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Problems of sustainable development of ecosystems

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Abstract. The present paper provides the concept of self-renewing of ecosystems. It is shown that multidimensionality and mutual exclusion of individual components of the environment make the problem of optimization, i.e. achieving the conditions of sustainable development, too difficult. However, the goal of sustainable nature management is possible with the existence of ecosystem properties for self-renewal due to the presence of cyclical processes, ecological capacity, migration capabilities of ecosystem components and pollutants metabolism, as well as the use of waste-free and energy-saving technologies. It is proposed to model the ecosystem in the form of the "eight", which reflects it as a closed cyclic system able for adaptation. When analyzing such a complex system, the following principles should be followed: simplification; consideration of processes in dynamics; considering the possibility of ambiguity, incompleteness and inaccuracy of information; using a risk-based approach to impact assessment; understanding the system as a hierarchical structure able for adaptation and development. It is noted that all local ecosystems in the region are interconnected and affect the characteristics of neighboring local ecosystems, usually requiring the adjustment of resources and connections.

1. Conditions of sustainable development of ecosystem

Sustainable development – is the overall concept, which requires a balance between meeting the modern needs of humanity and protecting the interests of future generations, including their need for a safe and healthy natural environment. The definition of sustainable development is formulated in the document of the UN Commission, that says about the development, which answers the essences of people without losses for future generations with their own essences [1-2]. The theory of sustainable development is an alternative paradigm of economic growth that ignores the environmental danger from development by the extensive model. Thus, sustainable development – is the development without global crises that arise, including the lack of resources, disruption of the structure, connections etc.

The buffer capacity of recreation system is proposed to consider as the presiding factor that defines the perspectives for the sustainable development of territorial recreation systems. According to the principle of the functional and integrated system, such systems are distinguished as the amount of space and geosystem is its framework.

Any ecological system is a complex system that is influenced by both internal and external factors. It is therefore important to consider the ecosystem in the context of complex systems that may evolve. Today, methods of theoretical analysis of complex systems are used for technical, environmental and



economic systems [3-4]. And it's about systems that are described either on the basis of deterministic functions, or using the methods of mathematical statistics and data mining [5-9].

From the ecological point of view, sustainable development must ensure the integrity of biological and physical natural systems. The viability of ecosystems, on which the global stability of the entire biosphere depends, is of particular importance. Moreover, the notion of "natural" systems and habitats can be broadly understood, including man-made environments, such as cities, roads, airports, landfills, various mining areas, and so on.

The focus is on maintaining the ability to self-healing and dynamically adaptation of such systems to change, rather than maintaining them in some "ideal" static state. Degradation of natural resources, environmental pollution and loss of biodiversity reduce the ability of ecological systems to self-renewing.

The relationship between the main components that form the living conditions of mankind and the social and economic standards of this existence are shown in Fig. 1.

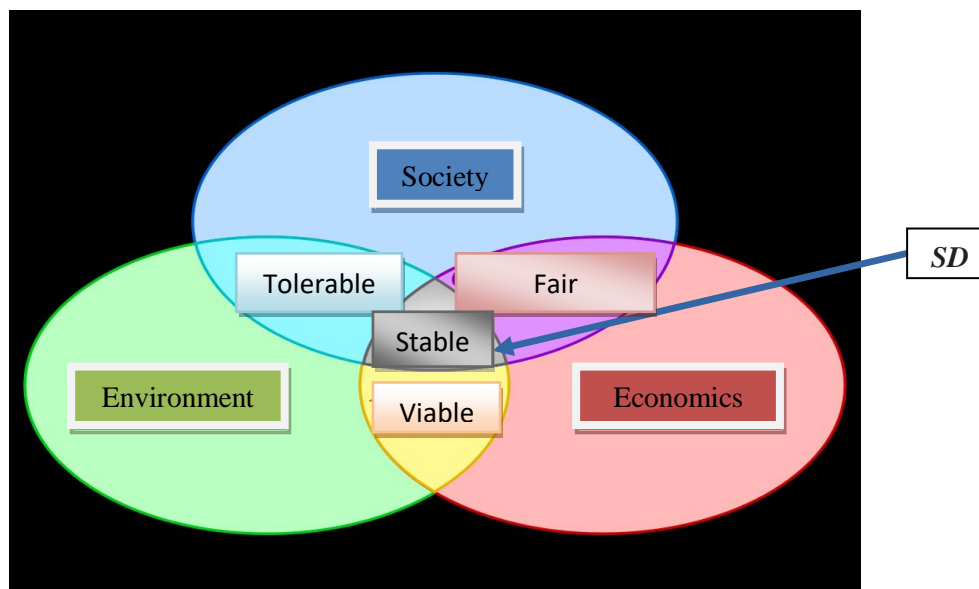


Fig. 1. Conditions for the optimal ratio of Society, Economy and Environment

The conditions for the optimal ratio of Society (*Soc*), Economy (*Eco*) and Environment (*Env*), i.e. for the sustainable development, follow from the Fig. 1:

$$SD = \min \{Env, Soc, Eco\},$$

where *Env* is determined by available resources *AR*, including alternatives, the presence of periodic cycles of changing conditions *YC*, environmental capacity (the ability to accumulate undesirable components for the environment without negative consequences for it) *AC*, migration capabilities (the ability of undesirable components to migrate outside the system) *MG*, the ability to metabolize environmentally harmful components into more acceptable forms *MT*, the status of a special area (e.g., reserve) *ST*, population density *PD*, building density *BD*, the presence of natural sources of environmental pollution *SE*. Other components of *Soc* and *Eco* environment are also multidimensional and, as a rule, mutually exclusive in many respects. All this makes the problem of optimization, i.e. achieving *SD*, too difficult. Fortunately, the environment has self-healing properties due to the presence of *YC*, *AC*, *MG* and *MT*, as well as the use, if necessary, of *ST*, as well as economic measures (implementation of waste-free and energy-saving technologies, use of alternative resources, energy and waste disposal, nanotechnology, etc.).

To model the ecosystem, it can be used the idea of considering the system in the form of the "eight", which reflects it as a closed cyclic system able for adaptation.

When analyzing such a complex system, the following main principles should be followed:

- Simplification of processes and complexes for their better understanding;
- Considering them in dynamics and perspective;
- Analysis of ambiguity, fuzziness, incompleteness and inaccuracy of information;
- Using a risk-based approach to assessing the possible consequences of certain steps or the effects of external factors;
- Understanding of the system as a hierarchical structure that is capable for adaptation and development taking into account the mutual influences of individual substructures.

Separate semi-autonomous substructures of such a system are formed due to interactions between sets of variables that exist in the environment common to each level of process velocities and spatial limits. Thus, the functioning of ecosystem as a system as a whole is a rather slow process that takes place within a particular region or country or many countries over the lives of many generations.

2. Concept of model of a complex ecosystem

The rapid (relatively) development of individual subsystems of ecosystem allows to make the whole "life" cycle of ecosystem as a whole system more stable, smoother, durable. But this requires a development of the model that may explain the need for carrying out (forecast) of certain measures to improve the functioning of the system as a whole. To form an adaptive development cycle (system model) it is necessary to take into account three main characteristics:

- The inherent potential of the system, which allows to make changes if it is necessary (resource);
- Internal controllability (connectivity) of the system, i.e. the degree of connectivity between internal controlled variables and processes;
- Ability to adapt, the elasticity of the system (a measure of its vulnerability to unexpected or unpredictable stresses).

These properties are common, regardless of scale: from the ecosystem as a whole, to its individual subsystems and even individual components of subsystems. The resource sets the possible limits and determines the number of alternative ways of development in the future. It can be represented by both a certain capital and the efficiency of the use of this capital. Connectivity or controllability determines the degree to which a system is able to control its own functioning, after which it can fall victim to external influences. It can be expressed both through the flexibility of the use of resources in order to prevent the reduction of system efficiency, and the availability of feedback between individual parts of the system, as well as the availability of alternative options. The resilience of the system, provided by the ability to adapt, determines how the system responds to unexpected disturbances and abnormal situations that can cause the system to fail. Elasticity characterizes to some extent the insensitivity to short-term significant changes in system parameters, its invariance and the ability to adjust the state in order to "filter" perturbations [10].

A stylized representation of the adaptive cycle of a complex ecosystem in the coordinates "resource - connectivity" is shown in Fig. 2.

The trajectory of the cycle changes between long periods of slow accumulation and transformation of resources (*Development*) and shorter periods of creating opportunities for innovation (*Reorganization, Adaptation*). The transition from development to reorganization is initiated by external or internal crises, catastrophes and is accompanied by significant resource costs and disruption of *connectivity* (reduction or change in the nature of connections) in the search for ways to overcome the problems that arise. The path to reorganization is sometimes accompanied by a certain (but small) accumulation of resources due to local optimization processes. It cannot be for a long time, otherwise the system is not able to function. After the reorganization phase is completed (if it is acceptable and effective), the adaptation phase begins, which requires significant resource costs to upgrade all parts of the system and adapt to new operating conditions.

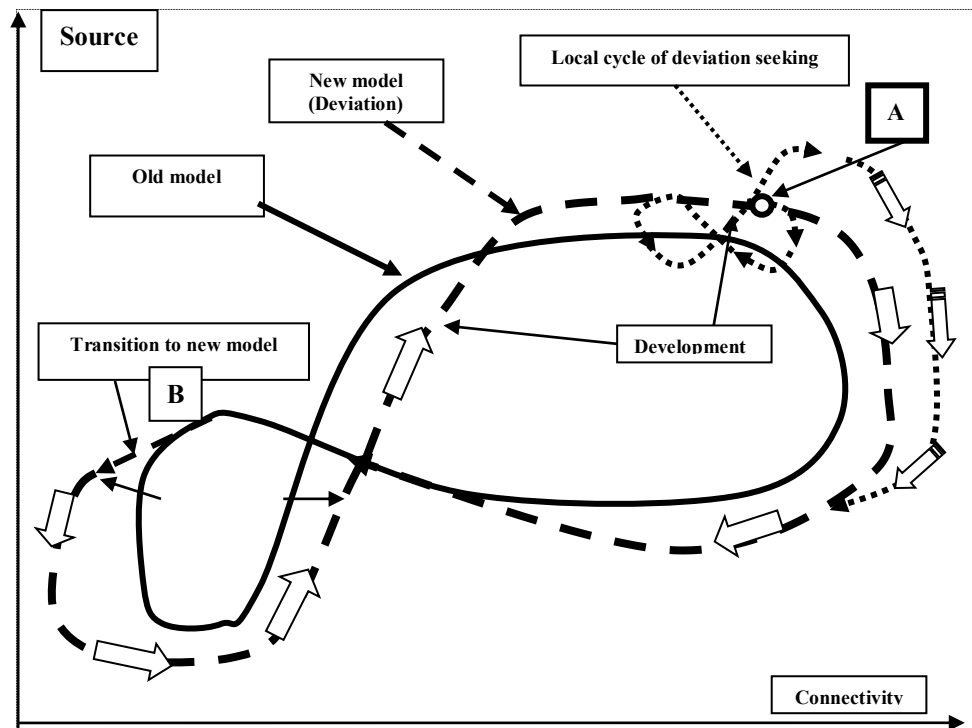


Fig. 2. Functioning of the complex system of ecosystem, when the old model disagrees with up-to-date objectives and the necessity to its replacement by search an optimal deviation exists:

- trajectory of the old model;
- - - trajectory of the new model;
- trajectory of the local cycle (local “figure-of-eight”);
- A – point on path with a result of local crisis;
- B – point of transition to new model.

Then the system begins to function properly, accumulating resources and increasing connectivity. If the reorganization of the existing system is not acceptable or ineffective, it is necessary to go to a fundamentally new one (both in terms of structure and in terms of means, goals and methods of operation and nature of the system). This transition may require significant changes (if possible) and excessive resource costs.

Therefore, it is worth considering certain cost priorities based on existing problems. Everyone knows these problems: energy dependence and ecology, which are closely linked. Indeed, we waste a lot of natural gas, which we are forced to buy at high prices. And this gas is burned (or otherwise used) to produce energy or certain products. The efficiency of this gas is in several times lower than in developed countries, and its combustion products intensively pollute the atmosphere. On the other hand, the rate of increase of solid wastes volumes is impressive: today the area occupied in the country for landfills for solid waste disposal is equal to the total area of state reserves and the need for further expansion of landfills is growing every year. Therefore, solving the problem of solid waste (which consists of 60-80% of organic components) by converting them into energy in incinerators or in gasification plants limits significantly the import of natural gas, or even refuse from it, and at the same time solves the problem of landfills, where it would be possible to remove only 20 to 40% of the share of solid waste that can not be utilized (and with separate collection of solid waste or after pre-sorting, such a share will be much less recycling). Therefore, financing the development of enterprises for solid waste management can be considered a priority. But should we start by building giant factories? They are very expensive, and the time of construction and commissioning (and payback period) is

quite significant. It is easier to pay attention to enterprises for small and medium-sized cities - they generate the biggest share of solid waste and create problems for unauthorized landfills. Outwear standard modules of such enterprises are inexpensive, production and installation time is relatively short, and the payback may not exceed one year. At the same time, there is an urgent need to stimulate energy conservation (including the transition to new technologies and the use of alternative energy sources) and to seek new effective forms of relationships between suppliers and consumers (this also applies to the term "connectivity").

After the reorganization and adaptation to new conditions the stage of development begins, it is necessary to monitor the transition at this stage as it is shown in Fig. 2.

As the resource grows as connectivity grows, the new model can be considered to function adequately. After reaching "saturation", i.e. after the process goes almost without increasing the resource, the system can perform its functions for a long time as a conservative system with feedback, controlling only the resource, or rather the sign of its increase. If at some point in the trajectory (for example A) it turns out that the increase in resource is negative, i.e. the efficiency of the system decreases, it becomes a signal of the need for a local cycle of innovation in the subsystem where efficiency is the lowest (or where the necessary for this innovation resource - is minimal). This cycle necessitates resource consumption for reorganization and adaptation, after that the system can reach a higher level both in terms of resource and connectivity. Such local cycles may occur periodically and the cost of their implementation can be considered as the cost of depreciation. Their implementation will contribute to a more efficient and long-term normal functioning of the system.

The following heuristics to ensure the adaptation processes in the system may be formulated:

IF (RI > 0) AND (CI > 0), THEN (D);
IF (RI ~ 0) AND (CI > 0), THEN (CS);
IF (RI < 0) AND (CI < 0), THEN (CR);
IF (RI > 0) AND (CI < 0), THEN (R);
IF (RI < 0) AND (CI ~ 0), THEN (A);
IF (RI < 0) AND (CI > 0) AND (PRT ≤ PRT_{ac}), THEN (LAC).

where *NM* - new model; *D* - development; *TNM* - transition to a new model; *R* - reorganization; *CR* - crisis; *A* - adaptation; *RI* - resource increment; *CI* - connectivity increasing, *CS* - conservation of the system; *LAC* - local artificial crisis (reorganization of the local subsystem in order to adapt it to new conditions or requirements), *PRT* - price of risk in the transition to LAC, *PRT_{ac}* - the most acceptable *PRT* under some conditions.

It should be added that all local ecosystems in the region are interconnected, i.e. affect the characteristics of neighboring local ecosystems, usually requiring the adjustment of resources and connections. Thus, the model of the regional ecosystem can be presented in the form of a hierarchical set of "eights", as it is presented in Fig. 3 on the example of the water treatment system of the river basin, which receives effluents from several sources of discharges of different capacity and quality (composition), and several local treatment plants work.

At any level of detail, the same components of the cycles can be observed: development *r*, conservation *K*, crisis *ω* and reorganization *α*, including restructuring *s* (Fig. 3). Here, the macrolevel corresponds to large treatment systems, which are both above and below (downstream) of these treatment plants, and the microlevel – to small artificial treatment plants, the efficiency of which is controlled and can be adjusted to some extent.

Because the functioning of the system at each level is cyclical and because the initial conditions for each cycle are usually not the same, there are conditions for creating "chaos", i.e. unpredictable developments that are characteristic as for biochemical treatment systems so and for ecosystems in general.

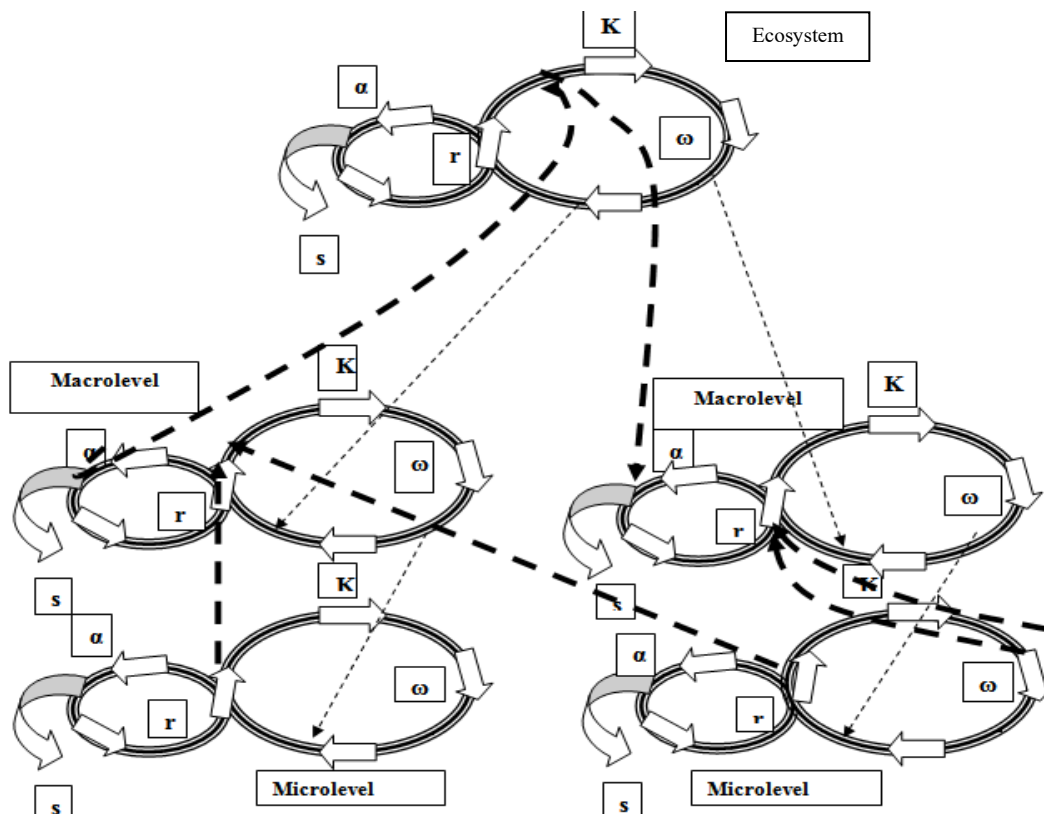


Fig. 3. Connections between the systems of different levels:
 r – development, K – conservation, ω – crisis, α – reorganization, s – restructuring

The developed model of a complex ecosystem does not contradict the basic economic, social and physical laws and promotes a deeper understanding of the processes occurring in the bowels of the system, and allows to find quickly and to detect ways to maximize system efficiency under real conditions.

Conclusions

1. The sustainable development of ecosystems depends on optimal ratio of society, economy and environment. Environmental component is determined by available recourses, including alternatives, environmental capacity, migration capabilities, population and building density, the presence of natural sources of environmental pollution etc.
2. Functioning of the complex system of ecosystem can be presented as the model of the “eight”, moreover its sustainable development depends on resources and connectivity.
3. All subsystems of ecosystem are interconnected and require the adjustment of resources and connections, forming hierarchical set of “eights” with micro- and macro- levels.

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