REVIEW ARTICLE

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Bioindicators as a fundamental element for assessing the state of forest and agrarian ecosystems

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Abstract

Introduction and Objective. The negative impact of pollutants on organisms is complex and still insufficiently investigated. This is caused by the diversity of organisms and by the high variability of the composition of foreign substances and their synergistic effects on each organism. The mechanisms by which living organisms are damaged differ depending on the type, intensity, and duration of the stress factor and interaction with biotic factors.

Review Methods. The study focuses on the importance of bioindicators and the process of bioindication which evaluate the selected organisms homeostastis, observation of ecological processes, and the overall assessment of environmental changes.

Brief description of the state of knowledge. In addition to traditional matrices, such as air, water and soil, bioindicators of plant and animal origin are used to monitor the level of environmental contamination and to control pollution. It is known that bioindicators often contain significantly higher concentrations of certain pollutants than those detected in the matrices themselves. Bioindicators of animal origin allow assessment of environmental quality and its changes over time. They serve as suitable indicators for evaluating the impact of negative anthropogenic activities on ecosystems by studying the reactions of biota to the resulting stress.

Summary. Bioindication is an important tool in ecotoxicological and veterinary studies, drawing on advances in human and veterinary medicine. As the negative impact of the human population grows on the environment, understanding the role of biodiversity in maintaining ecosystem functions becomes increasingly important. Wildlife biomonitoring using selected wild game mammals has become a common and effective approach for assessing environmental health.

Key words

environment, contamination, ecological status, bioindicator, wild game

INTRODUCTION AND OBJECTIVE

Basic aspects of bioindication. The assessment of the state of ecosystems is based on several factors. The importance and role of knowing the regular links between the occurrence and behaviour of individual species, physiological processes, morphological features and population dynamics of fauna and flora, has led to the use of ecological bioindication for assessing the state of the environment [1]. Ecological bioindication provides a full range of information about the action or presence of a factor through its reflection on living organisms. The standard of living of the population in functioning ecosystems is influenced by the environment [2].

The stability of the ecosystem and the quality of natural resources are an important factor that also affects the economic sphere, and a country with disturbed ecological stability directly affects further economic and financial development [3] disturbance of ecological stability in a country can cause serious social problems [4]. Various organisms are used to assess the environmental load and obtain knowledge about the toxicity of chemical compounds, along with assessing the risk and condition of living organisms. Bioindication and biomonitoring have an irreplaceable function in determining the level of contamination of ecosystems with harmful substances, but also in detecting the movement of these harmful substances. Bioindication is mainly used in ecological monitoring, which is predominantly of the nature of investigative methods [5]. These are various physiological, ecological and coenological methods that use the action of a factor or a whole set of factors on living organisms [6]. Organisms or their communities are used to detect foreign substances in the environment [7]. Under the influence of changed environmental conditions, foreign substances penetrate living organisms, accumulate in various organs, and disrupt physiological and biochemical reactions [8]. Bioindication serves for quick orientation where special knowledge and data are not available, or where it is the first approach to exploration. The assessment of ecosystem conditions is based on experimentally verified knowledge that there are very close correlations between the occurrence of certain species, groups of species and communities [9]. Biomonitoring is a set of methods using living organisms

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or their biological materials to assess the quality of the environment and the level of environmental pollution. It is based on the ability of organisms to respond to the presence of pollutants by accumulating toxic elements or by changing physiological, biochemical or molecular parameters. In contrast to single-time physicochemical measurements, biomonitoring provides an integrated view of long-term exposure and bioavailability of contaminants, thus enabling a more comprehensive assessment of the impact of pollution on ecosystems and the health of organisms.

Bioindicators are divided into the following groups

Accumulating bioindicators accumulate pollutants without noticeable damage, accumulate pollutants without changing their metabolic activity. They are organisms that can absorb and accumulate pollutants in their tissues at concentrations that are higher than in their environment. They are used to monitor the presence and concentration of certain substances without necessarily showing immediate signs of toxicity [10].

Reactive bioindicators respond sensitively to environmental pollution, exhibiting acute and chronic effects that manifest changes in cell properties or symptoms of cell damage when exposed to even small concentrations of toxic pollutants,

Indicator species, serve as indicators of certain phenomena or properties of the environment, according to the presence or absence of organisms,

Test organisms are used for laboratory testing of the effects of pollutants (verification experiments, toxicity tests).

Monitoring organisms are used for qualitative and quantitative detection of pollutants through active and passive monitoring using organisms living in a polluted environment [11, 12].

Biomarkers are also generally divided into three basic groups

Exposure biomarkers, which allow assessment of the presence of an exogenous chemical substance, its metabolite, or the product of the interaction of a xenobiotic and a target molecule or cell in biological samples taken from an organism (e.g. levels of bisphenol A and phthalate metabolites or DNA adducts in urine).

Susceptibility biomarkers, which serve as indicators of the specific susceptibility of individual organisms to xenobiotic exposure (e.g. specific genetic polymorphisms).

Effect biomarkers, which are indicators of biochemical, physiological or behavioural changes that occur in an organism as a result of exposure to exogenous chemicals, which may be related to adverse health effects or disease (e.g. levels of circulating hormones).

Valuable indicators of environmental pollution include wild animals of terrestrial ecosystems, as well as animals that inhabit watercourses and live in an aquatic environment [13]. These are various species of vertebrates, species from the group of wild small rodents, but especially species of aquatic macroscopic invertebrates. Any change in the aquatic environment will be reflected in the composition of these animals, their species composition and quantity [14]. Bioindication by terrestrial and aquatic organisms depends on a whole range of abiotic and biotic factors, such as the physicochemical properties of pollutants, temperature, basic characteristics of environmental components, etc. [15]. The toxic effect of pollutants is manifested in acute cases by the death and disappearance of some species, chronic poisoning can be manifested by the deformation of organs, loss of the ability to divide, and other functions of unicellular organisms [16]. The cumulative effect is manifested by the accumulation of pollutants in organisms. The greatest accumulation of these substances occurs in the body of higher-order consumers, e.g. fish, etc., and large amounts of pollutants, especially heavy metals, are collected by aquatic algae through adsorption on the cell surface [17, 18].

Bioindication through wildlife and game. Animal bioindicators have several advantages over plant bioindicators, especially in detecting contamination with persistent organic pollutants [19]. The most important representatives of herbivorous soil vertebrates are rodents (*Rodentia*) [20]. The advantage of small rodents is a relatively large set of individuals, which has a significant informative capacity for a given location [21]. The most frequently used bioindicator of agrarian ecosystems of animal origin is the European hare (*Lepus europaeus*) due to its occurrence in ecosystems, including locations with old ecological burdens. The European hare (*Lepus europaeus*) reproduces relatively quickly, which makes it possible to monitor the development of contamination even in the case of offspring, and the impact of genetic ecotoxicological influences [22]. Due to the relatively high lipid content in the tissues of wild animals and game, they appear to be the most suitable environmental bioindicators [23]. The fundamental requirements of bioindication and ecological monitoring, which is carried out in a certain habitat using animals, include a method of collecting, processing and evaluating the collected biological material, enabling gradual application in practice. For the detection and systematic monitoring of ecotoxicological disorders in agrarian and forest ecosystems, animal species that react to the presence or type of pollutants in the environment are suitable [24, 25].

Wild animals are used for the ecological monitoring of the environment, which have their habitat near large cities or sources of emissions originating from intensive industrial plants and are more exposed. These animals are therefore subjected to an increased concentration of these emissions, as well as an increased risk of poisoning [26]. For environmental diagnostics and monitoring of fluctuations in the ecological balance of the country, it is therefore appropriate to select groups of animals that can be used for bioindication [27]. It is also essential that they belong to systematically well-processed groups, where it is important to focus on detailed knowledge of geographical distribution, ecological requirements, physiological processes and the way of life of individual bioindicator species in agrarian and forest ecosystems [28]. Agriculture and forestry management reflect the habitat requirements of many species over time. The most suitable species are those that can be easily identified and monitored and whose functional relationships to habitat change are well understood [29]. Some species can be good indicators because they are habitat specialists and are particularly sensitive to biotop change. Monitoring the response of their populations to management is key to their use as indicators and their value is particularly important for planning and large-scale analysis, rather than for monitoring alone [30, 31]. Wild agricultural and forest game often falls into this category. Wild animals show a pronounced response to environmental stress and are sensitive to inappropriate

changes in the environment. The best bioindicators of animal origin for environmental monitoring of agrarian and forest ecosystems are the European hare (*Lepus europaeus*), the Roe deer (*Capreolus capreolus*), the Common pheasant (*Phasianus colchicus*), the mallard (*Anas platyrhynchos*), and small field rodents. In forest ecosystems, these are mainly the Grey wolf (*Canis lupus*), the Brown bear (Ursus arctos), lynx (*Lynx lynx*), moose (*Alces alces*), Red deer (Cervus elaphus), and Fallow deer (*Dama dama*). Many species of deer living in forests offer strong potential as ecological indicators of forestry management and diversity at broad landscape scales [32, 33, 34]. They have a high potential value for planning the use of the forest ecosystem, relatively large and often seasonally migratory home ranges, and therefore require landscape management rather than isolated areas of habitat. The habitat they require is diverse in terms of food requirements and vegetation, as well as spatially and genetically. Deer species therefore often provide a means of evaluating land-use alternatives in a biologically meaningful, theoretically sound and socially relevant way. Their potential should not be overlooked in efforts to manage forests in an ecosystem context, and to conserve biologically diverse wildlife communities [35].

Biomarkers and blood as a bioindication system. A special type of bioindication is the use of biomarkers. This medical method of detecting often very specific reactions of the organism to certain xenobiotics is of special importance, especially nowadays when there is a great development in this area. With the help of biomarkers, many problems related not only to medicine and disease diagnosis, but also to the environment can be determined, which has a significant impact on ecosystems [36]. The modern approach to assessing and evaluating biomarkers is based on the determination and quantification of molecular, biochemical, physiological, genetic and cellular changes, depending on xenobiotics – the exposure of the organism to toxic substances [37].

These include industrial chemicals, pesticides, pharmaceuticals, heavy metals, or combustion products that can enter the body through food, water or air. Xenobiotics can cause toxic effects, affect metabolic processes and induce specific biomarkers of exposure, effect or sensitivity. Their detection in blood therefore provides important information about the extent and nature of environmental exposure of the organisms under study. The fact of observing these changes arose because of assessing the bioavailability and bioaccumulation of substances in the organism and its response to xenobiotics. Their action is based on the principle that the biological effects of toxic compounds are initiated by the interaction of these substances with biological receptors in a living organism [38]. It is assumed that the biological effects of toxic compounds at the ecosystem level precede the chemical reaction in individual organisms. It can also be assumed that the concentrations of contaminants that initiate chemical reactions are lower than those concentrations that would cause a life-threatening situation for the target organism, or significant degradation in the ecosystem. Detection and proper quantification of these chemical reactions could provide a sensitive and specific indication of environmental stress [39]. Responses can range from changes in biochemical and physiological phenomena, such as the so-called homeostatic response in individuals, to overall toxicity related to an individual, species, population, or ecosystem [40]. Bioindicator responses signal that contaminants have been present in the environment for some time and in sufficient quantities to elicit this response. They are used to determine changes in important functions, such as cholinesterase inhibition, reproductive effects, teratogenic effects, haemoglobin synthesis abnormalities, DNA damage, histopathological effects, immune system effects, vitamin levels, specific protein effects, and others.

Blood tests are also used for these types of biomarkers, which are optimal for determining the burden on the body [41]. Blood is the main component of the internal environment of the organism and a suspension of cellular elements. Of the organic substances contained in blood plasma, plasma proteins are in the first place [42]. Peripheral blood is probably the most informative tissue that can be non-lethally sampled in vertebrates as it can reflect whole-organism function. This practicality and ecological relevance of blood variables, along with the advantages of incorporating standardised procedures and cutting-edge technology into blood analyses in wild game, is useful in wildlife studies [43, 44].

Variability of the benefit of bioindicators Ecology of forestry and agrarian ecosystems and wildlife management is the study of animals in their natural habitats and how these systems compete and interact with humans with the world. Wildlife ecology is about managing populations sustainability for the benefit of the relationship between wildlife and the negative environmental impact of the human population [45]. It can be noted that wild animals are living indicators of the characteristics of their environment or biotope, thus wildlife management is concerned with how to address these environmental features for the benefit of wildlife [46]. Animals have an important role in the balance of the environment and provide stability to various natural processes [47]. As the environmental pollution of agrarian and forestry ecosystem causes severe adverse effects on animals health, analysis of the physiology and ecology status from wild game may be a useful bioindicator system of environmental pollution over a long period of time. Wild animals, in particular highly territorial animals, such as red deer or roe deer, are useful for indicating environmental contamination [48, 49]. Environmental pollution in forest ecosystems arising from a combination of local and distant emission sources. The main mechanisms include atmospheric deposition of pollutants originating from industry, transport and energy, as well as long-term deposition of heavy metals and persistent organic pollutants in soil. Factors such as terrain relief, prevailing wind directions, soil type, vegetation cover and hydrological conditions contribute to spatial variability of pollution. These differences are subsequently reflected in the variability of bioindicators that respond to local environmental conditions, thereby providing valuable information on the distribution and intensity of environmental loads in forest ecosystems.

Figure 1 shows the complex scheme and key sources of pollution and stressors that affect the individual environmental matrices: air, soil and water. It also shows examples of bioindicators of plant and animal origin, mechanisms of damage to organisms, and the bioindication process itself with the resulting output for ecological and veterinary assessments as an assessment of environmental status, biodiversity and wildlife health.

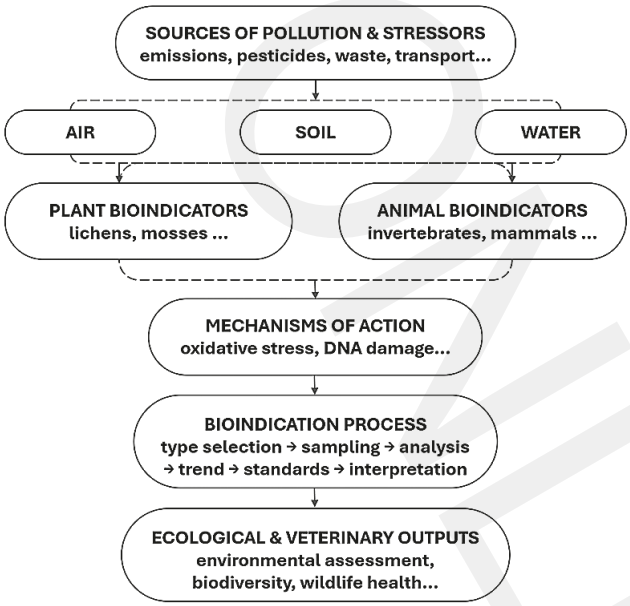

Figure 1. Sources of pollution & bioindication process

CONCLUSIONS

The natural values of agricultural and forest landscapes are threatened by the processes of intensification of agricultural production. These processes lead to the loss and degradation of habitats and ecosystems, the loss of biodiversity, soil erosion and degradation, water pollution by industrial fertilizers and pesticides, and changes in the hydrological regime. The result is a disturbed landscape with reduced ecological stability. To restore agrarian and forest ecosystems, it is necessary to change the current environmentally friendly approaches that will respect natural laws. Environmental changes can take various forms, from natural to anthropogenic.

Some manifestations of human activity are contemporary, or their biological effects have been observed relatively recently. One of the options for determining the impacts of human activity on the health of organisms, the function of ecosystems, and on the structure and functioning of the entire landscape, is the use of living organisms as indicators of environmental quality. Systematic monitoring of the development and spatial distribution of bioindicator signs can be used in two senses. In a narrower sense, it is about monitoring the state and changes in the environment with the help of living organisms, which are considered bioindicators, which can be perceived from two sides. An indicator that is a measure and output of bioindication methods, or an organism used in bioindication methods. Bioindication relies on the analysis of information structures of living systems, from individual organisms to complete ecosystems. The overall goal is to define environmental quality and assess environmental risks.

The current pace of environmental change is unprecedented, and it is not known whether the ability of wildlife species to adapt to such changes and to cope with their harmful and often combined effects can be successful. The current state of biota, flora and fauna, as well as their quality, is influenced primarily by the consequences of human activity, in addition to natural conditions and natural development. Humans have been involved in the transformation of the landscape and its individual components for a long time. Flora and fauna are therefore the components of nature that most reliably reflect the degree of human impact on the landscape, and the quality and direction of environmental development. A more multidisciplinary framework in field studies is also necessary to better understand outbreaks of disease among wildlife and multitrophic impacts on ecosystems.

There is no perfect method for determining the health of animals or ecosystems, and a combination of indicators of damage at different levels of organization will provide the best diagnostic picture. However, systematic analyses of the ecology and environment in wildlife vertebrates can serve as early indicators of a problem population before stress from the response significantly affects reproduction and other performance indicators.

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