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Phyton (Horn, Austria) Special issue: "Bioindication ..."	Vol. 36	Fasc. 3	(7)-(14)	15.09.96

Bioindication at Forest Sites - Concepts, Practice, and Outlook

By

MICHAEL TAUSZ[1)], FRANC BATIČ[2)] & DIETER GRILL[1)]

Key words: *Picea abies*, lichens, bioindication, active monitoring, passive monitoring, forest decline, air pollution, stress.

Summary

TAUSZ M., BATIČ F. & GRILL D. 1996. Bioindication at forest sites - concepts, practice, and outlook. — Phyton (Horn, Austria) 36(3): (7) - (14).

In the course of forest decline studies in the last decade a multitude of bioindication methods has been developed. This article is a short review on selected methods used in the TEMPUS program: Passive monitoring by lichens, either in form of reactive bioindication for the assessment of stress impact on forest ecosystems or in form of accumalitve indication for monitoring of heavy metals is still an important tool in forestry. Plant cultivars particularly sensitive to certain pollutants can be used for active monitoring concepts. Forest trees, especially Norway spruce, are widely used as indication plants: Besides the commonly applied forest monitoring systems based on visual classification of canopies, we describe the use of physiological parameters of spruce needles for bioindication of stresses including non-accumulating influences.

Introduction

Forest decline phenomena observed since the early eighties in both Europe and North America intensified the interest of environmental research in bioindication methods. Bioindication of environmental stresses, no matter if biogene, man-made, or natural by origin, provides a suitable means to evaluate the impact of these variables on biological systems (ARNDT & al. 1987).

Plants are most suitable bioindicators with respect to forest ecosystems due to their sessile life and biology. In field studies the most commonly used

[1)] Institut für Pflanzenphysiologie, Karl-Franzens-Universität Graz, Schubertstraße 51, A-8010 Graz, Austria.

[2)] Department of Agronomy, Biotechnical Faculty, University of Ljubljana, Jamnikarjeva 101, 1000 Ljubljana, Slovenia.

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bioindicators are, on one hand, the forest trees themselves and, on the other, highly sensitive organisms such as lichens.

The new type forest decline is presently considered a complex disease caused by multiple environmental stresses. This is why stress-physiological principles (LARCHER 1994) are generally accepted and new bioindication methods were developed to assess the stress responses of plants.

As it is done in the course of field studies in Slovenia within the framework of the TEMPUS-program 'bioindication of forest site pollution: development of methodology and training' it is still state of art to use many different bioindication methods. However, such large scale field studies show the problems of the synoptical evaluation of such a multitude of methods and results.

In the following paper we intend to give a short survey on selected methodologies of bioindication applied among various others (further detailed information in this volume) in the course of TEMPUS-studies in Slovenia. General reviews on bioindication methods are given by SCHUBERT 1985 and ARNDT & al. 1987. We want to emphasize the field of active and passive monitoring with the help of indicator plants, and a comparably new method of using biochemical stress responses of spruce trees for bioindication purposes. An outlook on possibilities to evaluate multivariate data on field studies simultanously will be given.

The use of bioindicator plants apart from forest trees

Plants can be used for bioindication purposes in a passive or active way (TRESHOW 1984, SCHUBERT 1985, ARNDT & al. 1987). In passive bioindication the effects of air pollution impact as well as other stresses are monitored by observing/measuring symptoms on plants already present in the ecosystems. Symptoms can be stress-specific but more often they are not. In many cases it is difficult to measure the quantity and duration of the stressor.

Passive monitoring by lichens

Besides the forest trees themselves epiphytic lichens have a long tradition as passive bioindicators (FERRY & al. 1995, HAWKWORTH & ROSE 1976). Lichens have been extensively used as air quality bioindicators also at forest decline studies in Slovenia (BATIČ 1991, BATIČ & MAYRHOFER 1995). The condition monitoring of epiphytic lichen vegetation is a substitute for air pollutant measuring devices on forest decline inventory plots. Passive bioindicators are usually reactive bioindicators (SCHUBERT 1985), which respond to long lasting actions of stresses in an integral way. Sometimes passive bioindicators can be used also as accumulators of the pollutant itself (accumulative bioindication - SCHUBERT 1985). Apart from Norway spruce as accumulator of sulphur, epiphytic lichens have been used in Slovenia for screening the deposition of trace elements and radionuclides (JERAN & al. 1995).

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Active monitoring

As it is very difficult to determine the response of passive bioindicators according to the type of stress, its quantity and duration, several active bioindicators have been introduced to screen specific pollutants like SO_2, O_3, peroxyacteylnitrate (PAN) etc. (STEUBING & JÄGER 1982, TRESHOW 1984, ARNDT & al. 1987). Active bioindicators are selected plant species or cultivars with well known responses to actions of certain pollutants. These plants are exposed to the environmental conditions of the site in question (ARNDT & al. 1987). One of the best known active bioindicators is a cultivar of tobacco, BelW3, widely used for screening of ozone. After the discovery and introduction in the USA (ASHMORE & al. 1978) it was used all over the word later. Recently, there is an coordinated and integrated ICP-Crops project based on screening of photooxidants by special cultivars of white clover (*Trifolium repens* L. cv. Menna), beans, tomatoes and some other cultivars of crop plants, weeds, and meadow vegetation (ANONYMOUS 1995).

Forest condition monitoring

The use of forest trees as bioindicator plant has the advantage that one is enabled to work with the plant of interest growing in the ecosystem of interest. In particular conifers, mainly Norway spruce (*Picea abies* (L.) KARST.) have quite a long tradition as bioindicators in forestry (HANISCH & KILZ 1990). Forest condition is monitored annually by visible criteria including evaluation of needle loss and needle discolorations of spruce. In Austria this survey is based on a classification system in five steps - 1: undamaged up to 5: dead (POLLANSCHÜTZ 1984).

Bioindication of accumulating pollutants by forest trees

Due to their longer life span conifer needles are particularly useful as accumulative bioindicators (ARNDT & al. 1987). The element content in spruce needles is used as a measure for pollutant impact, which has been legally approved as threshold values of sulfur, chlorine, fluorine, and heavy metals in spruce needles.

Bioindication by physiological responses of trees - assessment of damage and early diagnosis

Visible criteria allow only a limited assessment of the extent of forest decline phenomena. This is why quantitative and more objective methods for the quantification of forest damages are still highly requested (WOLFENDEN & al. 1988). For this purpose a variety of biochemical variables of spruce needles, such as pigment concentrations, buffer capacity, the activity of PEP-carboxylase etc., has been tested in the last years (review by WILD & SCHMITT 1995).

Especially the determination and evaluation of chloroplast pigment concentrations and -ratios (LICHTENTHALER 1993), in particular chlorophyll

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measurement, has turned out a reliable measure for the physiological vitality state of spruce trees (OREN & al. 1993, TAUSZ & al. 1994).

New type forest decline is closely connected to needle chlorosis, which is a manifestation of chlorophyll degradation. When needle chlorosis is already visible, chlorophyll measurement allows a quantification of discolorations (SIEFERMANN-HARMS 1992). Moreover, early diagnosis of vitality is possible by the measurement of chlorophyll concentration because biochemical damage precedes visible symtoms and is detectable before needle yellowing or needle loss can be observed. Trees at an early stage of decline exhibit not only lower chlorophyll concentrations, but the normally needle-age-related increase of chlorophyll concentrations in the first three needle-age-classes is supressed and even inverted (TAUSZ & al. 1994).

For the application of chlorophyll concentration as bioindicator it is necessary to standardize sampling conditions with respect to diurnal and annual variations (SIEFERMANN-HARMS 1977, BERMADINGER & al. 1989). Various environmental conditions, such as the position of the harvested branches (carrying light-exposed or shaded leaves) or the social role of the sampled individual in the stand have to be taken into account. Chlorophyll concentration is dependent on additional factors: In several case studies close connections of chlorophyll loss to nutrient status were found (e. g. OREN & al. 1993). Environmental gradients, such as altitude profiles, also revealed general relations of elevation to chloroplast pigments (Fig. 1).

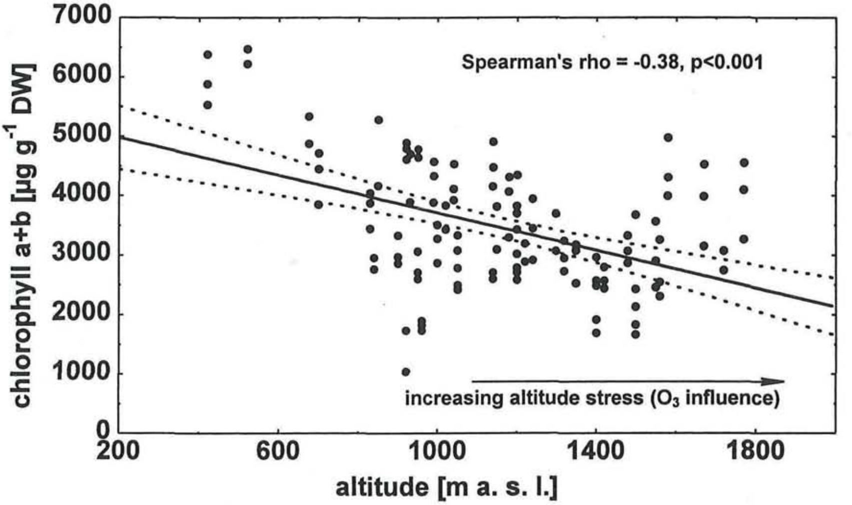

Fig. 1. Total chlorophyll concentrations of spruce needles harvested at differently elevated sites in Styria, Austria. DW = needle dry weight.

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Biochemical diagnosis of stress responses

The new type forest decline is not a simple loss of vitality, but is now generally considered a response of forest ecosystems to multiple stresses. As described by JÄGER & al. 1986 the impact of environmental stresses is associated with enhanced formation of cytotoxic free radicals. ELSTNER & OSSWALD 1994 biochemically defined cellular stress as the transition of ionic reactions to radical reactions. Plant cells counteract this radical stress by the action of a radical scavenging system (ALSCHER & AMTHOR 1988). Low molecular weight antioxidants, such as glutathione and ascorbic acid (SALIN 1988, ALSCHER 1989), carotenoids (SIEFERMANN-HARMS 1977) and antioxidative enzymes are components of the antioxidative defence system of plant cells. The measurement of these variables provide a tool to assess and quantify the stress stage of forest trees: Active responses of the radical scavenging system in the form of enhanced concentrations of antioxidants have been found either in plants exposed to oxidative stresses, such as oxidative air pollutants (MEHLHORN & al. 1986, BERMADINGER & al. 1990) or high altitude stress (GRILL & al. 1988, POLLE & RENNENBERG 1992), as well as in plants already showing decline symptoms (WILD & SCHMITT 1995). In order to use components of the antioxidative system as bioindicators, diurnal and annual rhythms of these parameters should be well-defined, and sampling procedures must be standardized in this respect (BERMADINGER & al. 1989). Furthermore, physiological parameters are not unidimensional responses to certain stresses: For instance, one has to take into account that glutathione is not only an important antioxidant but also a main compound in sulfur metabolisation. This is why glutathione concentrations can be increased in the course of antioxidative responses, but also as a consequence of sulfur impact (GRILL & al. 1982, Fig. 2). Taking into account all these facts the measurement of active stress responses allows a risk assessment for forest sites based on the present situation, including the action of non-accumulating air pollutant stresses like ozone impacts (TAUSZ & al. 1994, EHRLICH & GRILL 1994). Loss of vitality may adversely bias such evaluations, because antioxidative response (like every active metabolic action) is dependent on the level of metabolism. By relating the concentration of scavengers to chlorophyll concentration (as an indicator for vitality) the antioxidative responses remain determinable (EHRLICH & GRILL 1994). However, these analyses result in a quantification of the stress imposed on the forest trees, but the differential diagnosis of possible reasons of decline is very difficult by the separate evaluation of single parameters.

Physiological response patterns for differential diagnosis

Because of a multitude of stresses and physiological stress responses it has turned out necessary to evaluate multivariate patterns of variables. For the interpretation of response patterns multivariate statistical methods are inevitable. The simultanous evaluation of chemical and physiological bioindicators

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(chloroplast pigment concentration and composition, the antioxidants ascorbic acid and glutathione, peroxidase activity, total needle sulfur content) by factor analytic and cluster analytic methods leads to a considerable increase of the indicative value of the data compared to the interpretation of single variables (TAUSZ & al. 1996). Thus, a synthesis of the aspects of stress responses, vitality state, and accumulative pollutant impacts can be achieved.

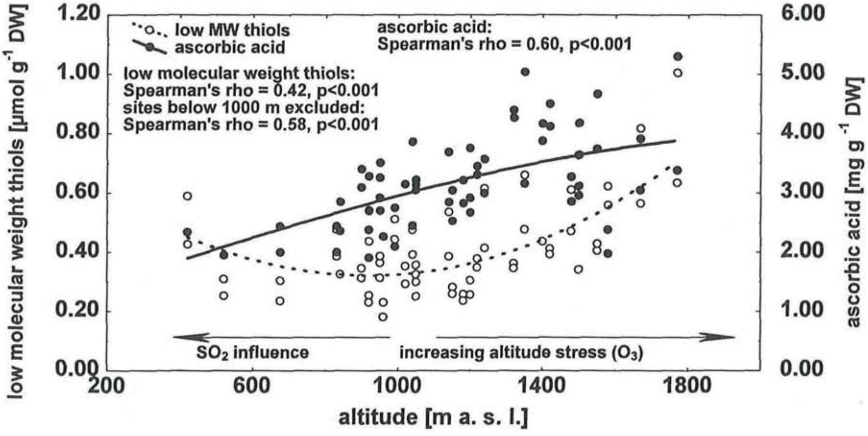

Fig. 2. Water extractable thiols and ascorbic acid in spruce needles harvested at differently elevated sites in Styria, Austria. DW = needle dry weight.

Conclusion and Outlook

In the course of field studies on forest decline in the last decade it has become evident that a complete indication of forest condition and stress impacts cannot be expected when only one or few indicators are used. In this article we worked out that different bioindication methods carried out at different levels of the ecosystem or the organism will identify different aspects of the system. Bioindication methods on test plants and plants at different levels of the investigated ecosystem (e. g. lichens versus forest trees), and methods on organism level and on biochemical level do not compete with each other but complement each other. The synoptical analysis of multivariate data provided by different methods on one study will be of essential importance in order to arrive at an overall conclusion of forest condition and risk assessment at particular case studies.

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Acknowledgements

We gratefully acknowledge financial support by the TEMPUS-Program, the Austrian 'Forschungsinitiative gegen das Waldsterben' (FIW II), the Austrian Federal Ministry of Science and Research, the Austrian Federal Ministry of Forestry and Agriculture, the Styrian Local Government, the Ministry of Science and Technology of the Republic of Slovenia, and the Ministry of Agriculture and Food of the Republic of Slovenia.

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Zeitschrift/Journal: Phyton, Annales Rei Botanicae, Horn

Jahr/Year: 1996

Band/Volume: 36_3

Autor(en)/Author(s): Tausz Michael, Batic Franc, Grill Dieter

Artikel/Article: Bioindication at Forest Sites - Concepts, Practice and Outlock. 7-14