably different values gained at a single site as well as similarity of network values to the values gained in a pristine area point to difficulties with application of throughfall measurements for estimation of total atmospheric deposition. Results are sensitive to differences in collection devices, sampling protocols, biometrics characteristics of the forest, i.e., its age, density, biomass, leaf area index (LAI), etc. This observation is crucial for regional (such as European – Ivens et al., 1990) comparisons based on throughfall fluxes. Our data indicate that in seriously damaged areas such as those found in the Black Triangle Region, where throughfall fluxes should be (at least for sulphur) at their maximum, large differences between sites and/or stands may be found reflecting large deterioration of the forest canopies at some sites, contrasting to less damaged sites with high capacity to capture dry deposition and consequently high influx of the acidifying compounds.

In spite of these problems, low throughfall fluxes measured at Načetín and other sites in the Ore Mts. (Havel et al., 1996), as well as extremely high value registered at Medvědí skála (ibid.) in the Jezeří catchment may be relevant for our understanding of the processes in the ecosystems of the Ore Mts. In this area proximity to the emission sources leads to increased importance of dry deposition. Forest canopies play an important role in this mechanism. Extreme air pollution led to large-scale defoliation and forest die-back over the last forty years (Kubelka et al., 1992). Remaining spruce stands, in which throughfall measurements were performed, are damaged and inefficient for scavenging of air pollutants (Načetín), unless they are extremely exposed and young (Medvědí skála).

Consequently, atmospheric deposition into the Ore Mts. significantly decreased in recent years. This trend has already started in the mid- 1970s, when catastrophic defoliation became apparent. Decreased atmospheric deposition is testified by observations of streamwater chemistry in the Jezeří catchment where a significant decrease in streamwater sulphate during the period 1978–1992 occurred (Černý, 1992, 1995).

Decreased sulphate concentrations are a consequence of reduced atmospheric deposition resulting from the forest die-back, defoliation and loss of forest cover. Future forest management strategies have either to rely on rapid decrease in the air pollution levels in the region or strongly prefer deciduous trees, where dry deposition does not play as important role as in coniferous stands (Matzner, Meiwes, 1994; Havel et al., 1996).

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SPAD SRÁŽKAMI VOLNÉ PLOCHY A PODKORUNOVÝMI SRÁŽKAMI V KRUŠNÝCH HORÁCH – KLESAJÍCÍ ATMOSFÉRICKÁ DEPOZICE V SMRKOVÝCH POROSTECH

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Monitorování podkorunových srážek ve smrkových porostech se používá ke stanovení velikosti suché depozice (Ivens et al., 1990). Suchá depozice a zvýšený tok látek v podkorunových srážkách může souviset se současným odumíráním jehličnatých porostů v Evropě. Předkládané výsledky měření podkorunových srážek byly získány v dospělém smrkovém porostu v Krušných horách, v jedné z nejvíce znečištěných oblastí Evropy. Dospělé porosty byly sledovány, protože právě v dospělých porostech byla zaznamenána převážná část poškození smrku v této oblasti (Kubelka et al., 1992).

Načetín (50°35' S, 13°15' V, 780 m n. m.) je smrkový (*Picea abies* L.) les v blízkosti německé hranice. Poškození je hodnoceno jako střední, tj. do 30 % stromů silně poškozených. Na lokalitě Načetín byly sledovány dva porosty – „původní“, stáří 102 let (oddělení 101B10) a „aPOS“, stáří 58 let (oddělení 101B6). Porost „aPOS“ byl v období VI/1994–X/1997 sledován pro potřeby projektu EU aPOS – *The Influence of Different Air Pollution Levels on the Degree of Forest Soil Acidification and Forest Stability*.

Srážky volné plochy se spadem (BD) byly odebírány na lesní mýtině jako 14denní kumulativní vzorek. Podkorunové srážky (TF) byly sbírány v síti 25 odběrůk uspořádaných v síti 5 x 5 s krokem 10 m. Vzorky byly odebírány s krokem čtyři týdny na „původní“ ploše, dva týdny na ploše „aPOS“. Pro obě plochy byl vypočten čistý odnos (NR) jako rozdíl mezi tokem chemických složek v podkorunových srážkách a srážkách volné plochy (TF minus BD), kde pozitivní hodnoty značí zdroj složky v korunách, negativní hodnoty značí spotřebu složky v korunách.

Průměrné iontové složení srážek volné plochy (BD), podkorunových srážek (TF) a čistého odnosu (NR) měřené na ploše Načetín jsou uvedeny na obr. 1. V kyselem roztoku převládá síranový iont (26–32 % celkového náboje), dále vodík (16–19 %) a dusičnan (10–14 %). Koncentrace Na^+ , Mg^{2+} , Ca^{2+} , Cl^- a F^- jsou nižší než 5 % celkového náboje. Organické sloučeniny jsou zastoupeny jen ve velmi malém množství. Zastoupení amoniaku, chloru a vápníku se velmi výrazně mění při průchodu srážek korunami: koncentrace amoniaku v podkorunových srážkách je nižší než ve srážkách, koncentrace draslíku a vápníku rostou.

Látkové toky ve srážkách, podkorunových srážkách i čistý odnos z korun v jednotkách $\text{mol}_e \cdot \text{ha}^{-1} \cdot \text{rok}^{-1}$ (moly náboje, obdoba dřívější jednotky ekvivalent) jsou uvedeny v tab. I jako průměry za dvouleté období, tj. období 1993–1994 a 1995–1996 (hydrologické roky).

Množství srážek volné plochy v období 1995–1996 bylo o 28 % vyšší než v období 1993–1994. Vstup všech látek srážkami (kromě fluoridů) byl vyšší v období 1995–1996. Rozdíl v látkovém toku fluoridů v obou obdobích byl velmi malý.

Množství podkorunových srážek sledovalo množství srážek volné plochy, ale látkové toky tomuto trendu neodpovídaly. S výjimkou látkového toku draslíku látkové toky v podkorunových srážkách nebyly vyšší ve srážkově bohatším období 1995–1996, naopak většinou poklesly, zejména v případě fluoridů.

Detailní údaje o změnách ve velikosti látkových toků ve srážkách, podkorunových srážkách a čistém odnosu měřené na „původní“ ploše jsou pro síru, dusík a vodíkový iont uvedeny v tab. II.

Na obr. 2 jsou zobrazeny časové řady koncentrace síranů v podkorunových srážkách na obou načetínských plochách. Vysoké koncentrace zastižené v zimě 1995/1996 na ploše „aPOS“ byly spojeny s tvorbou námrazy (viz tab. III, kde jsou srovnány tyto extrémně vysoké koncentrace s objemem váženými dvouletými průměrnými koncentracemi).

Data z Načetína jsou porovnávána na obr. 3 s hodnotami z Dolního Saska (L u x, 1995), Jezeří (R ů ž i č k a, 1991) a řady dalších evropských a severoamerických lokalit (odkazy jsou uvedeny v popisce).

Depozice síry ve srážkách volné plochy byly v období 1992–1996 stabilní (tab. II), v průměru $13,2 \text{ kg S} \cdot \text{ha}^{-1} \cdot \text{rok}^{-1}$. Tok síry v podkorunových srážkách ve stejném období byl $38,08 \text{ kg S} \cdot \text{ha}^{-1} \cdot \text{rok}^{-1}$. Hodnoty jednotlivých let nedosahují hodnoty $77 \text{ kg S} \cdot \text{ha}^{-1} \cdot \text{rok}^{-1}$, kterou uvádí R a b e n (v tomto čísle) pro smrkový porost na německé straně Krušných hor, 10 km od Načetína. Depozice sloučenin dusíku ve srážkách volné plochy vzrostla, mírně poklesl tok v podkorunových srážkách.

Toky látek (zejména síry) v podkorunových srážkách na lokalitě Načetín jsou relativně nízké, neodpovídají vysokému stupni znečištění ovzduší a blízkosti ke zdrojům emisí. Naopak je známa řada lokalit s mnohem nižším znečištěním ovzduší (Solling) dokonce i v Krušných horách, ale s lesem v lepším stavu (Oberbärenburg, Olbernhau), kde jsou měřeny látkové toky podstatně vyšší než na Načetíně (obr. 3).

Částečné vysvětlení nízkého látkového toku je chráněná pozice načetínského porostu. Na jiném, silně exponovaném místě (Medvědí skála – Havel et al., 1996), byl zastižen látkový tok síry v podkorunových srážkách $126 \text{ kg S} \cdot \text{ha}^{-1} \cdot \text{rok}^{-1}$.

Poškozené porosty jsou nehomogenní, silně poškozené stromy nezachycují škodliviny z atmosféry v ta-

kové míře jako stromy zdravé. V jednom porostu mohou proto existovat značné rozdíly mezi látkovými toky pod různě poškozenými stromy, zdravější stromy zachycují více a také látkový tok je zde větší. Ve stejném období byl čistý odnos síry ze zdravějšího porostu („aPOS“) téměř dvojnásobný než z poškozené „původní“ plochy.

Ztráta olistění korun je hlavním důvodem nízkých podkorunových látkových toků v silně znečištěném prostředí. Variabilita výsledků získaných na jedné lokalitě ukazuje na obtížnost použití podkorunových srážek ke stanovení celkové atmosférické depozice. Výsledky těchto měření jsou velmi závislé jednak na umístění odběráku, na vzorkovacím protokolu, jednak na biometrických parametrech porostu (např. věk, zakmenění, index listové plochy LAI). Toto pozorování je zásadní pro regionální (např. evropská – Ivens et al., 1990) srovnání podkorunových srážek. Naše výsledky naznačují, že v silně poškozených oblastech, jaké nacházíme v „černém trojúhelníku“, kde bychom očekávali maximální toky látek (zvláště síry) v podkorunových srážkách, nacházíme velmi proměnlivé hodnoty, které od-

rážejí různou intenzitou poškození listoví na jednotlivých lokalitách.

V důsledku extrémního a chronického znečištění ovzduší v oblasti Krušných hor je pozorované chřadnutí a odumírání porostů již déle než 40 let (Kubelka et al., 1992). Vzhledem k blízkosti zdrojů je mechanismus zachytu oxidu siřičitého dominantní pro celkovou atmosférickou depozici ve smrkových porostech. Poškozené stromy zachycují škodliviny méně efektivně (Načetiň), pokud nejsou na velmi exponovaných lokalitách (Medvědí skála). Celková atmosférická depozice v důsledku zhoršování stavu či odlesnění klesá. To je dokumentováno i studiem povrchového odtoku z povodí Jezeří, kde v období 1978–1992 významně poklesly koncentrace síranů, jejichž hlavním zdrojem je atmosférická depozice (Černý, 1992, 1995).

Další pěstování lesa v oblastech zasažených silným znečištěním ovzduší závisí buď na rychlém snížení koncentrací škodlivin v ovzduší, nebo se musí přeorientovat na listnaté druhy, o kterých je známo, že suchá depozice je v nich řádově nižší než v porostech jehličnatých (Matzner, Meiwes, 1994; Havel et al., 1996).

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SHORT- AND LONG- TERM PULSES OF ACIDIFICATION IN FOREST ECOSYSTEMS OF SAXONY (GERMANY)

KRÁTKODOBÉ A DLOUHODOBÉ VÝKYVY V ACIDIFIKACI LESNÍCH EKOSYSTÉMŮ SASKA (SRN)

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ABSTRACT: With the German reunion in 1989 a strong reduction in industrial emissions occurred in the former GDR. However, the acidity in precipitation is still very high. Since 1993 the Saxon State Institute for Forestry (LAF) monitors the element budgets at 6 different forest ecosystems within the scope of the European Level II Programme. The aim of the programme is to get regional informations of ecological risks for forest ecosystems and to achieve recommendations for forest management. Base cation deposition, concentrations of Ca and K as well as pH in soil solution of subsoils have decreased, while large amounts of previously stored sulphur and pedogenic aluminium are released from the soil matrix. This gives rise to concern about an increasing risk for root damages, nutritional imbalances and thus decreasing elasticity of forest ecosystems.

precipitation; throughfall; soil solution; acidification; forest ecosystems

ABSTRAKT: Po sjednocení Německa v roce 1989 došlo v bývalé NDR k výraznému snížení průmyslových emisí. Kyselost srážkové vody je však stále velmi vysoká. Od roku 1993 Státní lesnický ústav v Sasku (LAF) sleduje v rámci evropského programu ICP Forests – úroveň II koloběh prvků v šesti různých lesních ekosystémech. Cílem tohoto programu je získat regionální informace o ekologickém ohrožení lesních ekosystémů a vypracovat doporučení pro lesní hospodářství. Depozice bazických kationtů, koncentrace Ca a K a pH půdního roztoku se snižují, naproti tomu se z půdy uvolňuje značné množství dřívě nakumulované síry a hliníku. To zvyšuje zájem o stoupající nebezpečí poškození kořenů, poruchy výživy, s čímž souvisí snížená elasticita lesních ekosystémů.

srážky; podkorunové srážky; půdní roztok; acidifikace; lesní ekosystémy

INTRODUCTION

Since the beginning of industrialisation 150 years ago, especially the forests in Saxony experience different kinds of immission, mostly sulphur, heavy metals and base cations from industrial sources and nitrogen from agricultural activities as well as mobile sources (traffic). In the beginning the SO₂-immission („Rauchgas“) lead to severe damages in the vicinity of strong point sources resulting from the exceedance of high SO₂-concentrations (critical levels) on a local scale (Schröter, 1907; Stöckhardt, 1853). Since the end of the 1970s a new type of forest decline („neuartige Waldschäden“) was detected. It is related to needle yellowing (magnesium deficiency) and needle losses on a regional scale due to long-range transport and high loads of acidifying and eutrophating substances (critical loads) (UBA, 1996; Ulrich, 1993).

Despite of strong reductions in industrial emissions between 1989 and 1992, however, the acidity in rain water increased, due to the unbalanced decrease in acidifying sulphur dioxide and alkaline dusts (Marquardt, 1996). The fluxes of SO₄ in precipitation

were lowered to 50% (Ca-fluxes to about 20%) of the reference values (BMBF, 1996). On the other hand it should be noted, that the concentration of NO_x increased about 30% (Marquardt, 1996).

MATERIAL AND METHODS

Six permanent survey plots of 0.25–0.50 ha in size are situated in typical forest stands of Norway Spruce (plots 1–4), Scots Pine (plot 6) and Oak (plot 5; Fig. 1). The investigations are carried out according to the UN/ECE ICP Forests Manual (PCCs, 1994). Bulk precipitation and throughfall are collected weekly with 6(15) polyethylene funnels, stored at 4 °C and analysed monthly. Soil solution is continuously collected using ceramic suction cups with 3 replicates per depth at 20, 60 and 100 cm below soil surface and sampled twice a month. Analyses are carried out by the laboratory of the LAF. Quality assurance is achieved through participation in federal and European intercalibration programmes. For calculation of total deposition and internal element fluxes the canopy budget model described

Germany



1. Network of permanent monitoring plots in Saxony (European Level II Programme)

by Ulrich (1991) is used. The estimation of output fluxes was carried out on an annual basis applying the Turc equation (Turc, 1954).

RESULTS AND DISCUSSION

Throughfall: pH and concentrations of sulphate and nitrate; throughfall fluxes

Although a significant reduction of pollutant emission is reported for the eastern part of Germany after the reunion the acidity of precipitation is still very high (Marquardt, 1996; BMBF, 1996). During winter 1995/1996 the pH in throughfall dropped to 2.7 (Fig. 2), parallel to high concentrations of SO_4 and NO_3 (Fig. 3). This holds true especially for plot Olbernhau in the Central Ore Mountains. In combination with periods of strong frost heavy damages in spruce stands on about 50,000 hectares and a dieback on 3000 hectares have occurred (Raben et al., 1996; SML, 1996).

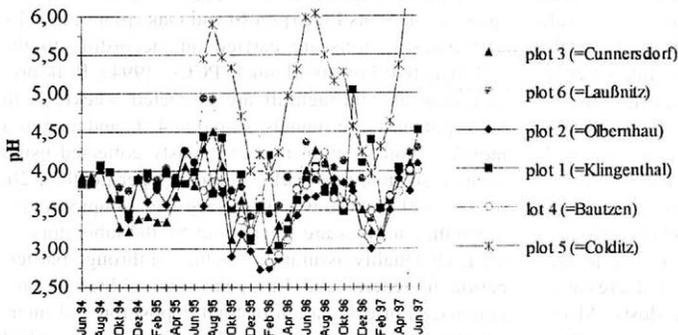
The throughfall flux of sulphur ($\text{SO}_4\text{-S}$) in the hydrological year 1996 (XI/95-X/96) was at Olbernhau $77 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$, Klingenthal $38 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$, and Cunnersdorf $44 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ (Fig. 4); the values are more than twice as high as in bulk deposition. Total

nitrogen input with throughfall sums up to $47 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ in Olbernhau (plot 2) while Klingenthal received $23 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$. It is nearly divided equal into $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$. Input of free acidity (H^+) in Olbernhau (plot 2) was $4.0 \text{ kg}\cdot\text{ha}^{-1}$ and $2.5 \text{ kg}\cdot\text{ha}^{-1}$ in Klingenthal (plot 1).

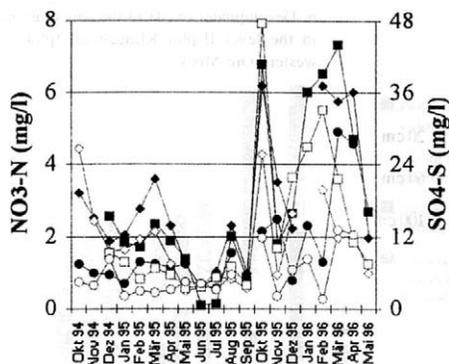
Canopy budgets indicate high rates of K-leaching by the needles. Thus, most of the potassium is part of the internal element cycle; calcium shows very similar patterns.

Soil acidification in Saxony

Like the 68 Saxonian plots of the Federal Forest Soil Condition Survey (BZE, $8 \times 8 \text{ km}$ -grid) the pH-values of soils at the level II – plots show very clear the dominance of the aluminium – (pH: 3.8–4.2) and aluminium/iron-buffer-range (pH: 3.0–3.8) in forested areas of Saxony (Fig. 5). This degree of acidification is caused by the atmospheric deposition of strong acids which is linked to the input of mobile anions like SO_4^{2-} and NO_3^- . The base saturation, which is accepted as a parameter to calculate the soil elasticity (resistivity) against acid deposition and toxic effects in the soil solution, is low. Soils developed on gneiss, phyllite,



2. Development of pH in throughfall on Saxonian level II-plots

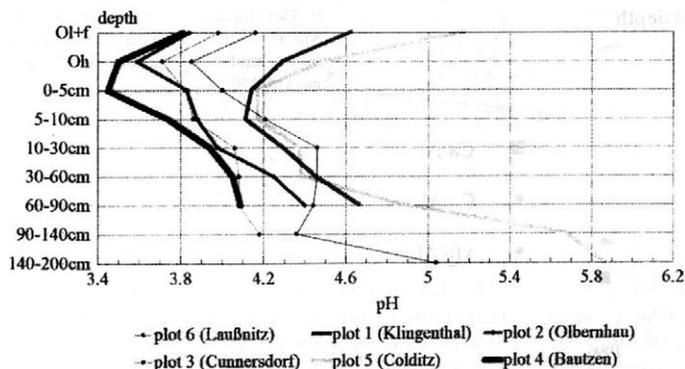


3. Concentrations of $\text{NO}_3\text{-N}$ and $\text{SO}_4\text{-S}$ in throughfall on Saxonian level II-plots

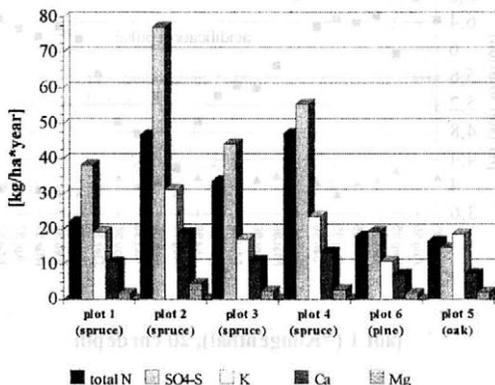
schists, granite and sandstone exhibit a base saturation lower than 15% in most cases. Only exceptionally higher values, up to 40% and more, are detected in subsoils developed on loess below 450 m a.s.l.

Soil solution: pH and chemical stress parameters

pH and concentrations of Ca and K were decreasing since the beginning of the investigations in July 1993 for example at plot 1 (Klingenthal; western Ore Mts.; Fig. 6) while the concentrations of $\text{SO}_4\text{-S}$ and Al remain high. Because of a very similar chemical situation (Al-buffer range, low base saturation and high loads of acidity) in many forest soils in Saxony it can be assumed, that this development is representative for actual chemical reactions in the soils. The long-term acidification process can be accelerated by acidification pulses (Figs. 6, 7). At Klingenthal they are related to heavy rainfall events which are often strongly acidified because of high atmospheric pollution concentrations (mostly from south-eastern directions) at the beginning of the heating period in October/November. Stress parameters in the soil solution (molar ratios of Ca/H, Ca/Al and Mg/Al) often have decreased (Figs. 8, 9), indicating high risk of root damages and further acidification of groundwater.



throughfall (11/95 - 10/96)

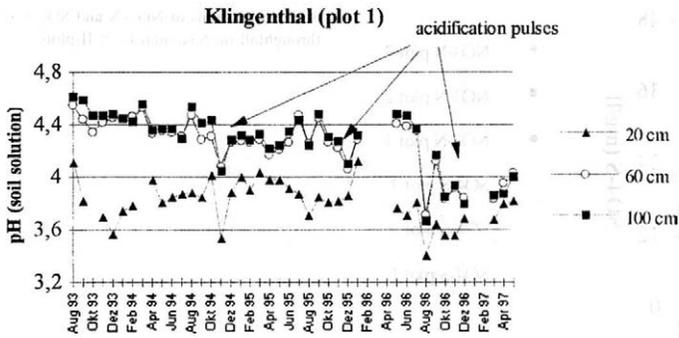


4. Input of elements with throughfall on Saxonian level II-plots (XI/1995-X/1996)

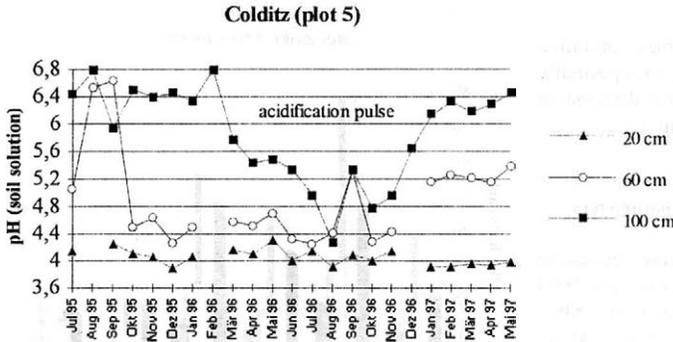
Output with seepage water, acidic load and trends of S- and N-input

The estimated mean values (1994 and 1995) of annual output fluxes of $\text{SO}_4\text{-S}$ at 100 cm depth are approximately $200 \text{ kg}\cdot\text{ha}^{-1}$ at Cunnersdorf (solution-pH 4.4-3.9) and $90 \text{ kg}\cdot\text{ha}^{-1}$ at Klingenthal (pH 4.7- 4.2). Thus, according

5. Vertical gradients of $\text{pH}(\text{H}_2\text{O})$ in the humus and mineral soil layers on Saxonian level II-plots

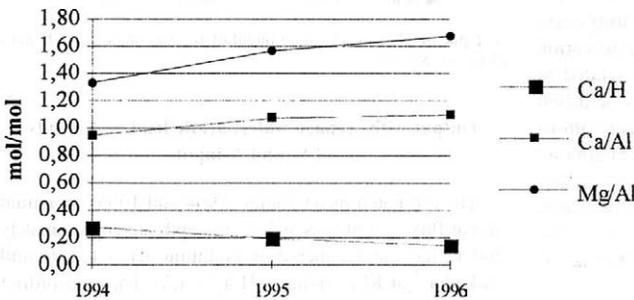


6. Development of pH in the soil solution in the level II-plot Klingenthal (plot 1; western Ore Mts.)



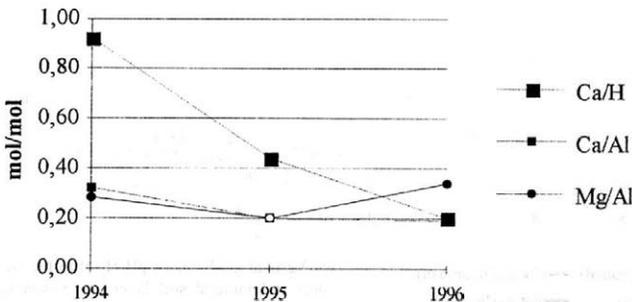
7. Development of pH in the soil solution in the level II-plot Colditz (plot 5)

plot 1 (=Klingenthal), 20 cm depth



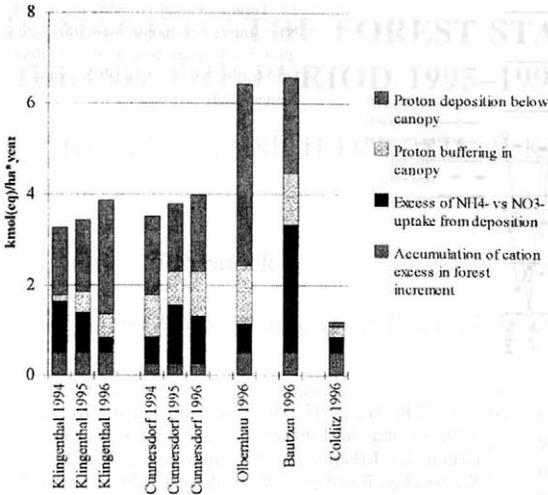
8. Development of Ca/H-, Ca/Al- and Mg/Al-molar ratios in the soil solution in 20 cm depth at Klingenthal (plot 1, western Ore Mts.)

plot 1 (=Klingenthal), 60 cm depth

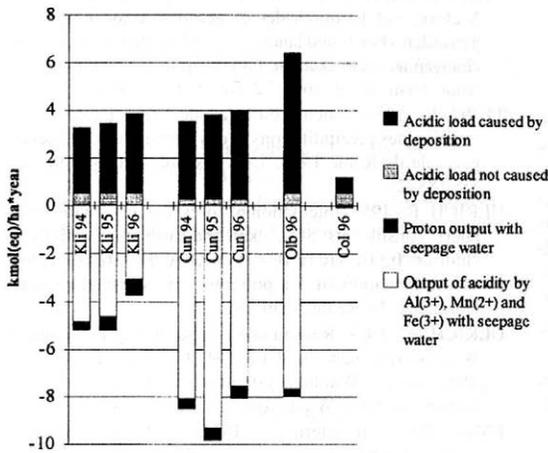


9. Development of Ca/H-, Ca/Al- and Mg/Al-molar ratios in the soil solution in 60 cm depth at Klingenthal (plot 1, western Ore Mts.)

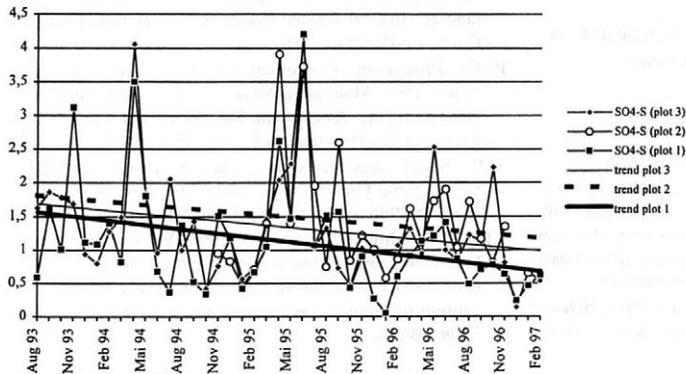
10. Annual rates of ecosystem internal proton production and total proton load of the forest ecosystems on Saxonian level II-plots



11. Input-output balances of acidity on Saxonian level II-plots

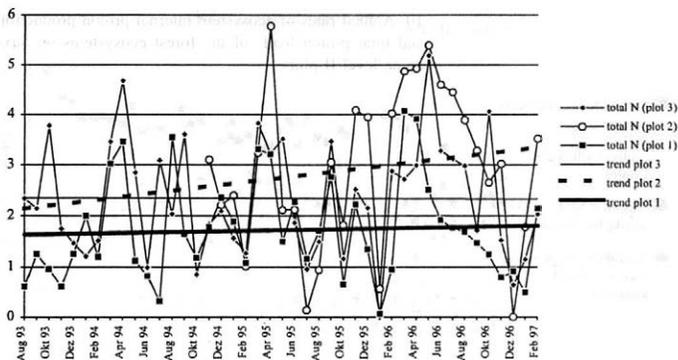


12. Trends of SO₄-S - input per month with bulk precipitation [plot 3 = Cunnersdorf; plot 2 = Olbernhau (only XI/1994-II/1997); plot 1 = Klingenthal]



to the principle of electroneutrality of solutions, the output of cations was also high, dominated by aluminium. The high fluxes of sulphur with seepage water indicate that the process of chemical S-release dominates the actual soil solution. This dissolution of aluminium sul-

phates represents the mobilization of a former input of H₂SO₄, that was previously stored in the soil solid phase. In addition the Al-output with seepage water and is still high [73 kg_{ha}⁻¹.year⁻¹ in Cunnersdorf (plot 3) and 41 kg_{ha}⁻¹.year⁻¹ in Klingenthal (plot 1)] because of



13. Trends of total N (=NO₃-N + NH₄-N) - input per month with throughfall [plot 3 = Cunnersdorf; plot 2 = Olbernhau (only XI/1994-II/1997); plot 1 = Klingenthal]

the increasing solubility of Al-hydroxy-compounds in the aluminium-buffer-range (SML, 1996). Therefore the acidic load of forest ecosystems in Saxony is still very high (Figs. 10, 11), although the input of sulphur seems to decrease (Fig. 12) while nitrogen input remains on a high level (Fig. 13).

CONCLUSIONS

Contrary to most expectations ecochemical stress in many Saxonian forest ecosystems was increasing since the German reunification - especially in the Ore Mts. - despite reduced SO₂-emissions and decreasing SO₄-fluxes into forests. Acidity in deposition regional has increased and acidification processes have been accelerated in forest soils within the last years. Elasticity of forest ecosystems often is decreasing and negative effects on quality of ground and surface water can be predicted. The emission of acidifying substances is a persistent problem. They still have to be reduced across the borders while the nutrient status of forest soils in Saxony mostly has to be improved.

Acknowledgements

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DAMAGE OF THE FOREST STANDS IN THE ORE MTS. DURING THE PERIOD 1995–1997

POŠKOZENÍ LESNÍCH POROSTŮ V KRUŠNÝCH HORÁCH V LETECH 1995–1997

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ABSTRACT: The aim of this contribution is to explain causes of damage of spruce and birch stands in the Ore Mts. after winters 1995/1996 and 1996/1997. The evaluation was done on sample plots in the damaged area. Meteorological factors, air pollution, and content of load elements in needles were analysed. The health state – defoliation and needle cast – of spruce and birch stands were evaluated as well. The results show that the stand damage was caused by combination of weather and air pollution factors. Spruce was impacted by long-term influence of the stress factors connected with low temperatures, hard rime, and high SO₂ concentrations. The triggering factor of birch damage might have been the warm period during February and March 1997, followed by frosts.

the Ore Mts.; winter damage; Norway spruce; birch; air pollution; meteorological factors

ABSTRAKT: Příspěvek se zabývá příčinami poškození smrkových a březových porostů v Krušných horách po zimách 1995/1996 a 1996/1997. Byly analyzovány meteorologické faktory, znečištění ovzduší a obsah zátěžových prvků v asimilačních orgánech. Na výzkumných plochách byla rovněž hodnocena defoliace smrkových a březových porostů. Výsledky ukazují, že poškození bylo způsobeno kombinací povětrnostních a imisních faktorů. Smrk byl postižen dlouhodobým působením vysokých koncentrací SO₂ spojeným s vlivem nízkých teplot a námrazy. Jako pravděpodobný spouštěcí faktor poškození břízy se jeví teplá perioda během února a března 1997, následovaná mrazy.

Krušné hory; zimní poškození; smrk; břiza; imise; meteorologické faktory

INTRODUCTION

The Ore Mts. are characterized by specific meteorological as well as air pollution and climatic conditions. This difference is caused, above all, by typical orography of the mountain range. The main ridge is situated from the south-west to north-east, it means across to direction of prevailing frontal systems coming from north-west and west. The mountain relief, gradually elevating from the German side, forms a wide and elongated ridge going up to the height 800–1000 m and suddenly falls down to the Podkrušnohoří basin. The ridge locations have always been characterized by hard rime occurrence. Significant damage caused by hard rime can be observed especially under the conditions of eastern flows, when a warm and humid air from the basin is quickly moved up to the localities situated several hundred meters higher where vapour desublimates on obstacles (Singer, 1916; Döbele, 1938).

The first signs of pollution damage began to occur approximately 50 years ago; later they resulted in extensive ecological disaster and vast forests damage on the plot of more than 40,000 ha. In the 60s and 70s, the spruce stands were cut down on large areas. The results

of deforestation in the Ore Mts. was an extreme situation which had to be solved promptly. The dead original forest stands were substituted by more resistant native tree species represented by birch, alder, aspen, rowan, sycamore maple, beech, dwarf pine and by introduced wooden species, like blue spruce, black spruce, Balkan pine and lodgepole pine. In the late 70s and early 80s the pollution load of the Ore Mts. by sulphur dioxide has culminated. Due to desulphurization of large pollution sources and reduction of industrial production, the emissions have decreased in the late 80s and early 90s (Kubelka et al., 1992). Concentrations of SO₂, depositions of hydrogen ions and sulphates have decreased significantly (Lochman, 1996).

As the development of substitute stands was positive and the health state of surviving spruce has improved (Lomský, 1995), the situation in the Ore Mts., with respect to pollution, was apparently stabilized. Next research activities should have been focused on the reconstruction of substitute forest stands using genetically suitable material of target tree species (Uhül, 1994). Pollution impact, including indirect influence through stand nutrition, did not seem to be of principal importance.

In spite of decrease of emitted SO_2 , the proportion of other pollutants started to rise in the Ore Mts. It was mainly fluorine (L o m s k ý, P a s u t h o v á, 1996) that was emitted by power plants burning brown coal, situated in the basin area (Tušimice, Prunčřov, Počerady and Ledvice) as well as by glass and china factories (Kláštřec nad Ohřĩ, Dubĩ, etc.). Development of motor-car traffic also contributes to the increase of nitrogen oxides content in the air. Nitrogen oxides are the precursors of ozone rise which begins to hit forest stands in the ridge parts of the Ore Mts. Chemical industry in the region is still the main source of organic matter emissions.

Moreover, it has been proved in recent years, that even at low emission level the pollution can accumulate under certain meteorological conditions. New discussions on the Ore Mts. have started after an extensive damage of spruce stands following winter 1996/1997, and dieback of substitute birch stands in winter 1996/1997. This contribution presents evaluation of abiotic stress factors causing the damage.

METHODS

METEOROLOGICAL FACTORS

Meteorological factors were evaluated on the basis of data bought from the Czech Hydrometeorological Institute (CHMI). The station of Měděnec (900 m a.s.l.), characterizing conditions of ridge locations of the eastern part of the Ore Mts., was chosen as the most suitable one. The average daily temperature, minimal temperature, hard rime occurrence, and wind direction were evaluated for the investigated winter periods. The course of meteorological factors from February to June 1997, when birch stands were damaged on large area, is being compared with the situation in 1996 and 1995. Average, minimal, and maximal temperature were evaluated, as well as day-degrees [(cumulative sum of average daily temperatures overlapping 5 °C ($E > 5$)), which are used in phenological models to determine the flushing period (K r a m e r, 1996); since April cumulative sums of negative minimal daily temperature ($E < 0$) characterizing freezing stress have been estimated.

The data of occurrence of synoptic situations were taken from S l a b ý (1989), and from individual volumes of Meteorological Bulletin for the years of 1988–1996.

AIR POLLUTION

To characterize the load by sulphur dioxide during winter periods, the data of the air pollution database (ISKO) of the CHMI were worked out. The average half-hour SO_2 concentration was measured by fluorescent method. Average daily values, maximal half-hour concentration, values of 90% quantil, frequencies of overstepping daily averages 300 and 500 $\mu\text{g}\cdot\text{m}^{-3}$ and

half-hour averages 1000, 1500, 2000 and 3000 $\mu\text{g}\cdot\text{m}^{-3}$ were evaluated for the station of Měděnec.

EVALUATED PLOTS

In April 1996, 18 sample plots situated within damaged areas, were chosen on the forest administrations (FA) Litvínov, Janov and Kláštřec. Two sample plots were chosen in spruce plantations, young stands, and mature stands of each forest administration. On the basis of visual evaluation of needle damage, the individuals slightly (discoloration to 10%), moderately (10–15%) and heavily (over 50%) damaged were selected in the stands. The same stands were evaluated also in 1997 (that time distribution according to damage was not possible). To compare some characteristics (defoliation, contents of sulphur and fluorine), the results measured on the permanent plots, established in young spruce stands, in the area ranging from Klínovec to Cínovec were used (P a s u t h o v á, 1994).

In July 1997, 16 plots in the damaged birch stands were chosen in the FA Litvínov, Janov and Kláštřec. Some of those plots were situated in the height profiles (Jelenĩ vrch, Sv. Anna).

DETERMINATION OF THE CONTENT OF LOAD ELEMENTS IN LEAVES

To determine of the load element content in needles and leaves of Norway spruce and birch, the method of leaf analysis was used. Needle samples were collected on 18 spruce sample plots, in the spring period (April 1996, 1997). The composite samples characterizing individual types of stand damage were taken from 10 individuals of each plantation, from 5 individuals of young stands and from two freshly cut trees of mature stands. Samples on permanent spruce research plots were taken in autumn (October–November). The composite leaf samples on birch plots were taken from 10 trees on each plot, from May to August 1997.

The sulphur content in assimilation organs was determined on ICP AES, after mineralization by acid in microwave oven, the fluorine content after mineralization by ion-selective electrode.

EVALUATION OF DAMAGE

Autumn evaluation 1996 – defoliation and types of needle cast

In September 1996, two young spruce stands (sample plots) on each FA were evaluated in order to find out the most frequent type of needle cast after winter 1995/1996. The degree and type of crown defoliation were evaluated at 150 trees in the transect 2 m wide. The 5-percentage defoliation scale was used as well as following types of needle cast:

0 – no needle cast; 1 – partial large-scale secondary needle cast; 2 – needle cast in the lower part of the crown; 3 – needle cast in the middle part of the crown; 4 – needle cast in the upper part of the crown; 5 – needle cast within the whole tree.

RESULTS

METEOROLOGICAL FACTORS AND AIR POLLUTION

From the viewpoint of the health state of forest stands, the course of meteorological factors in winter period of 1995/1996 was unfavourable. In the third decade of November the air flow changed from north-western to south-eastern direction (Tab. I). This change was accompanied by temperature decrease under the limit of 0 °C, minimal temperatures ranging from -9,6 to -11,7 °C. At the same time the atmosphere was stable stratified in such a way that the boundary of inversion layer was in the heights of 800–1200 m a.s.l., and the ridge of the Ore Mts. was directly covered by inversion cloudiness. It caused the permanent occurrence of fog and heavy growth of a hard rime, that resulted in mechanical damage of deciduous as well as of coniferous wooden species. Another consequence of the situation was accumulation of harmful matters in the inversion layer. Concentrations of sulphur dioxide in the third

EVALUATION OF HEALTH STATE OF BIRCH STANDS

In July 1997, the defoliation was evaluated on the birch plots. Cambium vitality was followed to determine the regeneration ability of selected individuals. The destructive analysis was done of one totally defoliated tree and one heavily defoliated tree (over 80%). Cambium was evaluated in the stem and branches of the 1st and 2nd order in segments 10 cm long. Green cambium was supposed to be vital. When the colour was less distinctive (yellowish-green) or when the cambium along one side of the branch was dying, the branch was classified as dead.

I. Meteorological factors during the winter 1995–1996 and 1996–1997

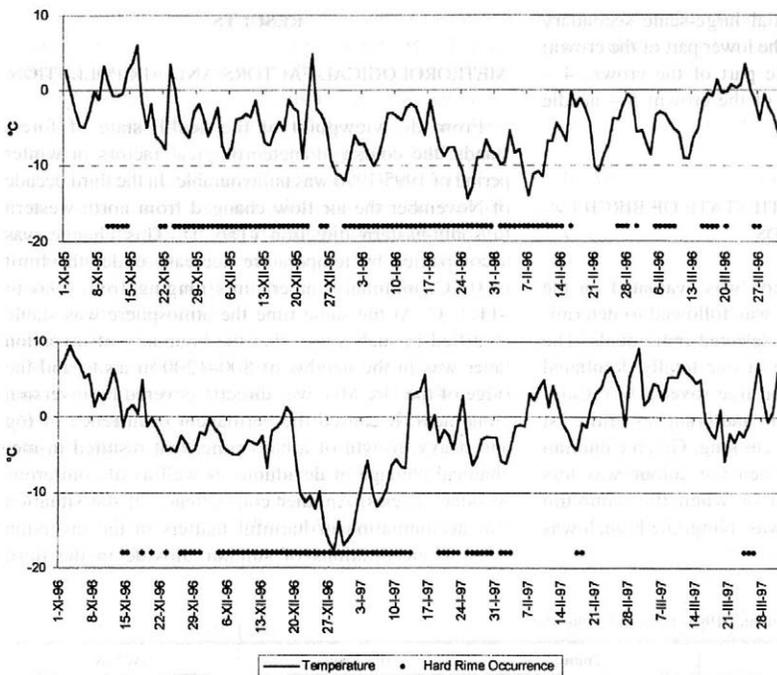
Month	T		Tmin		Hard rime		NW/SW	
	1995/1996	1996/1997	1995/1996	1996/1997	1995/1996	1996/1997	1995/1996	1996/1997
XI	-1.8	1.4	-4.8	-1.8	14	10	1.21	1.39
XII	-5.3	-6.6	-8.4	-9.7	26	28	0.35	0.27
I	-6.8	-4.2	-9.5	-7.8	30	24	0.15	0.56
II	-6.7	0.8	-10.5	-3.1	18	5	1.08	3.57
III	-2.9	2.3	-6.5	-1.7	13	3	0.62	2.54

Note: T – monthly average of temperature
 Tmin – monthly average of minimal temperature
 Hard rime – the number of days with the occurrence of hard rime
 NW/SW – proportion of the occurrence of air blowing from north-west (250°–340°) and south-east (70°–160°) quadrants.
 The sum of relative occurrence from both NW and SW quadrants differed from 74.4 to 93.1% in individual months

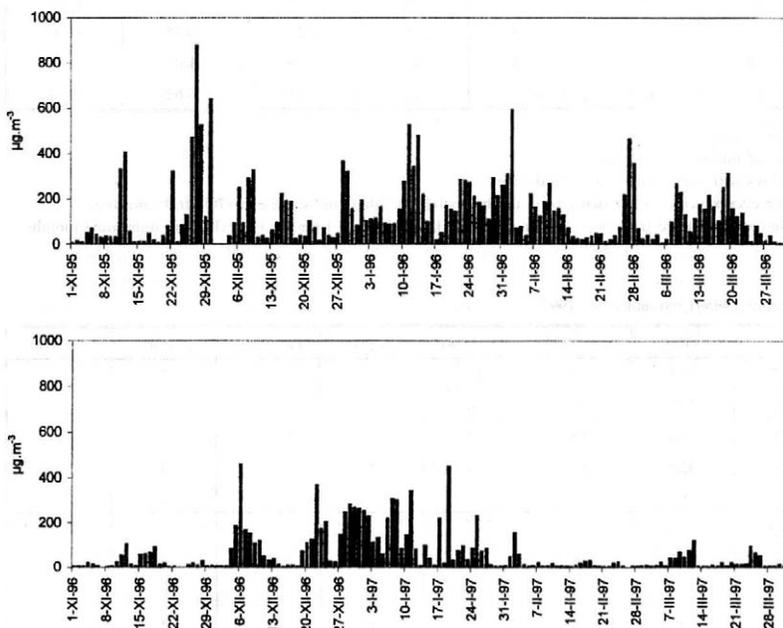
II. Air pollution (SO₂) during the winter 1995–1996 and 1996–1997

	Avg	Max	90%q	h > 1000	h > 1500	h > 2000	h > 3000	d > 300	d > 500
XI/1995	159	1907	575	43	10	–	–	7	3
XII/1995	122	2543	277	15	6	2	–	3	–
I/1996	193	1876	395	18	2	–	–	3	1
II/1996	138	2358	329	11	3	1	–	4	1
III/1996	102	1490	260	1	–	–	–	1	–
XI/1996	23	549	61	–	–	–	–	–	–
XII/1996	120	3606	267	8	6	4	1	2	–
I/1997	123	1972	313	5	3	–	–	–	–
II/1997	18	2063	41	2	1	1	–	4	–
III/1997	26	509	62	–	–	–	–	–	–

Note: Avg – monthly average of SO₂ concentration
 Max – maximal measured half-hour concentration
 90%q – 90% quantil of SO₂ concentration
 h>xxxx – number of 30 minutes concentrations exceeding xxxx µg.m⁻³
 d>xxx – number of daily averages exceeding xxx µg.m⁻³



1. Temperature and hard rime development on station Měděnec during the winter 1995–1996 and 1996–1997



2. Daily averages of SO₂ concentration on station Měděnec during winter 1995–1996 and 1996–1997

decade of November have overstepped the hygienic limit $150 \mu\text{g}\cdot\text{m}^{-3}$ in 45% of days, maximal measured half-hour concentration reaching $1908 \mu\text{g}\cdot\text{m}^{-3}$ (Tab. II, Fig. 2). This situation combined with the south-eastern blowing is not unusual in the Ore Mts. The winter

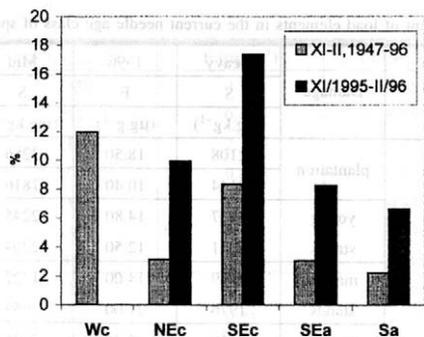
1995/1996 was, however, extraordinary in persistence of such unfavourable conditions. The described conditions have continued in fact till half of February 1996 (Tabs. I, II and Figs. 1, 2). During that period, the air flow have changed only for several days, in late Decem-

ber, which was connected with fast temperature growth (December 23, 4,8 °C). Exceptionality of the course of weather conditions can be seen also from the comparison of frequencies of synoptic situations during the period X/1995–II/1996 with the whole relative frequency of synoptic situation in these months for the years 1947–1996 (Fig. 3). The most significant feature is that the western anticyclonal situation, typical for these months, did not occur in winter 1995/1996. On the contrary, northern, north-eastern and south-eastern cyclonal and southern and south-eastern anticyclonal situations were represented at most.

In winter 1996/1997, the meteorological conditions were different. During November 1996 the temperature decreased slowly and regularly in connection with prevailing western to south-western wind directions causing only mild pollution degree. From the early December the temperature has stagnated, then it began to grow and overstepped the zero limit several times in the daily average – in that period the first more significant episode of air pollution was observed in December 4–12, 1996. Since December 20, 1996, the eastern blowing had prevailed accompanied by steep temperature decrease. The average daily temperature at Měděnec fell in 10,5 °C from December 19 to December 21, 1996. The lowest temperature during this winter period was measured in December 28 (average daily temperature –17,7 °C, minimal temperature –21,3 °C). The growth of SO₂ concentrations was also connected with eastern flows. The continual period of high pollution began in December 20, 1996, and lasted till January 12, 1997, without any interruption. So the similar situation as in the years 1995/1996 has been repeated in a shortened form. The average daily concentrations have decreased under the limit of 100 µg.m⁻³ only four times at the station of Měděnec, several times there were daily concentrations over 300 µg.m⁻³, with the maximum of 367 µg.m⁻³ (December 22, 1996). Half-hour concentrations extended the limit of 100 µg.m⁻³ in several cases, the highest half-hour concentration of 3605 µg.m⁻³ was measured in December 29, 1996.

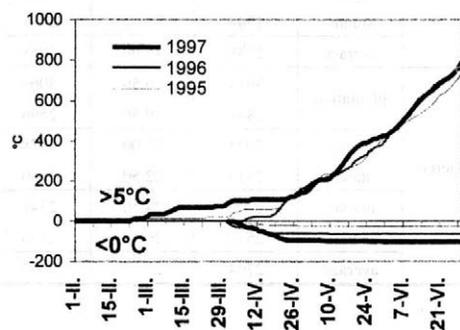
Low temperature (daily averages below –5 °C) continued till January 12, 1997. Following warmer period was connected with the change of flow direction. After several days of an average temperature above zero, mild temperature decrease was observed till the end of January. Another warmer wave came at the end of February. Especially February 24, 25 and March 1, 2 1997 were very warm. In late January, high SO₂ concentrations were still occurring, from February 3, extremely high pollution concentrations were not observed.

Warm periods in February and March were caused by the inversion cloudiness at the elevations of 600–800 m a.s.l. In the area of the Ore Mts. ridge, the weather was mostly very sunny and warm with average daily temperatures over 0 °C (from February 7–14, and again from February 21 to March 15). The highest average daily temperature of 9,1 °C was measured in March 2. That very warm period was followed by steep



3. Relative number of synoptic situations during the winter months 1995–1996 and winter months 1947–1996

Wc – West cyclone; NEc – North-East cyclone; SEc – South-East cyclone; SEa – South-East anticyclone; Sa – South anticyclone



4. The sum of day degrees (DDG(avg))>5C and DDG(min)<0C at the station of Měděnec. The sum of day degrees with minimal temperature below zero is displayed from April

cooling when the minimal temperature felled even below –10 °C. Also during April and May 1997, high temperatures alternated negative ones, the last day of minimal temperature below freezing point being July 1.

To compare with 1996 (cold spring) and 1995 (fast spring start), the temperature regime was significantly different in spring 1997. The sum curve (Fig. 4) of day-degrees in 1997 overstepped both values of 1995 and 1996 till the late April. Fast increase could be observed mainly in early March and in the turn of March and April. The curve of negative minimal temperatures shows the lowest values, and thus the highest possibility of frost damage for the year 1997.

CONTENTS OF LOAD ELEMENTS

Contents of load elements in needle found out in 1996 and 1997 are presented in Tab. III. Moderate to very high pollution load, as estimated according to the criteria of Tesař et al. (1982), is evident from the analysis of sulphur content in needles, in 1996. Results

F.A.	Damage	Heavy	1996	Mid	1996	Slight	1996	1997	
		S	F	S	F	S	F	S	F
		(mg.kg ⁻¹)	(µg.g ⁻¹)						
Janov	plantation	2108	18.50	2286	16.00	2165	15.00	1782	7.33
		2144	10.40	1816	8.80	1880	9.00	1381	6.39
	young stands	1937	14.80	2245	13.30	1872	9.80	1620	5.10
		2221	12.50	2204	13.00	1970	13.00	1519	7.77
	mature stands	2569	14.00	1722	12.30	1265	11.10	1083	5.67
		1976	21.00	1953	11.50	1891	9.50	1262	6.27
average	2159	15.20	2038	12.48	1841	11.23	1522	6.42	
Litvínov	plantation	2289	15.50	2109	8.00	2276	15.50	1962	11.43
		2230	13.00	2031	15.50	1960	9.00	1775	7.56
	young stands	1907	11.00	1846	9.50	1980	9.00	1775	6.69
		2487	19.50	2487	7.50	2559	16.00	1737	8.90
	mature stands	1973	14.00	1828	7.50	1672	7.50	1319	7.49
		1944	17.00	2048	16.00	1687	14.00	1466	9.65
average	2138	15.00	2058	10.67	2022	11.83	1714	8.62	
Kláštěrec	plantation	3014	26.50	3069	17.50	2587	16.30	1848	8.82
		2881	19.50	2596	20.00	2628	18.50	1639	7.77
	young stands	3035	20.00	2978	17.50	2726	17.00	1573	6.33
		2517	22.50	2680	18.50	2598	18.50	1716	9.22
	mature stands	2206	24.50	2341	23.50	1920	17.00	1420	6.72
		2570	26.50	2336	20.50	1500	13.50	1459	9.10
average	2704	23.25	2667	19.58	2327	16.80	1609	7.99	

of analysis of one-year-old needles were significantly different. As Tab. III shows, the highest sulphur content in needles was found out on the sample plot of FA Kláštěrec. Plantations and young stands of that forest administration have contained sulphur in needles in extremely high values, exceeding 3000 mg.kg⁻¹. In mature stands, the sulphur content in needles of heavily and moderately damaged trees was also high (over 2000 mg.kg⁻¹). The sulphur contents found out in the stands of FA Janov and Litvínov represent mean to high pollution load (1600–2400 mg.kg⁻¹).

Analysis of fluorine content in 1996, showed multiple accumulation of that harmful element in needles, regarding its limit of toxicity (5 µg.g⁻¹).

Mainly high load of the stands of FA Kláštěrec can be clearly seen from the results. In fact, value of 20 µg F.g⁻¹ (26.5 µg F.g⁻¹ for both plantations and mature stands) was overstepped at heavily damaged trees of all age categories. Values of fluorine content were exceeding 10 µg F.g⁻¹ at moderately and slightly damaged trees. In other FA, the fluorine contents as measured in needles were about 10 µg F.g⁻¹ in all age categories and damage types.

After winter 1996/1997, the sulphur contents in needles were slightly to significantly increased. The measured values of sulphur content in needles ranging from 1083 to 1962 mg.kg⁻¹. Sulphur was accumulated more in one-year-old needles of the plantations and young

stands than in the mature stands. Unlike the winter 1995/1996, pollution load was balanced on all the three forest administrations evaluated.

The average fluorine contents were above the natural level – they significantly overstepped the level of toxicity ranging from 5.10 to 11.43 µg F.g⁻¹ in FA Litvínov and Kláštěrec. Those values reflect continuing heavy pollution load of fluorine compounds. The highest fluorine accumulation were observed at plantations and natural advance growth stands. The total load was substantially lower than after winter 1995/1996.

POLLUTION LOAD OF THE BIRCH STANDS

The results of leaf analyses are presented in Tab. IV. Sulphur contents in birch leaves collected in July ranged from 1969 to 3469 mg.kg⁻¹. The highest concentrations were found out both at healthy and damaged trees on FA Kláštěrec. In comparison with June 1997, sulphur accumulation in leaves has slightly increased but even this level does not indicate heavy load. The increment of sulphur content in dependence on altitude was clearly proved in the height profile of the locality of Jelení hora. The highest value of 3469 mg.kg⁻¹ was estimated in the top part of profile (910 m a.s.l.). The sulphur accumulation in leaves was decreasing with decreasing altitude (in 900 m a.s.l. to 2747 or 2750 mg.kg⁻¹

IV. Birch damage 1997 – content of load elements

F.A.	Stand	Leaf cond.	S (mg.kg ⁻¹)	F (µg.g ⁻¹)	Cl (mg.kg ⁻¹)
Kláštevec 19. 6. 1997	228 B1	health	2550	0.50	0.381
	275 B1	health	2241	0.48	0.386
		damaged	2186	2.13	0.409
Kláštevec 19. 6. 1997	113 A1	health	2005	0.86	0.361
	113 A1	damaged	2480	1.13	0.429
Janov 19. 6. 1997	146 C1	damaged	2379	1.16	0.370
	146 C2Y	damaged	2090	0.78	0.369
Litvínov 8.–9. 7. 1997	319 A1	health	2258	0.12	0.431
		damaged	3032	0.23	0.508
	223 A1	health	3099	0.12	0.471
		damaged	3285	0.07	0.492
	103 C1	health	2629	0.08	0.450
		damaged	3326	0.07	0.492
	425 A17	health	2378	0.01	0.431
		damaged	2585	0.09	0.455
	419 C1	health	2937	0.86	0.405
		damaged	2694	0.02	0.455
	509 C2	health	2029	1.40	0.493
		damaged	2155	0.20	0.383
	519 E1	health	1969	1.71	0.439
		damaged	2352	0.97	0.414
Kláštevec 8.–9. 7. 1997	186 A1	health	2369	0.09	0.437
		damaged	2584	0.17	0.455
	186 C1	health	2892	0.23	0.459
		damaged	3258	0.12	0.464
	169 A1	health	2040	1.71	0.432
	275 B1	damaged	2728	0.33	0.486
		health	2253	0.09	0.401
	315 B1	damaged	2042	3.79	0.513
		health	2755	0.09	0.463
		damaged	2931	0.16	0.545
		damaged	2750	0.16	0.534
	114 F1	damaged	3469	0.09	0.495
	113 B1	damaged	2747	0.23	0.437
	113 A1	damaged	2438	0.32	0.403
		health	2523	0.12	0.379
	146 B2	health	2364	1.49	0.505
	147 A2	damaged	2423	0.01	0.433
146 C1	damaged	2533	0.46	0.491	
Janov 8.–9. 7. 1997	146 C2	damaged	2267	0.09	0.479
	137 B2	health	2691	1.91	0.420
	136 C2	health	2384	0.18	0.472
	225 B1	health	2263	0.50	0.476
		damaged	2906	0.02	0.500
Kláštevec 13. 8. 1997	239 D1	health	2005	2.27	0.431
		damaged	1723	2.36	0.416
	231 D1	health	2013	2.34	0.353
		damaged	1244	0.58	0.377
	260 B1	dead	1242	2.11	0.345
		health	2078	0.22	0.343
		damaged	1236	2.61	0.345
	dead	1416	2.79	0.330	

and in 850 m a.s.l. to 2438 mg.kg⁻¹ (Tab. IV), independently of the stand exposition.

Also the completing analyses from August 1997 have proved that the leaf damage was not caused by sulphur dioxide. The content of sulphur was lower in drying up and dry leaves to compare with the green ones. During the vegetation period of 1997, the birch stands were not significantly impacted by the air pollution of fluorine and chlorine compounds.

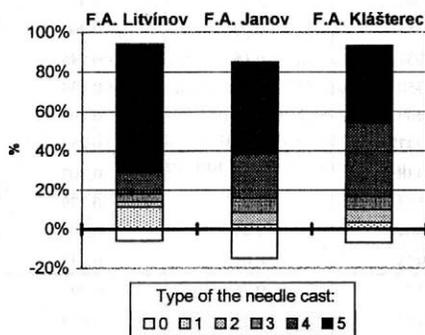
EVALUATION OF TREE DAMAGE

Autumn evaluation of the spruce stands

The results of the autumn evaluation of defoliation and types of needle cast in young stands are presented in Tab. V and Fig. 5. Defoliation of the young stands evaluated were compared with the results of defoliation on the permanent research plots.

V. Comparison of average defoliation in young stands (autumn 1996) and at the research plots (1995 and 1996)

F.A.	Young stands			Research plots	
	Janov	Kláštorec	Litvínov	1995	1996
Average	60.2	64.9	64.6	38.9	59
Min	20	20	25	15	15
Max	95	100	95	80	100
Median	65	65	65	45	55



5. Types of the needle cast in the young stands after winter 1995/1996

- 0 – no needle cast
- 1 – partial secondary needle cast
- 2 – needle cast in the lower part of the crown
- 3 – needle cast in the middle part of the crown
- 4 – needle cast in the upper part of the crown
- 5 – needle cast within the whole crown

The average defoliation has exceeded 60% on all the forest administrations. In autumn 1996, the values of damaged young stands were comparable with the aver-

age values found out on permanent plots (59%); the values of permanent plots were higher than in 1995 (38.9%). The median of defoliation on the plots evaluated was 65%, on permanent plots it was 55%. The most common type of the needle cast on all the forest administrations was shedding of needles in the whole crown [type of cast 5 – from 39% (FA Klášťorec) to 65% of trees (FA Litvínov)]. Second most frequently occurring type of needle cast was type 4 – in the upper half of the crown [from 11% (FA Litvínov) to 38% (FA Klášťorec)]. The highest percentage of undamaged trees (15%) was found on the FA Janov. There were only 6, resp. 7% of healthy trees on the other administrations evaluated.

Evaluation of damaged birch stands

All observed stands are in the top ridge part of the Ore Mts., at the elevation above 800 m. Defoliation on the sample plots is ranging from 30 to 90% (Tab. VI).

VI. Defoliation of birch stands in July 1997

Forestry Administration	Forest stand (exposition)	Altitude (m a.s.l.)	Defoliation (%)
Litvínov	319 a1	860	60
	103 c1	810	70
	425 a1z	860	50
	223 a1	840	70
Kláštorec	419 c1	860	75
	275 b1 (ENE)	1040	90
	275 b1 (N)	1040	40
	186 c1	910	60
	186 a1	910	40
	114 e1	900	60
Janov	113 b1	910	70
	113 a1	880	30
	146 c1	800	35
	146 c2y	860	90
	146 b1z	880	65

Especially low density stands, where previous signs of bark scorch and mechanical damage by hard rime was already observed, were damaged. More dense stands of comparable parameters were less damaged. In all-aged stands the lowest birch trees of the height up to 1.5 m have died – also the low branch whorls of mature trees were the most damaged. Observations in the height profiles (Jelení vrch, Svátá Anna) showed the damage graduating with the altitude, however, in the scope of the whole Ore Mts. ridge the dependence of damage on the altitude was not the rule. The most damaged stands were defoliated from 90 to 97% in July. Except the loss of leaves in the less damaged stands, both primary and secondary leaves turned yellow. Drying up and defoliation proceed from the top end of the branches, in oppo-

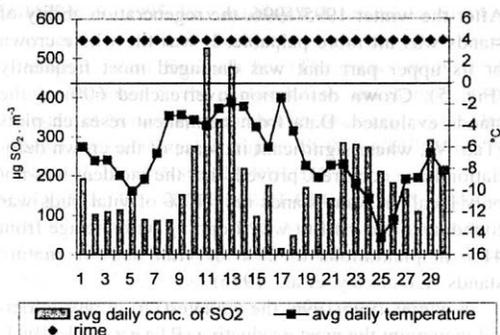
site the substitute flushing going from the crown interior to marginal parts.

Investigations of cambium vitality have proved, that cambium of quite defoliated individuals was vital only on the stem, branches were dead. On the contrary, in general only lower branches and marginal crown part (10–50 cm) was dry up even with trees of 90% defoliation. In lower parts of the crowns the boundary between vital and dead cambium appeared in branches with the diameter about 1 cm; it was often observed at the spots where branch thickness was suddenly changing. Cambium of the stem was vital at least up to two thirds of the tree height at all individuals.

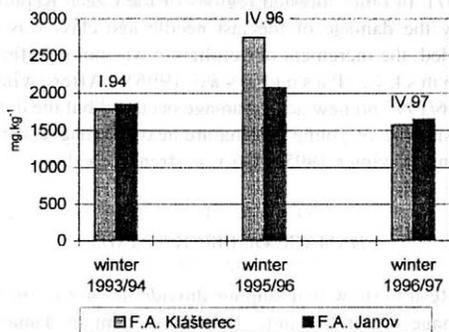
DISCUSSION

DAMAGE OF SPRUCE STANDS

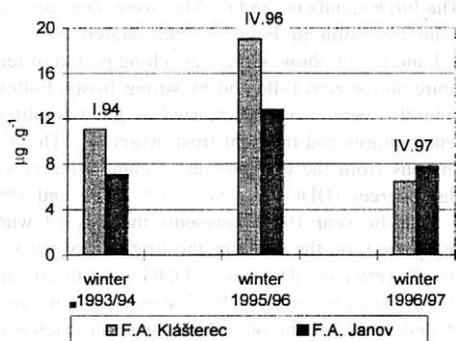
Vast damage of spruce stands has been observed after winter 1995/1996. Discoloration of the spruce needles and mechanical damage of all tree species began to appear from 600–700 m a.s.l. The intensity and extent of damage was growing with the altitude. Spruce stands were damaged at most of the plateau of the Ore Mts., from Kovářská (FA Klášterec) to Načetín (FA Janov). In the north-eastern direction (FA Litvínov) the intensity of damage was slightly lower. On the contrary, there was more mechanical damage of forest stands (top break) in the upland area of the FA Litvínov. Defined results (L o m s k ý et al., 1996) proved that the damage of needles was caused by mutual impact of several factors (Fig. 6). There were steep temperature falls in November 1995, inversion situation of high SO_2 concentrations, and hard rime occurrence lasting from November 1995 till the end of January 1996. Winter transpiration during February and March even worsened the physiological state of spruce stands (L a r c h e r, 1988), significant stand damage, however, had already appeared during December and January. In those months, south-eastern and eastern air flows began to prevail, which brought harmful substances directly from the sources situated in the Podkrušnohoří basin. Increased pollution load of the Ore Mts. was proved by high concentrations of load elements (S, F) in needle samples (Tab. III). Long-term inversion situation and the height of its boundary layer were significant for increasing content of load elements. The comparison of accumulation of sulphur and fluorine in needles of young stands from in the period 1993/1994 can be an example (L o m s k ý et al., 1996). The SO_2 concentrations have also reached high half-hour values (half-hour concentration 3000 $\mu\text{g}\cdot\text{m}^{-3}$ was exceeded, daily concentration overstepped 400 $\mu\text{g}\cdot\text{m}^{-3}$ in 14 cases). Inversion situation was much shorter (1.5 month) than in winter 1995/1996 (Figs. 7, 8). After winter 1995/1996 the contents of sulphur and fluorine in needles have exceeded significantly the values founded in the forest administrations in winter 1993/1994; in winter 1993/1994,



6. Cumulative impact of stress factors at Měděnec – January 1996



7. Average sulphur content in the first needle age class of young spruce stands



8. Average fluorine content in the first needle age class of young spruce stands

the average fluorine contents in needles of young spruce stands were extremely high (7 and 11 $\mu\text{g}\cdot\text{g}^{-1}$) in both forest administrations. After winter 1996/1997, the sulphur contents were only slightly higher, fluorine contents have exceeded the limit of heavy load (5 $\mu\text{g}\cdot\text{g}^{-1}$) as in previous winters. Similar trend was observed at the other age categories.

In winter 1993/1994 the buds were affected for relatively short period, so they were only slightly damaged.

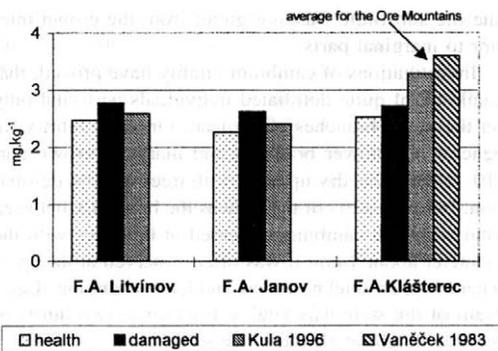
After the winter 1995/1996, the regeneration ability of stands was hit more palpable. It was the whole crown or its upper part that was damaged most frequently (Fig. 5). Crown defoliation overreached 60% at the stands evaluated. Data from permanent research plots (Tab. V), where significant increase of the crown defoliation have occurred, proved, that the incident was not only local. In some stands only 10% of vital buds was found, and bud vitality was dropping with the age from 41% in plantations to 27% of vital buds in mature stands (L o m s k ý et al., 1996).

In winter 1995/1996, the youngest, from physiological viewpoint the most productive (P f a n z et al., 1994) two to three needle age classes were damaged in the most loaded localities. The damage affected more than 12,500 ha of spruce stands (Ministry of Agriculture CR, 1997). In other forested regions of the Czech Republic only the damage of the last needle age class was recorded, the increment of defoliation was not significant (L o m s k ý, P a s u t h o v á, 1996). After winter 1996/1997 no new acute damage occurred but the dying persistence of young and mature heavy damaged stands from the winter 1995/1996 was strengthened.

DAMAGE OF BIRCH STANDS

Results show that sulphur dioxide did not cause the damage of birch stands. Sulphur content in damaged trees did not significantly overreached the values as found by K u l a, H r d l i č k a (1996) at the end of vegetation period. The load observed in early 80s by V a n ě č e k (1983) was substantially higher (Fig. 9).

The birch stands in the Ore Mts. were damaged during the inversion in February and March 1997. As Tab. I and Fig. 1 show, there was a long period of temperature above zero followed by strong frosts. Following months were also characterized by great amplitude of temperatures and frequent frost inversions. This fact is obvious from the comparison of cumulative curves of day-degrees (DDG) in years 1995, 1996 and 1997 (Fig. 4). The year 1995 represents the type of warm spring period, on the contrary the first half of the year 1996 was very cool. The sum of DDG was substantially higher in the early spring of 1997 than in previous years 1995 and 1996. On the other hand, from the viewpoint of negative minimal temperatures, the year 1997 could be evaluated as the coolest one. Other facts are also supporting the significant role of meteorological factors in birch damage. It is the character of damage that hits especially the lower density stands – stands of limited regulation ability of the microclimate (F o j t, 1988). Also dying of the external parts of crowns and weaker branches is typical for frost damage. The fact should be mentioned that similar damage of smaller extent has been observed in higher altitudes of other mountain regions in the Czech Republic, situated above the inversion boundary layer during spring (B a l c a r, 1997 – personal communication). The fact, that the damage in the



9. Average sulphur content in the birch leaves (July 1997) of healthy and damaged trees

Ore Mts. was more intensive than in other areas, can be explained in two ways. First – that birch is not planted in such an extent in other mountainous regions – the damage, therefore, is not such an importance for the forest management; second – in the Ore Mts. lower birch stands vitality is connected with the pollution load (J i r g l e, T i c h ý, 1981; V a n ě č e k, 1983), and unclear origin of the seed material used.

Birch is a tree species of considerable ecological valence chosen for the reforestation of air pollution clearcuts in the Ore Mts. due to low site demands, and high resistance against SO_2 (K u b e l k a et al., 1992). As a species typical for boreal forest, birch should be able to survive even in the temperatures of $-70^\circ C$ during winter period (W o o d w a r d, 1994). L a r c h e r (1988) informs that after the first stage of hardening, birch seedlings are tolerant up to $-35^\circ C$. In spite of this, birch resistance against low temperatures depends on the course of meteorological conditions, and ecotype (M y k i n g, H e i d e, 1995). In the second phase of the winter period, when the chilling requirements are already fulfilled, the absence of warm days prevents dormancy completing (K r a m e r, 1996). During longer periods of high temperatures, biochemical and physiological processes leading to flushing are initiated; when frost follows, these processes can be strongly affected (M y k i n g, H e i d e, 1995).

Another mechanism, that can cause damage of birch stands in connection to warm winter period, is cavitation of birch xylem during the repeated freezing (C o x, M a l c o m, 1997). That type of stress has probably caused large-scale dying of birch that took place in Canada at the area of 490,000 km^2 in the 1930s (B r a a t h e, 1995).

It is evident that the birch stands had to be impacted by a complex of other stress factors. Apart from unclear origin of seeds, and SO_2 pollutions, other significant load factors are represented by tropospheric ozone (M a t y s s e k et al., 1995) as well as by biotic factors that can influence the dormancy processes (P e r r y, 1971).

CONCLUSION

Damage both of spruce and birch stands were caused by combination of weather and air pollution factors. With regard to possibility of repeated extreme combination of these factors, further damage cannot be excluded. The forest stands in the Ore Mts. are being weakened by a long-term pollution impact resulting in load and degradation of forest soils and aggravated stand nutrition. Reduced resistance of the forest ecosystem against acute combination of stress factors is the consequence of such situation.

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POŠKOZENÍ LESNÍCH POROSTŮ V KRUŠNÝCH HORÁCH V LETECH 1995–1997

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V příspěvku se zaměřujeme na zimní období 1995/1996, kdy došlo v Krušných horách k rozsáhlému poškození smrkových porostů, a na následující zimu 1996/1997 a jaro 1997, kdy došlo k poškození březových porostů. V práci je hodnocen vývoj meteorologických a imisních faktorů, zdravotní stav porostů a obsah zátěžových prvků v asimilačních orgánech.

Výsledky ukazují, že na poškození smrku se podílela kombinace imisních a meteorologických faktorů. V listopadu 1995 došlo k prudkému poklesu teplot spojenému s inverzní situací, s vysokými koncentracemi SO_2 a silným výskytem námrazy. Tato nepříznivá situace, doprovázená převládajícím jihovýchodním prouděním, které přinášelo škodliviny přímo od zdrojů v Podkrušnohorské pánvi, trvala až do poloviny února 1996. Vysoká zátěž oxidem siřičitým (půlhodinové

koncentrace v některých případech překračovaly i hodnotu $2\ 000\ \mu\text{g}\cdot\text{m}^{-3}$) se projevila na poškození smrkových porostů, což dokazují obsahy zátěžových prvků v jehličí, které překročily hranici toxicity.

U poškozených bříz nebyl ve vegetačních orgánech prokázán zvýšený obsah zátěžových prvků. Březové porosty byly významně zasaženy zimní inverzí v únoru a březnu 1997, kdy se vyskytla delší období s kladnými teplotami a následnými mrazovými zvraty. Srovnání teplotního průběhu let 1995–1997 ukazuje, že jaro 1997 bylo z hlediska teplotního průběhu extrémní. Je ovšem pravdou, že plně vitální porosty břízy jsou schopné se i s takovými teplotními zvraty vyrovnat. Na tom, že došlo k poškození v takovém rozsahu, se významnou měrou podílí dlouhodobá imisní zátěž a narušený zdravotní stav krušnohorských březových porostů.

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CONTRIBUTION TO ECOLOGY AND HEALTH STATE OF BIRCH STANDS IN THE SUDETEN MOUNTAINS

PŘÍSPĚVEK K EKOLOGII A ZDRAVOTNÍMU STAVU BŘEZOVÝCH POROSTŮ V SUDETSKÉ SOUSTAVĚ

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ABSTRACT: Three species of genus *Betula* are important for reforestation of clearcuts emerged due to air pollution in the Czech Republic. European birch (*Betula pendula* Roth.) is recommended for sites up to the altitude of 900 m a.s.l., white birch (*Betula pubescens* Ehrh.) for forests between 900 and 1350 m a.s.l., and Carpathian birch (*Betula carpatica* W. et K.) above 1350 m a.s.l. White birch and Carpathian birch are also suitable for growing in lower elevated water-logged sites. From 1995, European birch (the most frequent from the mentioned species) is damaged by presently non-examined complex of abiotic and biotic factors. Birch stands growing in tops of the mountain ridges has been attacked by viruses, rust fungi and leaf-eating insects. In winter, the damaged stands are frosted and desiccated. Recent test-observation proved continuous dieback of the young birch stands in the Orlické hory Mts. and Jizerské hory Mts. Up to now, no injury symptoms has been observed in white birch and Carpathian birch. For solution of the birch damage problems, next detailed investigation is necessary.

reforestation; clearcuts induced by air pollution; injury to birch; European birch; white birch; Carpathian birch

ABSTRAKT: Pro obnovu lesních porostů vytěžených v důsledku imisní kalamity jsou v České republice z rodu *Betula* významné tři druhy. Bříza bělokorá (*Betula pendula* Roth.) je doporučována na lokality až do 900 m n. m., bříza pýřitá (*Betula pubescens* Ehrh.) do porostů mezi 900 a 1 350 m n. m. a bříza karpatská (*Betula carpatica* W. et K.) nad 1 350 m n. m. Bříza pýřitá a bříza karpatská mají své uplatnění i v porostech níže položených na podmáčených a zamokřených půdách. Na bříze bělokoré, která je z uvedených druhů rozšířena nejvíce, se od roku 1995 projevuje poškození dosud málo prozkoumaným komplexem biotických a abiotických faktorů. Porosty rostoucí v horských hřebenových polohách jsou atakovány viry, rzemi a listožravým hmyzem, v zimním období pak vymrzají a schnou. Orientační šetření v Jizerských a Orlických horách dokládají na vybraných lokalitách postupný úhyn mladých březových porostů. Na bříze pýřité a bříze karpatské poškození uvedeného typu dosud zjištěno nebylo. Pro řešení problému jsou nutná další podrobná šetření.

obnova lesa; imisní holiny; poškození břízy; bříza bělokorá; bříza pýřitá; bříza karpatská

INTRODUCTION

Already in the past, birch stands had developed on abandoned fields or not reforested clearings on sites situated from uplands to lower mountain elevations. Up to the air pollution increase (in the 50s), birch stands had only a provisional role, as a nursery crop for sensitive target tree species regeneration. With exception of infertile and waterlogged sites, high proportion of birch in the forest was commonly considered as a low degree of silvicultural activities. For not meeting economic demands, birch stands were changed and birch trees were removed from forests. When ecological conditions in the mountains and uplands had changed due to air pollution, attitude of foresters to birch changed. Up to now, birch had been considered as a tolerant species towards air pollution stress combined by other ecological stresses (climatic, soil, biotic).

PROBLEMS

For its stand-forming abilities under heavy air pollution stress and rough ecological conditions, birch became one of the most frequent tree species in substitute forest stands. In these stands, birch substitutes more valuable species (with higher degree of wood production) which are eliminated through heavy pollution stress. Significance of substitute forest stands is mainly to fulfil non-wood-producing functions (soil-conservation function, hydrological role, climatic-conservation role, and others), wood yield is more or less reduced. Advantage of birch for its planting in substitute forest stands is large ability of that species to be grown on sites with various soil and climatic conditions, its high reproductive potential, and tolerance to air pollution stress. (Natural regeneration of birch can be seen in all soil types.)

The following species of birches are used for forestry purposes: European birch (*Betula pendula* Roth.), white birch (*Betula pubescens* Ehrh.) and Carpathian birch (*Betula carpatica* W. et K.). Besides common site conditions, the latter two species are also suitable for growing in water-logged sites. From climatic viewpoint, ecological amplitude of birches is extra large. The optimal growing conditions of European birch are placed from Oak-Beech to Spruce-Beech altitudinal vegetation zones (approximately from 400 to 900 m a.s.l.), but it forms base component in oak-birch woods of Oak altitudinal vegetation zone (below 350 m a.s.l.) as well. White birch is good for growing on sites up to Beech-Spruce altitudinal vegetation zone (900–1050 m a.s.l.), in some suitable places even to Spruce altitudinal vegetation zone (1050–1350 m a.s.l.). Carpathian birch could be planted up to Mountain pine altitudinal vegetation zone (more than 1350 m a.s.l.).

For its good properties, proportion of birch in the Czech forests has markedly increased when Norway spruce stands had died due to air pollution and other complementary stresses (nearly from the 50s). At present, birch proportion is nearly 3.0% of the total forest area of the Czech Republic, it is ca. 77,000 ha. (Original – natural – percentage of birch was 0.8%.)

At present, large birch forest stands are grown on sites most influenced by air pollution (threaten zone A) in the Ore Mts. At the second place, birch stands are grown in the mountains of the Sudeten system. These stands are mostly smaller than the previous ones, the area of them is commonly up to 1 ha. They were developed partly by natural regeneration, partly by birch seed sowing. Origin of the stands determines (to a great extent) their structure and quality.

According to the large scale of the research results, birch is regarded as a tolerant species to air pollution stress with prevailing component of sulphur dioxide (Ferda, 1953; Samek et al., 1963; Antipov, 1979; Dässler, Börtitz, 1988; Balcar, 1986). Older experience is known from Saxony, where the forests damaged by air pollution were reforested by birch already at the end of the last century (König, 1924). Because air pollution and ecological stresses had lasted for a long time, birch stands became permanent substitute forest stands. Spontaneity of natural regeneration was the main cause of birch stands development instead of stands formed by other tolerant tree species, undemanding silvicultural measures (Lampadius, 1969). It has been observed in the Ore Mts., where the birch stand problems were investigated (Jirgle, 1979, 1980; Jirgle, Tichý, 1981; Kučera, 1984; Moravčík, 1990). In the mountains of the Sudeten system, the problems of substitute birch stands were solved as well, e.g. Vacek et al. (1987), Vacek (1990, 1992).

In spite of the present research results, problems of substitute birch stand cultivation have not yet been fully solved. Evidence of that are the marked negative changes of birch stand health state observed in the

mountain regions during the last three years. This problem is relatively new, and considering to birch stands value, is very serious as well. Publication of our observation results and notice of some relationships between damages and growing conditions may contribute to solution of these problems.

OBSERVATION RESULTS

Impairment of the birch stands health state in many regions of the Sudeten system (Jizerské hory Mts., Krkonoše Mts., Broumovské stěny Hills, Stolové hory Mts., Orlické hory Mts., Jeseníky Mts.) was observed for the first time in 1995. The most obvious injury symptoms appeared in the top localities (mostly in silver thaw zone), especially on sites where snow used to be blown away by wind. On these localities, young birch stands succeeded mature spruce stands destroyed by air pollution and bark beetle (*Ips typographus* L.) and harvested during last decade (the 80s).

During May and June 1995, large occurrence of aphids (*Phyllaphis fagi* L., and others) and flies (*Cecidomyiidae*) were seen on birch leaves. Birches with a lot of these insects were injured by viruses (up to 30% of the whole leaf area). On some places, caterpillars of *Biston betularius* L. occurred. The most injured trees formed proventative shoots during August. Up to the end of vegetation period, the shoots had not lignified. Both proventative and common shoots of the most injured trees were heavily damaged by frost in winter 1995–1996 and by freezing (physiological) desiccation before spring 1996, which injured mainly buds.

In spring 1996, marked impairment of phenological phases has been observed in the injured birch stands. For example: „U Kunštátské kaple“ locality in the Orlické hory Mts., small portion of trees flushed normally, while some other trees were dead (ca. 1–2%) and some flushed by proventative shoots as late as during July. Massive occurrence of insect (aphids, flies) injuring birch leaves by sucking and virulent contamination were observed from July to September. Occurrence of caterpillars of *Biston betularius* L. markedly increased, but clear-eating has not been seen. Birch beetle (*Scolytus ratzeburgi* Jans.) occurred in the most injured birch stands. Leaves with virus disease were shedded from July to the end of August. It reduced foliage of damaged trees reduced down to 40%. Moreover large part of remaining leaves (nearly from a quarter to one half) grown on proventative shoots, which did not lignify and frosted in the next winter.

In May 1997, only less than 50% of trees in the most damaged stands were flushing. Some of them, mostly growing in stand margins or gaps were injured again by late frost at the end of the month.

In 1997, aphid and fly occurrence was lower than the previous year (but viroses were spread and leaves were shedded again), occurrence of *Biston betularius* L. and *Scolytus ratzeburgi* Jans. increased.

I. Test observation results of birch stand damage

Region	Place	Location	Altitude (m)	Percentage of heavy injured trees
Orlické hory Mts.	„Pod Velkou Deštnou“	ridge	1100	50
Orlické hory Mts.	„U Kunštátské kaple“	ridge	1030	100
Orlické hory Mts.	„Pod Tetřevcem“	NW slope	1000	0
Orlické hory Mts.	„Pod Orlem“	W slope	980	20
Jizerské hory Mts.	„Nad Lasičí“	E slope	960	20
Jizerské hory Mts.	„Plocha Jizerka“	SE slope	960	up to 5
Jizerské hory Mts.	„Nad Jeřábem“	SW slope	920	20



1. Damaged European birches (*Betula pendula* Roth.) in „U Kunštátské kaple“ locality, trees with medium and high degree of defoliation (June 1998)



2. Damaged European birches (*Betula pendula* Roth.) in „U Kunštátské kaple“ locality, secondary shoots on tree with high degree of defoliation (June 1998)

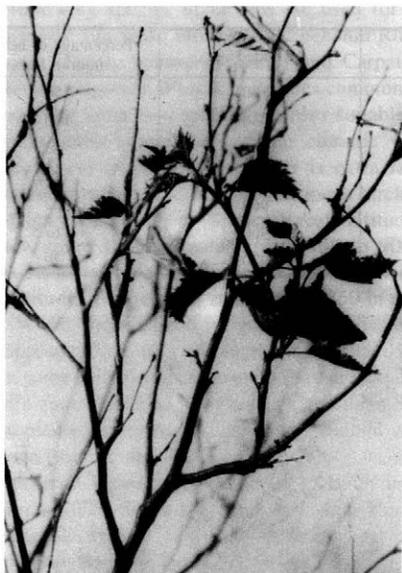
At the end of August 1997, test observation of damaged birch stands (age of 5–20 years) took place in selected high elevated localities of the Orlické hory Mts. and the Jizerské hory Mts. (Tab. I). The most damaged birch stand has been found in the top ridge locality of the Orlické hory Mts. called „U Kunštátské kaple“. In the young stand of several hectares area, all birches were heavily damaged. Nearly 20% of them were dead, and defoliation of the rest was higher than 50%. Majority of leaves had grown in not lignified preventative shoots, which are supposed to die by frost in the next winter. Many of leaves in common shoots (non preventative) have been eaten by larvae of *Croesus septentrionalis* L. and injured by rust *Melampsorium betulinum* (Pers.) Kleb. Contrary to birch, no serious damage has been found in other admixed tree species [mountain ash – *Sorbus aucuparia* L. and Norway spruce – *Picea abies* (L.) Karst.].

In the next stand („Pod Velkou Deštnou“ locality, Orlické hory Mts.), nearly one half of birches were

heavily injured. In other selected stands – placed on slopes of the Orlické hory Mts. and Jizerské hory Mts. – birch trees were damaged less. In all injured stands, presence of *Croesus septentrionalis* L. and *Melampsorium betulinum* (Pers.) Kleb. was examined.

The difference between injury of European birch and Carpathian birch was investigated in two stands (localities called „Pod Orlem“ in the Orlické hory Mts. and „Jizerka“ in the Jizerské hory Mts.). Contrary to the European birch, no frost and desiccative injury has been found in Carpathian birch. (The higher tolerance of Carpathian birch towards the mentioned environmental stresses was also examined by supplementary observation in the Krkonoše Mts. – localities called „Světlá hora“, „Kotelní jámy“, and „Labský důl“.)

It should be stressed, that mentioned injury of European birch in the Sudeten mountains was found in localities of higher mountains elevations – ridges and neighbouring slopes exposed to climatic stresses. In lower elevation, this injury of birches (with little excep-



3. Damaged European birches (*Betula pendula* Roth.) in „U Kunštátské kaple“ locality, detail of secondary shoot on tree with high degree of defoliation (June 1998)

tions) has not been examined. No other tree species was injured – special attention was paid to mountain ash, which had grown in each observed areas.

In accordance with the present health state of investigated birch stands in the Sudeten Mountains, it is supposed, that the trend of damage will continue in the next year (1998). Moreover, spread of fungus disease [*Piptoporus betulinus* (Bull. ex Fr.) P. Karst. and *Lennitis betulina* (L. ex Fr.) Fr.] in injured stands is very presumable.

Hitherto field observation are only considered as preliminary, with no ambition to solve whole described complex problems. Considering importance of the mentioned damages, more detailed observations are proposed on some sites, in which the birch injuries have been seen. According to our information, it was in localities called „Ptačí Kupy“, „Ořešník“ (Jizerské hory Mts.), „Soví sedlo nad Pomezními boudami“, „Pláně“ (Krkonose Mts.), „Koruna“, „Bor“ (Broumovská vrchovina Highlands), „Hejšovina“ (Stolové hory Mts.), „Červenohorské sedlo“, „Šerák“, and „Medvědí hřbet“ (Jeseniky Mts.).

CONCLUSIONS

In accordance with results of the damaged birch stands observation and occurrence of biotic pests in the Sudeten Mountains, it should be presumed possibility of opinion change concerning to European birch. Up to present, European birch has been supposed as a tolerant and suitable tree species for large calamity clear-cut reforestation in the mountains. For its high vitality, birch has been recommended in a large extent to form

new substitute stands in air polluted areas. Problems with birch stand damage are complex, and its solution needs more attention (than up to present) and cooperation of specialists of various disciplines – dendroecology, fytopathology, entomology. Hitherto it is not clear biotic pests portion and climatic factors portion (atypical winters 1995–1996, 1996–1997) on the mentioned damages. Besides birch, research attention should be paid to some other tree species, which have shown injury symptoms (defoliation, increased mortality) during the last years (1995–1997). The threatened species are black alder [*Alnus glutinosa* (L.) Gaertner], speckled alder [*Alnus incana* (L.) Moench] and European beech (*Fagus sylvatica* L.).

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PŘÍSPĚVEK K EKOLOGII A ZDRAVOTNÍMU STAVU BŘEZOVÝCH POROSTŮ V SUDETSKÉ SOUSTAVĚ

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Až do počátků imisní kalamity měla břiza v lesních porostech většinou podřadnou úlohu. Z lesů byla odstraňována jako plevelná dřevina a souvisejší plochy zaujímal na opuštěných zemědělských pozemcích a kalamitních holinách, které se nepodařilo zalesnit dřevinami poskytujícími vyšší hospodářský užitek (hlavně smrkem, borovicí aj.). Změněné růstové podmínky – imisní stresy, nepříznivé mikroklima imisních holin, degradace půd a přemnožení biotických škůdců – zúžily sortiment dřevin použitelných pro obnovu lesních porostů v imisních oblastech. Zde došlo uplatnění růstové vlastnosti břízy. Pro svou toleranci k imisní zátěži a klimatickým výkyvům, nenáročnost na půdní živiny, vysokou reprodukční schopnost a velký růstový potenciál již v juvenilním stadiu byly břízy vysévány a vysazovány ve většině postižených oblastí. Kromě Krušných hor se jednalo hlavně o pohoří Sudetské soustavy, devastované znečištěním ovzduší a doprovodnými stresy (hlavně přemnožením hmyzích škůdců) od konce sedmdesátých let.

Původně byla břiza v lesích Sudetské soustavy zastoupena méně než 1 %, v současnosti se zde její podíl pohybuje zhruba v rozmezí 2–5 %, což představuje celkovou rozlohu cca 5 130 ha. Pro obnovu lesních porostů byla používána téměř výhradně břiza bělokora (*Betula pendula* Roth.). Pouze výjimečně (z výzkumných důvodů) se pro zalesnění používala břiza pýřitá (*Betula pubescens* Ehrh.) a břiza karpatská (*Betula carpatica* W. et K.), které mají uplatnění i na podmáčených a zamokřených půdách.

Zhoršení zdravotního stavu březových porostů bylo poprvé pozorováno v Orlických horách, a to v roce 1995. Na jaře byl zaznamenán zvýšený výskyt mšic (*Phyllaphis fagi* L. aj.), bejlomorka (*Cecidomyiidae*) a viróz, které místy postihovaly až 30 % asimilačního aparátu. Jednotlivě se vyskytovala píďalka březová

(*Biston betularius* L.). Po poškození těmito škůdci následovala tvorba jánských prýtlů, které do konce vegetačního období nestačily vyžrát. V průběhu zimy byli pak postižení jedinci poškozeni mrazem. V následujícím roce (1996) poškozené břízy rašily později (většinou sekundárními výhony), byly opět atakovány biotickými škůdci a přes zimu poškozeny mrazem. V roce 1997 na některých lokalitách již rašilo méně než 50 % jedinců. Ti byli navíc silně poškozeni pozdními mrazy ke konci května, a to zejména v porostních okrajích a v prosvětlených porostech. Jen necelých 30 % z nich pak vyrašilo z proventativních pupenů. Výskyt bejlomorka a mšic v roce 1997 byl méně častý než v roce předchozím (i zde však opět docházelo k šíření viróz a předčasnému opadu listů), výskyt píďalky březové a bělokoka se zvýšil.

Shodné symptomy i dynamika poškození byla zjištěna v dalších pohořích a vrcholnách Sudetské soustavy – v Jizerských horách, Krkonoších, na Broumovských stěnách a v Jeseníkách. K nejvýraznějšímu poškození došlo v oblastech s vrcholovým fenoménem (především v pásnu námrazy) a zejména pak na lokalitách chianofobních (kde dochází k vyfoukávání sněhu). Jedná se převážně o lokality, kde v průběhu osmdesátých let došlo ke značné likvidaci odumírajících smrkových porostů v důsledku působení imisně ekologických vlivů (imisní a kúrovcová kalamita).

Z výsledků šetření na pokusných plochách založených Výzkumnou stanicí Opočno je zřejmá vyšší tolerance břízy karpatské a břízy pýřité k uvedeným stresům. Vzhledem k tomu, že problém velkoplošného úhynu březových porostů je závažný a velmi aktuální, jsou k jeho řešení doporučována výzkumná šetření, která by měla vyústit v návrhy optimálních druhových skladeb lesních porostů na zvláště exponovaných lokalitách.

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EPICUTICULAR WAXES OF SPRUCE *PICEA ABIES* (L.) KARST. NEEDLES AS INDICATORS OF AIR POLLUTION IN THE ORE MTS.

EPIKUTIKULÁRNÍ VOSKY U JEHLIC SMRKU *PICEA ABIES* (L.) KARST.
JAKO INDIKÁTOR ZNEČIŠTĚNÍ OVZDUŠÍ V KRUŠNÝCH HORÁCH

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ABSTRACT: After winter 1995/96 the assimilatory apparatus of spruce *Picea abies* (L.) Karst. was heavily damaged in the region Ore Mts. The destruction of needles was analysed by evaluating the changes of epicuticular wax structure with the help of SEM and quantitative determination of waxes. The most intensive wax degradation and the lowest amount of wax on needles was evident at the highest altitudes. Assimilatory apparatus was not damaged at *Picea pungens* Engelman. In the control stands in regions with minimal pollutant load there were no destructive changes of epicuticular waxes even in the highest altitudes.

Picea abies (L.) Karst.; *Picea pungens* Engelman; spruce; epicuticular waxes; air pollution; degradation; structure

ABSTRAKT: Po zimě 1995/96 došlo v Krušných horách ke značnému poškození asimilačního aparátu smrku *Picea abies* (L.) Karst. Destrukce vosků na jehlicích byla analyzována prostřednictvím změn struktury epikutikulárních vosků pomocí SEM a kvantitativního stanovení vosků. Nejintenzivnější destrukce vosků a nejnižší množství vosků u jehlic bylo patrné v nejvyšších nadmořských výškách. Asimilační aparát *Picea pungens* Engelman nebyl poškozen. V kontrolních porostech s minimální imisní zátěží nedošlo k destrukci epikutikulárních vosků ani v nejvyšších nadmořských výškách.

Picea abies (L.) Karst.; *Picea pungens* Engelman; smrk; epikutikulární vosky; znečištění ovzduší; degradace; struktura

INTRODUCTION

Forest damage caused by air pollution in the region Ore Mts. lasts already from the 1960s. In the recent period the problem has seemed to be solved. However the winter 1995/96 did not prove this fact. Long winter with numerous frost deposits in higher altitudes and unfavourable atmospheric conditions caused damage of trees in the altitude 600 m and higher. The higher the altitude was, the more intensive the damage was. At *Picea abies* (L.) Karst. majority of the stands was damaged. In spite of it there are individuals in the stands that are significantly more tolerant to air pollution.

The aim of the present study was to determine negative changes of assimilatory apparatus using the examination of structure and amount of epicuticular waxes in the region with high pollutant load.

Since the epidermis with its cuticle and epicuticular waxes is the interface between a plant and its atmospheric environment, it is continuously exposed to natural and anthropogenic influences. Epicuticular waxes of conifer needles have numerous functions and roles. The protective role of epicuticular waxes is particularly important for conifers that have to ensure their investment

in leaf tissue for several years (Chabot, Chabot, 1977).

Due to the changed chemical microenvironment of the needles, the conifers are predisposed to various biotic and abiotic stresses. Since the epicuticular waxes are one of the first targets of a variety of air pollutants, they can be widely used as an early indicator of air pollution effects (Turunen et al., 1995).

Studies of the epicuticular wax of conifer needles revealed that the structural degradation of tubular wax crystals is greatly accelerated by air pollution. Since then this result has been repeatedly confirmed (Turunen, Huttunen, 1990). Several authors have postulated that damage of the wax causes changes in the rate of photosynthesis and transpiration, and may affect the growth or vitality of the tree (Huttunen, Laine, 1983).

Degradation of the epicuticular waxes which appears as a fusion on wax tubes in the epistomatal chambers and finally results in an amorphous appearance of the waxes, is the most common micromorphological injury type observed in studies on *Picea abies* (L.) Karst. The rate of erosion correlates well with the level of air pollution (Turunen, Huttunen, 1990).

MATERIAL AND METHODS

Sampling took place in the region Ore Mts. (Janov) in October, 1996. Samples of *Picea abies* (L.) Karst. were taken at the altitudes 600 m, 700 m, 800 m and 860 m. Samples of *Picea pungens* Engelman were taken at the altitudes 620 m and 800 m. At *Picea abies* (L.) Karst. the samples were collected from heavily damaged trees and also from moderately damaged trees that sporadically appeared in the stands, while the trees of *Picea pungens* Engelman were not damaged. Considerable shedding of needles was evident at second year-class needles of heavily damaged trees (the youngest needles in the critical winter 1995/96). Stands of *Picea abies* (L.) Karst. at Dražanská vrchovina (altitude 620 m) and Brdy (altitude 860 m) were chosen as control stands. All observed trees were 18 years old. Study material was collected from the fourth whorl in the upper part of the crown of very damaged as well as tolerant trees and the epicuticular wax structure of second year-class needles was analysed using SEM Tesla BS 300 at a magnification 3000 x in a laboratory of electron microscopy at Mendel University of Agriculture and Forestry, Brno. Quantitative analysis of epicuticular waxes of needles from all altitudes was made from the same material using the method developed by Moseley (1983), Günthardt et al. (1994). In this study the total amount of sulphur in needles in all observed stands was also determined. The chemical analysis was made using the method Leco.

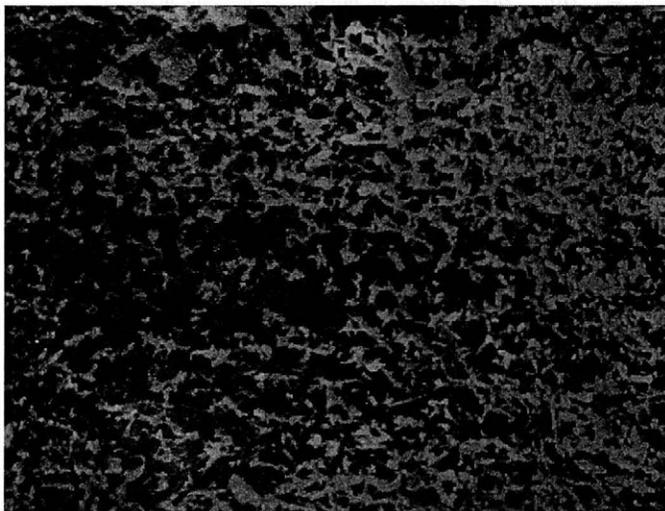
RESULTS AND DISCUSSION

Spruce needles that are not damaged are covered with tube structure of epicuticular waxes which are well noticeable in stomata (Fig. 1). Air pollution causes negative changes of epicuticular waxes. Air pollution

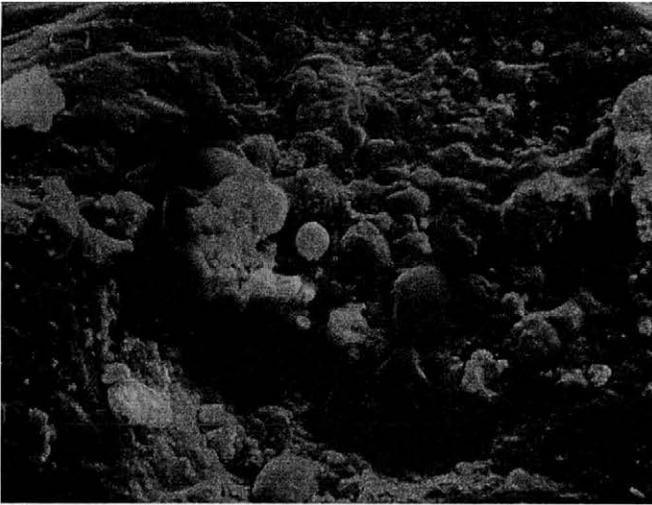
load of needles manifests not only with changes of epicuticular wax structure, but also with loss of total wax amount (Günthardt et al., 1994; Bednářová, 1996, 1997; Huttunen, 1985). This process was confirmed in the present study as well. Degradation of the epicuticular waxes appears as a fusion of wax tubes in the epistomatal chambers and finally results in an amorphous appearance of the waxes (Fig. 2). Turunen, Huttunen (1990) refer that the rate of erosion correlates well with the level of air pollution, which was proved in this study as well. Fig. 2 shows considerable degradation of epicuticular waxes at heavily damaged trees of *Picea abies* (L.) Karst. at the altitude 860 m. Fig. 3 shows moderately damaged trees at the same altitude. The structure of epicuticular waxes is less changed. The damage of assimilatory apparatus was not visible in these trees, but the epicuticular waxes already show latent damage. Spruce stands in the altitude 700 m showed low degree of wax destruction. The least damaged wax structures were in the stands in the altitude 600 m.

Picea pungens Engelman did not show damage of needles caused by air pollution. Wax destruction was not observed even at the highest altitudes (Fig. 4).

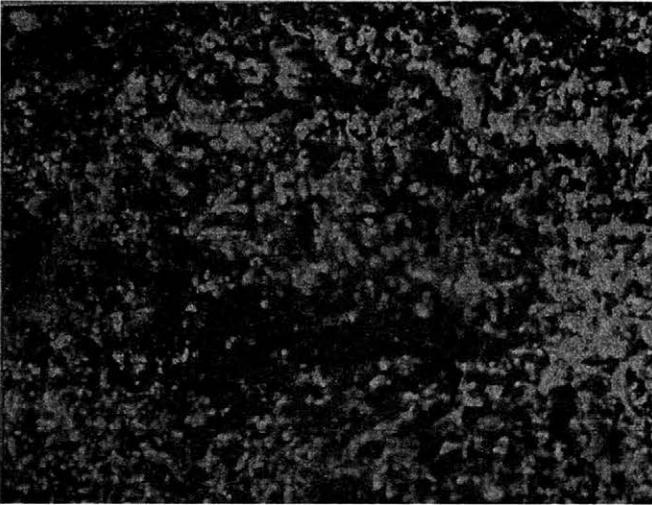
The degradation of epicuticular waxes at *Picea abies* (L.) Karst. intensified with increasing altitude in the Ore Mts. Degradation of epicuticular waxes was connected with loss of wax amount on needles. The amount of waxes lowered with increasing altitude and pollutant load. Tab. I shows changes of epicuticular wax amount at spruce. The highest loss of waxes was observed in the stands in altitude 600–700 m. This level was also critical for epicuticular wax destruction. The relation between altitude and amount of waxes on needles is expressed by linear regression on Fig. 5 ($r^2 = 0.77$). The total amount of sulphur in needles was determined in observed trees from all altitudes. The amount of sulphur in needles increased in correlation with increasing alti-



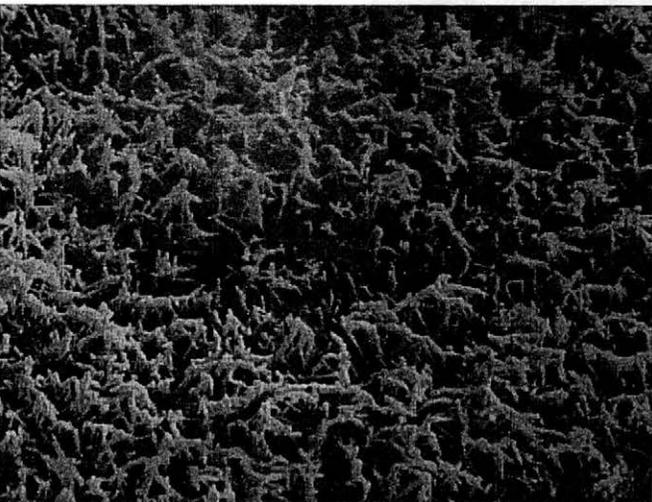
1. Epicuticular waxes at *Picea abies* (L.) Karst., needles not damaged. Altitude 860 m – Brdy



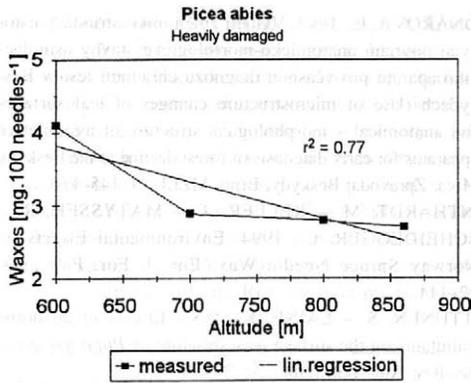
2. Epicuticular waxes at *Picea abies* (L.) Karst., needles heavily damaged. Altitude 860 m – the Ore Mts.



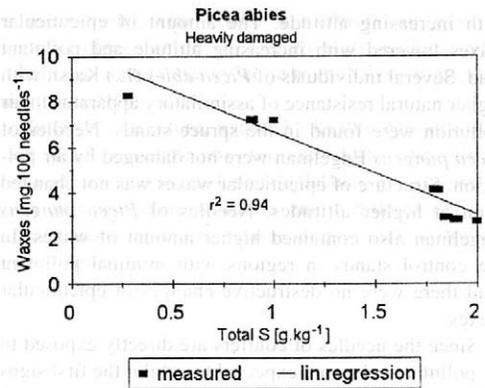
3. Epicuticular waxes at *Picea abies* (L.) Karst., needles moderate damaged. Altitude 860 m – the Ore Mts.



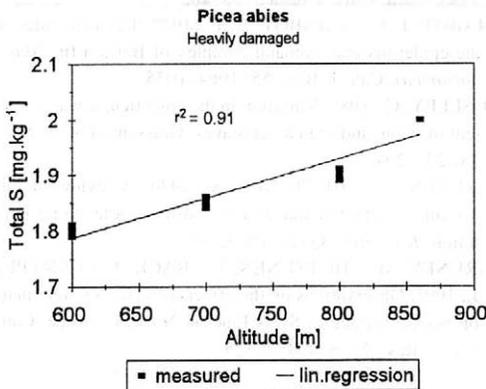
4. Epicuticular waxes at *Picea pungens* Engelman, needles not damaged. Altitude 820 m – the Ore Mts.



5. Dependence of the amount of needle surface waxes on the altitude



7. Relation between the amount of needle surface waxes and sulphur content in needles



6. Relation between the amount of needle sulphur content and the altitude

connected with loss of epicuticular waxes (Fig. 7). ($r^2 = 0.94$).

Monitoring the fusion of fully developed current wax tubes in stomatal areas provides the best information about the direct effects of air pollutants on the epicuticular waxes of conifer needles. The rate of erosion correlates well with the level of air pollution (Turunen, Huttunen, 1990). Degradation rate of the epicuticular wax can be used as a bioindicator of the general degree of air pollution and it can characterize the level of damage of assimilatory apparatus. The results show that the epicuticular waxes react on pollution first, however there is no damage evident on the entire leaf amount of tree yet.

CONCLUSIONS

Considerable changes of epicuticular wax structure were found at *Picea abies* (L.) Karst. in the region Ore Mts. The degradation of epicuticular waxes intensified

tude and damage of assimilatory apparatus. The relation between sulphur amount and altitude is evident on Fig. 6 ($r^2 = 0.91$). Great amount of sulphur in needles was

I. The amount of epicuticular waxes in needles

Place of observation, altitude	Species (<i>Genera Picea</i>)	Degree of forest damage	Waxes amount mg.100 needles
Janov 600 m	<i>Picea abies</i>	heavily	4.10
		moderately	6.10
Janov 700 m	<i>Picea abies</i>	heavily	2.89
		moderately	3.63
Janov 800 m	<i>Picea abies</i>	heavily	2.80
		moderately	3.33
Janov 860 m	<i>Picea abies</i>	heavily	2.71
		moderately	3.33
Janov 600 m	<i>Picea pungens</i>	not damaged	13.12
Janov 820 m	<i>Picea pungens</i>	not damaged	13.06
Drahanská vrchovina 620 m	<i>Picea abies</i>	not damaged	7.19
Brdy 860 m	<i>Picea abies</i>	not damaged	7.20

with increasing altitude. The amount of epicuticular waxes lowered with increasing altitude and pollutant load. Several individuals of *Picea abies* (L.) Karst. with higher natural resistance of assimilatory apparatus to air pollution were found in the spruce stands. Needles of *Picea pungens* Engelman were not damaged by air pollution. Structure of epicuticular waxes was not changed even at higher altitudes. Needles of *Picea pungens* Engelman also contained higher amount of waxes. In the control stands in regions with minimal pollutant load there were no destructive changes of epicuticular waxes.

Since the needles of conifers are directly exposed to air pollutants, they are expected to exhibit the first signs of damage caused by air pollution. Colour changes and shedding of needles were used as bioindicators of damage by air pollution, but they may be caused by many other factors as well. Before the needles shed, they show various stages of damage that can be detected by SEM. Rate of epicuticular waxes degradation can be used as an indicator of the level of air pollution. Epicuticular waxes characterize very well the level of forest damage caused by air pollution and their study enables to reveal forest damage already in the latent period.

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EPIKUTIKULÁRNÍ VOSKY U JEHLIC SMRKU *PICEA ABIES* (L.) KARST. JAKO INDIKÁTOR ZNEČIŠTĚNÍ OVZDUŠÍ V KRUŠNÝCH HORÁCH

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Dlouhotrvající zima 1995/96 a nepříznivé rozptýlové podmínky v Krušných horách měly za následek opětovně značné poškození asimilačního aparátu smrku *Picea abies* (L.) Karst. Nejvíce byl poškozen nejmladší ročník jehličí. V porostech se však našli i jedinci s přirozenou odolností.

Cílem práce bylo studium změn u epikutikulárních vosků, nacházejících se na povrchu jehlic. Tyto vosky tvoří nejzevnější ochrannou vrstvu pro jehlice, ale jsou také jako první imisemi poškozovány. Následkem imisní zátěže dochází k úbytku epikutikulárních vosků a ke změně struktury vosků. Odběr vzorků byl proveden v říjnu 1996 na LS Janov u *Picea abies* (L.) Karst. v nadmořské výšce 600, 700, 800 a 860 m, vždy ze silně poškozených stromů a jedinců tolerantnějších. Kromě toho byl studován i smrk *Picea pungens* Engel-

man ve výšce 620 a 820 m n. m. Tento smrk nejevil známky poškození asimilačního aparátu. Jako kontrola byly odebrány vzorky z porostů s minimální imisní zátěží na Dražanské vrchovině v nadmořské výšce 620 m a v Brdech ve výšce 860 m n. m. Všechny sledované porosty byly ve stáří 18 let. Vždy byly sledovány změny struktur epikutikulárních vosků pomocí rastrovacího elektronového mikroskopu u druhého ročníku jehličí (nejmladší ročník jehličí v kritické zimě 1995/96) a analyzováno množství epikutikulárních vosků na povrchu jehlic. U smrku *Picea pungens* Engelman nedošlo ke změnám struktury epikutikulárních vosků. U *Picea abies* (L.) Karst. byla patrná destrukce vosků v Krušných horách i u stromů odolnějších. Při zvyšující se nadmořské výšce se stupňovala degradace struktur epikutikulárních vosků; tento jev byl provázen sniže-

ním celkového množství vosků na jehlicích. U kontrolních porostů s minimální imisní zátěží nedošlo k poškození struktur epikutikulárních vosků a jejich úbytku ani v nejvyšších nadmořských výškách. Jako doplňující charakteristika byl stanoven obsah celkové síry v jehličí. V Krušných horách se zvyšoval obsah síry v jehličí s nadmořskou výškou porostů. Mezi obsahem síry v jehličí a úbytkem vosků na jehlicích byla prokázána vysoká korelace ($r^2 = 0,944$). K velkému úbytku vosků i změně struktur vosků došlo v porostech v nadmořských výškách nad 600 m. Rovněž byla počítána regre-

se mezi množstvím vosků a nadmořskou výškou v imisní oblasti ($r^2 = 0,777$), závislost celkové síry v jehličí na nadmořské výšce je rovněž vysoce průkazná ($r^2 = 0,910$).

Změny ve struktuře, kvantitě i kvalitě epikutikulárních vosků, vyvolané imisemi, mají dostatečně velkou vypovídací schopnost a dopad do dalších ekofyziologických procesů. Metody studia změn epikutikulárních vosků mohou sloužit ke včasné diagnóze poškození lesů imisemi.

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LEAF AREA INDEX AND ITS DEVELOPMENT IN SELECTED SPRUCE AND BEECH STANDS IN THE ORE MOUNTAINS

INDEX LISTOVÉ PLOCHY A JEHO VÝVOJ VE VYBRANÝCH SMRKOVÝCH A BUKOVÝCH POROSTECH KRUŠNÝCH HOR

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ABSTRACT: Leaf area index (LAI) is an important parameter describing the amount of assimilatory apparatus in the canopy and it is needed for many physiological and ecosystem studies. It is also an indicator of stand vitality for a wide application in forestry. This contribution brings the results of LAI measurements obtained by the indirect method using a LAI-2000 Plant canopy analyzer (LI-COR, USA) in selected Norway spruce [*Picea abies* (L.) Karst.] and beech (*Fagus sylvatica* L.) stands in the Ore Mts. during growing seasons between 1994–1997.

leaf area index; *Picea abies* (L.); *Fagus sylvatica* (L.)

ABSTRAKT: Index listové plochy (LAI) je parametr popisující množství asimilačního aparátu v korunové vrstvě porostu; je významný v ekosystémových a fyziologických studiích. Je také indikátorem vitality porostu. Široké uplatnění nachází zejména v lesnictví. Příspěvek uvádí výsledky měření indexu listové plochy získaných nepřímou metodou pomocí přístroje LAI-2000 Plant canopy analyzer (LI-COR, USA) ve vybraných smrkových a bukových porostech Krušných hor v průběhu vegetačních sezon 1994–1997.

index listové plochy; *Picea abies* L.; *Fagus sylvatica* (L.)

INTRODUCTION

Leaf area index (LAI), is defined as the one-sided projected area of leaves or needles above a given unit of surface area of ground ($m^2 \cdot m^{-2}$).

LAI is an important characteristic of forest tree stands, because the amount and quality of leaves or needles influence the radiation regime, photosynthetic production and finally also total production of the stand. Additionally, it is strongly dependent on canopy structure. Canopy structure may be thought of as the amount and organization of aboveground plant biomass. A more detailed definition of canopy structure might include the size, shape, orientation and positional distributions of various plants organs such as leaves, stems, branches, flowers and fruits (Norman, Campbell, 1989). LAI is an important canopy parameter needed for many physiological and ecosystem studies (Nemani, Running, 1989). Leaf area has been shown to be highly correlated with productivity in a variety of ecosystems, including forests (Holz, 1982; Waring, 1983; Webb et al., 1983). Waring (1985) suggested monitoring LAI as an indicator of stress in forests.

The amount and quality of leaf apparatus, and also the value of the leaf area index is dependent on:

- the age, density and health of the tree stand,
- the location – on the quality of the soil, availability of water and nutrients in the soil, exposition of the stand to the light radiation, wind, precipitations and also, for example, to pollutions.

The variation of the leaf area index in the chosen spruce and beech stands during several growing seasons in the Ore Mountains will be show.

THEORY

Leaf area index is possible to measure or estimate by many experimental methods, which we can separate into:

- direct methods,
- subjective – valuation methods,
- indirect methods.

Direct methods

The base of the direct methods of LAI estimation is destructive analysis of chosen sampled trees or the whole stand. There is assessed a value of specific leaf

area (SLA) as a ratio between fresh projected area of leaves or needles (cm^2) and their dry weight (g) for the whole tree or for different parts of the crown (the individual whorls, crown layers, needle age classes, etc.). Leaf or needle area for the whole tree or for the different parts of the crown (m^2) is obtained from the known values of SLA and from the known amounts of dry weight of leaf or needle biomass. The leaf area of sampled trees is then recalculated for the whole stand. The value of LAI is then obtained as a ratio between total leaf area of the stand and its ground area ($\text{m}^2 \cdot \text{m}^{-2}$).

It is quite clear that these methods are laborious and time consuming, and it is not possible to repeat this measurement very often in the same stand. The accuracy of these methods depends, for example, on the choice of the sampled trees, method of the leaf area estimation and on the accuracy of recalculation of the data from the sampled trees on the whole stand.

Subjective – valuation methods

Estimation of the LAI by „sight“. It is possible to estimate the value of the LAI on the base of experience with measurements of the LAI, and by comparing it with the stands where the LAI was measured. But the value of the LAI assessed by this method is very inaccurate and available just for orientation. This method can be used, for example, in the case of estimation change of the LAI in the same stand in a some time period (from season to season, etc.).

This method is often need to estimate the degree of defoliation as a diversion from the standard state of a given forest stand.

Indirect methods

These methods are based on the fact that the difference between the amount of the light radiation incoming to the stand and the amount of the radiation below the crown level (penetrating radiation) is dependent on the amount of biomass and its area within the crown level. It is possible to use different systems of light sensors (ceptometers, web of the sensors, etc.) or portable devices [Plant Canopy Analyzer LI-2000 (LI-COR, USA)], ALAI-02 (Ases, CR), ALAI-02D (Finemech, CR), Ceptometer (Degacon, USA) for measurement of the radiation above and below the crown level of the stand (Opluštilová et al., 1995).

It is necessary say that the indirect methods produce only a relative LAI value and therefore, only results obtained from the same instrument using the same acceptable method can be compared. The measurements described in this contribution have been done by Plant Canopy Analyzer LI-2000 (LI-COR, USA).

MATERIAL AND METHODS

The measurements were taken on a Norway spruce [*Picea abies* (L.) Karst.] stand (age 58 years, mean height 19.7 m, dbh 24.4 cm, density 622 trees. ha^{-1} – stand data from 1995) at Načetín aPOS research site in the Ore Mts. (NW Bohemia, Czech Republic, 50°35' N, 13°15' E, 775 m a.s.l.) and on a beech [*Fagus sylvatica* (L.)] stand at Jezeří in the Ore Mts.

Optical instrument LAI-2000 Plant canopy analyzer (LI-COR, USA) was used to measure LAI in the Norway spruce stand at the aPOS research site and in the beech stand at Jezeří in the Ore Mts.

The LAI-2000 PCA measures diffused blue light (400–490 nm) from the sky simultaneously in five equal zenith angle ranges from 0 to 75°. It is assumed in the PCA that foliage is black and scattering of blue light in the stand is negligible. To minimize the scattering effect, all PCA measurements were made under very small or no direct light conditions. This was achieved by taking the measurements near sunset or during overcast conditions.

PCA measurements in the given stands were made along five transects with five measurement points in each transect and the measurement was repeated at least six times.

The calculations of LAI from PCA measurements have been done by PCA program c2000.exe (LI-COR, USA) and in agreement with common methods for estimation of leaf area index by PCA LI-2000 (Gower, Norman, 1991). The values of LAI in Norway spruce stand were estimated by this equation:

$$\text{LAI(PCA)} \cdot 1.6 = \text{LAI}$$

where: LAI(PCA) – value obtained by PCA program.

1.6 – a clumping factor for Norway spruce (Gower, Norman, 1991).

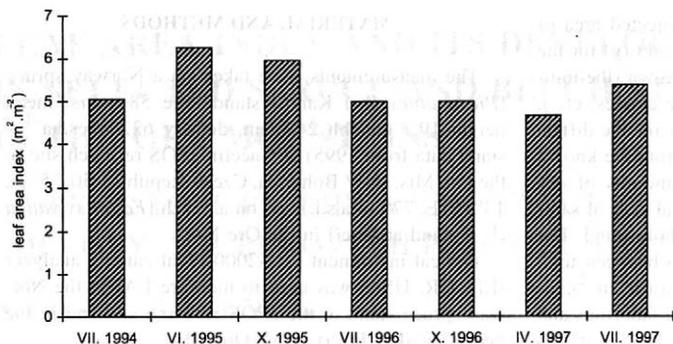
The values of LAI in the beech stand were obtained as the difference between the value of LAI(PCA) measured during the growing season (the sum of the leaf area index and the skeleton index) and LAI(PCA) measured after growing season (the skeleton index only).

RESULTS AND DISCUSSION

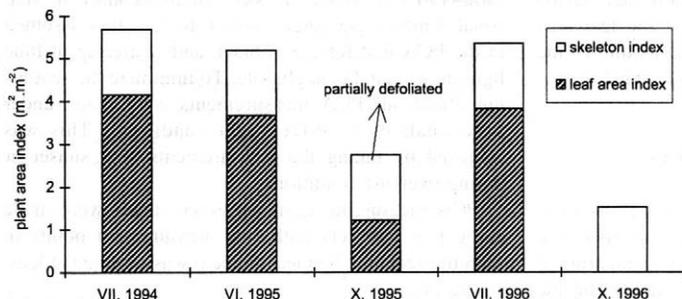
The results of measurement are shown in Figs. 1, 2, and the standard errors in Tab. I.

Norway spruce stand at Načetín aPOS research site

The value of LAI was normally developing during the seasons 1994 and 1995, but after winter 1995/1996 the value of LAI had been strongly decreased. The reason for this decrease was probably the course of weather during the winter 1995/1996 (long period of low temperature, no snow cover, wind, inversion weather, air pollutions and further factors). From July to October 1996, after the end of the growth of new shoots, the LAI appeared stable – without needle falls.



1. The average values of the LAI in the Norway spruce stand at the aPOS research site



2. The average values of the plant area index, as a sum of skeleton index and leaf area index, in the beech stand at Jezeří in the Ore Mts.

1. The average values of the LAI in the Norway spruce stand at the aPOS research site and in the beech stand at Jezeří in the Ore Mts.

Plot	VII. 1994		VI. 1995		X. 1995		VII. 1996		X. 1996		IV. 1997		VII. 1997	
	LAI	SE	LAI	SE	LAI	SE	LAI	SE	LAI	SE	LAI	SE	LAI	SE
aPOS	5.06	0.13	6.25	0.08	5.95	0.16	4.99	0.17	4.99	0.31	4.65	0.16	5.37	0.21
Jezeří	5.68	0.13	5.19	0.15	2.74*	0.13	5.34	0.32	1.52**	0.11				

SE – standard errors, * – partially defoliated stand, ** – skeleton index

There are five factors influencing the later foliage loss of older needles (1) scantiness or excess of PhaR, (2) extreme hot or cool weather, (3) insufficiency of air oxygen, (4) longer photoperiod, and (5) nitrogen fertilization (Lercher, 1988). During the vegetation season 1997 the value of LAI developed normally – slowly increased.

Beech stand at Jezeří research site

The value of the leaf area index in the beech stand was measured during the three seasons (1994–1996) and has been found to be stable („climax“ stadium of the stand).

Leaf area index depends on amounts of leaf area in a canopy and it follows the growing function. In coniferous forest stands LAI varied during growing season slowly and with smaller differentiations than in broad leaf forest stands, because broad leaf trees usually replace all leaves every year. The differences between various course of LAI and possibilities of disturbances of stands depend on different species composition, stand struc-

ture and function, allocation of stand (amount of precipitation, sun and wind exposition, slope, orientation of the site, etc.) and preservation against pollutions and extreme weather conditions (Oliver, 1981; Runkle, 1985; Sprugel, 1984; Grier, 1988).

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INDEX LISTOVÉ PLOCHY A JEHO VÝVOJ VE VYBRANÝCH SMRKOVÝCH A BUKOVÝCH POROSTECH KRUŠNÝCH HOR

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Index listové plochy (LAI) je důležitou charakteristikou lesních porostů, neboť množství a kvalita listoví ovlivňuje radiační režim porostu a jeho produkci. Při dlouhodobějším monitorování může být LAI indikátorem stresu lesních porostů.

Vývoj indexu listové plochy závisí na množství asimilačního aparátu v koruně stromu nebo v korunové vrstvě porostu a sleduje tak růstovou funkci dřevin. V jehličnatých porostech se LAI v průběhu vegetační sezony mění relativně málo ve srovnání s listnatými porosty, neboť ty obvykle každoročně nahrazují celý svůj asimilační aparát. Rozdíly mezi různým vývojem LAI a možným poškozením porostu závisejí na rozdílech v druhovém složení porostu, jeho struktuře a funkci, sklonu a orientaci porostního stanoviště a ochraně proti vzdušným škodlivinám a extrémním klimatickým podmínkám.

Index listové plochy porostů lesních dřevin lze stanovit pomocí přímých či nepřímých metod nebo subjektivním odhadem. Jednotlivé metody se liší pracností, časovou náročností, možnou opakovatelností získání potřebných dat a jejich přesností. Za nejméně náročné metody stanovení LAI s dostatečnou mírou přesnosti lze považovat metody nepřímé.

Ke stanovení indexu listové plochy smrkových a bukových porostů v oblasti Krušných hor byla použita nepřímá metoda stanovení pomocí přístroje LAI-2000 Plant canopy analyzer (LI-COR, USA). Stanovení výsledné hodnoty LAI přístrojem LAI-2000 se liší pro porosty jehličnatých a listnatých dřevin korekcí aktuální naměřené hodnoty LAI tímto přístrojem. Při měření ve smrkových porostech je nutné aktuální hodnotu LAI násobit korekčním faktorem 1,6 (Gower, Norman, 1991), zahrnujícím překryv a stínění jednotlivých jehlic na letorostech. V listnatých porostech je pak třeba znát hodnotu tzv. skeleton indexu, která se odečítá od aktuální měřené hodnoty LAI v průběhu vegetační sezony. Hodnotu skeleton indexu lze zjistit aktuálním měřením LAI přístrojem LAI-2000 v období po opadu listů.

Z dlouhodobého měření LAI smrkového porostu na ploše aPOS v Načetíně lze vysledovat náhlější pokles hodnot LAI po zimním období 1995–1996, a to pravděpodobně v důsledku extrémního průběhu počasí. Za další odchylku proti normálnímu vývoji LAI, který byl zaznamenán v období vegetačních sezon 1994 a 1995, lze považovat pozdější opad starších ročníků jehlic, prokázaný naměřením shodné hodnoty LAI v říjnu

1996 stejně jako v červenci 1996. Na pozdější opad asimilačního aparátu má vliv několik faktorů (Larcher, 1988), z nichž však v tomto případě přichází v úvahu pouze nadbytek fotosynteticky aktivní radiace, delší fotoperioda a relativně větší množství dusíku v půdě, a to v důsledku proředění korun opadem jehlic po zimním období 1995–1996 a zachování relativně stejně rozsáhlého kořenového systému.

Hodnoty LAI bukového porostu na ploše Jezeří stanovených v průběhu sezon 1994–1996 dosahují na vrcholu vegetačních sezon téměř stále stejných úrovní, což z dlouhodobějšího hlediska svědčí o klimaxovém stadiu porostu a možné vyšší odolnosti vůči poškození z hlediska silného růstového sinku listnatých dřevin.

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