

## Monitoring and role of terrestrial invertebrates in bioindicators evaluation of environment condition and changes

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**Abstract.** The paper presents the objective, extent and methods of monitoring of terrestrial invertebrates. The criteria for selection of targets of species monitoring and a monitoring of faunistic complexes are defined. Possibilities of using invertebrate animals as bioindicators in evaluation of the condition and of changes in the environment are discussed.

**Key words:** terrestrial invertebrates, monitoring, bioindication, biodiversity.

### INTRODUCTION

Monitoring of invertebrate animals, which constitute the most diverse biotic subsystem of the environment, is still carried out on a small scale. While monitoring of abiotic elements already has a considerable tradition (a routine system of data collection, tables of standards for interpretation of results, reports published regularly, etc.), invertebrate monitoring still remains in the initial phase, mainly at the conceptual and experimental stage. Therefore, both the theoretical assumptions and the methods of data collection and analysis should be tested in practice and perfected in detail.

So far, the fauna has frequently been treated objectively and used as an indicator of environmental pollution. Most studies have been centered upon accumulation of heavy metals: Cd, Zn, Hg, Co, Pb in animal tissues. Indeed, these elements accumulate in tissues and occasionally occur at concentrations much higher than those in the environment – in the soil, water or air, but never is this interdependence simple. The content of heavy metals in animal tissues depends on a number of factors that are not necessarily influenced by the degree to which the environment is polluted. For instance, an analysis of earthworm tissues shows that accumulation of heavy metals in the tissues of these animals depends on such factors as soil acidity and structure and this is connected with the extent of absorption of heavy metals on the surface of soil particles. Moreover, heavy metal content in tissues depends on the type of compounds on which these metals occur, on the kind of combination and proportion of heavy

metals occurring together, on the kind of organic matter constituting the surface layer of the soil (LEE 1985). Thus the heavy metal content in animal tissues is made and modified by a variety of environmental factors and not just by the degree of environmental pollution alone (STERZYŃSKA and PILIPIUK 1994). Moreover, different species represent a whole gamut of physiological and biochemical adaptational possibilities when under environmental stress. An analysis of animal tissues may therefore be used for pollution monitoring in a given area, yet in order to compare data from another area there must be considered comprehensive information on various environmental factors which may considerably modify the degree to which heavy metals are accumulated in animal tissues. In other words, animal tissues must not be seen as a substratum which reflects, in a simple way, the degree of environmental pollution although it is unquestionable that they are important in the circulation of these elements in the ecosystem.

Although the scope of bioindication and that of monitoring are closely interconnected, their objectives are essentially different. It has only recently been pointed out that these two notions should be distinguished (LEŚNIAK 1995). Bioindication is a process which, by evaluating the condition of a given bioindicator, makes it possible to determine the general condition either of the environment or of some parameter which describes it, e.g. pollution or the degree of aridity. Faunistic monitoring is aimed at recording and evaluating the wealth of the animal world at a given place and time. Studies made within the framework of monitoring may be helpful in pointing out faunistic objects useful in bioindication. The animal organism (or its fragment), a single species or a group of species may be the object of monitoring. An object through which the environment condition and changes can be described and interpreted may serve as a bioindicator. Living complexes at different organization levels have bioindicatory properties and hence the enormous variety of the features analyzed. The species is, for practical reasons, the most frequently selected object.

## MONITORING OF SPECIES AND MONITORING OF FAUNISTIC COMPLEXES

### Aim and basic assumptions

Nowadays, with regard to nature, monitoring activities should serve as a means of verifying the essential assumptions and of working out a way to describe biodiversity. In the practical aspect, however, they should form a basis for activities aimed at preserving the current state of biodiversity, at preventing too rapid extinction of species and even at restitution of species.

Different international organizations and specialists from different countries have recently begun to acknowledge the necessity of such an outlook on the environment. In 1992, IUBS-SCOPE-UNESCO organized an international conference "Inventorying and Monitoring Biodiversity" devoted to specifying the preliminary assumptions of biodiversity monitoring (CASTRI DI et al. 1992). In Poland, for some time now, scientists have been elaborating a general concept of how to study biodiversity and what monitoring methods and protection strategies to use. Their work has yielded several detailed reports on monitoring of different elements of nature, reports including both theoretical

assumptions and concrete programs as well. A number of seminars and conferences devoted to these problems have been held (WEIGLE 1994, KOSTRZEWSKI 1995).

In 1992, a "Project of a system of bioindicators of environment condition and changes" was prepared for monitoring purposes; this paper presents a compact array of views on the place and role of bioindication in the system of environment monitoring. Moreover, the project brings a number of bioindicators which characterize the state of ecological systems comprehensively and complementarily and which make it possible to follow and evaluate changes occurring in them. These bioindicators have been selected in such a way that they may form a basis for a reliable prediction of changes in the environment (SOLON 1992).

With regard to terrestrial invertebrates, preliminary suggestions for objects in monitoring of faunistic complexes, and theoretical foundations for using faunistic data in evaluation of the condition and environment of the fauna have been presented in the "Project of a system of bioindicators of environment condition and changes" (CHUDZICKA et al. 1992) and in Project Proposals for Integrated Monitoring of the Natural Environment (SKIBIŃSKA and CHUDZICKA 1995). A detailed draft of species monitoring and of faunistic complex monitoring was outlined in a 1996 "Programme for nature monitoring between 1997 and 2005" (SKIBIŃSKA and CHUDZICKA 1996). Each programme is aimed at a different objective and each is characterized by a different methodological approach.

In faunistic monitoring, information which is obtained is at various levels of minuteness of detail, depending on the object agreed upon. If a single species (or genus) is used as the object, we deal with species monitoring in which changes in populations of selected species in a definite area are recorded. Such monitoring must, on principle, be limited to a small number of precisely selected objects, although these are not chosen on the basis of identical criteria. An object may be a species which is endangered, relic, rare, expansive or significant from the point of view of man's economy, etc. Species monitoring provides individual information which may serve as a basis for preparation of strategies, e.g. protective measures for the species monitored.

Monitoring of faunistic complexes concerns higher levels of the organization of nature. This monitoring is aimed at evaluation of species diversity of the natural complex at a given time and place. By using comparative analysis carried out in temporal and/or spatial series, an analysis of features of a selected complex, it is possible to determine the state of this object, the changes occurring there and, in the long run, even the direction and pace of these changes. Evaluation of species diversity of the natural system as a whole is impossible in practice. Since natural complexes are not formed of a random combination of species, evaluation of the species diversity of particular ecosystems must be restricted to selected groups. In the case of invertebrates the taxa selected should represent different trophic levels and groups, and they should inhabit different stratocoenoses because this will make it possible to draw conclusions about changes in species richness and variety of other taxa belonging to the same trophic levels and groups. Therefore, animal communities monitored should constitute a model reflecting the configuration of relationships within the biocoenosis. Monitoring of faunistic complexes provides far more complete and comprehensive bases for conclusions about changes occurring in the environment

than does an analysis of reactions of individual species. In this case we deal not only with individual responses of particular species but also with those of the complex as a whole. This type of monitoring makes it possible to determine the courses of changes affecting entire faunistic complexes and particular species within them, which may eventually be a basis for preparing comprehensive strategies of protection measures.

Selection of objects of monitoring is also, to a degree, influenced by strictly practical reasons. Useful for analysis is only a taxon whose biology is fairly well-known and whose habitat requirements can be defined; in the case of species monitoring the condition of a given species in a given area or habitat must be evaluated. In monitoring of faunistic complexes the condition *sine qua non* is that the representative material is fairly easy to collect by standard quantitative methods.

#### Examples of selected objects of species monitoring

A project of terrestrial invertebrate monitoring (SKIBIŃSKA and CHUDZICKA 1996), prepared within the "Programme for nature monitoring between 1997 and 2005", takes into consideration both species and genera belonging to groups greatly differ in their biology and ecology, and in their position in the taxonomic system. The groups selected – terrestrial snails, bees, ants and lepidopterans – are, in Poland, a traditional and therefore fairly well-known object of studies. Scientists working on particular taxonomic groups that have chosen concrete monitoring objects and areas, selected features to be monitored, and defined the frequency of observations and measurements and the methods of collecting and determining the material. Most of the species (genera) selected belong to a group of threatened ones in Poland; some expansive species have also been selected for monitoring.

The presence and abundance of species at selected sites are the basic parameters which should be defined in species monitoring. The information on each species monitored should also include all of a specialist's remarks on the condition and state of the object analyzed.

If comparable data are to be obtained, the methods used in monitoring must be standardized. Therefore, concrete methods of collection, frequency of observation and measurement and information recording have been proposed for particular groups. The following have been suggested: thorough, and within a definite time unit, searches for and counts of individuals of the selected species occurring in the habitat studied – in the case of snails, lepidopterans and bees; counts of all nests within the area selected – in the case of ants.

#### Examples of selected objects of monitoring of faunistic complexes

Multispecies communities which may be regarded as model systems exemplifying the picture of the structures within the entire ecosystem should be the object of monitoring of faunistic complexes. In order to construct a comprehensive model system it is necessary to take into consideration animal communities representing different trophic levels, and this means saprophages, zoophages and phytophages, including chewing and sucking phytophages. Moreover, the communities selected should represent different stratocoenoses, both the soil layer, epigeon and the higher

layers of vegetation, because changes occurring in a given habitat may develop at different paces in different layers. When faunistic complexes are employed in monitoring, a variant application of the model system is possible. Ideally, a complete model system may be the object of monitoring, a system which comprises trophically diverse communities inhabiting different stratocoenoses. In a minimalized variant, monitoring may be limited to different communities in one stratocoenosis or to selected individual communities inhabiting different stratocoenoses.

Selection of objects (taxa) for the model system depends on the type of habitat in which monitoring is to be carried out. In a project of terrestrial invertebrate monitoring prepared within the framework of the "Programme for nature monitoring between 1997 and 2005" a model for the fauna of coniferous forests (*Peucedano-Pinetum* and *Leucobryo-Pinetum*) has been worked out. In the optimum variant, taxa representing three stratocoenoses have been selected; within the soil fauna – springtails (*Collembola*), potworms (*Enchytraeidae*) and mites (*Acarina*); within the epigeous fauna – carabids (*Carabidae*), centipedes (*Chilopoda*) and ants (*Formicidae*); within the tree canopy fauna – leafhoppers (*Auchenorrhyncha*), heteropteran bugs (*Heteroptera*), weevils (*Curculionidae*), lepidopterans (*Macrolepidoptera*), digger wasps (*Sphecidae*), neuropterans (*Neuroptera*), ladybirds (*Coccinellidae*) and vespids (*Vespoidea*).

The main objective of monitoring of faunistic complexes is to evaluate the state and condition of the fauna expressed by species richness and by the diversity of faunistic wealth. The parameters which should be defined, for each community selected, are as follows: list and number of species, abundance of particular species, status of particular species within communities (dominance structure) and abundance of the entire community. With regard to the complex as a whole the monitored characteristics to be defined are as follows: species richness, total abundance and species diversity of particular trophic groups, and total abundance and species diversity at particular trophic levels.

In monitoring of faunistic complexes, just as in species monitoring, collecting techniques and methods of data processing must be adequate and comparable, and their choice is dictated by the specific character of the animal groups selected and by the necessity to eliminate individual approach of particular researchers. Methods of collection and data processing which are routinely used in zoocoenological studies could be particularly useful in monitoring of faunistic complexes.

#### FAUNISTIC INDICATORS OF THE ENVIRONMENT CONDITION AND CHANGES

Bioindication provides information on how living organisms respond to the world around them. The fact that invertebrates are useful in bioindication seems indisputable. For a number of reasons. Firstly, particular species or groups of invertebrate species are associated with different types of habitat more evidently and closely than most vertebrates, and due to their relatively short life their reaction to environmental stress may be recorded more quickly. Secondly, since invertebrates are represented by such a big number of species each habitat may be characterized through the multispecies communities settled there. Thirdly, since invertebrate communities occur in all strata – soil, epigeon, undergrowth, in the shrub and tree

canopy layers – their internal organization provides grounds for a multilayer characteristics of the environment and for evaluation of its condition and the changes occurring there.

It is generally believed that good bioindicators should meet the following requirements:

- 1) they have a characteristic look and therefore can easily be distinguished within the material collected;
- 2) identification to the species is simple and need not be performed by a specialist;
- 3) they are easily collected by standard methods.

In the case of invertebrates, the first two are simply theoretical postulates because they are very difficult to realize in practice, and may even be hazardous. Only the third is not controversial. Moreover, it is generally assumed that a good indicator has one indispensable feature, namely its indications are proportional to the intensity of a given environmental factor. It is accepted that organisms which accumulate environmental pollution are characterized by such a feature. And in this case, the level of environmental pollution is estimated by the degree to which these substances accumulate in living organisms. This approach is a direct projection of the principles of technical monitoring used while evaluating pollution of abiotic elements in the environment. The living organism – an animal – is treated as yet another instrument for pollution measurements.

There is no one, universal taxon reflecting explicitly all manner of changes occurring in each type of environment. This is so mainly because different species, and different faunistic complexes too, are associated with different types of habitat, and changes occurring in the environment may take a different course. Therefore, different taxa may be useful in evaluation of changes occurring in different types of habitat or in evaluation of changes in different environmental factors. Yet it is true that different multispecies communities, irrespective of their taxonomic status, may be used as indicators in bioindicatory evaluation of the environment condition, although not in overall evaluation. Each change in the species composition, structure and abundance of faunistic communities reflects changes going on in the environment, and the fauna may reflect the course of these changes. However, most bioindicatory methods do not consider temporary perturbations in the biocoenotic equilibrium but only detect what modifies the ecosystem fairly permanently. Bioindicatory methods supplement, in a special way, the well-tested methods of instrument measurement, used in environment monitoring for a long time, but they never replace them. Bioindicatory methods answer questions such as these: "how does a given fragment of the environment function?, is it subject to degradation?, what is the overall impact of anthropogenic pressure?, has the capacity and resistance of the system been abused?" These questions are much more general and complex than the question about the quantity of particular elements (SOLON 1992).

The aim of two-decade-long, large-scale studies carried out in Poland is to increase the knowledge of the species composition and structure of the fauna inhabiting typical habitats in the country and to determine what impact various environmental factors have on the composition and structure of many taxa and functional groups. Results of these studies provide an essential basis for faunistic monitoring, and an analysis of

changes occurring in communities of different invertebrates makes it possible to determine the direction and to evaluate the degree of environment deformations under various types of anthropogenic pressure. Most studies have been devoted to man-induced transformations of invertebrate communities in forests and in agricultural areas. Reactions of invertebrate communities, representing a number of different taxonomic groups, to urbanization pressure of different intensity are relatively well-known.

Study results show that different invertebrate communities belonging to the same trophic group react in a very similar way to anthropogenic pressure, which is a term covering all manner of man's activities. The course of transformations of faunistic complexes under urbanization pressure is similar to that under industrial pressure (DĄBROWSKA-PROT 1985). The varying intensity of anthropogenic pressure bears upon the course of faunistic complex transformations which runs in several stages, with characteristic structural and functional changes in each; degradation changes appear only during the final stage (CHUDZICKA and SKIBIŃSKA 1994, DĄBROWSKA-PROT 1996). However, it must be pointed out that it is not easy to distinguish the effects of anthropogenic pressure from those of the normal and natural transformation of the environment. As a result of this pressure, just as in the case of natural processes of succession character, a new configuration of habitat relationships is formed, and this in turn brings about various reactions of particular species, groups of species, and in consequence of the entire ecosystem (TROJAN 1980).

It has already been said that selection of taxa should depend both on the type of habitat and on the kind of threat as well. And it should also be dictated by purely practical reasons. Useful for analyses is only a taxon with its fairly well-known biology, and this means that its environment requirements can be defined. Moreover, material must be easy to collect by robust standard methods (which are neither time-consuming nor expensive).

There are many bioindicators known at present. They may be divided into two groups differing in the object of indication, the way of data collection and the methods of result processing. The first group includes indicators which describe synthetically the general situation of the environment and the courses of the processes occurring there, whereas the second group is used for precise characteristics of the condition of selected environmental components. A faunistic indicator may be a basis for analyses with different minuteness of detail. At the species level – the presence or disappearance of a species with a narrow ecological value i.e. selective in relation to a given habitat parameter, is a signal of a change in this parameter. On the other hand, an analysis at the level of taxa, trophic groups and levels provides a wide spectrum of information on the condition of the environment and the changes there. Determination of the course and intensity of environmental transformations, and evaluation of the degree of complexity of the entire system make valorization of habitats possible.

Some parasitic *Diptera* of the genera *Pollenia* and *Sarcophaga*, earthworms (*Lumbricidae*), or certain species of springtails (*Collembola*) may be indicators of changes in the humidity ratios in the environment. Changes in the abundance proportions of *Diptera* of the genera *Pollenia* and *Sarcophaga* indicate changes in the degree of humidity in oak-hornbeam forests and in open areas. An increase, due to aridity, in

the abundance of *Diptera* of the genus *Sarcophaga* occurs only because *Pollenia* prefers humid habitats (DRABER-MOŃKO, pers. comm.). Most earthworms react to aridity of their habitat by going into diapause (PILIPIUK, pers. comm.). Such species of springtails as *Anurophorus septentrionalis*, *Isotoma sensibilis*, *Xenylla boernerii* and *Hypogastrura inermis* may be treated as indicators because they are characteristic of dry habitats (STERZYŃSKA, pers. comm.). Potworms and earthworms are good indicators of soil acidity. A number of species of potworms occur more abundantly when soil pH is within the definite ranges they prefer. Earthworms do not occur, as a rule, in soils with pH below 3.5 (PILIPIUK, pers. comm.).

Among invertebrates, many taxa (of different taxonomic status) reflect the general condition of the environment and the courses of the processes occurring there. For instance, in the case of communities of digger wasps living in oak-hornbeam forests an enrichment of their species composition, an abundance increase and a transformation in the dominance structure indicate that the habitat is being transformed into a coniferous one (SKIBIŃSKA 1989). When *Diptera* of the species *Pangonius pyritosus*, *Chrysops parallelogrammus* and *Ochrops rusticus* (*Tabanidae*) begin to appear it is a sign that the habitat is becoming a steppe one (TROJAN, pers. comm.), and when the housefly (*Musca domestica*) appears in thermophilous light mixed forests and in open areas it is a sign of an increasing degree of synanthropization of the environment (DRABER-MOŃKO, pers. comm.).

A number of authors have reported that there are many good indicators among invertebrates, indicators that make evaluation of the condition of the environment possible. Such indicators include click beetles and carabids – an analysis of the species composition and structural characteristics of their communities makes it possible to evaluate the extent of anthropogenic deformations in forest habitats (BUCHHOLZ and OSSOWSKA 1995, LEŚNIAK 1977, 1995, 1997, SZYSZKO 1997). Ants and spiders, too, are useful in such evaluation (PUZSKAR 1997). A pest outbreak is frequently treated as an indicator of a poor state of tree stands or of unfavourable environmental changes influencing tree stands (SIERPIŃSKI 1971, SZUJECKI 1980). Environmental pollution causes various directed changes in invertebrate communities. For instance, a decrease in the number of species and in their abundance is a reaction of communities of potworms to an increase in soil contamination, irrespective of the substances emitted. An increase in environmental pollution is also indicated by changes in the species composition and in the structure of ant communities. Another phenomenon has been recorded in communities of carabids, namely while their forest habitats gradually become more and more degraded due to pollution, large predaceous forms are replaced by small hemizoophagous ones or by small, entirely phytophagous species (LEŚNIAK 1977).

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## STRESZCZENIE

**Monitoring bezkręgowców lądowych i ich rola w bioindykacyjnej ocenie stanu i zmian środowiska**

Monitoring i bioindykacja są pojęciami ściśle powiązаныmi, chociaż istotnie różnią się zakresem znaczeniowym. Zadaniem monitoringu faunistycznego jest rejestracja i ocena zasobów świata zwierząt w danym miejscu i czasie. Celem bioindykacji jest określenie w danym miejscu i czasie ogólnego stanu środowiska lub któregoś z charakteryzujących je parametrów na podstawie stanu wskaźnika biologicznego (bioindykatora). Obiektem monitoringu może być organizm (bądź jego część), gatunek lub grupa gatunków. Obiekt monitoringu, na którego podstawie można opisać i zinterpretować stan środowiska i zachodzące w nim zmiany może służyć jako wskaźnik w bioindykacji. Właściwości bioindykacyjne mają układy żywe na różnych poziomach organizacji, z czym wiąże się olbrzymia różnorodność cech możliwych do wykorzystania w analizach. Najczęściej jako podstawowy obiekt jest wybierany gatunek.

W monitoringu faunistycznym, zależnie od przyjętego obiektu, uzyskuje się informacje o różnym poziomie szczegółowości. W przypadku tzw. monitoringu gatunkowego, którego obiektami są pojedyncze gatunki lub rodzaje, rejestrowane zmiany dotyczą kondycji wybranych gatunków na określonym obszarze, a podstawowe parametry, które powinny być określone, to obecność i liczebność tych gatunków w danych miejscach. Monitoring układów faunistycznych dotyczy wyższych poziomów organizacji przyrody. Głównym jego celem jest ocena stanu i kondycji fauny, wyrażonych przez różnorodność i bogactwo gatunkowe. Analiza cech (parametrów) wybranego układu przeprowadzona w szeregach czasowych i (lub) przestrzennych pozwala na określenie stanu tego układu i zmian w nim zachodzących, a w dalszej perspektywie także kierunku i tempa tych zmian. Obiektami w takim monitoringu winny być wielogatunkowe zgrupowania, które można traktować jako układy modelowe struktur całego ekosystemu. Wybór obiektów (taksonów) wchodzących w skład układu modelowego jest uwarunkowany typem środowiska, w którym monitoring ma być prowadzony.

Bioindykacja informuje, jak organizmy odbierają zmiany środowiska. Przydatność bezkręgowców w bioindykacji jest bezsporna. Powiązania poszczególnych ich gatunków lub grup gatunków z różnymi środowiskami są ściślejsze i wyraźniejsze niż w przypadku większości kręgowców, a reakcja na stres, ze względu na stosunkowo krótki czas życia osobnika, może być zarejestrowana szybciej. Ponadto bezkręgowce są reprezentowane przez tak ogromną liczbę gatunków, że każde środowisko można scharakteryzować poprzez zasiedlające je wielogatunkowe zgrupowania.

Nie ma uniwersalnego taksonu, który jednakowo reagowałby na zmiany zachodzące w środowisku każdego rodzaju. Dlatego, jako wskaźników w bioindykacyjnej ocenie stanu środowiska, winno się używać różnych gatunków lub różnych ich zgrupowań. Znanych jest już wiele biologicznych wskaźników. Można je podzielić na dwie grupy różniące się przedmiotem indykacji, sposobem rejestracji danych i metodami opracowania wyników. Pierwsza grupa obejmuje wskaźniki syntetycznie określające ogólną sytuację środowiskową i kierunki zachodzących procesów, druga – służące do precyzyjnej charakterystyki stanu wybranych komponentów środowiskowych.