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Recognition of Stages of Montane Norway Spruce Response to Multiple Stress Impact Using Crown and Branch Structure Transformation Analysis

By

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Summary

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Crown structure transformation (formation of secondary shoots of different orders in successive series on damaged and/or defoliated branches) is a very sensitive indicator of life history analysis of the tree. Response of six probably autochthonous Norway spruce stands in the Krkonose Mts. to synergistic action of natural and anthropogenic stress impacts has been investigated using selected indicators since 1992. Tree crowns on the plot were visually investigated and classified into several categories of crown structure transformation. One or more trees from most frequent categories were selected for investigation of the branch structure transformation. Distinct secondary shoot formation, which compensates a defoliation of primary shoots, indicates overcharging of „stress exceedance starting level". „Significant harmful effect time" can be detected by estimation of the time of termination of annual wood production of primary shoots. Trends of annual wood production time series of the branch base and of the sum of all lateral shoots of branch investigated inform us about possible subsequent development of the branch.

Introduction

Montane forests have been under long-term synergistic chronic effects of natural and anthropogenic stress impacts imposed from time to time by acute climatic and pollution stress events. Course of damages to needles, caused by chronic and acute stress impacts, and of regenerative responses of the branches

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were not distinguishable in past, using either defoliation observation or dendrochronological methods (GRUBER 1994).

The aim of this paper is to introduce our method of branch structure transformation analysis, demonstrated on the example of six montane forest stands in the Krkonose Mts. (CUDLÍN & al. 1995, 1999), as a basis for studies of forest stand stress response history, and to propose this approach for other ecological applications.

Material and Methods

Crown status estimation

All trees on the permanent plots were monitored for mean defoliation, defoliation of the primary structure, percentage of secondary shoots (LESINSKI & LANDMAN 1985), and some other routine parameters (ICP Forest Programme). From these parameters two crown transformation types with four progressive phases were derived:

A. Mosaic transformation type.- Crowns with different injury types (LESINSKI & LANDMAN 1985), counteracted by weak or strong secondary shoot formation. The rate of this compensation results in the value of total crown defoliation. Phase 1 (M1) - defoliation from the stem; phase 2 (M2) – sub-top injury and/or beginning peripheral (ends of primary branches) injury, often in combination with phase 1; phase 3 (M3) – prevailing peripheral injury, often in combination with phase1 and/or sub-top injury; phase 4 (M4) - top injury and/or whole dead branches, often in combination with phases 1, 2 and 3.

B. Equalized transformation type.- Crowns with equalized injury type; four phases of increasing intensity correlate linearly with total crown defoliation (E1: 25-34 %, E2: 35-44 %, E3: 45-59 %, E4: > 60 %).

Branch analysis

One branch (age of 30 to 50 years) from 5 to 10 trees, representing the most frequent categories of crown transformation, was cut for analysis below the juvenile part of the crown, mostly from the border of the fourth and fifth sections of the crown length. The windward side of the crown, supposed to be the most exposed to airborne pollution, was sampled. The partitioning of the foliated shoots between primary and secondary shoots of single orders, formed in successive series (GRUBER 1994), was estimated using results of tree ring counting of shoots thicker than 5 mm.

Dendrochronological analysis

Cookies from the base of the sampled branches were cut, scanned and analysed by DendroScan software. Missing annual rings and other disproportions were corrected by cross-dating methods. Annual rings of perpendicular sections from small shoots (thicker than 5 mm) were counted under a microscope in two directions. Time series of the annual wood production from all shoots were prepared.

The annual wood production (the area between two subsequent growth ring boundaries) of a particular structure order was obtained by the sum of the annual net wood production of all shoots of the same order during their whole life (after elimination of part of the annual increment, formed due to the support from assimilates, originating from a shoot of the subsequent structure order). Time series of annual wood production of regular and secondary structure orders formed in successive series were compared (CUDLÍN & al. 1999). If the annual wood production of the secondary structure order is greater than the annual wood production of regular shoots for some period, the annual wood production at the branch base is maintained mainly by export of assimilates from the secondary shoots. This phenomenon can be called "secondary shoot prevailing".

For modelling of trends of time series of annual wood production of the branch base and of the sum of all lateral shoots of branch investigated after stress exceedance starting time, the second degree (quadratic) polynomial equation and modified exponential equation were chosen. Kendall's tau test was used to determine if the computed trend models of both time series are stationary. We determined whether the trends of annual wood production of the branch base and of the sum of all lateral shoots of branch investigated are upward (+), downward (-) or stationary (0).

Results and Discussion

Different indicators, derived from studies on crown and branch structure transformation, were selected to recognize critical periods in the stress response history of the tree - "stress exceedance starting time", "significant harmful effect time", length of "secondary shoot turnover period" and period when either degradation (exhaustion phase) or regenerative processes (recovery phase) prevail. Characterization of above mentioned indicators using dendrochronological analysis is given in Table 1. Regarding to the time and labour consuming branch structure studies, indicators of the same processes have been looked for in the crowns of the sampling trees using binoculars (Table 1).

Table 1. Indicators of critical phases in branch and crown structure transformation (see Fig. 1) as a response of Norway spruce to multiple stress impact.

Phase of response to stress impact	Indicators	
	Branch	Tree
Stress exceedance	Distinct, several years decline of annual wood production at the branch base, caused by primary shoot injury, and followed by increased formation of secondary shoots	Defoliation of primary structure ≥ 50%
Significant harmful effect	Termination of annual wood production of primary structure	Dry top of branches (decline of the primary structure)
Secondary shoot turnover period	1.Number of secondary structure order prevailing in annual wood production 2.Number of secondary structure orders formed	Trees without either exhaustion nor regeneration processes (see below for explanation)
Exhaustion process	Significant reduction of annual wood production both of the branch base and of the sum of all lateral shoots of branch investigated in last growth periods	1.Total defoliation > 40 % and simultaneously transformation categories M3, M4 (percentage of secondary shoots > 60 %) 2.Transformation categories E3, E4
Regeneration process	Significant increase of annual wood production both of the branch base and of the sum of all lateral shoots of branch investigated in last growth periods	Total defoliation ≤ 20 % and simultaneously transformation categories M3, M4 (defoliation of primary structure ≥ 80 %)

Crown transformation of trees, representing the most widespread categories of crown structure transformation, as well as structure transformation of their sampling branches, were described in detail using these indicators (CUDLÍN & al. 1999). The stress response history reconstruction for individual Norway spruce trees, subjected to multiple stress impact of different duration and intensity in the studied Norway spruce forest stands, was performed using the hypothetical stress response curves (see explanation in Fig. 1).

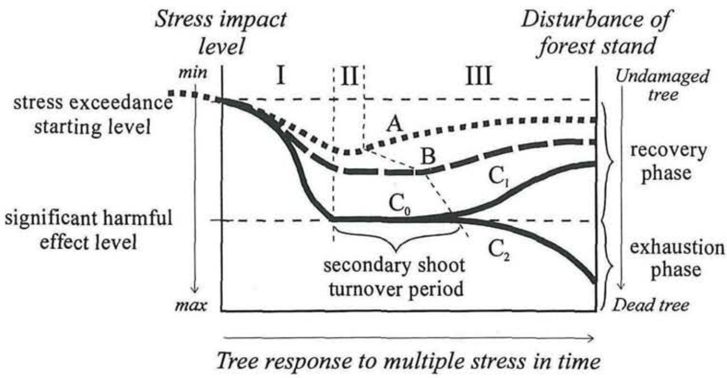

Fig. 1. Hypothetical stress response history reconstruction of Norway spruce trees subjected to multiple stress impacts of different duration and intensity.

A – stress response history of trees, where multiple stress impact exceeded "stress exceedance starting level"; recovery phase succeeded tree injury in short time. B – stress response history of trees, where multiple stress impact exceeded "stress exceedance starting level"; recovery phase almost compensated tree injury after shorter or longer "secondary shoot turnover period". C – stress response history of trees, where multiple stress impact exceeded "significant harmful effect level"; long-term "secondary shoot turnover period" may result in the exhaustion (C_2) or partial regeneration (C_1) of the tree.

I – Period of the tree response to multiple stress impact, exceeding "stress exceedance starting level", when degradation processes prevail temporarily upon regenerative processes. II – "Secondary shoot turnover period" - period when degradation processes are in an equilibrium with regenerative processes. III – Period of tree response to multiple stress impact, when either regenerative processes (recovery phase) or degradation processes (exhaustion phase) prevail.

Results of this study give us a better understanding of the relationship between forest stands and environmental factors and a more precise prediction of the subsequent development of these valuable forest ecosystems. In addition, this approach could be used for the evaluation of loss in wood production of trees, caused by the need of a tree to replace damaged assimilative organs by secondary shoots.

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