Phyton (Horn, Austria) Special issue: "Bioindication ..."	Vol. 36	Fasc. 3	(69)-(76)	15.09.96

Degradation and Restoration Processes in Crowns and Fine Roots of Polluted Montane Norway Spruce Ecosystems

By

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Key words: Norway spruce, montane forest stands, multiple stress, crowns, fine roots, ectomycorrhizal fungi.

Summary

CUDLÍN P. & CHMELÍKOVÁ E. 1996. Degradation and restoration processes in crowns and fine roots of polluted montane Norway spruce ecosystems. - Phyton (Horn, Austria) 36 (3): (69) - (76)

Degradation and restoration processes, as a response of montane Norway spruce (*Picea abies* /L./Karst.) stands to multiple stress impacts, are demonstrated on four permanent research plots in the Krkonoše Mts. State of assimilative organs, crown transformation processes, regenerative capacity of fine roots and fungal fruitbody occurrence were estimated. These features, especially the occurrence of secondary shoot formation in successive series, indicate the duration and intensity of multiple stress impact to trees and their regenerative driving force.

Introduction

Forest decline is a complex multifactorial problem caused by natural and anthropogenic global environmental change imposed by acute climatic and pollution stress events. It can be considered as one of the most dangerous and significant degradation processes on landscape scale presently occurring in Central Europe. Both shoot and root responses to stress impact (as a source and sink of nutrients and assimilates) are mutually related and thus the investigation of the stress action within the whole plant context should be considered (MCLAUGHLIN 1988).

There are two principle mechanisms of damage to spruce trees: direct acute or chronic effects of pollutants on the needles and roots, and indirect effects through alteration of soil properties. A plant weakened by long-term pollutant impact is not able to ensure regular sustenance for all organs and must make

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adjustments to recover a balance between synthetic and degradation processes. Saving young organs is preferred by plants and thus old needles are usually lost. If the regenerative driving force is sufficient, proventitious (secondary) shoots are formed. However, an increased formation of secondary shoots cannot be considered as a symptom of spruce response to pollutant effects only. Secondary shoots always occur when the correlation between total biomass of active assimilative organs and outer (light income) or inner (starting carbohydrates, water and nutrients supply) conditions is out of balance (GRUBER 1994).

Material and Methods

Thirteen permanent research plots (2, 500 m^2) have been established in montane Norway spruce forests of the Krkonoše Mts., the Beskydy Mts., the Krušné hory Mts., the Lužické hory Mts. and the Slavkovský les Mts. Four plots in Krkonoše Mts. (Table 1) are introduced in this paper.Our study monitored immission input into forest ecosystems, changes in soil features (CUDLÍN & al. 1995), the state of the assimilative organs and fine roots of Norway spruce and the occurrence of fruitbodies of ectomycorrhizal fungi (CUDLÍN & CHMELÍKOVÁ 1995c).

Crown status.- Following crown features were evaluated: social class, branching type, shape of upper part of the crown, top shape, percentage and type of defoliation, percentage of needle yellowing and of secondary shoots, and fertility. Trees on the plot were grouped according to the shape of the upper part of the crown (regular, wide, narrow, irregular, and irregular with dry top; Fig.1). Percentages of defoliation and of secondary shoots were computed for each shape type.

Crown structure transformation.- One branch of the 1st order (about 25 years old) was cut off from the border of the first and second thirds of the crown of five selected trees, representing different most frequent defoliation classes within the forest stand under study. The partitioning of the total and fotosynthetically efficient needle mass (green and unshaded needles) between primary and secondary shoots of individual orders was visually estimated. In addition, status and injury of shoots and needles of single structure orders (shoot age, needle set number, percentage of defoliation, chlorosis, necrosis and green needles) were recorded (CUDLÍN & CHMELÍKOVÁ 1995b).

Status of fine roots and their regeneration capacity.- Spruce roots from ten soil cores per plot were washed and divided into four diameter classes (<1 mm, 1-2 mm, 2-5 mm, > 5 mm). Length and dry weight of each class, and total root tip number were estimated. In addition, five root tip and mycorrhiza development phases (from F1 - start of rhizogenesis to F5 - fully developed mycorrhizas) and three vitality classes (turgid root tips - absorptive function assumed, shrivelled root tips - absorptive non-functioning, dead root tips) were assessed (CHMELÍKOVÁ & al. 1992). In 1991 ingrowth bags (4 mm nylon sieve mesh) filled with a homogenized soil without roots from the upper soil horizons (F, H, A) were placed in the holes (PERSSON 1990). After two growing periods the ingrowth bags will be removed and analysed by the above mentioned method.

Fungal fruitbody occurrence.- Periodical observations of diversity and abundance of ectomycorrhizal and saprotrophic fungi were carried out.

Results

Crown status.- Fig. 1 shows relatively big differences between studied forest stands in a proportion of dead trees, as well as in a representation of different shapes of upper part of the crown. Contrarily, the average defoliation in 1993 does not differ so dramatically (Mumlavská hora 53 %, Alžbětinka 45%, Slunečné údolí 30 %, Pašerácký chodníček 42 %).

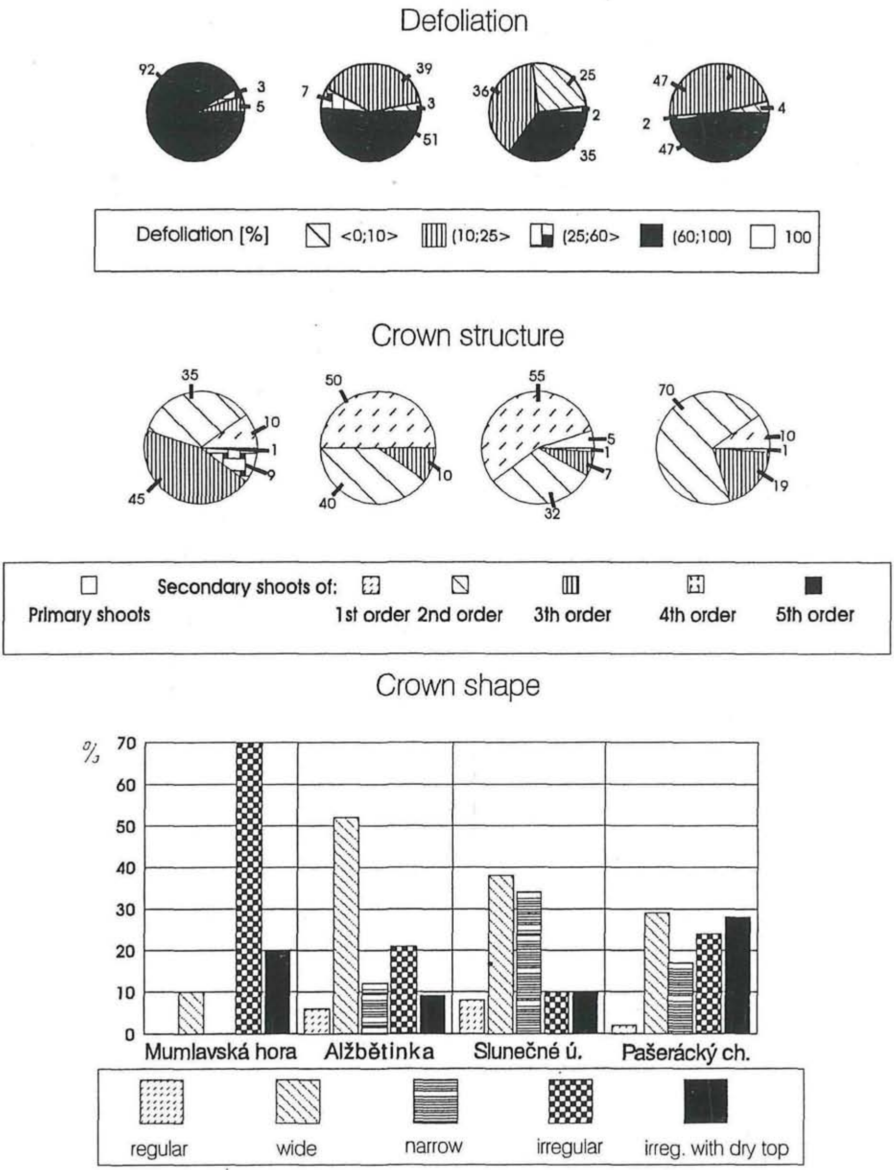

Fig. 1. Defoliation classes, needle percentage of primary and secondary shoots of individual orders, and representation of shape types of upper part of the crown of Norway spruce on permanent research plots in 1994.

Crown structure transformation.- The difference in information obtained from defoliation class determination and crown structure transformation analysis (Fig. 1) can be found in the comparison of these data for Alžbětinka and Pašerácký chodníček sites. Defoliation classes of these two forest stands are very similar but crown structure differs. The forest stand in the Alžbětinka plot seems to be under shorter stress exceedance and its adjustment- and regenerative capacity is a bit lower compared to the Pašerácký chodníček plot. The defoliation classes and crown structure transformation, and shapes of upper part of the crown in the Mumlavská hora stand show the long-term stress exceedance and weak regenerative capacity of this stand.

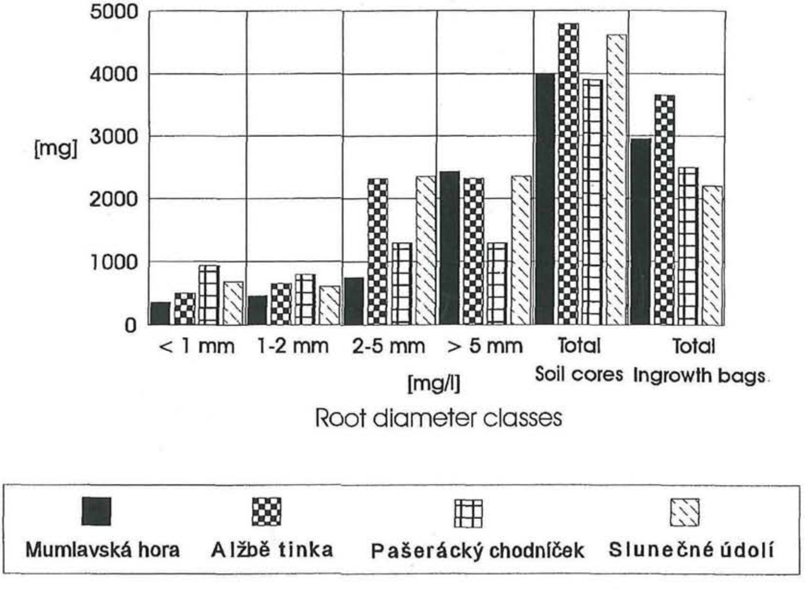

Fig. 2. Root dry weight of Norway spruce from soil cores in 1994 and root ingrowth bags from permanent research plots (mean from 10 samples per plot) in 1993.

Status of fine roots and their regenerative capacity.- The highest quantity of fine roots (roots with diameter less than 1 mm) was found in soil cores from a forest stand under strong climatic stress impact (Pašerácký chodníček plot, Fig. 2). The lowest values were counted in plots situated in the most exposed western Krkonoše plots (Mumlavská hora and Alžbětinka). However, the trees from the Alžbětinka plot proved to have the highest regeneration potential, i.e the highest quantity of roots in ingrowth bags (Fig. 2) albeit with the lowest percentage of turgid root tips (Fig. 3).

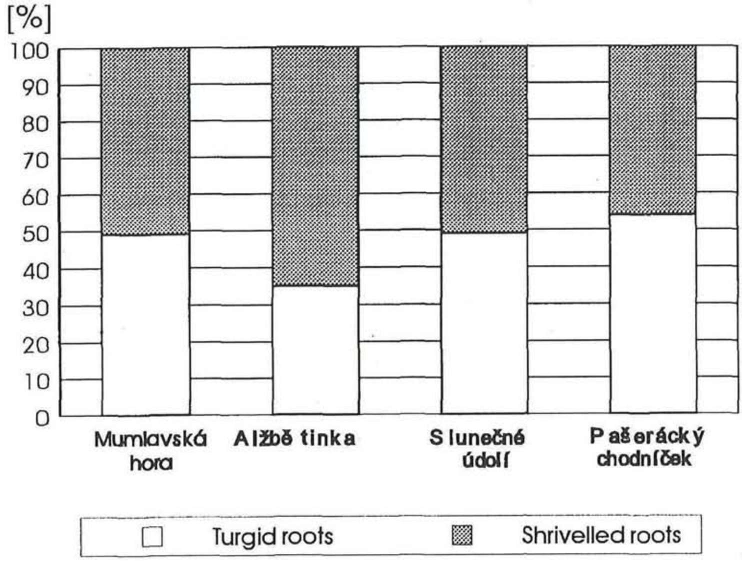

Fig. 3. Contribution of turgid and shrivelled roots of Norway spruce in ingrowth bags from permanent plots in 1993.

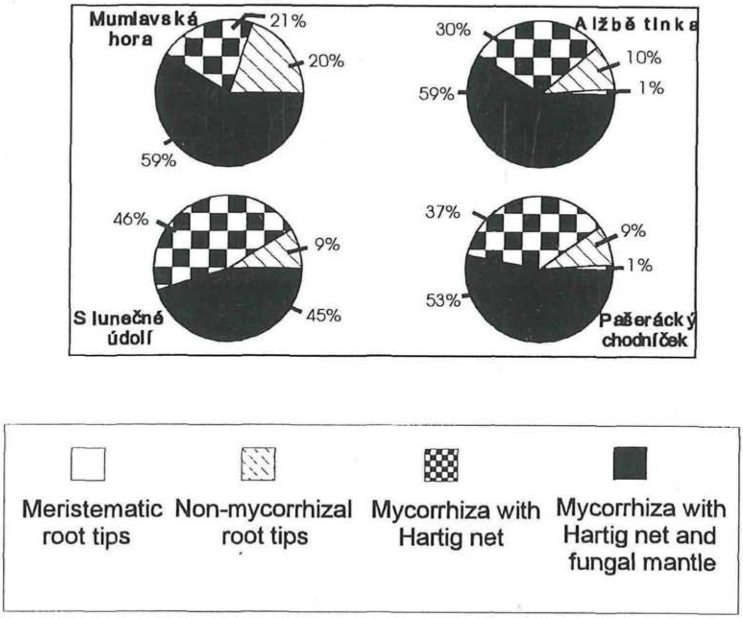

Fig. 4. Contribution of non-mycorrhizal root tips and mycorrhizas of Norway spruce in ingrowth bags from permanent plots in 1993.

The fine roots ingrown into bags on the plot with the most extreme conditions, Mumlavská hora, had the highest percentage of non-mycorrhizal root tips, but the same proportion of fully developed mycorrhizas in comparison with Alžbětinka and Slunečné údolí plots. Together with the roots from the Pašerácký chodníček plot, where the highest percentage of noncompletely formed mycorrhizas without fungus mantle was observed, they can be considered as roots with retarded mycorrhiza development (Fig. 4).

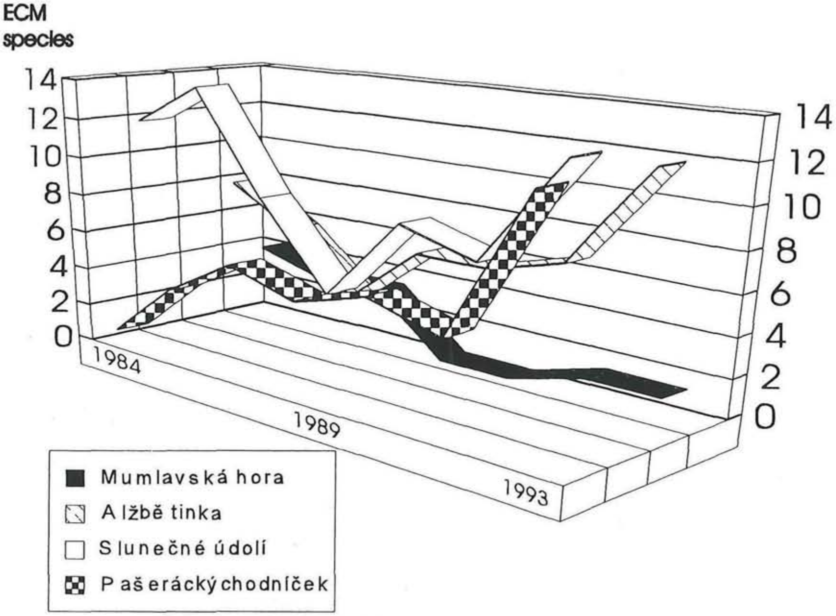

Fig.5. Number of ectomycorrhizal fungal species on permanent plots from 1984 to 1994.

Fungal fruitbody occurrence.- Numbers of ectomycorrhizal fungal species on permanent plots have changed very dramatically during the last 10 years (Fig. 5). Species diversity on Alžbětinka and Slunečné údolí plots was lowest in 1987. Contrarily, it has been increasing continuously on the Pašerácký chodníček plot. During the last 10 years the heaviest and most protractive decline of species has been recorded on the most exposed Mumlavská hora plot.

Discussion

Periodic investigations of defoliation, needle damage, regeneration processes in the crown, status and regenerative capacity of fine roots, and ectomyccorhizal fungi occurrence may detect changes in forest stands due to fluctuating environmental impacts, including atmospheric pollution (CUDLÍN & ŠIFFEL 1992). This enables us to specify the critical limits for forest stands under different site conditions more precisely (CUDLÍN & CHMELÍKOVÁ 1995a).

Individual shapes of upper part of the crown (from the regular to the irregular shape with dry top) show us the deterioration of growth conditions and multiple stress exceedance in forest stands under study (Fig. 1). The dual features of regenerative processes in the crown and fine roots and the mycorrhizal potential of the tree are sufficient indicators of the regenerative driving force of individual trees. The occurrence of shoot formation in successive series (GRUBER 1994) and progressive damage to older shoot series can be considered simultaneously as indicators of stress exceedance and of a regenerative driving force (together with fine root regenerative capacity). In future the regenerative potential of fine roots could be computed through comparison of quantitative and qualitative features of roots including ectomycorrhizas occurring in the soil cores, with roots ingrowing into ingrowth bags substituted for removed cores.

Each forest ecosystem responds in an individual way to long-term multiple stress impacts (CUDLÍN & CHMELÍKOVÁ 1995c). Forest stands which are relatively protected by their topographic situation resist damage for a relatively long time (e.g. Slunečné údolí plot). Gradually, a deterioration of certain measurable characteristics such as fructification and diversity of ectomycorrhizal fungi can be observed (Fig. 5). Subsequently, the health of the forest stand deteriorates rapidly (often in connection with a mass yellowing of needles). In future years, the regeneration of both above- (primary-like secondary shoot formation) and below-ground parts of the tree (fine root regeneration, adaptation of ectomycorrhizal fungi) may be observed frequently. Spruce forest stands subjected to greater levels of environmental stress impacts (higher elevation, greater exposure, adverse soil conditions) start to create secondary shoots in succesive series, after a shorter phase of resistance and health deterioration (e.g. Alžbětinka, Pašerácký chodníček plots). The permanent needle loss caused by chronic multiple stress imposed by acute climatic and pollution stress periods can be compensated in this way for a long time (sometimes more than 20 years). In case the stress decreases the trees regenerate step by step. Under long-term stress continuation the trees die after exhausting their energetic supply (e.g. Mumlavská hora plot).

Acknowledgments

This research was supported by the grant project CEC (Abatement Strategy and Environment in the Black Triangle) and project of the Grant Agency of the Czech Republic no. 204/94/0832.

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