BIOINDICATORS

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Summary

Bioindicators of environmental quality are widely used in ecological and ecotoxicological research as well as in applied environmental conservation and protection practice. Bioindicator research is done in several ranges to identify and separate the effects of man-induced stressors from the effects of natural stressors. All three groups of organisms--microorganisms, plants and animals can be indicators of environmental quality. Stress conditions and stress-induced damage can be detected by using bioindicators. Biological indicators have been developed to assess the impact of anthropogenic activities on the environment and have been applied to current monitoring problems. Bioindicator systems are expected to play a significant role in the evaluation of effects of environmental stressors. Bioindicators are subjected to establish causal relationships between stressors and biological response at various levels of biological organization. The realization of novel technical processes creates new molecular biomarkers which are generally used to indicate exposure of organisms to contaminants.

Organisms selected as bioindicators should have certain characteristics. Integrated approaches of bioindicators are applicable in the biogeographical sciences (i.e. environmental planning, urban ecology). From this point of view, research work is done on different scale levels leading to results of different orders of magnitude.

Increased research in this area could help maximize the benefits associated with using bioindicators as "instruments" for assessing environmental quality. The use of biomonitors in the field combined with analytical chemistry and laboratory toxicity tests

allows for a complete assessment, not only of the amount of contamination present, but more importantly, of the influence the toxicant is having on the organisms of concern.

The results should be integrated in a model that refers to the multidimensional aspects of ecosystems´ response to environmental changes and to various aspects of assessing the effects of anthropogenic activities for the environment.

1. Introduction

Global climate change, reductions in biodiversity, and the potential implications of pesticide and toxic chemical releases have all raised public awareness of ecological issues in the last decade (36). Global or more local environmental changes such as increased atmospheric CO_2 concentration (13) or N deposition (14) are also likely to interact with changes in biodiversity and ecosystem processes (21,22). These environmental changes may have profound effects on ecosystem processes such as productivity, soil acidification and nutrient mineralization including aquatic ecosystems and biogeochemical cycling driven by microbial communities. Biological indicators have been developed to assess the effects of anthropogenic activities for the environment and have been applied to current monitoring problems. Bioindicator systems are expected to play a significant part in the evaluation of effects of environmental stressors. The application of bioindicators will stimulate the overall development of sustainable environmental management strategies that will anticipate and minimize anthropogenic changes and will provide both environmental administrators and scientists (23) to solve potential ecological problems human action has caused.

2. Levels of Bioindication

Bioindicator research is done in several ranges at different spatial (local, regional, global) and temporal (short-term, long-term) scales and has been developed to identify and separate the effects of man-induced stressors from the effects of natural stressors in aquatic and terrestrial ecosystems (3;23;45;54). Bioindicators interact with environmental changes at different hierarchical levels (as macromolecules, cell, organ, organism, population, biocoenosis) and range from biomolecular/biochemical to population and community-level responses. The realisation of novel technical processes in molecular biotechnology and nanotechnology (43) creates new molecular biomarkers which are generally used to indicate exposure of organisms to contaminants at lower levels of biological organization while bioindicators are typically used to reflect effects of stressors on biological systems at higher levels of organization.

Any unfavorable condition or substance that affects or blocks a metabolism, growth or development can be regarded as stress (29,45,47) . Stress can be induced by various natural and anthropogenic stress factors. The different kinds of natural and anthropogenic stress factors are listed in Table 1. We differentiate between short-term and long-term stress effects as well as between low-stress events (which can be partially compensated for by acclimation, adaptation and repair mechanisms) and strong stress or chronic stress events causing (which cause considerable damage that may eventually lead to cell and plant death). Stress is a dose-dependent matter: at low doses a stressor can have a opposite effect than at higher doses. When the threshold of stress-tolerance or stress-resistance has been passed, a short-term high level stress can in principle induce the same damage as a long-term low level stress (29).

I. Natural stress factors:

- **high irradiance** (photoinhibiton, photooxidation),
- **heat** (increased temperature),
- **low temperature** (chilling),
- **sudden and late frost,**
- **water shortage** (desiccation problems),
- **natural mineral deficiency** (e.g. nitrogen shortage),
- **long rainy periods,**
- **insects,**
- **viral, fungal and bacterial pathogens.**

II. Anthropogenic stress factors

- **herbicides, pesticides, fungicides,**
- **air pollutants, e.g. (SO_2, NO, NO_2, NO_x),**
- **ozone (O_3) and photochemical smog,**
- **formation of highly reactive oxygen species ($^1O_2$, radicals $O_2^{\bullet-}$ and $OH^{\bullet}$, H_2O_2),**
- **photooxidants (e.g. peroxyacylnitrates),**
- **acid rain, acid fog, acid morning dew,**
- **acid pH of soil and water,**
- **mineral deficiency of the soil, often induced by acid rain (shortage of the basic cations K, Mg, Ca, often Mn and sometimes Zn),**
- **over-supply of nitrogen (dry and wet NO_3-deposits),**
- **heavy metal load (lead, cadmium, etc.)**
- **overproduction of NH_4^+ in breeding stations (uncoupling of electron transport),**
- **increased UV-radiation (UV-B and UV-A),**
- **increased CO_2 levels and global climate change.**

Table 1. List of Anthropogenic Stress Factors Acting on Terrestrial Vegetation (29).

Stress conditions and stress-induced damage can be detected using bioindicators. Many animals have been used as bioindicators, including clams, mussels, fish, tadpoles, snapping turtles and earthworms (3,45).

Plants exposed to environmental and anthropogenic stressors demonstrate numerous, easily recognizeable, visual symptoms such as lesions, changes in pigmentation, stunting. Survival, reproductive activity, and clonal growth are other common measures of plant stress. Physiological, biochemical, or genetic changes such as DNA/RNA synthesis, peroxidase activity, altered respiration, leaf chlorophyll content, and fluorescence can also demonstrate exposure to stressors. There are several methods currently being developed for measuring these subcellular alterations.

Bioindicators enable us to establish causal relationships between stressors and biological response at various levels of biological organization by measuring (54):

- biochemical and physiological reactions
- deviation from the norm in anatomic, morphologic, biorhythmic and behavioral terms
- change of floristic and faunistic populations (composition and distribution)
- changes in biocoenoses including their distribution
- change in the structure and function of ecosystems including their distribution
- change in landscape characteristics.

Field biomonitors can be divided into two basic groups. The first group include the indigenous organisms, which are already present in the field and act as "passive" biomonitors. The use of native species can provide pertinent information regarding the spatial distribution of bioavailable pollutants. The second group of biomonitors consists of organisms that are either cultured in the laboratory or collected from a non-contaminated reference site and transplanted into "stressed" environments for a known period of time. Using this type of system allows the exposure time to be controlled, so that both temporal and spatial environmental changes can be determined (35).

In addition to active monitoring, which deals with test organisms exposed under standardized and field conditions, passive biomonitoring by bioindicators enables us to analyse visible or invisible damage or any deviation from a normal state. Thus by monitoring the change of the distribution pattern in nature it is possible to illustrate environmental change (3;45;54).

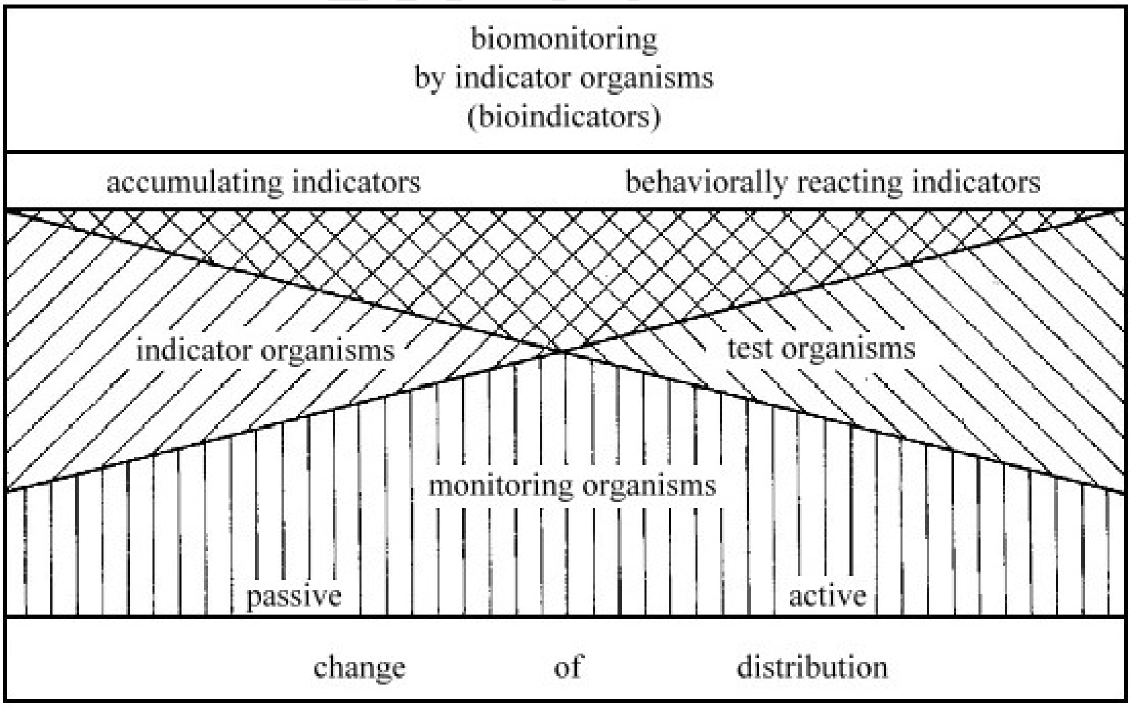

Figure 1. Relation between Bioindicator Types (3;45;54).

Organisms selected as bioindicators should have certain characteristics. They should be endemic to the area of concern. The indicator organisms need to be sensitive to the stressor, and a statistically reliable relationship between the concentration of the toxicant in the organism and the concentration in the environment should be demonstrated. In selecting appropriate bioindicators it may be useful to employ a database containing information on different species exposed to various test chemicals under both laboratory and field conditions (9;40;50).

The ecophysiological investigation of bioindicators represents basic research. Using the results of bioindicator research in practice, it is obvious that uncertainties exist in predicting effects on organisms in the field compared to their responses in controlled laboratories. This is also true when assessing the roles of different species in ecosystems and the point at which damage to individual species or populations can be considered as damage to the community or ecosystem.

The differences in spatial and time scales between population and community changes and single- species effects make single-species toxicity test results a very doubtful value for predicting impacts at higher levels of biological organization. To understand the structure and functioning of ecosystems (and the relationship between the two) (27) the biogeographical sciences (i.e. environmental planning, urban ecology) apply integrated approaches to bioindicators (8). The methodical difference between the bioecological and biogeographical way of studying bioindicators lies primarily in the scale in which the work is done. In applied landscape ecology bioindicators researching into measuring and predicting the behavior of complex ecosystems is presently conducted in the topical and cortical dimension.

From this point of view, research work is done on different scale levels leading to results of different orders of magnitude. The results should be integrated in a model that refers to the multidimensional aspects of ecosystems response to environmental changes and to various aspects of assessing the impacts of anthropogenic activities on the environment.

See: Biocoenosis, nanotechnology, environmental stressors, anthropogenic stressors, "passive" biomonitors.

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Bibliography

1. Aery N.C. Tiagi Y.D. (1986). Bioindicators and accumulators in geobotanical and biogeochemical prospecting of metals. *ACTA BIOLOGICA HUNGARICA* **37,** 67-78.

2. Anderson T.A. Hoylmann A.H. Edwards N.T. Walton B.T. (1997). *Uptake of polycyclic aromatic hydrocarbons by vegetation: a review of experimental methods. Plants for Environmental Studies*, (ed. W Wang J W Gorsuch J S Hughes), 451-477. New York: Lewis Publishers.

3. Arndt U. Nobel W. Schweizer B. (1987). *Bioindikatoren, Möglichkeiten, Grenzen und neue Erkenntnisse*, Stuttgart: Ulmer.

4. Asztalos B. (1986). LDH enzyme as a tool on monitoring tissue necrosis in fishes caused by pesticides. *ACTA BIOLOGICA HUNGARICA* **37,** 59-65.

5. Baker A.J.M. (1981). Accumulators and excluders - strategies in the response of plants to heavy metals. *J. Plant Nutr*. **3,** 643-654.

6. Bohác J. Fuchs R. (1991). The structure of animal communities as bioindicators of landscape deterioration. *Bioindicators and Envrionmental Mangement*, (ed. D W Jeffrey B Madden), 165-178. London: Academic Press.

7. Braun-Blanquet J. (1964). *Pflanzensoziologie*, 865. pp. Wien:

8. Calow P. Forbes V.E. (1997). Science and Subjectivity in the Practice of Ecological Risk Assessment. *Environmental Management* **21,** 805-808.

9. Debus R. Dittrich B. Schröder P. Volmer J. (1989). *Biomonitoring organischer Luftschadstoffe*, 64. pp. Landsberg, München: ecomed.

10. Ellenberg H. Weber H.E. Düll H.E. Wirth R. Werner W. Paulissen D. (1991). Zeigerwerte von Pflanzen in Mitteleuropa, 258. pp. Göttingen: *Scripta GeobotanicaXVIII*, Goltze.

11. Ernst W. (1975). Mechanismus der Schwermetallresistenz. *Verhandlungen der Gesellschaft für Ökologie* 187-195.

12. Fomin A. Arndt U. (1996). Aktuelle Aufgaben und Ziele aut- und synökologischer Bioindikation. *Verhandlungen der Gesellschaft für Ökologie* **26,** 9-15.

13. Forstreuter M. Tschuschke A. Overdieck D. (1994). *Atmospheric CO2 record from Osnabrück. Trends 93: A compendium of data on global change*, (ed. T A Boden D P Kaiser R J Stepanski F W Stoss), 157-160. Oak Ridge: Carbon Dioxide Information Analysis Center.

14. Galloway J.N. (1998). The global nitrogen cycle: changes and consequences. *Environmental Pollution* **102,** 15-24.

15. Gilbert O.L. (1968). Bryophytes as indicators of air pollution in the Tyne Valley. *New Phytol.* **67,** 15-30.

16. Glawion R. (1989). Einsatzmöglichkeiten biotischer Faktoren und Bioindikatoren in der gross- und kleinmassstäbigen ökologischen Raumgliederung. *GEOMETHODICA* **14,** 47-83.

17. Heggestad H.E. (1991). Origin of Bel-W3, Bel-C and Bel-B tobacco varieties and their use as indicators of ozone. *Environmental Pollution* **74,** 264-291.

18. Herpin U. (1997). *Moose als Bioindikatoren von Schwermetalleintraegen*, 183. pp. Osnabrueck: Dissertation Universitaet Osnabrueck.

19. Hill B.H. (1997). *Aquatic plant communities for impact monitoring and assessment. Plants for Environmental Studies*, (ed. W Wang J W Gorsuch J S Hughes), 277-305. New York: Lewis Publishers.

20. Hippeli S. Elstner E. (1996). Mechanisms of Oxygen Activation during Plant Stress: Biochemical Effects of Air Pollutants. *J.Plant Physiol*. **148,** 249-257.

21. Jarvis P.G. (1998). *European Forests and Global Change*, 379. pp. Cambridge: Cambridge University Press.

22. Jarvis P.G.ed. (1999). Predicted Impacts of Rising Carbon Dioxide and Temperature on Forests in Europe at Stand Scale - Final Report of *ECOCRAFT*, 308. pp. Edinburgh: University of Edinburgh.

23. Jeffrey D.W. Madden B. (1991). *Bioindicators and Environmental Management*, San Diego: ACADEMIC PRESS.

24. Knapmeyer K.H. (1993). *Geoökologische Untersuchungen in Ackerökosystemen unterschiedlicher Maisanbauverfahren und ihre Verknüpfungen mit der Besatzdichte der Collembolen und Acarina* (speziell Gamasina), 182. pp. Vechta: Dissertation Universität Osnabrück, Standort Vechta.

25. Kolkwitz R. Marsson M. (1908). Ökologie der pflanzlichen Saprobien. *Ber.Dtsch.Bot.Ges*. **24 A,** 505-519.

26. Kovács M. Podani J. (1986). Bioindication: A short review on the use of plants as indicators of heavy metals. *ACTA BIOLOGICA HUNGARICA* **37,** 19-29.

27. Leser H. (1989). Biotische Faktoren und Bioindikatoren als methodische Probleme landschaftsökologischer Forschungen. *GEOMETHODICA* **14,** 5-176.

28. Lewis M.A. Wang W. (1997). *Water quality and aquatic plants. Plants for Environmental Studies*, (ed. W G J W Wang J S Hughes), 141-175. New York: Lewis Publishers.

29. Lichtenthaler H.K. (1996). Vegetation Stress: an Introduction to the Stress Concept in Plants. *J.Plant Physiol*. **148,** 4-14.

30. Lindström-Seppä P. Pesonen M. (1986). Biotransformation enzymes in fish as tools for biomonitoring aquatic environment. *ACTA BIOLOGICA HUNGARICA* **37,** 85-92.

31. Lovett Doust J. Schmidt M. Lovett Doust L. (1994). Biological assessment of aquatic pollution: a review, with emphasis on plants as biomonitors. *Biol.Rev*. **69,** 147-186.

32. Manning W.J. v.Tiedemann A. (1995). Climate changes: Potential effects of increased atmospheric carbon dioxide (CO_2), ozone (O_3) and ultraviolet (UV-B) radiation on plant diseases. *Environmental Pollution* **88,** 219-245.

33. Nyholm N. Peterson H.G. (1997). Laboratory bioassays with microalgae. *Plants for Environmental Studies*, (ed. W Wang J W Gorsuch J S Hughes), 225-276. New York: Lewis Publishers.

34. Peintner U. (1995). Schwermetallgehalte von Basidiomyceten und deren Eignung als Bioindikatoren. *FBVA-Berichte*, (ed. Federal Forest Research Center), 161-169. Vienna:

35. Powell R.L. (1997). The use of vascular plants as field biomonitors*. Plants for Environmental Studies*, (ed. W Wang J W Gorsuch J S Hughes), 335-365. New York: Lewis Publishers.

36. Power M. Adams S.M. (1997). Perspectives of the Scientific Community on the Status of Ecological Risk Assessment. *Environmental Management* **21,** 803-830.

37. Puri R.K. Qiuping Y. Kapila S. Lower W.R. Puri V. (1997). *Plant uptake and metabolism pf polychlorinated biphenyls (PCBs). Plants for Environmental studies*, (ed. W Wang J W Gorsuch J S Hughes), 482-501. New York: Lewis Publishers.

38. Reddy M.V. (1986). Soil-inhabiting arthropods as indicators of environmental quality. *ACTA BIOLOGICA HUNGARICA* **37,** 79-84.

39. Richardson D.H.S. (1991). *Lichens as Biological Indicators- Recent developments. Bioindicators and Environmental Management*, (ed. D W Jeffrey B Madden), 263-272. London: Academic Press.

40. Royce C. Fletcher J. Risser P. Benenati F. (1984). PHYTOTOX: a database dealing with the effects of organic chemical on terrestrial vascular plants. J.Chem.Info.Comput.Sci. **24,** 7-10.

41. Römbke J. Egeler P. Füll Ch. (1998). Literaturstudie über Bioakkumulationstests mit Oligochaeten im terrestrischen Medium, 84. pp. Berlin: *Umweltbundesamt, Forschungsbericht 20603909*, UBA-FB 98-035.

42. Salánki J. (1983). Biological monitoring of the state of the environment. *Biology International* **8,** 7-9.

43. Scheller F.W. Schubert F. Fedrowitz J. (1987). Present state and frontiers in biosensorics. *Frontiers in Biosensorics, Fundamental Aspects*, (ed. F W Scheller F Schubert J Fedrowitz),269. Basel: Birkhäuser.

44. Schroeder von J. Reuss C. (1883). *Die Beschädigung der Vegetation durch Rauch und die Oberharzer Hüttenrauchschäden*, Berlin: Paul Parey.

45. Schubert R. (1991). *Bioindikation in terrestrischen Ökosystemen*, 338. pp. Jena: Gustav Fischer Verlag.

46. Schwarz O.J. Jones L.W. (1997). Bioaccumulation of xenobiotic organic chemicals by terrestrial plants. *Plants for Environmental Studies*, (ed. W Wang J W Gorsuch J S Hughes), 417-440. New York: Lewis Publishers.

47. Selye H. (1956). *The Stress of Life*, New York, London: Academic Press.

48. Streit B. (1989). Zum Problem der Bioindikatoren aus zoologisch-ökologischer Sicht. *GEOMETHODICA* **14,** 19-45.

49. Sukopp H. Wurzel A. (1995). Klima- und Florenveränderungen in Stadtgebieten. *Angewandte Landschaftsökologie* **4,** 103-130.

50. U.S.Environmental Protection Agency (1996). *Ecotox Database*. (ed. National Health and Environmental Effects Research Laboratory), Duluth, Minnesota:

51. VDI - Verein Deutscher Ingenieure (1995). Messen von Immissionswirkungen. Ermittlung und Beurteilung phytotoxischer Wirkungen von Immissionen mit Flechten. Flechtenkartierung zur Ermittelung des Luftgütewertes (LGW). (ed. *VDI-Richtlinie 37009*), Blatt1-

52. Wadleigh M.A. Blake D.M. (1999). Tracing sources of atmospheric sulphur using epiphytic lichens. *Environmental Pollution* **106,** 265-271.

53. Wang W. Lewis M.A. (1997). Metal accumulation by aquatic macrophytes. *Plants for Environmental Studies*, (ed. W Wang J W Gorsuch J S Hughes), 367-416. New York: Lewis Publishers.

54. Weinert E. (1991). *Biomonitoring of Environmental Change Using Plant Distribution Patterns. Bioindicators and Environmental Mangement*, (ed. D W Jeffrey B Madden), 179-190. London: ACADEMIC PRESS LIMITED.

55. Zechmeister H.G. (1995). Correlation between altitude and heavy metal deposition in the Alps. *Environmental Pollution* **89,** 73-80.

Biographical Sketch

Dr.rer.nat. Manfred Fortsreuter, who was born on 29 August 1958 at Lünne, aquired a diploma in biology at the university of Osnabrueck. During his study he spent one year of research at Duke university/Durham NC. He was holder of a scholarship at Lower Saxony, and in 1993, took his doctor´s degree in the working group ´General Ecology´ under the leadership of Prof. Dr. H. Lieth. In 1995, he became university assistant at the TU Berlin, where he habilitates in the field of botanics and plant ecology.

His scientific interest focuses on the research in "Global Change", above all on the direct effects of rising atmospheric CO_2 and temperature on trees and forests. Another focal point of his research deals with the effects of silvicultural regimes on ecological and genetic diversity of European beech forests.