Summary: For a number of years “classical” programs for environmental monitoring are being supplemented by bioindication measures already. Here, investigations on living organisms or their remains (e.g. peat) are used to indicate the environmental situation in either qualitative (bioindication) or quantitative (biomonitoring) terms. This provides pieces of information on environmental burdens of a region at a given point of time or on its changes with time (trend analysis). Classical bioindication often deals with observation and measurements of chemical noxae (both inorganic and organic ones) in well-defined bioindicator plants or animals (including man). Both for reconstruction of former situations (in retrospect) and the investigation of future trends similar approaches in the field of methods between environmental specimen banks and more general bioindication protocols are used. Thus environmental specimen banks are just one specific instrument of bioindication or biomonitoring, respectively. In terms of analytical procedures and results there are parallel developments between progresses in bioindication and innovation in analytical methods, too. After some 30 years of development in bioindication there are now following lines of further development: 1) more frequent inclusion of multi-element total analyses for a thorough investigation of mutual correlations in the sense of the Biological System of Elements, 2) more work on (analytical) speciation issues to proceed into real effect-oriented environmental sciences, and 3) there should and must be a focus on integrative bioindication methods because for a large number of environmental monitoring problems a single bioindicator will not provide any meaningful information: a single bioindicator is about as good as none at all. Integrative concepts such as the Multi-Markered Bioindication Concept (MMBC) provide basic means to get into precautionary environmental protection effects drawing upon such a second-generation bioindication methodology.

Keywords: environmental specimen banking, biomonitoring, bioindication, biological system of the elements, integrative biomonitoring, multi-markered-bioindication-concept (MMBC)
Introduction

Roughly speaking, during history of biological sciences there were three different phases in acquisition of information and knowledge concerning our environment or environmental conditions and the natural and anthropogenic changes these are undergoing (although these are arbitrary and do not claim to be precise). These are:

a) descriptive, observational biology up to about 1950,

b) development of the environmental sciences in the second half of the last century (1950-2000) and eventually,

c) the present synthesis of “old” and “new” ecology which takes the principle of sustainability as its scientific objective. This includes use of the latest information and communication techniques and of biotechnology [1].

Information concerning the quality of the environment can be gathered by bioindication or biomonitoring, respectively, in an elegant manner.

One of the simplest yet most meaningful first-hand definitions of “bioindication” was given by Müller back in 1980 [2]: "Bioindikation ist die Aufschlüsselung des Informationsgehaltes von Biosystemen für die Bewertung von Räumen" (more recent and detailed definitions will be given later on). Bioindication is essentially a tool of traditional conservation biology. Indicator taxa are used to elucidate the effects of environmental changes and of alteration or fragmentation of habitats. Since a few years additionally drawbacks of climate change and of rapid changes are considered. Indicator species may be taken to represent other groups of organisms or larger communities.

General information on the environment

Bioindication and biomonitoring must supply information on the extent of pollution or degradation of (eco-)systems. Two different forms of information are available from bioindication: firstly, general ones with the risk of oversimplifying matters and secondly highly specific information which latter is provided in a very detailed, objective, reproducible and precise manner; eg a certain pollutant may be linked to one physiological reaction in a bioindicator organism in order to obtain some more general information on the environment.

When data and information obtained by bioindication are extrapolated to provide some higher knowledge the subjectivity of interpretation increases with the complexity and dynamics of a system. This increase in subjectivity linked to an increase in knowledge is depicted by the “staircase of knowing” [3]. On the first step of this staircase (Fig. 1), observations and measurements become data when verified according to agreed standards. When data are properly selected, tested and related to subject areas they can become (pieces of) information: In turn information, once being organized and interpreted or applied to areas of interest or concern, can become established knowledge. If assimilated and mentally assessed and backed by additional information, this knowledge may be comprehended and integrated into a basis of facts and notions assimilated before,
eventually leading to understanding. And understanding combined with judgement according to certain values can become wisdom. In general, by moving up the staircase, the material and ideas become increasingly subjective, with increasing human value added [3].

![Image](image-url)

**Fig. 1.** The staircase of “knowing”, modified after Roots (1992) [4]. Explanations are given in the text [1]

### Specific information on the environment

Specific and detailed information of systems are essential within bioindication to draw clear-cut conclusions eg in between a pollutant and an effect of an organism (bioindicator). Figure 2 gives a simplified representation of complex (eco-)system interrelations being influenced by some pollution, and of the consequences of changes as revealed by bioindication and biomonitoring [5].

As a rule, it is assumed that a pollutant affects an organism which latter is taken as bioindicator or biomonitor. Both the organism and the pollutant interact closely with other ecosystem compartments (Fig. 2). The life activity of the organism is therefore influenced by a great number of abiotic and biotic factors and may often be subject to joint action of several pollutants, especially under “natural” field conditions [6, 7]. With regard to the interpretation of the “information” given by the bioindicator/biomonitor, often the problem arises from where changes observed or measured by the bioindica-
tor/biomonitor really originate. Even a combined multi-functional and multi-structural view of the various ecosystem compartments often left the specific operative mechanisms unaccounted for. What makes matters even more difficult is that the pollutant to be monitored is closely connected to all other environmental compartments. So it is by no means certain, although rather probable, that pollutant A does not interact synergistically or antagonistically with pollutant B (Fig. 2).

![Diagram of ecosystem interrelations with pollutant and bioindicator](image)

**Fig. 2.** Simplified representation of complex (eco-)system interrelations with regard to a pollutant, and consequences for bioindication and biomonitoring [5]

Moreover, the absorption pathway, sites of actions and metabolisms of both A and B usually are not yet adequately described. Nevertheless pollutant A may also affect other biota which may react even more sensitively to A than the bioindicator itself. If this sensitivity alters the population density of a more sensitive organism the abundance of the very bioindicator may also be affected, at least if the former is in direct or indirect competition with the latter. It is an unsettled issue whether a statement about the current condition of an entire ecosystem can be obtained by examining a single bioindicator [5].

With respect to the age of “information technologies”, Lieth (1998) [8] tries to render the “digitalized bit world” more efficient for ecosystem research. According to Lieth we have to ask: what is the crucial point of ecosystem research? What information does an ecosystem offer? Given the information content of all its parts an ecosystem readily compares to the level of an intelligent system. Toxicological implications often involve the flow of information as the cause of significant changes in material fluxes and energy fluxes in the system. Plants may produce chemicals to protect themselves against animal grazing. Animals may produce toxic chemicals as weapons; humans may produce toxic
chemicals to kill each other. Each process is controlled by “bits of information” which flow from one point in the ecosystem to another, the so-called biobits [1, 9]. A detailed description of this straightforward concept for further study is given in Lieth (1998) [8].

Definitions

It seemed clear from the start that bioindication and biomonitoring are promising (and possibly cheap) methods of observing the impact of external factors on ecosystems and their development over a long period, or of differentiating between one location (e.g. an unpolluted site) and another (polluted site) [1, 9]. The overwhelming enthusiasm shown in developing these methods has resulted in a problem that is still unsolved: the definitions of bioindication and biomonitoring, respectively and therefore the expectations associated with these methods, have never led to a common approach by the international scientific community, so that different definitions (and expectations!) now exist simultaneously [1, 9]. A fine overview of the various definitions is given by Wittig (1993) [10]. As a first starting point for the difficult use of bioindication methods following literature might be helpful (subjective election of the large amount of literature by the author): [8, 11-38].

In the following some definitions will be given that have been developed and used by us over the last 20 years [39, 1], since they differentiate clearly between bioindication and biomonitoring using the qualitative/quantitative approach to chemical substances in the environment. This makes bioindicators directly comparable to instrumental measuring systems [1]. From that angle it is possible to distinguish clearly between active and passive bioindication (biomonitoring). Especially where the bioindication of metals is concerned, the literature often makes a distinction between “accumulation indicators” and “effect indicators” in respect of the reaction of the indicator/monitor to changes in environmental conditions. Here we should bear in mind that this differentiation does not imply a pair of opposites; it merely reflects two aspects of analysis. As the accumulation of a substance by an organism already constitutes a reaction to exposure to this substance which - at least in the case of high accumulation factors - is measurably reflected in at least one of the parameters used in defining the term “effect indicator/monitor” (e.g. morphological changes at the cellular level; formation of metal-containing intracellular granules in many invertebrates after metal accumulation), we should discuss whether it is worthwhile distinguishing between accumulation and effect indicators or whether both terms fall under the more general expression “reaction indicator”. Often, too, it is not until a substance has been accumulated in organisms that intercellular or intracellular concentrations are attained that produce effects which are then analysed in the context of effect and impact monitoring (Fig. 3).

From these preliminaries we come to the following definitions, given in Markert et al. 1997 [40] and 1999 [39]: A bioindicator is an organism (or part of an organism or a community of organisms) that contains information on the quality of the environment (or a part of the environment). A biomonitor, on the other hand, is an organism (or a part of an organism or a community of organisms) that contains information on the quantitative aspects of the quality of the environment. A biomonitor is always a bioindi-
We speak of active bioindication (biomonitoring) when bioindicators (biomonitors) bred in laboratories are exposed in a standardized form in the field for a defined period of time. At the end of this exposure time the reactions provoked are recorded or the xenobiotics taken up by the organism are analyzed. In the case of passive biomonitoring, organisms already occurring naturally in the ecosystem are examined for their reactions. This classification of organisms (or communities of these) is according to their “origin”.

A classification of organisms (or communities of these) according to their “mode of action” (Fig. 3) is as follows: Accumulation indicators/monitors are organisms that accumulate one or more elements and/or compounds from their environment. Effect or impact indicators/monitors are organisms that demonstrate specific or unspecific effects in response to exposure to a certain element or compound or a number of substances. Such effects may include changes in their morphological, histological or cellular structure, their metabolic-biochemical processes, their behavior or their population structure. In general the term “reaction indicator” also includes accumulation indicators/monitors and effect or impact indicators/monitors as described above.

When studying accumulation processes it would seem useful to distinguish between the paths by which organisms take up elements/compounds. Various mechanisms contribute to overall accumulation (bioaccumulation), depending on the species-related interactions between the indicators/monitors and their biotic and abiotic environment. Biomagnification is the term used for absorption of the substances from nutrients via the epithelia of the intestines. It is therefore limited to heterotrophic organisms and is the
most significant contamination pathway for many land animals except in the case of metals that form highly volatile compounds (e.g., Hg, As) and are taken up through the respiratory organs, (e.g., trachea, lungs). **Bioconcentration** means the direct uptake of the substances concerned from the surrounding media, i.e., the physical environment, through tissues or organs (including the respiratory organs). Besides plants, that can only take up substances in this way (mainly through roots or leaves), bioconcentration plays a major role in aquatic animals. The same may also apply to soil invertebrates with a low degree of solarization when they come into contact with the water in the soil.

Besides the classic floristic, faunal and biocoenotic investigations that primarily record rather unspecific reactions to pollutant exposure at higher organizational levels of the biological system, various newer methods have been introduced as instruments of bioindication. Most of these are **biomarkers** and **biosensors**.

**Biomarkers** are measurable biological parameters at the suborganismic (genetic, enzymatic, physiological, morphological) level in which structural or functional changes indicate environmental influences in general and the action of pollutants in particular in qualitative and sometimes also in quantitative terms. Examples: enzyme or substrate induction of cytochrome P-450 and other Phase I enzymes by various halogenated hydrocarbons; the incidence of forms of industrial melanism as markers for air pollution; tanning of the human skin caused by UV radiation; changes in the morphological, histological or ultra-structure of organisms or monitor organs (e.g., liver, thymus, testicles) following exposure to pollutants.

A **biosensor** is a measuring device that produces a signal in proportion to the concentration of a defined group of substances through a suitable combination of a selective biological system, e.g., enzyme, antibody, membrane, organelle, cell or tissue, and a physical transmission device (e.g., potentiometric or amperometric electrode, optical or opto-electronic receiver). Examples: toxiguard bacterial toximeter; EuCyano bacterial electrode. Biotest (bioassay): routine toxicological-pharmacological procedure for testing the effects of agents (environmental chemicals, pharmaceuticals) on organisms, usually in the laboratory but occasionally in the field, under standardized conditions (with respect to biotic or abiotic factors). In the broader sense this definition covers cell and tissue cultures when used for testing purposes, enzyme tests and tests using microorganisms, plants and animals in the form of single-species or multi-species procedures in model ecological systems (e.g., microcosms and mesocosms). In the narrower sense the term only covers single-species and model system tests, while the other procedures may be called suborganismic tests. Bioassays use certain biomarkers or - less often - specific biosensors and can be used in bioindication or biomonitoring.

With regard to genetic and non-genetic adaptation of organisms and communities to environmental stress we have to differentiate between the terms tolerance, resistance and sensitivity.

**Tolerance** [41]: desired resistance of an organism or community to unfavorable abiotic (climate, radiation, pollutants) or biotic factors (parasites, pathogens), where adaptive physiological changes (e.g., enzyme induction, immune response) can be observed.

**Resistance**, unlike tolerance, is a genetically derived ability to withstand stress [41]. This means that all tolerant organisms are resistant, but not all resistant organisms are tolerant. However, in ecotoxicology the dividing line between tolerance and resistance is
not always so clear. For example, the phenomenon of PICT (Pollution Induced Community Tolerance) is described as the phenomenon of community shifts towards more tolerant communities when contaminants are present. It can occur as a result of genetic or physiological adaptation within species or populations, or through the replacement of sensitive organisms by more resistant organisms [42, 43].

Sensitivity of an organism or a community means its susceptibility to biotic or abiotic change. Sensitivity is low if the tolerance or resistance to an environmental stressor is high, and sensitivity is high if the tolerance or resistance is low.

**Integrated approaches in biomonitoring**

For purposes of bioindication and biomonitoring of chemical elements obviously both a highly specific approach concerning each single chemical species of an element and a comprehensive treatment of general features are required. The latter is included in a Biological System of Elements (Fig. 4). The Biological System of the Elements is compiled from data on correlation analysis, physiological function of the individual elements in the living organism, evolutive development out of the inorganic environment, and with respect to their uptake form by the plant organism as a neutral molecule or charged ion. The elements H and Na exercise various functions in the biological system so that they are not conclusively fixed. The ringed elements can at present only be summarized as groups of elements with a similar physiological function since there is a lack of correlation data or else these data are too imprecise.

Fig. 4. The Biological System of the Elements for Terrestrial Plants (Glycophytes) [44]
An integrated toolbox model for prophylactic human health care condition

Bioindication and biomonitoring must supply information on the degree of pollution or degradation of ecosystems. For integrative approaches bioindication is not an “environmental monitoring machine” for a specific constellation of factors; ideally, it is an integrated consideration of various bioindicative test systems which attempts, in conjunction with other environmental parameters, to produce a definite picture of a pollution situation and its development in the interests of prophylactic care of health and the environment.

![Diagram](image)

Fig. 5. Possible hierarchical structure of a bioindicative toolbox model for integrative approaches in human- and ecotoxicology. The toolboxes MED and ECO contain single sets of tests that can be combined functionally to allow an integrated approach to the particular frame of reference or a specific scientific problem. The toolboxes HSB (human specimen banking) and ESB (environmental specimen banking) represent years of results from international environmental sample banks specializing in environmental and human toxicology; in addition to MED and ECO they provide important information on the ecotoxicological and human-toxicological behavior of environmental chemicals. In the integrated approach, all the results obtained singly are substantiated by existing basic data available from (eco-)systems research, toxicology and environmental sample banks. The parameter constellations necessary for this are taken from the toolboxes TRE and DAT [1].

Figure 5 is a diagram of a complete dynamic environmental monitoring system supported by bioindication. It can re-combine its measurement parameters according to the
particular system to be monitored or the scientific frame of reference. The two main subjects of investigation - man and the environment - and the disciplines human toxicology and ecotoxicology derived from them are associated with various “toolboxes” and sets of tests (“tools”, e.g. bioassays) for integrated environmental monitoring. The system shown in Figure 5 consists of 6 toolboxes. The first two are derived mainly from environmental research: DAT (for data) and TRE (for trend). DAT contains, as a set, all the data available from the (eco-)system under investigation, i.e. including data acquired by purely instrumental means, for example from the meteorological sphere. DAT also contains maximum permissible concentrations of substances in drinking water, food or air at the workplace and the data for the relevant ADI (Acceptable Daily Intake) and NO(A)EL (No Observed (Adverse) Effect Level). The toolbox TRE contains data on trends; these have been compiled mainly from years of investigations by national environmental sample banks, or information available from long-term national and international studies (e.g. [45-47]). Specific conclusions and trend forecasts can then be prepared using the subsequent toolboxes HSB (Human Specimen Banking) and ESB (Environmental Specimen Banking) (see also Kettrup 2002 [48]). The toolbox MED (medicine) contains all the usual methods employed in haematological and chemical clinical investigations of sub-chronic and chronic toxicity, whereas ECO is largely made up of all the bioindicative testing systems and monitors relevant to ecosystems which may be combined to suit the particular situation to be monitored.

The data from all the toolboxes must interact with each other in such a way that it is possible to assess the average health risk for specific groups of the population or determine a future upper limit of risk from pollutants by forming networks. This risk assessment ultimately makes use of all the toxicological limits that take the nature of the effect and dose-effect relationships into account according to the current status of scientific knowledge. Since toxicological experiments cannot be carried out on human beings, recourse has to be made to experience at the workplace and cases of poisoning in order to permit an evaluation and risk assessment. Besides examining reports on individual cases, greater efforts must be made to reveal the effects of substances as a cause of disease by means of epidemiological surveys with exposed groups as compared with a control group. The development and use of simulation models supported by information technology, taking all the data collected into account, will play an important role here, since a large number of parameters that do not interact directly have to be combined. They include various data from the field of epidemiology, from mutagenicity studies, toxicokinetics, metabolism research and structure-effect relationships.

The conclusions of such networking in between different tool boxes can be used for a whole concept of bioindication in general, outlined in the so-called Multi-Markered Bioindication Concept (MMBC), which is outlined in Markert et al. [1, 9].

Environmental sample banks

Within an integrated tool box model Environmental Specimen Banks play especially role according to their constance of the chemical sample composition by storing samples on liquid nitrogen an helpful toll for concentration/effect relationships of a pollutant. In combination with the holistic approach of the Biological System of the
Elements a promising technique of observation the environmental living conditions for man has been created, which should be developed scientifically further on.

The purpose of environmental sample banks is to acquire samples capable of providing ecotoxicological information and to store them without change over long periods to permit retrospective analysis and evaluation of pollution of the environment with substances that could not be analyzed, or did not seem relevant, at the time the samples were taken [49]. Individual aspects and background is given in detail in Kettrup (2002) [48]. The tasks and objectives of environmental sample banks may be outlined as follows [50]:

- to determine the concentrations of substances that had not been identified as pollutants at the time the samples were stored, or which could not be analyzed with sufficient accuracy (retrospective monitoring);
- to check the success or failure of current and future prohibitions and restrictions in the environmental sector;
- regular monitoring of the concentrations of pollutants already identified by systematic characterization of the samples before archiving;
- prediction of trends in local, regional and global pollution;
- description of standardized sampling methods;
- documentation of the conditions under which the sample material is stored as a requirement for obtaining comparable results.

For further reading of the ‘specimen banking philosophy’ following literature are elementary: eg [51-56].

The German sample bank strategy also assumes that pollution at a particular location cannot be demonstrated by one bioindicator alone because of the different degree of exposure of the organisms in an ecosystem to pollutants and their different genetic prede terminants [50]. Only a set of suitable bioindicators is capable of reflecting the pollutants present in the ecosystem.

Table 1 shows the bioindicators available at the German Federal Environmental Sample Bank.

<table>
<thead>
<tr>
<th>Sample Species</th>
<th>Target Compartment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce (Picea abies) / pine (Pinus sylvestris)</td>
<td>Annual shoots</td>
</tr>
<tr>
<td>Red beech (Fagus sylvatica) / Lombardy Poplar (Populus nigra “Italica”)</td>
<td>Leaves</td>
</tr>
<tr>
<td>Domestic pigeon (Columbia livia f. domestica)</td>
<td>Eggs</td>
</tr>
<tr>
<td>Roe deer (Capreolus capreolus)</td>
<td>Liver (kidneys)</td>
</tr>
<tr>
<td>Earthworm (Lumbricus terrestris/Aporrectodea longa)</td>
<td>Worm body without gut contents</td>
</tr>
<tr>
<td>Zebra mussel (Dreissena polymorpha)</td>
<td>Soft parts</td>
</tr>
<tr>
<td>Bream (Abramis brama)</td>
<td>Muscle tissue and liver</td>
</tr>
<tr>
<td>Brown algae (Fucus vesiculosus)</td>
<td>Thallus</td>
</tr>
<tr>
<td>Edible mussel (Mystis edulis)</td>
<td>Soft parts</td>
</tr>
<tr>
<td>Blenny (Zoarces viviparus)</td>
<td>Muscle tissue and liver</td>
</tr>
<tr>
<td>Herring gull (Latus argentatus)</td>
<td>Eggs</td>
</tr>
<tr>
<td>Lagworm ( Arenicola marina)</td>
<td>Worm body without gut contents</td>
</tr>
</tbody>
</table>
The criteria for choice of the sample species are discussed in detail in Klein and Paulus (1995) [57]. The expected functional connections between ecosystems are shown in Figure 6.

![Diagram](image)

**Fig. 6.** Selected sets of sample species at the ecosystem level for the German Federal Environmental Sample Bank [50]

A problem posed by the environmental samples, which are carefully stored and refrigerated under liquid nitrogen, is the very high operating cost of the facility and the needed high experience of the scientist involved in ESB business. There is also a certain lack of flexibility in taking in or handing out a bioindicator organism that has been analyzed previously and over a period of years. The highly specific sampling guidelines often make it difficult to carry out comparisons with “normal” sampling protocols. These problems could be solved by integrating the results from the Environmental Sample Bank with other bioindication studies (e.g., the integrated tool box model of Fig. 5).

**Example of integrated monitoring in the Euroregion Neisse (CZ, PL, DE)**

By quantifying 12 chemical elements in the organ systems of rats (Rattus norvegicus) living wild in Zittau Zoo (Saxony) it was aimed to investigate the suitability of this species as a passive bioindicator [58, 59]. Besides determining “background concentrations” the emphasis was on sex and age specific accumulation of individual elements in the organ system of Rattus norvegicus. Individual elements were found to show an affinity for certain tissues and organs. In particular the sex and age specific characteristics found to exist for individual elements make it essential to prepare a detailed sampling strategy for later use of the rats as passive bioindicators.
Besides permitting an isolated view of individual elements in the animal’s organ system, *Rattus norvegicus* is particularly suitable as an integrative bioindicator from the ecotoxicological point of view since it is affected indirectly by all the environmental media and directly via the food chain. But in order to ascertain such connections it is necessary to have study areas for which an adequate volume of additional ecotoxicological data with relevance to prophylactic health care has been acquired. In the Euroregion Neisse we are in the fortunate position of having data on both atmospheric deposition (from moss analyses) and soil data from years of research work.

Figure 7 is a comparison of the element concentrations from deposition, soil analyses and stomach content and the highest median concentrations revealed by tissue and organ analyses. The stomach content of the rats did not show unusually high levels of individual elements. This is surprising in that high arsenic concentrations were found in the environmental medium “soil”, and an examination of the arsenic levels in the organ system of the rats revealed arsenic levels well above those of the stomach content.

![Fig. 7. Integrated comparison of element distributions in the media air (deposition), soil, stomach content and tissue and organs in the study area. The highest median concentrations shown in the figure “Tissue and Organs” were measured in the following tissues and organs: Al, Ni, Pb, Sr, Ti and Zn in bones; Cd, Co and Tl in the kidneys; Cu and As in the heart; Mn in the liver. All concentrations are stated in µg/g dry weight; k.A.: no information [58, 59]](image)

Using the calculation from the body-burden method it was possible to show that some tissues and organs have typical depot characteristics. In our investigations, for example, the elements Ni, Pb, Sr and Ti showed an increased affinity for bone tissue, whereas Cd and Tl tended to choose the kidneys as a depot organ. The tissue and organ concentrations shown here may therefore be regarded as possible initial background values for moderately polluted regions. The considerable natural fluctuations of individual elements according to organs, sex and age which are described in this study make it
essential to devise a detailed sampling strategy if *Rattus norvegicus* is to be used successfully as a passive bioindicator.

**Time- and site integration**

The chief objective of biomonitoring is to permit statements about pollution and changes in biodiversity on various spatial and temporal scales. The site dependency of bioindicators/biomonitors is often affected by different biotopes which are characterized by different population structures and climatic, soil and food conditions. The latter can be delimited fairly easily by sampling the bioindicator from various locations at the same time. For this Wagner (1992) [49] developed a system (Tab. 2) for fitting the sampling network to the quality of pollution control to be expected from the selected bioindicators (biomonitors) in use.

<table>
<thead>
<tr>
<th>Types of monitoring network</th>
<th>Objectives</th>
<th>Characteristics of the network</th>
<th>Methods, examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Permanent measuring sites / permanent observation sites, including ecosystem approaches</td>
<td>Reference and background data; time lines; integrated pollution and effect surveys; basis for comparison for environmental quality standards</td>
<td>Strictly according to regional statistics, avoiding local sources of interference; selected measuring points or sites to be observed</td>
<td>Widest possible range of methods as a reference basis, eg “Integrated Monitoring”, DUFI Baden Württemberg, also UBA monitoring network, ecosystem research + UPB, DWD</td>
</tr>
<tr>
<td>2 Monitoring networks for individual states</td>
<td>Overview of regional statistics; background data</td>
<td>Coordinate-based, wide-meshed networks (10-max. 50 km, avoiding local sources of interference)</td>
<td>Preferably passive biomonitoring, eg Bavarian moss and spruce monitoring network, Saarland poplar/spruce network</td>
</tr>
<tr>
<td>3 Regional monitoring networks</td>
<td>Screening (identification and delimitation of polluted areas or zones); integrated effects of complex or unknown types of pollution</td>
<td>Usually regular, relatively close-meshed measuring networks (approx. 1÷10 km) limited in size (eg rural district, county, “polluted area”)</td>
<td>Active and passive biomonitoring, effect cadaster in polluted and “clean air” regions, without reference to specific emitters</td>
</tr>
<tr>
<td>4 Emitter-related monitoring networks</td>
<td>To determine the extent of spread of pollution and the pollutant effects of an emitter</td>
<td>Usually close-meshed, often radial or linear networks or transects (&lt; 1÷10 km between measuring points)</td>
<td>Primarily active or experimental methods geared to specific emitters or pollutants</td>
</tr>
<tr>
<td>5 Environmental impact analyses</td>
<td>To determine the degree of existing pollution and maximum tolerated burden before planned measures take effect (preservation of evidence)</td>
<td>As 4</td>
<td>As 4. Possibly additional unspecific methods + UPB as preservation of ecotoxicological evidence</td>
</tr>
</tbody>
</table>

Table 2
Types of environmental monitoring networks used in ecological observation in Germany [49]
Compared with parameters resulting from the site, however, the behavior of the bio-
indicator (biomonitor) along the time axis is much more difficult to determine. Especially
in temperate climates, the great variation of seasonal effects causes variations of the
pollutant concentration in one and the same bioindicator organism. For example, the
seasonal fall in most of the heavy metal concentrations in spring (northern hemisphere)
can be explained by the dilution effect of the first biomass of the year [60]. In particular
a comparison of data obtained by different working groups using the same bioindicator
has to be carefully checked with site-dependent and especially time-dependent parame-
ters.

Example of an integrated approach to bioindication
of the biodiversity of a region and the influences acting on it

A question much discussed internationally is that of the correlations in the biodiver-
sity of different groups of organisms and those of the prime movers behind such connec-
tions. In a cultivated landscape, anthropogenic impacts naturally have to be taken into
account in addition to natural parameters.

In a joint project carried out in the context of the extremely extensive study “Culti-
vated Landscape Research in Austria”, over 30 research workers from 8 institutions took
10 random samples from each of 41 sampling sites with a side length of 600 m x 600 m.
The sites were chosen by means of a random number generator according to totally ob-
jective criteria. The exact documentation of positions naturally makes it possible to re-
peat the procedure at any time to permit monitoring. The manner of choosing sites, espe-
cially, has been unsatisfactory (ie subjective) in many previous bioindication studies.
Greater attention should in future be given to this topic in general in the interests of
proper statistical evaluation.

Data on the following organisms were collected at all 410 sampling points: ants;
grasshoppers; ferns and spermatophytes; lichens; mosses and liverworts; ground beetles;
mammals; snails and slugs; spiders and birds. These groups were chosen according to
ecological/functional criteria. The objective was to determine the correlation between the
various groups and the resulting indicative function of the individual groups of organisms
in respect of others (eg biodiversity indicators; shopping basket approach [61]).

A simultaneous analysis was made of the connections between the variability of
physical, chemical and biochemical soil parameters and the abundance of species. Links
were further established between various Net Primary Production parameters (real NPP, po-
tential NPP, NPP after deduction of the harvest etc.) and biodiversity parameters.

In a subsequent step, links were determined between parameters of landscape mor-
phology, location and biogeography (including the history of vegetation) and biodiver-
sity. Information on the landscape was incorporated in a GIS (Geographical Information
System) by means of digitized aerial photographs. This made it possible to relate geo-
graphic structural data to other parameters (eg biodiversity) via complex links (eg Frag-
stats [62, 63]). Finally, structures defined in terms of landscape ecology [64] are also
a suitable means of determining basic properties of the areas under review in order to
establish or test ecological theories. It is hoped that the establishment of links between
basic patterns of landscape ecology (eg density, distribution of corridors) and biodiver-
ity on the same sampled areas as were selected for the closer biodiversity analysis will make it possible to understand the effects of landscape on patterns of biodiversity and interpret them in the light of theoretical concepts.

Parameters relevant to cultivated landscapes have also been viewed in relation to biodiversity patterns, with the inclusion of socioeconomic data, and connections established that permit forecasts of how the biodiversity of the country will alter according to various scenarios of change in the cultivated landscape.

In this study the future development of various anthropogenic activities is forecast by individual disciplines in conjunction with specific frames of reference. When developing the scenarios it generally has to be taken into account that the individual anthropogenic impacts have different dynamics. For example, certain structural and functional impacts (e.g. drainage) develop over long periods of more than a century, whereas the release of pesticides and the effects of road traffic can be observed in periods of only decades [65, 66]. Further technological developments (such as genetic engineering) may have ecological effects that are not yet known.

In conclusion there is very much interest on integrated monitoring which will require an interdisciplinary design and formation of research groups in future surveys, too. This would permit rapid and flexible adjustment of the working groups to the particular frame of reference and enable a quick exchange of information between the individual disciplines [67-69].

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OD BIOMONITORINGU DO ZINTEGROWANEGO SYSTEMU OBSERWACJI ŚRODOWISKA - KONCEPCJA BIOINDYKACYJKI WIELORAKIEJ

Streszczenie: Od wielu lat klasyczne metody monitorowania środowiska przyrodniczego są uzupełniane metodami bioindykacyjnymi. Badania organizmów żywych lub ich pozostałości (np. torfu) są używane do zarówno jakościowej (bioindykacja), jak i ilościowej (biomonitoring) oceny stanu środowiska. W ten sposób uzyskuje się informacje o środowisku w rozpatrywanym regionie w danym momencie lub o jego zmianach w czasie (analiza trendów). Klasyczna bioindykacja zajmuje się obserwacjami i pomiarami działania szkodliwych czynników chemicznych (organicznych i nieorganicznych) w stosunku do określonych gatunków wskaźnikowych roślin lub zwierząt (w tym człowieka). Zarówno rekonstrukcja stanu przeszłego (retrospekta), jak i analiza trendów przyszłych są wykorzystywane w podobny sposób, poczynając od oceny banku próbek środowiskowych i metod ich analizy. W zakresie procedur analitycznych i interpretacji wyników pomiarów także ma miejsce postęp dotyczący zarówno bioindykacji, jak i metod analitycznych. Po około 30 latach rozwoju bioindykacji obecnie można wyróżnić następujące kierunki dalszego rozwoju: 1) czystsze łączenie analizy wielu składowych do badania wzajemnych korelacji pomiędzy nimi w ramach Systemu Składowych Biologicznych, 2) dalsze prace nad analityką specyfiką, aby przejść do badania realnych wpły-
wów róznich czynników na środowisko i 3) konieczność integracji metod bioindykacyjnych, ponieważ ze względu na złożoność środowiska przyrodniczego monitorowanie pojedynczego gatunku wskaźnikowego nie dostarcza jednoznacznych informacji. Metody zintegrowane, takie jak Koncepcja Bioindykacji Wieloindykacyjnej (MMBC) umożliwiają postęp w zakresie ochrony środowiska naturalnego za pomocą metod bioindykacji drugiej generacji.

Słowa kluczowe: bank próbek środowiskowych, biomonitoring, bioindykacja, biologiczne elementy systemu, integracja biomonitoringu, koncepcja bioindykacji wieloindykacyjnej (MMBC)