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Issues of computer simulation for management of restorative successions of degraded vegetation cover in the epicenters of desertification of the North-Western Pre-Caspian region

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Abstract*—The tendency to an increase in the foci of desertification in the region of the North-Western Pre-Caspian region is currently taking shape. The North-Western Pre-Caspian region serves as a geographical standard of the arid belt of the Russian Federation and is a combination of arid complexes highly responsive to anthropogenic stress due to insufficient moisture, soil salinity, land exposure to erosion, deflation, etc. Activities leading to the restoration of vegetation and soil cover were developed to combat desertification. Common and particular desertification models have been developed. In particular, the concepts of evolutionary modeling in conditions of limited information of the processes of self-organization of plant communities through restorative successions of degraded vegetation can be used in the context of this task. This issue has not been developed sufficiently, which underlines the relevance of research in this area. The aim of the study is to discuss the problems of computer simulation of restorative succession dynamics of soil and vegetation in the foci of desertification. The main universal approaches, including the properties of the object being modeled, form the basis of the general methodology for modeling self-organizing systems. It is optimal to use a finite-state Mealy machine in the simulation of succession dynamics.

Keywords — desertification, succession, North-Western Pre-Caspian, restorative successions, restoration of vegetation

I. Introduction

The tendency to an increase in the foci of desertification in the region of the North-Western Pre-Caspian region is currently taking shape. The North-Western Pre-Caspian region serves as a geographical standard of the arid belt of the Russian Federation and is a combination of arid complexes highly responsive to anthropogenic stress due to insufficient moisture, soil salinity, land exposure to erosion, deflation, etc. [1].

The bioclimatic potential (precipitation regime, temperature, hydrothermal coefficient, phytocenosis water consumption) determines the provision of the main factors of life (temperature, water availability) for the vegetation period of plants. Therefore, the justification of planting dates is possible only in the study of the bioclimatic potential of the territory during the year and the evolving conditions depending on the limiting factor that determines the state of the crops.

In the arid zone of the North-Western Caspian, the limiting factor is soil moistening depending on the amount of precipitation during the annual bioclimatic cycle and their distribution over the seasons of the year. In such conditions, the problems of computer simulation of the bioclimatic potential of the North-West Caspian is particularly relevant in the cultivation of crops under rainfed conditions.

Due to the rapidly growing population and the continuous development of the agricultural production industry in the desert and semiarid areas, the anthropogenic and technogenic impact on vegetation and soil cover increases every year, which quite often causes a violation of the structure and normal development of the soil and plant cover of arid ecosystems. Natural arid ecosystems primarily serve as the main feed base for cattle breeding in deserts and semi-desert areas. Along with the restoration of biodiversity and the forage productivity of disturbed ecosystems, it is also necessary to develop a rational system for the use of pasture ecosystems through the determination of the capacity of these systems for restoration.

The composition of these pasture ecosystems includes biological and inert components, which constitute a single global ecological system. Weak disturbances of ecosystem components lead to the spread of the disturbance on the global level of the system. Desertification processes are no exception. Aridization of climate, combining an increase in air temperature and solar insolation, leads to the desiccation of the soil cover, which leads to degradation of vegetation cover. At the same time, excessive anthropogenic stress due to overgrazing of livestock leads not only to qualitative, but also to quantitative changes in vegetation cover [1; 2]. Activities leading to the restoration of vegetation and soil cover were developed to combat desertification. Common and particular desertification models have been developed. In particular, the concepts of evolutionary modeling in conditions of limited information of the processes of self-organization of plant communities through restorative successions of degraded vegetation can be used in the context of this task. This issue has not been developed sufficiently, which underlines the relevance of research in this area.

Digital technologies in the world are widely used both in forestry and agriculture [3; 4]. There are many technologies that can provide information gathering, be it cartographic information or any other. Therefore, effective methods of processing this information are necessary. Computer simulation is one of the methods that can be used in a given subject area.

Currently, there are several different approaches to the modeling of ecological systems, including pasture plant communities [5; 6], as well as the production process of agricultural plants in the agrocenosis [7]. One of the approaches frequently used by ecologists and agronomists is an empirical-statistical approach. However, this method is very limited in use, because it does not reveal the dynamics of the system and has limited predictive ability. A more advanced method of modeling is the method of simulation. This method is currently the main method for studying complex dynamic systems, including ecological ones. The applied aspect of evolutionary modeling is actively developing, which is more natural for such systems [6]. One of the drawbacks of this approach is the so-called subjective moment introduced by the researcher during the construction of the model. To a large extent, evolutionary modeling excludes the “subjective moment” when building a model, and the model is closer to a natural object.

The purpose of this study is to discuss the problems of computer simulation of restorative successions in the foci of desertification.

II. Methodology

The general methodology of modeling self-organizing systems is based on the main universal approaches, including the properties of the object being modeled (what elements the object consists of and how these elements interact with each other).

The task includes identifying interdependencies, choosing the determining factors, building models, evaluating with the help of relevant metrics, choosing the optimal models. The main feature of this modeling approach is that the model conforms to the property of the system itself.

III. Discussion of the Problems of Self-Organizing Modeling

Evolutionary modeling of large distributed systems is the most natural choice among a variety of options and approaches for modeling such systems. The classic system of this type is suprabiological objects (as well as biological in themselves) ecosystems, in particular pasture ecosystems of any type, including sown pastures or natural pastures in a state of degradation, where vegetation must be restored.

Consider a specific case where it is possible to apply evolutionary modeling in a natural way [8]. Suppose there is a degraded pasture where land cover is lost due to the high degree of exposure of this system to human impact, in particular after irregular cattle grazing. It is necessary to understand how it is possible to restore the vegetation cover, which species and in what ratio they should be presented, at what optimal time it is necessary to sow these types of grazing varieties. Suppose we know the cultivated species of plants and their varieties, the properties of these species and varieties of crops. There are several types of algorithms for the behavior of plants in the habitat (Fig. 1, 2), they are called ecological-phytocenotic types of life strategies. Brief description of the types of strategies (Fig. 1, 2) [5]:

SL – ecotopic patients experiencing abiotic stress in extreme conditions (drought, salinity, cold, high temperatures, etc.);

SK – phytocenotic patients experiencing stress under the influence of violyants;

R – true explerents (succession and degradation according to Rabotnov), which are present during the period of complete degradation of the plant community and are not compatible with the presence of plant species that belong to the violyants and to the patients;

K – violents causing stress in phytocenotic patients;

RL – false explerents that appear in a favorable period (in spring and autumn in the desert).

The closer the community approaches degradation, the more species there are, since these types of species are not resistant to abrupt mechanical impacts, such as overgrazing, where mechanical trampling occurs [5].

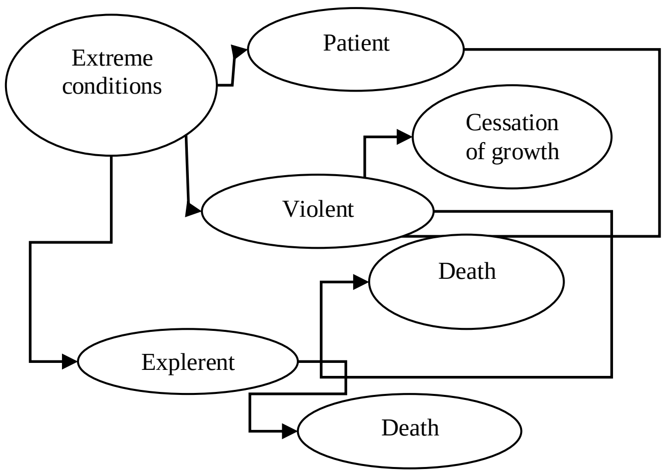

Fig. 1. Interaction with the environment of algorithms for the behavior of plants in adverse conditions.

If we know that these species have a behavioral algorithm inherent in valents, explerents and patients, then the question of finding the optimal combination of species required for organization in different environmental parameters (soil and surface layer of the atmosphere) appears. To answer these questions, it is necessary to model the system and its evolution in certain environmental parameters. In such a situation, the so-called evolutionary modeling implemented on computers in certain virtual environments is natural. Each type of plant with a specific behavior algorithm can be represented as a finite-state Mealy machine [6].

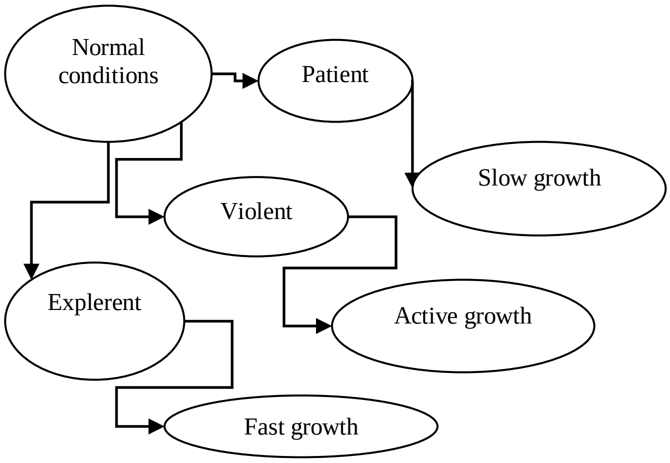

Fig. 2. Interaction with the environment of algorithms for the behavior of plants in a favorable environment.

The finite-state Mealy machine is an object A={X, Z, S, fz, fs}, where X = {x1, x2, …, xn} – finite set of input symbols ("input alphabet"); Z = {z1, z2, …, zm} – "output alphabet"; S = {s1, s2, …, sp} – finite set of states of the machine; zj = fz(xj, sj) – exit function, as a result of which a signal appears at the output of the machine zj, if the input state sj, signal xj was received; finally, sj+1 = fs(xj, sj) – transition function from state sj to state sj+1, if signal xj was received at the input [6]. State s0, to which the first signal of the input sequence {xt1, xt2, xt3, …., xtn} is sent at time t0, is called the initial state. As a result of "consistent" work at the moments of time t1, t2, …, tn, symbols of the output sequence {zt1, zt2, zt3, ….., ztn} appear at the output of the machine. The graphical way of specifying Mealy machine is to build a directed graph whose vertices are the states of the machine S, while the oriented arcs connecting the vertices are given a symbol of the input alphabet causing the machine state to change in the direction of the oriented arc and the resulting output (for example, xj/zj). This formal model of the Mealy machine can be implemented in software, for example, in NetLogo, the environment of imitational multi-agent modeling NetLogo [9]. After launching the model, it is possible to conduct a series of computational experiments with adjustment of the optimal parameters of the pasture ecosystem and its successive restorative dynamics. The initial condition of this system will be the complete absence of vegetation cover, the corresponding parameters of the environment of the annual meteorological cycle and characteristics of the soil environment.

Another powerful method for modeling distributed systems in the environment is reinforecement learning in a given environment (for example, plant species with a specific behavior algorithm), which is most natural as agents behave like living organisms in an ecosystem reacting to changes in the environment, adapting to it. For the first time, reinforcement learning was proposed in 1961 in the work of M. Tsetlin [10], a famous Soviet mathematician. M. Tsetlin developed a state machine of a certain design and placed this machine in an environment with certain parameters. The state machine reacted to the effects of the environment with certain probabilities, and the environment encouraged and punished this machine, thereby undergoing the learning process with reinforcement. To analyze the reactions of such machines in the environment, Markov chains, which allowed to obtain an exact training model with automaton reinforcement in the external environment, were used.

This method of modeling of distributed systems, including ecological systems, is the most relevant and natural at the moment. At the moment, the development of machine learning makes it possible to implement reinforcement learning technique with reinforcement, and to predict the state of the ecosystem, its evolution and development dynamics based on these models. Knowing a certain algorithm of behavior of plant species representatives, it is possible to create expert decision-making systems in extreme situations based on machine learning with reinforcement in order to minimize losses in desertification centers.

At the end of a series of computational experiments, it will be possible to establish the following conditions:

- the optimal ratio of certain species and varieties of pasture plants;
- optimal timing of agrotechnical measures, as well as the timing of the seeding of pasture plants;
- productive opportunities with different parameters of the pasture ecosystem environment;
- optimal grazing parameters in this pasture ecosystem with inherent parameters.

It is necessary to identify the parties interested in solving the problems of desertification. In particular, these are farmers involved in crop and livestock production, environmentalists concerned with the problem of desertification, as well as the state represented by the ministry responsible for agricultural development in the region. In addition, the problem of desertification concerns construction companies, geological services and geological companies. Interest is the process of restoring land cover, its acceleration and biological reconstruction. This can be achieved by applying advanced methods and technologies that allow to determine the optimal parameters for restoring a destroyed ecosystem in the shortest possible time.

The problem of desertification may worry farmers from several points. First, livestock tend to trample pasture farms, resulting in the degraded state of the field, both for future grazing and for growing crops. This may result in the field becoming unusable for future generations, and their restoration may take a long time (if it is to be restored). Second, knowing the approach to restoration of pastures and having on hand a tool for simulation modeling and forecasting of restoration processes, the farmer can effectively plan their activities. This may lead to an increase in agricultural production, bring agricultural producers to a new frontier of science, increase not only productivity, but also product quality. In addition, computer simulation can help to anticipate risks that can be successfully avoided.

The described problem of managing of restorative successions of degraded vegetation in the epicenters of desertification is an important and urgent task for ecologists. Degraded vegetation in the epicenters of desertification (for example, the North-West Caspian region) can be a serious environmental catastrophe, entailing the destruction of certain plant and animal species. This problem can be avoided by introducing the mechanisms proposed in this study in close cooperation with ecologists. Computer modeling of ecosystems will solve many environmental problems. Since ecosystems are complex and multicomponent systems, it is very difficult to trace or establish the relationship between hundreds of components in a real experiment, and in some cases it is impossible to do that without applying the described approach.

The development of agriculture as an important part of the concept of food security in the region and the whole country should not be at risk of reduction due to problems with food supply as a result of degradation of vegetation. It requires the joint work of scientists and specialists of the regional Ministry of Agriculture on the study of the epicenters of desertification and the management of restoration successions of degraded vegetation cover. The described approach can solve the problem of food supply and optimize the grazing of animals.

IV. Conclusion

The conclusions of this theoretical study:

- the optimal approach to modeling large distributed systems (including pasture ecosystems) is evolutionary modeling using the finite-state Mealy machine.

At the end of a series of computational experiments, it will be possible to establish the following conditions:

- the optimal ratio of certain species and varieties of pasture plants;
- optimal timing of agrotechnical measures, as well as the timing of the seeding of pasture plants;
- productive opportunities with different parameters of the pasture ecosystem environment;
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