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RECOVERY AND RESERVATION IN THE FORMATION OF ECOSYSTEM RELIABILITY

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Abstract

Reliability is one of the main characteristics of ecosystem, its ability to effectively maintain its structure and perform functions without fail when environmental conditions change due to natural or anthropogenic negative impacts. It is shown that in the assessment of ecosystems, the leading role belongs to environmental monitoring to determine the condition of ecosystem components and identify the possibility of ensuring reliability. Methodical approaches to environmental monitoring have been developed. Mechanisms of ensuring and principles of reliability assessment of different types of ecosystems are considered. The main attention is paid to the recovery, reservation and conditioning of ecosystems under the influence of negative factors. To quantify the ability of ecosystems to recover, it is proposed to use appropriate criteria, which are determined by certain calculation formulas. With insufficient reliability of ecosystem elements due to the actions of negative factors, its reliability is ensured by reservation at the expense of additional means and capabilities. In the case of agroecosystems, which are artificially created biotic groups of organisms that are supported by humans, it is an integrated approach using the theory of ecosystem reliability that expands the range of means to study their effective functioning. It is noted that the increase in the reliability of the agroecosystem is provided by the use of its reliable elements, as well as special systems for ensuring recovery and reservation. It is emphasized that the application of reliability theory in the study of agroecosystems contributes to the management of their functional efficiency for obtaining environmentally safe products.

Keywords: ecosystem, agroecosystem, reliability of ecosystem, recovery, reservation, environmental monitoring, pollution, environment.

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1. Introduction

An ecological system is a complex of organisms living together and the conditions of their existence, which are in a regular relationship and form a system [1]. This is the main natural unit on the surface of the Earth. The ecosystem is characterized by species composition and abundance of organisms, biomass, ratio of autotrophic and heterotrophic organisms, spatial localization of the organisms, intensity of processes of production and destruction of organic substances, etc. [2]. The environment in which living organisms exist is not only their environment, but also a set of space-time events [3].

Depending on the intensity of the impact of negative factors on ecosystems, they can disappear (for example, as a result of an earthquake, flood, volcanic eruption, etc.), and new ones appear in their place over time. At the same time, under the non-critical adverse effects, ecosystems may be fully or partially preserved with retaining the dominant biota. This property of ecosystems is determined by their reliability – the ability to exist and function effectively, to regenerate and to self-regulate for a long time in case of variability of environmental conditions due to natural or anthropogenic adverse impacts. The essence of reliability is the ability to recover damage and eliminate its consequences.

Depending on the way of ecosystem analysis, methods for determining their reliability are divided into two classes [4]:

1) structural methods based on the determination of reliability indicators of ecosystem components (elements) and the relationships of these components with each other and with the environment;

2) functional methods, which are formed on the determination of indicators of reliability of performance of ecosystem functions.

An important indicator of ecosystems is that, when analyzing their reliability, it is necessary to have a prediction based on knowledge and assessment of the effectiveness of reliability formation as well as responses to adverse impacts.

The reliability of ecosystems under normal and extreme conditions is determined by their properties: the reliability of the elements, the type and nature of the organization of structures, the functioning of their reliability systems – recovery, reservation and conditioning [5].

Based on the analysis of scientific information, the role of recovery, reservation and conditioning in the formation of the reliability of ecosystems, as well as their importance for assessing the reliability of agroecosystems, is considered.

2. Materials and methods

To assess the reliability of ecosystems, environmental monitoring is carried out: observation, control and assessment of the state of the environment, determination of the composition and quantification of environmental pollutants (air, soil, water, biota), their migration routes; the extent of adverse impact on both biota, including human health, and nature in general [6].

Physical and chemical methods of environmental monitoring play a leading role in assessing the state of ecosystems, comparing pollution of selected ecosystem components with normative concentrations. This analytical approach is a priority in identifying contaminated areas in ecosystems, but it is impossible to identify the nature of the action of pollutants on biota with their simultaneous impact (synergistic or antagonistic effect), the possibility of secondary effects of pollutants, etc. Monitoring of ecosystems is impossible without the use of biological indication approaches, which provides direct information about the response of organisms to the effects of negative factors. Bioindication is the identification of the biologically significant influence of negative factors, which is based on the reaction of living organisms and their communities; assessment of the state of the environment (ecosystems) using biological objects [6, 7]. The environmental monitoring program should contain the following steps (**Fig. 1**).

Ecological monitoring of environmental objects has features depending on the type of ecosystems. So, for example, monitoring of agroecosystems includes [6]:

1) in crop production – soils of arable and pasture lands, agricultural plants, crop products, irrigation water, reclamation systems, fertilizers, pesticides;

2) in animal husbandry – fodder, feed additives and feed raw materials; farm animals and livestock products (milk, meat, etc.); water, including that used for commercial fish breeding; waste from livestock farms and fattening complexes, poultry farms, livestock premises, etc.

Depending on the terms and frequency, the following types of ecological monitoring of ecosystems are distinguished:

1) initial – those that record pollution levels at the time of monitoring;

2) planned (periodic or seasonal) – carried out in accordance with the monitoring regulation;

3) unscheduled (operational) – conducted in case of accidents at environmentally hazardous facilities;

4) continuous examination – is carried out in order to determine the affected area (terrain).

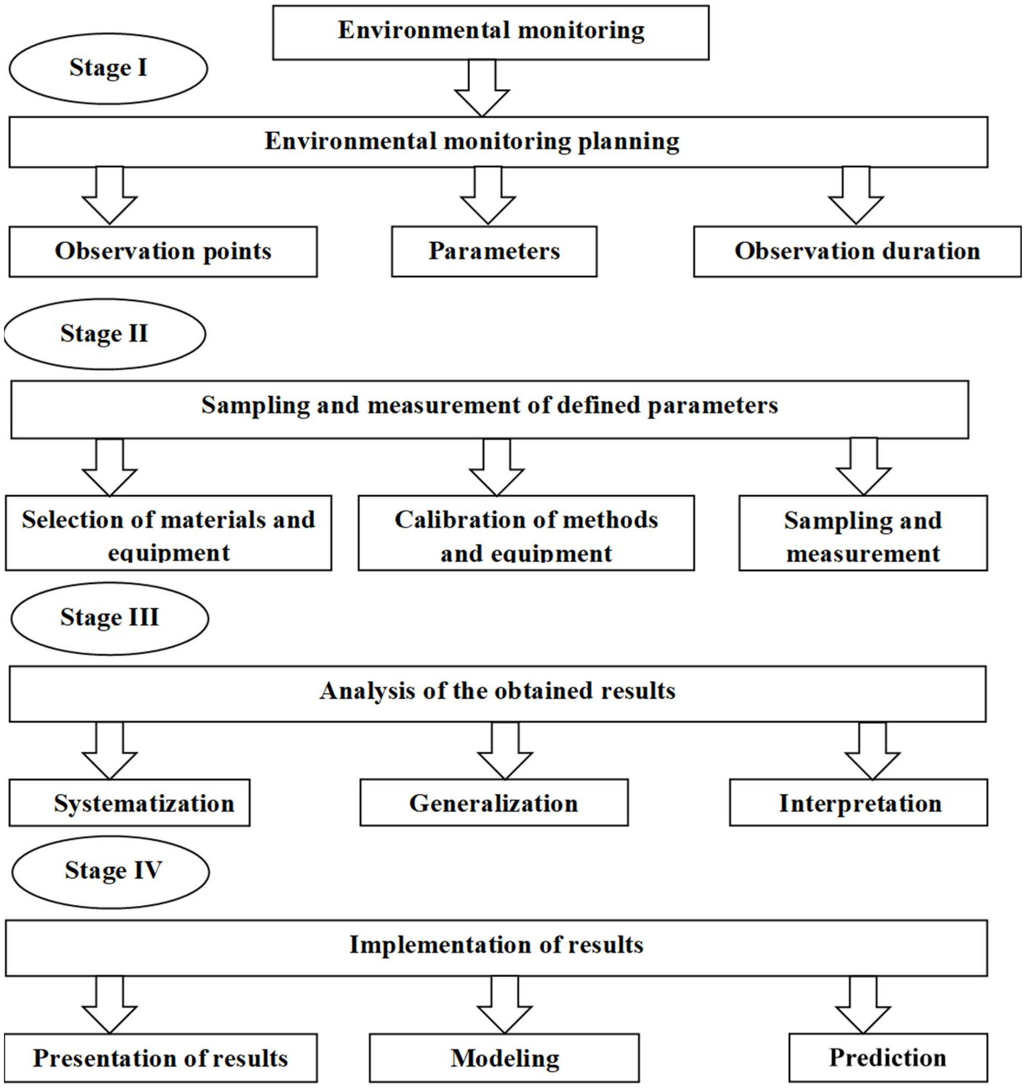

Fig. 1. Stages of ecological monitoring

3. Results and discussion

The main objective of ecosystem monitoring is to determine the state of components, establishing the possibility of ensuring reliability, in particular, through recovery and reservation of the elements that are integral parts of these ecosystems.

The term "recovery" in a more general sense is a bringing to the previous state (restoration) of an object that was damaged, spoiled or destroyed. In the case of biological restoration systems, this is the process leading to partial or complete renovation of biological objects that have been exposed to natural and/or anthropogenic processes [5].

In most cases, the recovery of ecosystems means their restoration, which initiates or accelerates the return of ecosystems to normal state after its deterioration or even temporary loss under the influence of negative factors. Recovery of ecosystems concerns primarily their productivity, preservation of species diversity and biota abundance.

Essentially, the recovery of the ecosystem, in particular the agroecosystem, is an ecological restoration, which includes the wide range of phenomena and processes: the fight against prolonged pollution, reclamation of disturbed lands and water resources, the use of local biota species and much more. Such approaches are appropriate for restoring ecosystems that already have clear signs of future degradation or have already degraded (for example, as a result of a man-made disasters). However, the ability of an ecosystem to withstand changes arising under the influence of external negative factors, to resist anthropogenic factors and recover after their influence determines the resistance of the ecosystem [8, 9]. On the other hand, the ecosystem resistance is the ability to adapt to changing conditions, not to reduce some vital permissible ecological level, to resist external anthropogenic influences or to maintain the existing mode of functioning under the influence of negative effects.

Adaptation is an adjustment of organism structure and functions to changes in living conditions or the processes and result of ecosystem resistance increase. On the other hand, ecosystem resistance is the ability to effectively preserve its structure and spatio-temporal functioning in changed environmental conditions, which is a form of manifestation of reliability in specific environmental conditions [5].

Nevertheless, self-regeneration is natural for ecosystems that are not destroyed or not critically damaged, which is ensured by the reproduction of biota individuals, which, first of all, are able to adapt to changed living conditions.

Regarding the determination of the role of adaptation in recovery processes, it is essential to assess the ecological adaptive potential as a measure (limit) of the adaptive capabilities (modification variability) of organisms, which determines their resistance to the action of negative factors.

To assess the ability of ecosystems to recover under the influence of negative factors, it is possible to use such a criterion as the coefficient of readiness for recovery, known in the theory of reliability of technical objects. It determines the probability that the ecosystem will be able to perform its functions at an arbitrary moment in time under the influence of negative factors.

Unlike the reliability of ecosystems after recovery, the value of which is determined by the value of the average lifetime of the restored state, the readiness of the ecosystem for recovery also depends on the average time required for the system to return to the state of performing its functions (manifestation of restoration).

The coefficient of readiness for recovery of ecosystems (*Kr.r.*) can be determined using the following formula (similar to the determination of the coefficient of readiness for recovery of technical objects):

$$Kr.r. = \frac{tl}{tl + te}, \quad (1)$$

where *tl* – average total lifetime of the restored state;

te – average total expected time before recovery.

Reservation in terms of general interpretation is the use of additional tools and or capabilities in order to preserve the functionality objects in case of failure of one or more elements. In relation to ecosystems, the term "reservation" refers a way to ensure the reliability of ecosystems with insufficient reliability of their components (elements) under certain conditions (for example, the influence of negative factors) due to additional means and capabilities [4].

Thus, reservation is a method of improving the reliability of objects or systems (including ecosystems), which is a universal principle of reliability.

The main types are distinguished in ecosystems [8–15]:

1) structural reservation – introduction into the object (system) the backup elements or subsystems that are in different modes of operation and, depending on this, are able to function instead of those elements or subsystems that are functionally inactive;

2) time reservation – such planning of the functioning of the object (system), in which a time reserve is created for a reliable and effective existence;

3) functional reservation – use of the ability of elements to perform additional functions;

4) mixed reservation – a combination of different types of reservation in one object (system).

Each type of reservation has a different ways to implement it.

To evaluate the reservation efficiency, a reliability improvement coefficient due to reservation (*Kr.i.*), is used, which is determined as follows [10]:

$$Kr.i. = \frac{P(t)r}{P(t)}, \quad (2)$$

where *P*(*t*)*r* – the probability of effective functioning of the reserved element (system);

P(*t*) – the probability of effective functioning of a non-reserved element (system).

In ensuring the reliability of ecosystems, in addition to biota recovery and reservation systems, significant importance belongs also to the conditioning, i. e. the permanent maintenance of biota habitat in state that is suitable for specific ecosystems [10].

The most important components of ecosystems are soil, atmosphere, and water. Soil is a complex bioorganic-mineral layer on the surface of the earth's crust, which together with living organisms forms complex ecosystems. The continuous process of biogenic accumulation, energy transformation and redistribution, the primary source of which is solar radiation, occurs in them; they are also involved into turnover of chemical elements [12]. Plants grow on the soil surface and this component of ecosystems combines other biological objects through consumption cycles.

There are a number of factors that can disrupt soil properties, especially its fertility. This is, first of all, soil erosion – the process of destruction of the upper, most fertile layer of soil and subsoil. It is divided into: water erosion – destruction by melt, rain or drain water, improper irrigation (irrigation erosion); wind erosion – blowing of the upper fertile soil layer by air flows; pasture erosion – destruction of turf and surface soil by excessive unregulated grazing; anthropogenic erosion is caused by irrational human economic activity [12].

Soil fertility is substantially affected by its depletion due to improper use of agricultural technology, crop rotation disturbance, as well as pollution by ecotoxicants. Sources of ecotoxicants are extremely diverse: both natural (volcanic eruptions, hurricanes, tornadoes, floods, etc.) and anthropogenic (emissions and discharges of toxic substances from various industries, enterprises of the nuclear energy complex; wastewater from livestock farms; toxic chemicals (in particular, pesticides) and excess amount of fertilizers.

A significant destructive force is the military-industrial complex. The modern army needs an permanently growing space for its functioning. The size of the territory and the degree of negative impact on the environment are multiplied by maneuvers and military exercises, and especially in combat operations [13].

Water is the dominant factor of all living organisms, a constant component of their environment, participates in metabolic processes as a solvent and metabolite, a regulator of the body's heat balance, etc. [12].

Atmospheric pollution is the result of emissions of solid, liquid and gaseous pollutants in such quantities that it affects the quality of the outdoor air, causing harm to living and non-living nature, in particular, agro-ecosystems and the entire environment.

The Earth's climate, which significantly depends on the state of the atmosphere, periodically changed: epochs of significant cooling and warming alternated [14]. But recently it has been observed that the atmosphere is warming up much faster than ever in the past. It is determined that due to the combustion of a large amount of various fuel materials, the atmosphere warms up, because it accumulates an excess of carbon dioxide (CO_2), carbon monoxide (CO), nitrous oxide (N_2O), methane (CH_4) and other greenhouse gases. The presence of such gases and water vapor contribute to greenhouse effect. The reflected from Earth's surface sun energy do not return into space. The infrared radiation is absorbed by an increased amount of greenhouse gases trapping its heat in the atmosphere and creating a greenhouse effect above natural level.

The consequence of this – an increase in the temperature of the surface atmosphere, which leads to acceleration of climate changes and destructive problems of global warming both in this layer of the atmosphere and on the Earth's surface [15].

Ukraine is a state with a powerful agro-industrial potential and great prospects for agricultural development. It has favorable climatic conditions and quality land resources. Priority should be given to agroecosystems, which are artificially created groups of organisms (crops or plantations of cultivated plants) maintained by humans for agricultural production. However, a characteristic feature of an agroecosystem, which has a high yield of one (several) species or varieties of cultivated plants, is low reliability and inability to exist for a long time without human support. The reliability of agroecosystems is directly related to sustainability and stability. According to the laws of general ecology, acroecosystems are unstable. The stability of ecosystems is determined by their ability to be in an equilibrium state or return to it after a temporary withdrawal from this state under the negative impact of external factors, that cause non-critical damage, i.e. do not lead to its destruction. Therefore, the ability to recover after exposure to negative factors (in particular, ecotoxicants) is essential to maintaining the stability of the agroecosystem.

During the assessment of the reliability of agroecosystems, it is fundamental to establish a capacity for ecotoxicants – the pollution limits beyond which changes in the ecosystem that are essential for the existence and performance of functions are not yet observed. The capacity parameter can act as a degree of reliability both for each element and for the entire ecosystem, since if it is exceeded, the life activity of the biota can be inhibited in the ecosystem [11].

It should be noted that when assessing the reliability of the agroecosystem, it is necessary to take into account not only the properties of ecotoxicants, including their toxic effect on the ecosystem biota, migration ability between elements (components) of the ecosystem, mechanisms for entering the plant, etc., but also the entire set of properties of the agroecosystem itself, in particular the species and variety of agricultural crop, argochemical properties of the soil, the capacity of the ecosystem for this ecotoxicant, fertilization, weather and climatic conditions, environmental situation and much more.

Increasing the reliability of the ecosystem, as noted, is also ensured by the use of special effective systems of recovery, reservation and conditioning (preservation of the habitat). To a large extent, this also applies to agroecosystems, which are characterized by the dependence of existence on human activity. For the process of recovery of agroecosystems, various methods are used, in particular, the application of adsorbents for toxicants, fertilizers, growth stimulants, the use of plant protection products, the improvement of soil treatment methods, etc.

For the reliable existence of agroecosystems, it is necessary that they be productive (constantly restored, maintain the necessary biomass), as well as conditioned (maintain the habitat in a state that is suitable for the functioning of this ecosystem). The ecosystem will be reliable under conditions of simultaneous manifestation of these functions. Thus, high productivity without environmental conditioning (for example, waste disposal) will inevitably lead to a deterioration in the state of the agroecosystem, and on the contrary, highly efficient conditioning without sufficient productivity will lead to the capture of released ecological niches by other organisms, which will cause changes in ecosystems.

The main ways of maintaining the reliability of the agroecosystem are shown on the example of crop field (**Fig. 2**).

At the same time, it should be taken into account that the production of agricultural products, in particular, crop production, faces a number of risks, including dependence on climatic conditions, which is least regulated by humans. This should be taken into account when planning means of the agroecosystem recovery. With the study of the problem of the reliability of agroecosystems, an understanding of their complex system organization arises, where a person significantly affects only individual links, and the whole system continues to develop according to natural laws. That is, solving the issue of the reliable existence of agroecosystems must be approached extremely carefully, and this will pay off with their ecological safety.

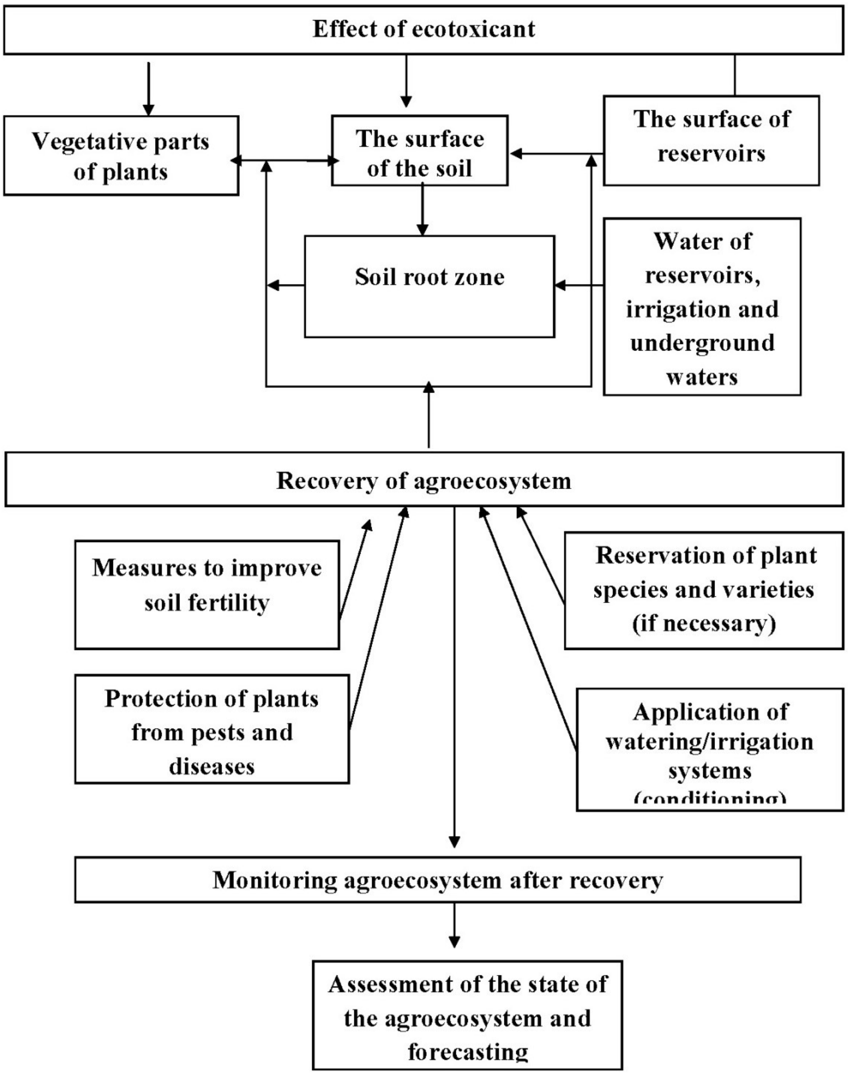

Fig. 2. Main ways of forming the reliability of the agroecosystem (on the example of crop field)

4. Conclusions

The high reliability of ecosystems that have undergone evolutionary selection and the influence of constantly changing living conditions cannot be fully determined by the reliability of their constituent components. Therefore, the high reliability of ecosystems also largely depends on the efficient functioning of interdependent recovery and reservation systems. And for the reliable existence of ecosystems, constant maintenance of the biota habitat (ecosystem conditioning) is essential. The interaction of recovery, reservation and conditioning of ecosystems provides them with high reliability.

Just the complex approach in implementation of the ecosystem reliability theory for the agroecosystems expands the range of means for researching their effective functioning, which contributes to obtaining a high and safe harvest.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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Data availability

The manuscript has associated data in the data repository.

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