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Complex bioindication and environmental stress assessment

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Abstract

The indicative quality of bioindicators, ranging from organelles, organs or single organisms to complex ecosystems, depends on inherent ecophysiological properties, population dynamics, and stress reactions with regard to physical and chemical changes in site conditions as described in Section 2 of the present contribution. Section 3 provides a systematic review of both typology and rational selection of bioindicators on the species, population, biocenotic, and ecosystem levels. It is to show that the primary task of bioindicators is the general determination of physiological effects in the sense of strain reactions rather than the direct measurement of environmental concentrations of stressors. Thus, in early recognition perspective the lack of specificity has the advantage of a broad-based caveat, inducive to subsequent systematic search for quantitative causal inter-relationships.

A further advantage of biomonitoring is its comparatively low cost on the one hand and the integrative recording character on the other. Contrary to these positive aspects of bioindicator use there is, however, an essential deficiency resulting from the highly variable susceptibility of the test species exposed to stressors, which leads to difficulties in comparing specific effect data. In view of such problems, the possibilities of fuzzy logic approaches for evaluative data interpretation and inter- and intraspecific comparison purposes are emphasized.

Active and passive biomonitoring approaches on the basis of single-species reactions yield spatially valid data only on condition the underlying sampling networks are implemented in compliance with geostatistical requirements or the corresponding test methodologies of variogram analysis and kriging procedures, respectively. Analogously, also the selection of complex bioindicators such as biocenoses or ecosystems must be based on rigid criteria of spatial and temporal representativeness. The last section then is a critical comparative appraisal of the problems encountered in biomonitoring, which leads to a set of suggestions for improving both the technical practicability and the data quality of biomonitoring approaches.

Keywords: Bioindicators; Chemical risk assessment; Stress; Strain

1. Introduction

Hans Selye's discovery of the stress syndrome opened a new perspective in medicine and biology. Before Selye (1936), specificity was the fundamental question of pathology, and consequently in pathological diagnosis the so-called pathognomistic signs (Virchow, 1854) were considered the most important parameters. Selye was the first to emphasize the non-specific common symptoms of diseases, which he summarized under the term ‘‘stress’’. Owing to its very general character the stress concept is used here to introduce a unified perspective into the discussion of bioindicators, and in particular complex ones, in

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order to more precisely define their scale-dependent realm of applicability and the requirements for an adequate selection of such indicators and the rational evaluation of pertinent monitoring data.

2. Stress and non-specific resistance

Stress is the state of a biotic or abiotic system under the conditions of a 'force' applied, *strain* is the response to the stress, i.e., its expression before damage occurs, while *damage* is the result of too high a stress that can no longer be compensated for (cf. Csermely, 1998). Focussing on biological systems, it is indicated for reasons of terminological clarity not to apply the term ''stress'' to fast readjustments of metabolic fluxes, photosynthetic or transpiration rates induced by fluctuations in the photon flux density, slight changes in temperature, or rapid variations in air humidity. Plants are acclimated, i.e., usually respond flexibly to such steadily occurring normal changes of cell metabolism induced by variable environmental conditions. The same applies to the diurnal fluctuations in metabolic activities, growth patterns, and in cell division and differentiation processes. Besides such fast acclimations, plants can also respond to environmental changes by means of somewhat longer-term adaptations such as modifications of size and thickness of leaves, number and density of stomata, ultrastructure and function of the chloroplasts by raising the levels of photoprotecting enzymes and of stress metabolites.

When subjected to a stress, an organism is in a state of strain. As long as the strain is completely reversible, it is said to be elastic; beyond this point or threshold, the strain will be only partially reversible, and the irreversible part is called the permanent set or plastic strain. Unlike elastic strains, plastic strains are not constant for specific stresses, since they may eventually lead to disintegration of the system (organ, organism, population, biocenosis, ecosystem) affected. Since plastic strains may be dependent on the time exposed to the stress, the time factor must be measured whenever the resistance of biological systems to plastic strains is determined. Thus, elastic resistance is a measure of the system's ability to prevent reversible or elastic strains (physical or chemical changes) when exposed to a specific environmental stress, while plastic resistance is a measure of its ability to prevent irreversible or plastic strains and, therefore, injurious physical or chemical changes (Levitt, 1980).

Before stress exposure, the organism will be in a certain standard situation of physiology that is relatively optimum within the limits of the respective site or habitat factors, e.g., light, water, nutrient supply in the case of plants. Individual stressors or complex stress events will then lead to a series of strain reactions which can be subdivided into three phases. Considering plants by way of example, they respond at the beginning of a stress event (alarm phase) with a decline of one or several physiological functions, for example, the performance of photosynthesis, transport of metabolites, and uptake and translocation of ions. Thus, the plants deviate from their normal physiological standard, and as a consequence their vitality declines. Under these circumstances acute damage and senescence will occur rapidly in plants with low stress tolerance mechanisms or low resistance minimum, respectively. Normally, at the end of this phase plants begin to activate their stress-coping mechanisms such as acclimation of metabolic fluxes, activation of repair processes, and long-term metabolic and morphological adaptations. In the following restitution phase, this leads to a hardening of the plants, which attain their maximum resistance by establishing new physiological standards (Levitt, 1980; Lichtenthaler, 1984). Under conditions of long-term stress and stress intensities exceeding the plants' stress-coping mechanisms, however, the stage of exhaustion follows, when physiological activity and vitality are progressively reduced, which causes severe damage and finally death. However, when the stressors are removed in time, i.e., before senescence processes become dominant, the plants regenerate and develop new physiological standards (cf. Larcher, 1987, 1994; Lichtenthaler, 1998).

3. Fields of bioindication

Knowledge of the existence of an environmental stress situation is the prerequisite for its solution or amelioration. In view of the different time scales of the resultant strains and their complex nature, early recognition of such situations is necessary before changes and damages become wide-spread and obvious. In this connection, habitual predictive