BIOINDICATOR SPECIES AND THEIR USE IN BIOMONITORING

A. Gerhardt
LimCo International, Ibbenbüren, Germany

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Contents

Summary

The concept of indicator species is based on the stress-response model and has evolved in severals aspects, 1) the definitions of a bioindicator have been stretched thus creating confusion on one side and a wider field of applications on the other side. 2) The bioindicator concept has been integrated in rapid bioassessment methods, followed by the integration in multimetric biomonitoring methods, which combine the use of the indicator concept as well as ecological methods based on community structure and function. The different types of approaches are discussed in the light of their advantages and limitations and some examples of their applications are presented. There is no general conclusion in favour of certain biomonitoring methods, however, they have to be chosen according to the aims, policies, actual and future human uses/needs, pollution state and cost-effectiveness. 3) The most recent step in the evolution of the indicator conept represents the "environmental indicator systems for ecosystem health", health being based on the pressure-state-impact-response model with parameters such as biodiversity and sustainability.

The use of data bases, models and grouping/summation parameters favours cost-effectiveness. This approach may lead to a holistic and global biomonitoring concept. In the last part of the article several bioindicator taxa from aquatic and terrestric environments are presented and discussed.

1. Introduction

1.1 Bioindicator

Bioindicators are organisms or communities of organisms, which reactions are observed representatively to evaluate a situation, giving clues for the condition of the whole ecosystem. The bioindicator has particular requirements with regard to a known set of physical or chemical variables such that changes in presence/absence, numbers, morphology, physiology or behavior of that species indicate that the given physical or chemical variables are outside their preferred limits. Mostly, bioindicators are restrictively defined as species reacting to anthropogenical effects on the environment, whereas bioindicators for "natural" environmental changes and conditions are not much used. However, a general, all-encompassing definition of a biological indicator would be: "a species or group of species that readily reflects the abiotic or biotic state of an environment, represents the impact of environmental change on a habitat, community or ecosystem or is indicative of the diversity of a subset of taxa or the whole diversity within an area".

Bioindicators are useful in three situations: 1) where the indicated environmental factor cannot be measured, *e.g*. in situations where environmental factors in the past are reconstructed such as climatic change, studied in palaeo-biomonitoring 2) where the indicated factor is difficult to measure, *e.g*. pesticides and their residues or complex toxic effluents containing several interacting chemicals and 3) where the environmental factor is easy to measure but difficult to interprete, *e.g.* whether the observed changes have ecological significance.

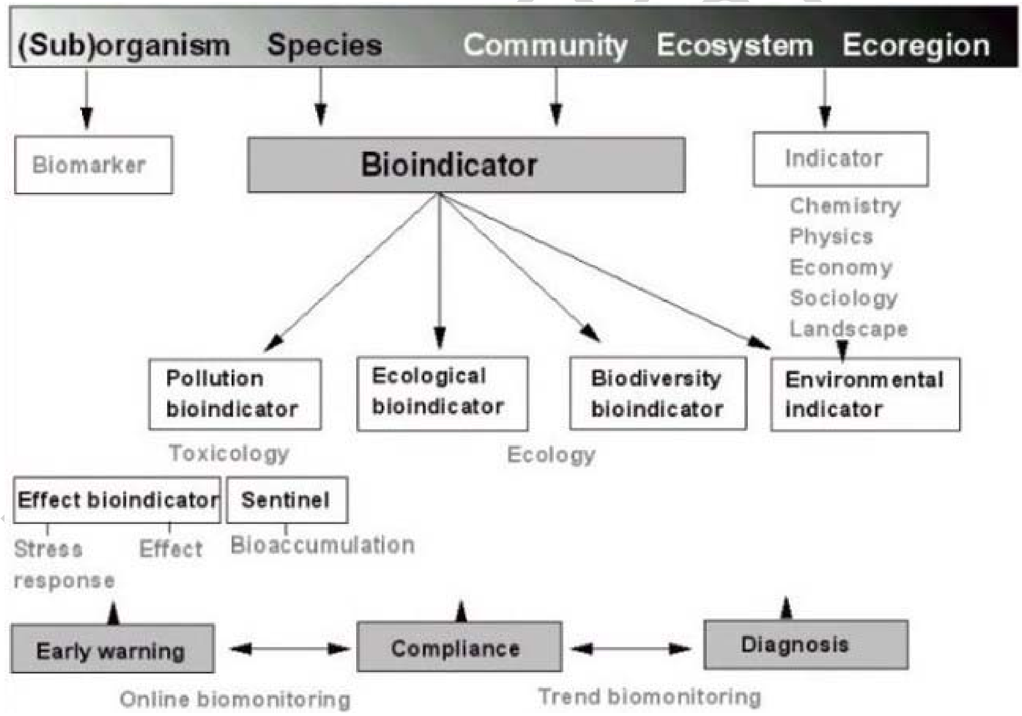

Figure 1. Types of bioindicators in the context of their use in biomonitoring.

Different types of bioindicators can be described from different perspectives (Figue1). According to the aim of bioindication, three types of bioindicators can be distinguished:

1. compliance indicators
2. diagnostic indicators
3. early warning indicators.

Compliance indicators: For example, fish population attributes are measured at the population, community or ecosystem level and are focussed on issues such as the sustainability of the population or community as a whole. Diagnostic and early warning indicators are measured on the individual or suborganismal (biomarker) level, with early warning indicators focussing on rapid and sensitive responses to environmental change. Accumulation bioindicators (*e.g.* mussels, mosses, lichens) are distinguished from toxic effect bioindicators, with the effects being studied on different biological organization levels.

According to the different applications of bioindicators, three categories can be distinguished:

1. environmental indicator: This is a species or group of species responding predictably to environmental disturbance or change (*e.g.* sentinels, detectors, exploiters, accumulators, bioassay organisms). An environmental indicator system is a set of indicators aiming at diagnosing the state of the environment for environmental policy making.
2. ecological indicator: This is a species that is known to be sensitive to pollution, habitat fragmentation or other stresses. The response of the indicator is representative for the community.
3. biodiversity indicator: The species richness of an indicator taxon is used as indicator for species richness of a community. However, the definition has been broadened to "measurable parameters of biodiversity", including *e.g.* species richness, endemism, genetic parameters, population-specific parameters and landscape parameters.

At the landscape level, indicators *sensu latu* can be distinguished within the stress-response model (PSIR chain): A pressure indicator (P) describes the intensity of human activities that cause changes in quality and/or quantity of the ecosystem. A state indicator (S) describes the status of the quality and/or quantity of the system. A pressure may result in a new state. The impact indicator (I) describes the influence of the status of the system on functions and uses of the system. When functions or uses are affected, a societal response may be expected. This is described by the response indicator (R). The response aims at a new balance of the system. The PSIR chain is a new formulation of the stress-response model on the ecosystem level and has been applied in the new "environmental indicator system" apporach. In the environmental indicator system approach, bioindicators are being selected, that not only indicate stresses in the ecosystem such as toxic emissions, but also have indicative function in greater contexts. Examples are the international river basin program "Salmon 2000" in the River Rhine or the return of the beaver in the River Elbe. The indicator species embodies elements of ecological function, environmental problems (water quality, land use) and measures (reduction of emissions, ecological restoration goals).

Distribution • wide, cosmopolitan distribution, useful for international comparisons
Ecological characteristica • fidelity – high abundance and wide-spread in a certain type of environment • specifity

– restricted mobility, site specifity – low genetic and ecological variability, *i.e.* indicators should have narrow and specific ecological demands and tolerances • clear position in the trophical system • clear feeding strategy, *i.e.* not omnivorous • constant metabolism rate, *i.e.* no diapause stages • medium to long generation time • clear position in one ecosystem compartment • good knowledge about the ecology, physiology and distribution of the species. • ecologically relevant position in the ecosystem (*e.g.* keystone species) • sensitivity – sensitive to specific pollutants (only effect indicators)
Representativeness • the response of the bioindicator should be representative to responses of other taxa or even the ecosystem
Practicability • easy sampling, sorting and storage • easy taxonomy and recognition by the nonspecialist • robust during handling • easily culturable in the laboratory • low cost and man power effectiveness
Societal importance • relevance to policy or management decisions (relate to water uses) • economic importance as a resource or pest • importance in agriculture or environment
Sentinel (additional criteria) • The organisms are not impaired by the pollutant • The species should accumulate and concentrate the toxin to measurable levels above those in the surroundings.

Table 1. Criteria for bioindicators.

The ideal bioindicator should fulfill the criteria in Table 1, however, as not one species can fulfill all criteria, the trend goes to the use of a group/set of indicator species. The utility of bioindicators lies in their predictive capacity, which is determined by their sensitivity, specifity and the prevalence of the response or the relationship that it demonstrates. The indicator value (IndVal) depends on 1) high specifity, *i.e.* a bioindicator should be unique to a certain type of environment and 2) high fidelity, *i.e.* a bioindicator should be abundant and wide-spread in this type of environment. The indicator value (IndVal) is then defined as degree (per cent) to which a species fulfills the criteria of specifity and fidelity within any particular group of sites. As the IndVal is calculated independently of other species in the community, direct comparisons between taxonomically unrelated species can be made. This system is rather similar to the Braun-Blanquet system used by phytosociologists, where the so called "Zeigerwerte" (indicator values) describe the value of plants as bioindicators. Examples are halophytes as salt indicators, metal bioindicators and nitrophilic plants as N-indicators.

High abundance of the indicator species at the study site is a controversial criterium. Very abundant species are often rejected as indicators because they may have opportunistic characteristics, such as high reproductive capacity and good dispersal mechanisms, rather than being tolerant to pollutants. On the other hand, rare species cannot be used either because they may be rare for a variety of reasons other than the effects of pollution. Therefore, species occurring at intermediate abundance classes are recommended as pollution indicators.

1.2 Sentinels

Bioaccumulation indicators are a special kind of indicator organism. These so called "sentinel" organisms accumulate and concentrate pollutants from their surroundings and/or food so that an analysis of their tissues provides a time-integrated estimate of the environmentally available concentrations of these pollutants. Accumulation indicators are organisms which are not damaged by stressors. The species should be sedentary, so that the results can be linked to local areas. They should be large and present in high abundance in order to provide enough tissue for analysis. They should be widely distributed to facilitate comparisons.

They should be longlived to allow for long-term studies and they should be robust and easy to collect and handle. The use of sentinel organisms to monitor aquatic pollution has started ca. 25 years ago in coastal and marine environments, *e.g*. with bivalve molluscs ("Mussel Watch") and crustaceans for metal pollution and mosses for metals and radionucleids in terrestric environments. In the Mussel Watch Program, the widespread blue mussel *Mytilus edulis* was used to monitor metal pollution in the USA. The mussel is a good indicator for coastal pollution due to its wide distribution, easy transfer in other regions for "active" biomonitoring, high abundances, high accumulation rate of many xenobiotics, with a lifetime of three years allowing for long term monitoring. Seaweeds or macroalgae (*e.g. Fucus* spp.) also accumulate metals.

The selection procedure of an appropriate sentinel includes 1) the survey approach, where the current state of contaminants in an ecosystem is the focus. The concentrations of selected contaminants in tissues of sentinel organisms are determined periodically. 2) The experimental approach aims at the calibration of sentinel organisms. The effects of abiotic and biotic variables on the uptake of contaminants by the sentinel species have to be determined. 3) The concentration of the toxin in the water has to be related to that in the sentinel organism.

1.3 Keystone Species

A keystone is a stone at the top of an arch that supports the other stones and keeps the whole arch from falling. A keystone species is a species on which the persistence of a large number of other species in the ecosystem depends. The removal of a keystone species has large effects on many other taxa and ecosystem functions (*e.g*. trophic links, engineering).

Ecosystem engineering species are organisms that directly of indirectly modulate the availability of resources (other than themselves) to other species (*e.g.* the beaver in rivers). They may be top carnivors that keep prey in check (*e.g.* sea otters in the kelp forest) or large herbivores that shape the habitat for other species.

1.4 Endangered Species

Endangered species are species, which have decreased in distribution and abundance over the past times, mainly due to anthropogenic impacts. In the so called "Red Lists" (RL) different categories according to the rareness of a species are mentioned: 0) doomed, 1) threatened to die out, 2) immensely endangered, 3) endangered, 4) potentially endangered, 5) species on the early warning list, 6) species with geographical restriction, 7) lack of data to evaluate the species, 8) not listed in "Red List", 9) extremely rare. These lists exist for different countries and regions in Europe, and are an important basis for species protection and nature conservation activities. The main critics to this system include 1) the ecology of the rare species is often not well known, 2) the classification of species in the categories differs, 3) RLs should refer to minimal areal sizes. In general, this method should only be used as complement. In order to evaluate an area for nature conservation the following criteria should be considered: Degree of originality of the area, rareness of species (RL), degree of anthropogenous impact, size of populations, representativeness (biotop-typical species).

SERCON (System for Evaluation of Rivers for Conservation) is a good example for the holistic evaluation of sites for nature conservation. This method is based on physical, chemical and biological parameters of streams, banks and backwaters. Thirty-five indicator values are classified into six conservation criteria: physical diversity, degree of originality, representativeness, rareness, species richness, special local characteristics. Eleven parameters for "disturbances" have been chosen. This system, developed in UK has also been used in Sweden and South Africa.

1.5 Bioindication *sensu latu*

Bioindication *sensu latu* uses all kinds of indicative parameters and comprises suborganismal biomarkers, bioindicator species, biomonitor species and sentinel species as well as ecological indicators, *e.g.* species diversity (Figure 2). Bioindication is the basis for biomonitoring and modern bioindication tries to establish links between the different indicative biological levels.

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Webpages

Specific

http://h2osparc.wq.ncsu.edu/info/biomon.html [Introduction to biological monitoring, methods and examples]

http://cmea.rsmas.miami.edu/Workshop/Workshop.html [Workshop on "South Florida Ecological Sustainability Criteria", a holistic approach for evaluation of a landscape/seascape restoration process]

General

http://www.epa.gov

http://www.biodiv.org

http://www. umweltbundesamt.de

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Biographical Sketch

Almut Gerhardt holds a PhD (1995) in aquatic ecotoxicology from Lund University (Sweden). Her Post-Doc research projects led her to South-Africa, China and Portugal. As head of LimCo International she is leading international research and development in aquatic ecotoxicology , water quality assessment and online biomonitoring. She edited the book "Biomonitoring of polluted water" (1999) and has published about 50 scientific articles.