Assessment of taxonomic diversity of soil biota for landscape planning

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Abstract. Biological (taxonomic) diversity is the potential for self-organization of the biosphere, ensuring its regeneration, resistance to the effects of various environmental factors, including anthropogenic, as well as a resource for compensating the losses of individual biotic elements. Disturbance of ecological balance is a prerequisite for the emergence of conflict situations of local and regional nature, leading to irretrievable losses of certain types of natural resources, as well as aesthetic value and recreational significance of landscapes. Various indicators can express the degree of change in the biodiversity of transformed geosystems as well as the state of biotic communities as a whole: indices of diversity, dominance and occurrence of species, as well as through evaluation scales, where the deviation of the indicator from the background characteristics is shown in percentages or points. This assessment has identified three main categories of situations in the spectrum of biotic communities: critical, conflict and relatively prosperous. The main trend of changes in the taxonomic diversity of soil invertebrate communities is a decrease in the number of species in the gradient of increasing climate aridity, strengthening of the hypothermia and anthropogenic pressure. The revealed regularities of soil biota’ changes can be used to optimize environmental control.

1. Introduction

Landscape planning, being a tool used to organize the life of society in a particular landscape, involves the introduction of new land-use principles that are oriented towards the long-term preservation of the natural potential in all its manifestations as a natural basis for human life, that is, the choice of an environmentally sustainable regional development strategy. For landscape planning, it is necessary to identify indicators and criteria that determine the nature and intensity of land use and reflect the main trends in the change of geosystems under the influence of anthropogenic factors in a specific natural environment. The most rational is a component-wise targeted assessment of the state of biotic complexes at training grounds and key areas, covering the main types of the environment, followed by a comprehensive cartographic analysis of the available information throughout the territory. Depending on the geographical dimension of landscape units, certain indicators are selected, as well as methods for their preparation and analysis options.

Biological diversity as an object of conservation is not only the species composition of organisms with their quantitative parameters but also a qualitative system of relationships between these organisms, ensuring the functional integrity of ecological systems. The problem of preserving biological diversity, on the one hand, is closely related to the activities to protect natural resources and the environment carried out in the environmental management system. On the other hand, it is an
independent specific area of activity aimed to reduce the impact of environmental management on the state of ecological systems.

A comparative analysis of the structural and functional organization and spatiotemporal variability of soil zoocenoses in natural and transformed geosystems is an important area of research within the framework of the problem of anthropogenesis of the natural environment in the Siberian regions and the search for ways to preserve the socio-ecological functions of landscapes and biological diversity by regulating the economic activity. The poor development of the general theory for assessing the state of diversity and the methodology for their practical application complicates an informed choice of indicators for characterizing the studied landscape units, including individual biotic communities and local faunas.

Biological diversity is directly related to coenotic and landscape diversity. From the whole variety of ideas about the mechanisms of stability of geosystems [1-3] one of the leading mechanisms for maintaining functional stability is the ability of biota to restore their properties after temporary external influences, the so-called stability of the “regenerative” type. This stability type is controlled mainly by zonal factors, i.e. geographical background with certain geological and geomorphological, climatic, hydrological, and edaphic conditions that determine the nature and speed of restoration processes.

2. Objects, data and methods
The objects of the analysis are the species (taxonomic) structure and diversity of terrestrial invertebrates, forming community and having systemic and functional relationships. Focused on the mesopopulation (supraspecific taxonomic level), i.e. relatively large invertebrates inhabiting the soil and its surface.

The data resulted from a detailed study of the quantitative characteristics of invertebrate communities on key ranges in the taiga, mountain taiga and steppe geosystems of the Lake Baikal region. Numerous literary and cartographic materials, information on land cover and vegetation conditions were analyzed, and data on the thermal conditions of soil and moisture were taken into account. To formulate and perform a method of soil-zoological and biogeocenotic studies, the comparative geographical approach was used. Based on theoretical concepts about the relation and interdependence of all natural components within a certain genetically homogeneous space, opportunities of landscape indication were used to compile a map model of distribution of soil and biotic community patterns [4, 5].

Spatial patterns of change in species diversity in gradients of environmental factors, such as high-altitude zone, temperature and soil moisture, were identified in the most well-studied model groups of invertebrates in the Baikal region, the members of the families Lumbricidae, Carabidae, Staphylinidae, and Elateridae.

The collection and processing of material were carried out uniformly using both traditional and modern approaches and methods recommended for ecology-faunistic, soil-zoological, biogeocenological and landscape-ecological studies. To determine the number and biomass of the inhabitants of soil and litter, 6-8 samples with a depth of 25-40 cm (depending on the limiting occurrence of invertebrates) were taken in each area in a checkerboard pattern on a 25x25 cm with a monolithic drill [6-8].

3. Results and discussion
One of the most important criteria for community sustainability is biodiversity, reflecting the complexity of its species structure. Biological diversity is in multilevel functional dependence with the characteristics of the geosystem, its dimensionality and stability, dynamic structure (biota and abiotic environment), representing a single whole. The indicator of diversity at the species level considers the correspondence between the number of species and their specific gravity (abundance, biomass, productivity, occurrence, etc.) or the ratio of the number of species to unit area. The predominance of rare species in the community, which create many coenotic relationships, as well as the presence of a
group of dominant species that form the core of the community, indicates the stable functioning of the ecosystem.

The most powerful factor in destabilizing the geosystem as a whole and its components at all levels of the organization is the increasing human impact: elimination of the forest due to logging, fires, man-caused contamination, plowing of land, over-use of fertilizers and pesticides, high pasture and recreational loads. The cumulative, often turning into irreversible, consequences of chronic and radical anthropogenic disturbances lead to the transformation, reduction or degradation of the living environment of living organisms, a change in the structure of habitats and biogeographic boundaries, the intensification of fragmentation and ecotonization of natural landscapes, and, sometimes, the complete destruction of the least stable ecological systems [9-11].

Violation of the ecological balance is a prerequisite for conflict situations of local and regional nature, leading to irretrievable losses of certain types of natural resources as well as aesthetic value and recreational significance of landscapes.

In most situations, the mechanism of anthropogenic transformations is a change either in the physicochemical properties of the soil or the hydrothermal regime, causing the corresponding changes in biotic communities. The structural and dynamic inequality of landscape units and degree of anthropogenic impact determine the negative aspects of these changes. The most profound changes in the structure of biotic communities and biodiversity are observed in the most dynamic categories of landscape units, where, during transformation, the action of limiting factors is significantly enhanced.

During the transformation of natural landscapes, the restructuring of biotic communities, as a rule, goes towards reducing species diversity and simplifying the structure of zoocenoses. In the composition of invertebrate complexes, mesophilic species decrease in their numbers or disappear, and, as a rule, xeroresistant representatives of the fauna less demanding on edaphic conditions begin to prevail. The proportion of the phytotrophic group increases due to the appearance of specialized phytophages as well as eurytopic, more adaptive species. The depletion of the structure of the animal population and a decrease in its functional activity in the soil can act as indicators of adverse environmental conditions: changes in the soil and vegetation cover towards its degradation, pollution or desiccation of the upper layers, etc.

The environmental assessment (diagnosis) of the state of geosystems carried out according to the scheme "impact - changes - consequences" suggests the following steps:

1 – analysis of the spectrum of geosystems by physical and geographical parameters and the identification of the main forms and a degree of anthropogenic impact;

2 – a selection of key areas, covering the dominant types of geosystems (or polygons according to the impact gradient), and natural analogues located outside the influence sphere of this anthropogenic factor;

3 – a selection of indicators and criteria for bio-diagnostics and rating scales in specific environmental conditions;

4 – comparative analysis of the obtained characteristics and the integration of individual indicators according to the standards and rating scales;

5 – a generalization of information in the form of summary matrices, cartographical diagrams or maps.

Biota changes are manifested at the species, population, and coenotic levels. Assessment of the condition can be carried out using organisms of various taxonomic ranks. The main criteria for the transformation degree of natural complexes and the assessment of their state are as follows: 1) changes in the species composition and the structure of soil-biotic communities by comparing the taxonomic diversity of natural and disturbed analogues or according to the impact gradient; 2) the ratio of the life forms of dominants and functional trophic groups of invertebrates; 3) a change in productivity under the influence of an anthropogenic factor.

Depending on the resistance of animals and their reaction to the effects of anthropogenic factors, both sensitive (positively or negatively reacting) and indifferent (without indicative value for this type of pollution), can be distinguished.
During monitoring in zones of environmental anomalies, special attention should be paid to the criteria characterizing the degradation processes of biogeocenoses: in plant cover — phytocenotic restructuring of communities and a decrease in productivity; in the soil-biotic block — a change in the structure of zoocenoses, destabilization of the abundance of background species, a reduction in taxonomic diversity, the introduction of alien species, and a decrease in the biological activity of the soil. Various indicators can express the degree of change in the biodiversity of transformed geosystems as well as the state of biotic communities as a whole: indexes of dominance and occurrence of species, similarity coefficients of compared cenoses, as well as through rating scales, where the deviation of the indicator from background characteristics is shown in percent or points.

This assessment has distinguished three main categories of situations in the spectrum of states of biotic communities: critical, conflict and relatively prosperous. The first category includes communities with a high (IV, V) disturbance degree and low stability, an almost irreversibly transformed structure where the state of the environment adversely affects the vital activity of soil-biotic complexes. The second category includes communities with medium resilience reversibly weakened with a medium disturbed (III degree) structure where the ecological situation is very dynamic, and an increase in the load leads to a sharp deterioration of the state of the biota and environmental conflicts. Improving the situation and restoring the normal functioning and reproduction of renewable resources is possible through the regulation of adverse effects and environmental protection measures. A relatively prosperous situation is characterized by a weak (I, II) disturbance degree of biotic communities, stable functioning and a high “regenerative” stability.

To systematize the states and cartographic presentation of the obtained data, matrix gratings, which are constructed considering the typological features of elementary geosystems, biodiversity and local factors of destabilization of communities as well as the intensity of anthropogenic impact, can be used. Such an approach allows for an integrated assessment of the degree of transformation and stability of each specific biogeocenosis (or landscape unit) and establishment of the limits of permissible, critical and unacceptable anthropogenic loads as well as identification of territories to be restored and protected. An ordered range of conditions can serve as a source of information for creating a map of optimizing land use, taking into account their sustainability and developing recommendations for rationing anthropogenic impact to preserve rare and unique ecosystems and prevent degradation of natural landscapes.

These criteria can be used to identify zones of anthropogenic transformation, i.e. ecological zoning of territories, which implies strengthening the environmental regime within the exposure ingredient from the most stable landscape structures to more sensitive and less stable as well as the control and regulation of negative impacts from the periphery up to the protected object.

4. Conclusion

Environmental conditions at various hierarchical levels of the spatial organization of the landscape refract the effects of anthropogenic factors, due to which there are significant differences in the response of individual structural elements of the animal population.

The taxonomic diversity of invertebrate communities in the mesoscale space (at the level of facies groups) varies mainly in the gradient of edaphic and climatic and phytocenotic factors, which depend on the location of the biogeocenosis in the landscape. Monitoring the state of biotic communities can be performed at two levels: coenotic, when biological diversity decreases due to the loss of individual taxa, and landscape, when, under the influence of anthropogenic factors, differences between individual geosystems are leveled or some of them are completely degraded. The likelihood of undesirable effects grows adequately with increasing exposure, refracting through environmental parameters.

A conjugate analysis of climatic situations and patterns of structural change in a fairly informative biotic block within a wide typological spectrum of geosystems can serve as a methodological basis for analyzing local manifestations of climate warming in various types of the environment and optimizing the monitoring system: when choosing, on the one hand, key and test sites and, on the other hand,
representative elements of biota as objects of observation, which reduces the volume of recorded indicators in various landscape-zonal conditions.

For building a system of economic and special environmental protection measures, it is necessary to take into account the landscape-ecological heterogeneity of the territory. Human activities to create a sustainable landscape should be aimed at preserving its diversity and maximizing the use of natural self-healing opportunities. Along with the use and extraction of natural resources, it is advisable to preserve, with no subject to increased influence, the least stable categories of landscape units, which can be sources of biotic elements for regenerating communities. Transformed biogeocenoses, which act as potential foci of a high number of forests’ pests and cultural landscape, deserve special attention.

The landscape-ecological approach provides typological and spatial certainty of the estimated and predictive constructions as well as the ability to trace the manifestation patterns of the consequences of various forms of anthropogenic impact.

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