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Research Note

Methodological Problems in the Modeling of Ecosystems and Ways of Solutions

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Abstract

The great variety and complexity of natural ecosystems leads to methodological problems of simulation and lack of understanding of a common framework in the organization of ecosystems prevents the construction of the universal ecosystem models that are suitable for efficient integration in the model of the biosphere and for the successful solution of theoretical and practical problems. The aim of this work was to develop a systematic theoretical basis for universal description, analysis, and modeling of ecosystems as structural units of the biosphere as the highest-level ecosystem. Analysis of the literature and special studies of the authors demonstrated that a reliable basis for universal models is a multidisciplinary approach that includes three types of concepts (substrate, energy and information) and is based on such fundamental properties of living systems as the attractiveness, adaptability, fractal, network organization. It was found that the most promising are the methods of computer mathematics, based on adaptive networks. The network models can be formed using various tools for operation with artificial neural networks that were developed in neuroinformatics. The entire range of the model states, from excessive to minimally possible, can be investigated. In the network models, one can obtain arbitrarily complex static and dynamic regimes correctable both in the process of model tuning (identification) and during operation of the model (adaptation). The models based on the self-organizing adaptive networks can potentially reflect the most general and fundamental properties of the complex natural systems.

1. Introduction

Climate change and increasing anthropogenic impact leads to a decrease in the stability of the biosphere and its ecosystems, environmental degradation (Ingels et al., 2012; Maiti et al., 2014; Chytrý et al., 2015). Increasingly, there are concerns about the threat of human life support (Global Biodiversity Outlook, 2006; Pavlov, Bukvareva, 2012; Maiti, 2014). Global warming is a fact, and human impacts intensify its manifestation (Climate Change, 2008; Loftus et al., 2015). The larger the area of disturbed landscapes and higher the degree of their transformation, the sooner there are processes of environmental degradation. Currently, the Earth's climate is at the limit of stability (Pavlov, Bukvareva, 2012). The climatic instability leads to increased of probability of local and global food crises (Pavlov, Striganova, Bukvareva, 2010). Frequent hot periods, uneven rainfall and increased water scarcity leads to a decrease in the stability of agricultural production (Climate Change…, 2008; Battisti and Naylor, 2009). Large-scale reduction in the area of natural ecosystems, accompanied by the destruction of biodiversity on the planet, will inevitably lead to a decrease in their regulatory capacities (Pavlov, Striganova and Bukvareva, 2010). If earlier the consequences of human-induced disturbance of ecosystems led to environmental damage in the local and regional scales, now become apparent global implications of this process (Foley et al., 2005). The mechanisms for resolving this problem are much-needed.

Many models describe the climate change (Hasler, Werth, Avissar and 2009; Edwards, 2011; Loftus et al., 2015; Franzke et al., 2015). However, these models do not identify mechanisms that can slow down the process and are working on restoring the planet's climate. Special studies have shown that such arrangements are in natural undisturbed ecosystems (Pavlov, Bukvareva, 2012). It is therefore extremely important to develop realistic models of ecosystems. Universal ecosystem models are of greatest interest. Scenarios of the transition to the stable use of natural resources can be developed on the basis of universal models of ecosystems. However, by now the concept of uniqueness of natural ecosystems has been formed. On the one hand, natural ecosystems are highly diverse; on the other hand, current research is aimed mainly at revelation of distinguishing features in their organization and not the common properties. The lack of understanding of the organizational basis of ecosystems prevents constructing universal models of the latter that could be effectively integrated in biosphere models. The problem is complicated by the lack of powerful yet flexible mathematical methods that would reflect the fundamental properties of natural ecosystems that give rise to the observed diversity.

The aim of this work was to develop a systematic theoretical basis for universal description, analysis, and modeling of ecosystems as structural units of the biosphere as the highest-level ecosystem. Modeling is grounded on the developed concept of adaptive self-organization (CAS) of complex natural systems (Lankin, Khlebopros, 2001; Lankin, 2002, 2009). The models are verified by forest ecology and forest typology (Ivanova, Zolotova, 2014).

2. Methodological Problems and Search for their Solutions

Ecosystems are very diverse. This diversity is evident even within a one ecotope (Ivanova, 2014). We present an example. Clear-cuts and fires lead to the formation at the site of one of the indigenous forests of many different types of ecosystems: felling, ecosystem after fire, various secondary forests. Their structure and dynamics are very different. Figures 1 and 2 illustrate this feature of the forest vegetation. In view of great diversity, dynamicity, and polyvariance of ecosystems, the development of a general theoretical approach to their description and analysis seems to be a challenging problem.

The situation is even more difficult in mathematical ecology, since the development of mathematical methods requires accurate and unambiguous definitions. Moreover, there are no principle divisions of modern mathematics that would enclose all the variety, complexity, and flexibility of living nature.

The aforementioned led to the huge break between experimental (field) and mathematical ecology. As was said in (Sukhovol'skii, 2011), there arise two disciplines: mere paper ecological modeling based on bookish postulates easily solving any stated problems and real modeling that often fails to apply these postulates to real ecological situations. The authors doubt whether the universal theory of description and modeling of ecological systems could be rapidly developed.

Observing the present state of affairs in modern science, we may assert the following. Science evolves wave-like, from holism to reductionism and backwards. The previous stage in the evolution of science was characterized by prevailing reductionism, i.e., accumulation of facts, plunging in details, growing specialization and disconnection of knowledge, and gradual lost of future prospect due to impossibility of generalization and monitoring of vast amount of accumulated data. One of the aspects of this disconnection is the gap between theory and experiment, typical especially of ecology. It is time of holistic generalizations, i.e., revelation of the most important, fundamental things in accumulated experience, formalization of the quintessence of knowledge, and integration of the theoretical and experimental science at a qualitatively new fundamental level.

Many domestic and foreign scientists attack this problem using various concepts. For example, A.M. Gilyarov (2010) seeks for universal regularities of organization of communities and the origin and mechanisms of the formation of biodiversity on the basis of the neutralism concept. In study, V.A. Usol'tsev (1997) developed universal multidimensional regression models of tree biomass using physiologic regularities and its vertical fractional distribution as the characteristic of the structural and functional organization of forest phytocenosis. On the basis of unified principles of the ecological floristic approach (Braun-Blanquet, 1964; Mirkin, Naumova, 1998), highly diverse vegetation all over the world is classified. The fractal approach is used in the search for regularities of organization of ecosystems with different scales (Gelashvili, Rozenberg, 2002) and taxonomic diversity (Gelashvili et al., 2010). The category-functor mathematical theory for quantitative and dynamic description of the World (Levich, 2008) and the Gaia concept (Lovelock, 1979) that includes not only qualitative theory but also a number of quantitative models are developed.

Nevertheless, the problem is very deep and requires nontrivial solutions, up to the change in the prevailing scientific paradigm. In mathematical theories, this process manifests itself in the

Figure 1: Indigenous dark coniferous forest in the Middle Urals (Russia)

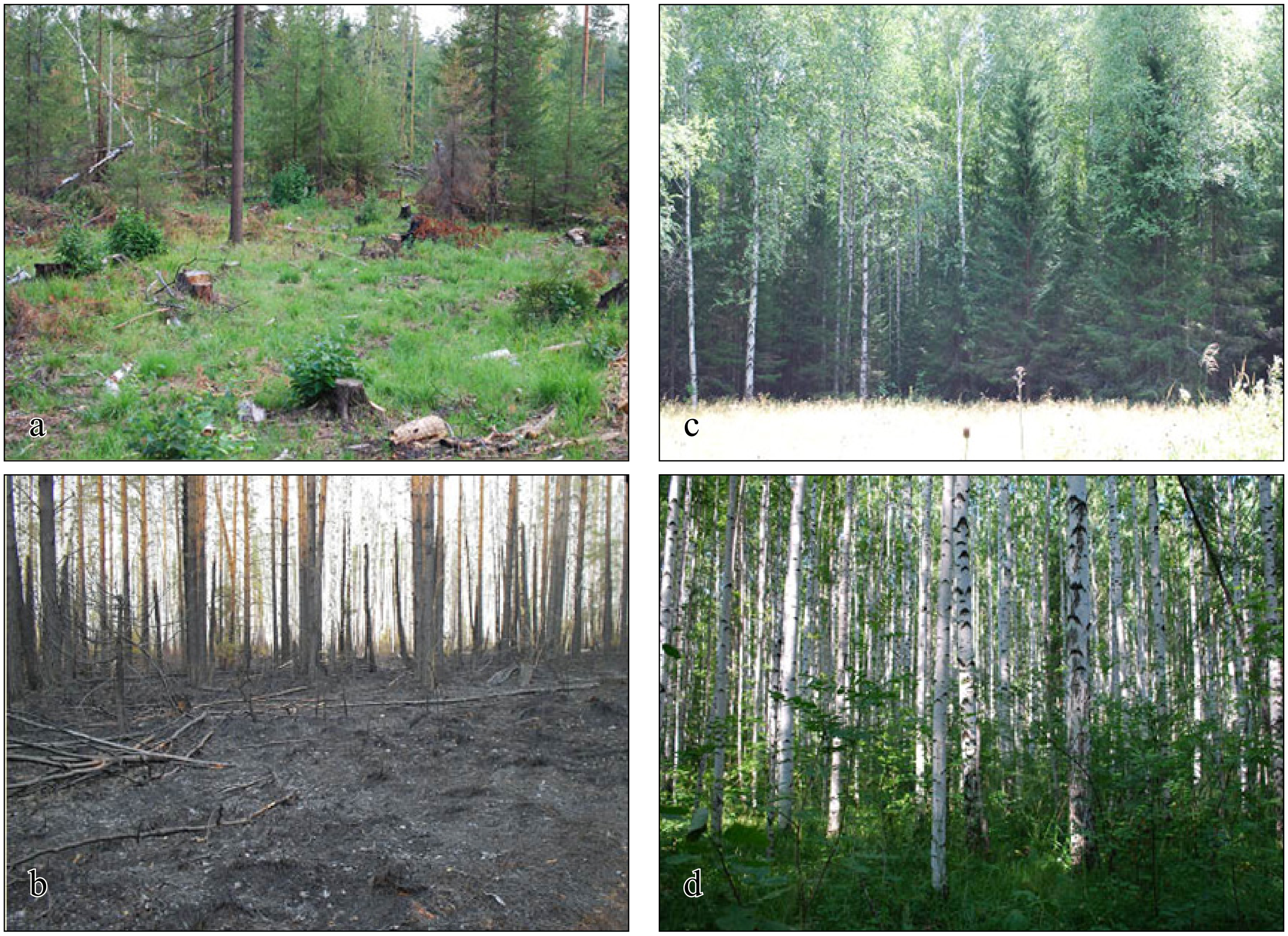

Figure 2: Divergence of forest vegetation in the Middle Urals (Russia) after clear-cutting and fire: a - cutting, b - forest after fire, c - secondary birch with spruce, d - secondary birch forest without undergrowth of conifers

occurrence and rapid development of synergetics, dynamic systems theory, self-organized criticality theory, and other fields of science.

3. Attractiveness, Adaptability, Fractality, and Network Organization

Viewing the planet in the biosphere scale, one can see that ecosystem modeling requires a general approach. Being the global ecosystem, the biosphere represents a hierarchical set of subsystems: ecosystems of different scales and complexity.

However, the traditional systematic approach to a system as hierarchy of interconnected blocks built manually by a researcher that was formed in the last century in cybernetics does not work here because of high flexibility and polyvariance of the development of ecosystems. In addition, a feature of the systematic approach, which limits applicability of traditional mechanistic and statistic methods is the well-known thesis about irreducibility of properties of a system to the sum of properties of system's elements and undeducibility of properties of a system from properties of its elements. The paradigm of linear causality is inapplicable because of nonlinearity of properties of complex natural systems, which rapidly leads to the problems like the prediction horizon in simple models; extremely high sensitivity to weak signals and effects that can sharply change the state of a system; variety of possible functioning regimes; ability of different reacting to similar situations and similar reacting to outwardly different situations, etc.

In trying to understand the complexity and polyvariance of the biosphere and ecosystems comprising it, one should base on a number of fundamental principles many of which are already known. These principles are attractiveness, adaptability, fractality, complexity of the network organization, etc.

Here, attractiveness suggests that there are many attractors (stationary or quasi-stationary states) of a system that ensure its stability against various factors breaking the dynamic equilibrium of the system. The biosphere and ecosystems comprising it tend to stationary states or stationary oscillating regimes, although reach them not always. In this trend, the biosphere and its ecosystems avoid the growth of chaotic, nonstationary regimes whose development would inevitably lead to the break of a system. This thesis is grounded on the fact that, along with high stability of the biosphere and its components, there are many examples of the development of uncompensated instabilities in ecology that led to the break of ecosystems. These instabilities are of different origin, for example, entering of alien species in the ecosystem that have no natural enemies in the latter; natural cataclysms, and man's impacts. Fortunately, due to flexibility and adaptability of the biosphere, these breaks in the thin film of life on the Earth's surface and in the ocean are generally compensated.

The ability of complex natural systems to compensate destructive changes and effects was reflected in the well-known physical Le Chatelier's principle and the cybernetic degenerative feedback principle and, in ecology and biology, in the adaptation concept. We can suggest that the systems in which this mechanism did not work or was ineffectively organized did not survive in the evolution. Considering the key thesis on internal integrity and close interconnection of elements of any natural systems, including the biosphere and organisms that form its ecosystems, along with the mechanisms of stabilizing feedback, we inevitably arrive at the concept of the biosphere homeostasis, which phenomenologically corresponds to the organism homeostasis.

In view of this, it would be useful to compare the hothouse Earth's conditions with the rapid processes occurring on the nearest planets, Mars and Venus, which have no biosphere. The attempts to reduce the existing differences to purely physical factors are unconvincing. A hypothesis that looks more plausible and sound is that rough self-organization processes on the planets in the Solar system occurred without participation of life, while fine tuning of conditions is performed by the biosphere. Mathematically, this process can be compared with the rough search for the global minimum and finishing of the solution obtained. The rough component was described in study (Kolesnikov, 2006a) where the gravitation theory was refined by the synergetic control theory (Kolesnikov, 2006b). The fine component is facilitated by huge rates of biochemical processes with participation of ferments; these rates exceed by far the rates of chemical processes and allow rapid and accurate compensation of local and global nonstationarities by means of numerous nested feedback iterations.

Possibility of the biosphere homeostasis is quite obvious, since it is necessary to ensure the corridor of allowable conditions for existence of living organisms, like the organism homeostasis ensures cell survival and maintains effective regimes of the biochemical processes occurring in an organism. The quantitative (mathematical) side of organization of the biosphere homeostasis involving ecosystems and organisms will be discussed in the next study.

The internal systematic integrity of the biosphere in combination with the mechanisms of the stabilizing feedback allows one not only to establish the continuous interrelation and interdependence of all living things on the planet but also to construct a universal theory for consistent and mathematically accurate description of the biosphere, ecosystems involved in it, and organisms comprising the ecosystems as a united coordinated synergetic process.

Such an integral mathematical theory can describe not only all living things but also their environment (atmosphere, hydrosphere, and lithosphere) and take into account the near space factors affecting the life on the planet.

The next important factor is organization of complex natural systems in networks of interconnected elements. From the quantitative point of view, the most important feature of the network structures is the possibility of obtaining a very reach and adaptively tunable spectrum of reactions to the variation in a situation and to external effects. This makes it possible to compensate effectively destructive effects on the biosphere and its ecosystems. With increasing dimensions and complexity of a network, the number of stationary states that can be formed in it in response to certain situations grows. Consequently, an ecosystem becomes increasingly stable. Unlike the case of reductionist mechanistic models whose stability drops with increasing complexity, the properties of the self-organizing network models coincide with the properties of the biosphere and its ecosystems, both structurally and functionally. On the one hand, this ensures highly realistic representation of quantitative processes occurring in ecosystems and the biosphere as a whole by the network self-organizing models. On the other hand, study of such models is very important for understanding of fine organization of the processes occurring in ecosystems.

Fractality (self-similarity) of processes and structures in the networks is related to the concept of chaos understood by modern science as a complex order with a large number of degrees of freedom. Chaotic regimes arise in the networks when synchronization, which can restore due to adaptive processes, is broken (Malinetskii, 2008). The fractal properties of the networks of organisms allow forming finely organized, consistent, and well-ordered structures. Fractal properties of living systems (for example, trees) are usually far poorly ordered as compared with those of non-living ones (for example, snowflakes). This is related to the necessity of co-organization of complex living structures at the adaptive self-organization of the networks of organisms.

Similar to the physical structures theory (PST) (Kulakov, 2003), the CAS is aimed at the formation of a minimum necessary yet sufficient number of unreplicated fundamentals required for constructing models of the biosphere and ecosystem and organisms comprising it.

4. Evolution

In the context of the considered fundamental processes of system self-organization of the biosphere, the accumulated contradictions in the concepts of life evolution (Chaikovskii, 2008) can be unambiguously resolved in the form of qualitative and quantitative models of adaptive self-organization of the biosphere. Drawing a phenomenological analogy between the organism and biosphere homeostasis as the trend of an organism and the biosphere to stationary states in order to retain dynamic stability of their structures on numerous invariants, one can observe coordination of the adaptive self-organization processes at all hierarchical levels of the biosphere and its ecosystems on lifetimes of organisms (system elements). Evolution appears to be the adaptive reaction of the biosphere as an integral system to the current state and variation of the environment. Such a statement of the problem eliminates many contradictions.

In this statement, evolution looks not as random fluctuations of selection (this algorithm is extremely ineffective, from the mathematical viewpoint, at dimensionalities over ten) but as a highly effective and realistic process of adaptive self-organization of the biosphere as a complex system.

As was said in (Chaikovskii, 1990), science obviously reorients from the mechanical-statistical to systematic understanding of the World. The emphasis on the adaptive self-organization of complex systems does not imply the other extreme: the appeal to complete denial of a role of randomness. Here, we agree with Charles Darwin (1939): randomness is an additional factor but not a driving force of evolution. Evolution of living things is the many-sided process, which should be taken into account in understanding of evolution, along with hypothesis verification with the use of systematic quantitative models.

5. Substance, Energy and Information

In was mentioned in (Lankin, Pechurkin, 2008) that, methodologically, all the current concepts of evolution of life can be divided in the three basic types: substrate (S), energetic (E), and informational (I). The S concept is grounded on biochemical, genetic, and morphological ideas. The E concept is related to the idea on evolution of complex open systems experiencing permanent pumping with energy from the outside, improvement, acceleration of substance cycles, and growing energy recycling by each structural unit. The Iconcept, in virtue of its complexity for the description of ecosystems, has been underdeveloped.

Meanwhile, the best results can be expected from combination of these three concepts (S+E+I). Improvement of the I concept in the framework of the CAS makes it possible to describe, without loss of generality, the formation of the attractive landscape, co-tuning of a complex structure of nested cycles of the open systems permanently pumped with energy from the outside, improvement, acceleration of substance cycles, growing energy recycling by each structural unit of the ecosystem, etc.

Note that the term information, for lack of a proper equivalent, is used here not in the same meaning as in the Shannon's information theory. Information is stored in a network structure in the form of the values of connections and other parameters and is implemented in the form of connecting, transforming, and disconnecting substance and energy flows (cycles). These flows develop into a broad spectrum of adaptive reactions of a system to various effects.

The models can be conventionally divided in two classes: process models and structural models. The first class is more abstract. It is close to the ecosystematic representation and focused on the S+E+I flows, including the case of accenting one of the three. The second class is more specific. It can take into account the species composition of biogeocenosis organisms and structure of forest and subordinate stages, describe the competition between species and co-organization of them, and simulate specific territories accurate to individual trees. These two classes of models are mutually transformable.

6. Modeling Methods

Despite the numerous studies on modeling of natural ecosystems (Jiang et al., 2012; Reside et al., 2012), there has been a huge gap between mathematical and field (experimental) ecology. Apart from the considered causes, much difficulty is made by the existing methods of formalization (specialization and mathematization) of knowledge of a researcher about an object of his investigations. The point is that it is natural for a man to go top-down, i.e., from general, quantitative representations to specific and exact ones. In practice, however, the transition between qualitative and quantitative representations often appears very sharp. The problem is complicated by the fact that intuition of a man who is used to think by qualitative representations can be easily misled at the transition to the quantitative ones. A mathematician dealing with a complicated nonlinear model can appear in the same situation, though. Moreover, in the theory of beds and jokers for simple nonlinear models (Malinetskii, 2008), the prediction horizon concept is introduced and attempted to be raised to the law.

The formalization process can be made easier to use for any man by computational mathematics methods based on the adaptive networks. This possibility is grounded on the following considerations:

a. Ecosystems are formed from the adaptive networks of organisms (plants, animals, and others). The network representation of the problem is quite natural. The structure of artificial adaptive networks in the models reflects this fundamental property of ecosystems.

b. Networks with strongly different structures but similar properties can yield the same results. This allows one to form different models on standard networks with a sufficiently simple homogeneous structure. At the same time, networks based on the same organization principles can demonstrate, if necessary, very different results. These properties are tuned by adaptation.

c. In the simulation of the step-by-step formalization from the general qualitative representation to the exact model structure, the qualitative representation can be simulated even by a fully connected network, without going into details. Such a network is a priori excessive and adapts better than it does after removal of excess connections. This gives odds of an immediately operable model. Already at the first modeling stages, one can observe and correct characteristics of the model, experiment with it, study it, and then, step by step bring its structure closer to that of the object under investigation.

d. If the structure of the networks requires further refinement, they can be easily rearranged. In this case, the data obtained are restored by repeated adaptation of a network. Thus, the model can be both simplified and complicated.

e. It is possible to form mixed models (networks), in which one fragments of interest are subjected to detail quantitative processing with structure refinement, while others (systematic environment) are used as qualitative models mentioned in item 3.

f. Unlike human qualitative representations, structureless and structured models yield quantitative results of the same accuracy.

g. The network models can be formed using various tools for operation with artificial neural networks that were developed in neuroinformatics (science dealing with information processing with the use of simplified models of neural networks of human brain). For example, one can use the procedure of automatic simplification of a network to minimally possible but retaining the functions of a modeled system. Simplification should have certain limitations with the use of multi-variance of this procedure in estimating the spectrum of possibilities for reconstruction of the model structures. Thus, the entire range of the model states, from excessive to minimally possible, can be investigated.

h. In the network models, one can obtain arbitrarily complex static and dynamic regimes correctable both in the process of model tuning (identification) and during operation of the model (adaptation).

i. The network models can be formed from fragments and co-tuned to each other by adaptation. For example, the biosphere model can be formed from the models of ecosystems of different regions of the planet or the model of interaction between the biosphere and atmosphere, ocean, soil, and near space can be build.

j. The models based on the self-organizing adaptive networks can potentially reflect the most general and fundamental properties of the aforementioned complex natural systems and, in this sense, be improved analogs of mechanistic models, since the fundamental properties allow obtaining a complete spectrum of possible revelations of real ecosystems and the biosphere as a whole. On the other hand, the structureless network models can be used as purely simulation. Thus, the network models can overlap the entire range of model representations, from deeply fundamental to purely simulation. It offers the opportunity of simulation of the gradual formalization of knowledge (see item 3).

All these potentials can be used in improvement of the mathematical part of the rapidly developed theory, with simultaneous development of appropriate software.

Note also that any system of interdependent equations represents a network of interdependent processes. Equations of the system play a role of network elements. The role of connections is played by coefficients at the equations that serve for recalculation of solutions of other equations. The structure of natural systems in itself predetermines the necessity of such model constructions.

Of principle importance is that the ecosystem models can be easily integrated in the biosphere model or combined with other fragmentary models.

7. Conclusion

A reliable basis for universal models is a multidisciplinary approach that includes three concepts (substrate, energy and information) and is based on fundamental properties of living systems (attractiveness, adaptability, fractal, network organization). Methods of Computational Mathematics based on adaptive networks are the most promising. Developing direction will allow to simulate different ecosystems: terrestrial ecosystems (forest, steppe, arid), aquatic ecosystems (marine and freshwater). Principles of modeling ecosystem are useful for different scales (from local and regional to the biosphere).

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9. References

Battisti, D.S., Naylor, R.L., 2009. Historical warnings of future food insecurity with unprecedented seasonal heat. Science 323, 240-244.

Braun-Blanquet, J., 1964. Pflanzensociologie. Grundzuge der Vegetationskunde. 3 Aufl. Wien-New York, Springer-Verlag, 865.

Chaikovskii, Yu.V., 1990. Elements of Evolution Diatropics. Moscow: Nauka, 272.

Chaikovskii, Yu.V., 2008. Active Connected World. Experience of the Life Evolution Theory. Moscow: Tovarishchestvo nauchnykh izdanii KMK, 726.

Chytry, M., Chiarucci, A., Pillar, V.D., Pärtel, M., 2015. Plant communities: their conservation assessment and surveys across continents and in the tropics. Applied Vegetation Science 18(1), 1-2.

Climate change and water. Technical paper of the Intergovernmental panel on climate change. Eds.: Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P., Geneva: IPCC Secretariat, 2008.

Darwin, Ch., 1939. Works, On the Origin of Species by Means of Natural Selection or the Preservation of Favored Races in the Struggle for Life. vol. 3, Moscow and Leningrad, 226.

Edwards, P., 2011. History of climate modeling. Wiley Interdisciplinary Reviews: Climate Change 2(1), 128-139.

Foley, J.A., DeFries, R., Asner, G.P., et al., 2005. Global consequences of land use. Science. 309, 570-574.

Franzke, Ch.L.E., O'Kane, T.J., Berner, J., Williams, P.D., Lucarini, V., 2015. Stochastic climate theory and modeling. WIREs Clim Change 6(1), 63-78.

Gelashvili, D.B., Yakimov, V.N., Iudin, D.I., Rozenberg, G.S., Solntsev, V.A., Saksonov, S.V., Snegireva, M.S., 2010. Fractal Aspects of Taxonomic Diversity. Journal of General Biology 71(2), 115-130.

Gelashvili, D.B., Rozenberg, G.S., 2002. Fractal Organization of Ecosystems of Different Scales. In Proceedings of the Scientific Conference "Problems of Practical Ecology", Penza, 42-43.

Gilyarov, A.M., 2010. Searching for Universal Regularities of Community Organization. Progress in the Way to Neutralism. Journal of General Biology 71(5), 386-401.

Global Biodiversity Outlook 2, 2006. Montreal, Secretariat of the Convention on Biological Diversity. Available from https://www.cbd.int/doc/gbo/gbo2/cbd-gbo2-en.pdf.

Ingels, J., Vanreusel, A., Brandt, A., Catarino, A.I., David, B., De Ridder, Ch., Dubois, Ph., Gooday, A.J., Martin, P., Pasotti, F., Robert H., 2012. Possible effects of global environmental changes on Antarctic benthos: a synthesis across five major taxa. Ecology and Evolution 2(2), 453-485.

Ivanova, N.S., 2014. Differentiation of Forest Vegetation after Clear-Cuttings in the Ural Montains. Modern Applied Science 8(6), 195-203.

Ivanova, N.S., Zolotova, E.S., 2014. Development of Forest Typology in Russia // International Journal of Bio-resource and Stress Management 5(2), 298-303.

Jiang, Y., Zhuang, Q., Schaphoff, S., Sitch, S., Sokolov, A., Kicklighter, D., Melillo J., 2012. Uncertainty analysis of vegetation distribution in the northern high latitudes during the 21st century with a dynamic vegetation model. Ecology and Evolution 2(3), 593-614.

Kolesnikov, A.A., 2006a. Gravitation and Self-Organization. Moscow, KomKniga, 112.

Kolesnikov, A.A., 2006b. Synergetic Methods of Complex Systems Control. Theory of Systematic Synthesis. Moscow, KomKniga, 240.

Kulakov, Yu.I., 2003. Theory of Physical Structures. Novosibirsk, Al'fa Vista, 880.

Lankin, Yu.P., 2002. Adaptive Simulation of Atmospheric Phenomena. SPIE 4678, 669-680.

Lankin, Yu.P., 2009. Modeling of Ecological Complexity Using the Self-Organizing Adaptive Networks. In Proceedings of National Conference with International Participation "Mathematical Modeling in Ecology" EkoMatMod-2009. Pushchino: Institute of Physicochemical and Biological Problems of Soil Science of the Russian Academy of Sciences, 153-154.

Lankin, Yu.P., Khlebopros R.G., 2001. Ecological Grounds for the Conception of Self-Adapting Networks and Systems with Search Behavior. Inzhen. Ekol. 2, 2-26.

Lankin, Yu.P., Pechurkin N.S., 2008. Perspectives for the Information Approach Application to Natural and Artificial Ecosystems Investigation. 37th COSPAR Scientific Assembly, Montreal, Canada, COSPAR2008, Paper-Number: F41-0014-08.

Levich, A.P., 2008. The Language of Categories and Functors as an Archetype of Quantitative and Dynamic Description of the World. Systems and Models: Borders of Interpretations. Tomsk, Tomsk State Pedagogical University, 25-33.

Loftus, P.J., Cohen, A.M., Long, J.C.S., Jenkins, J.D. 2015. A critical review of global decarbonization scenarios: what do they tell us about feasibility? *WIREs Clim Change*

6(1), 93-112.
Lovelock, J.E., 1979. Gaia: A New Look at Life on Earth, Oxford University Press, 252.
Maiti, R., 2014. Research Needs on Conservation of Native Plant Species and Increasing Crop Productivity under Sustainable Agriculture. International Journal of Bio-resource and Stress Management.
Maiti, R., Rodriguez, H.G., Satya, P., Sagar, P.V., 2014. Low Cost Technology Developed and Used for Screening and Selecting Few Field and Vegetable Crops for Tolerance to Few Abiotic Stresses. International Journal of Bio-resource and Stress Management 5(2), 304-311.
Malinetskii, G.G., 2008. Synergetics and Prediction. Robotics, Prediction, and Programming. Ed. by G.G. Malinetskii. Moscow., Izd. LKI, 68-97.
Mirkin, B.M., Naumova L.G., 1998. Science of Vegetation: History and Current State of Fundamental Concepts, Ufa, Gilem, 410.
Pavlov, D.S., Bukvareva, E.N., 2012. Climate_Regulating Functions of Terrestrial Ecosystems and an "Ecologocentric" Concept of Nature Management. Biology Bulletin Reviews 2(2), 105-123.
Pavlov, D.S., Striganova, B.R., Bukvareva, E.N., 2010. An Environment-Oriented Concept of Nature Use. Herald of the Russian Academy of Sciences 80(1), 74-82.
Reside, A.E., VanDerWal, J., Kutt, A.S., 2012. Projected changes in distributions of Australian tropical savanna birds under climate change using three dispersal scenarios. Ecology and Evolution 2(4), 705-718.
Sukhovol'skii, V.G., 2011. Simulation of Ecological Systems: Problems and Possible Solutions. In Proceedings of 2d National Conference with International Participation "Mathematical Modeling in Ecology" EkoMatMod-2011. Pushchino: Institute of Physicochemical and Biological Problems of Soil Science of the Russian Academy of Sciences, 259-261.
Usol'tsev, V.A., 1997. Bioecological Aspects of Tree Phytomass Taxation. Yekaterinburg, Russian Academy of Sciences, Ural Branch, 216.