General principles of studying regularities of biological populations’ dynamics for environmental protection and reclaim

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Abstract. Currently the ecological problems, including those arising in the process of environmental protection and sustainable use of resources, are solved within the paradigm of dynamic stability of biological communities in the natural environment. This paradigm is canonic in the ecology, it was formed during almost a century. Materials on the studies of various species populations and their generalizations are presented in books and monographs on the ecology of plants, animals, general ecology. It has almost become a rule in the scientific literature to include the discussion of mathematical modeling methods into the parts on dynamics of various organisms populations. On this way we can find a lot of monographs of domestic and foreign scientists. Populations of forest insects have become especially popular with the scientists completing their comprehensive research which includes building mathematical models and providing suggestions on various corporate actions aimed at environmental protection and reclaim. The forest insects are a rewarding object not only due to their numerosity which makes it possible to apply the apparatus of differential calculus to describe the population (density), discrete mathematics to study the structure of the populations (generations, age groups, sex dimorphism, etc). Different groups of xylophages and phytophagans demonstrate breeding grounds development, pandemic irruptions with unfailing regularity, allow the researcher making controlled experiments and assessing quantitative characteristics of the population and parameters of the animal units cooperation which are so necessary and indispensible for building the mathematical models.

1. Introduction
The living systems possess a number of remarkable, functionally and structurally effectual, properties. In their systematic totality these properties are referred to as self-regulation mechanisms by the academic community. Depending on the reversibility or irreversibility of events these self-regulation mechanisms are also called adaptation or homeostasis. Despite the surprising variety and unique character of the functions of the self-regulation mechanisms they are all based on the highly similar principles of the object state regulation at all organization levels of a living being (organism, population, biogeocenotical, biospheric, including the sublevels) [1,2,3].

2. Results and discussion
When solving the problem of biocommunities stability and finding the criteria for “norm” and “pathology” as far as the structure and functioning of variously ranked natural associations are concerned the scientific research in various environmental areas brings us to the conclusion that the primary elements of the regulation mechanism ensuring the dynamic stable state of populations are a complex of reactions and acts of collective and individual behavior of organisms and their populations caused by endogenous population and exogenous environmental changes. They are very diverse by their nature: experience gained; instinctive; congenial – sexual, eating, defensive; physiological; behavioral; adaptive; reflex; with or without time lag and other possessing certain stabilizing properties and systems principles of both deviation and advance regulation. This mechanism ensures correlating the biological characteristics, properties and parameters of a population (magnitude or density, age and sexual structure, reproduction capability, survivorship rate, mortality,
capability for emigration, immigration and expansion, the pronouncedness of collective and individual behavior, nurture and protection of the offsprings from the unfavorable biotic and abiotic environmental factors and so on) and the biogeocenotic capacity of habitats in the natural environment.

The suitable regulation mechanisms allow achieving such qualitative composition of organisms or species diversity and magnitude that is optimal in the asymptotic for various characteristic times or spaces and corresponds to the environmental and resource gradient [4,5,6].

The regularities of the biological community functioning and its habitats in the habitats (even land, highland, deciduous or coniferous forests, moor, steppe, river-basin, other landscape units) are a certainty, an unbiased fact [1,2].

Various interactions between the components of the community (mutually useful, useful-neutral, useful-harmful, harmful-neutral, mutually harmful) and their quantitative values which the researcher always wants to take into consideration when he or she analyses the populations to estimate the state of the community and to forecast its spatiotemporal dynamics [7], inevitably make him or her face two sets of problems.

The first one is the “curse of dimensionality” (a large amount of parameters and variables). The researcher analyses qualitative and quantitative traits and properties which are essentially incomparable. Their values are fixed on the various axes of the multidimensional space. The space is not homogenous and isotropic. Fluctuations of the value levels of all factors and resources (biotic and abiotic) are the objective reality.

The second problem is associated with the system properties of the biological community. From the viewpoint of the system analysis it is the problem of the non-linearity of the biocommunity components interaction, emergence, synergy, equifinality, robustness, opportunity of bifurcation points formation, manifestation of collective behavior and other qualities and properties that “make” the living system remain such a unit with its immanent structure and functions within some natural-territorial complex at the intervals of its characteristic time and space.

Any naturalist understands that these two problems – the “curse of dimensionality” and the system properties of the biological community – make the analysis of the biological community too difficult or even unrealizable. Multidimensional and combinatorial problems are impossible to solve in the general way. Only in some special cases the methods of the probabilistic-statistical pattern recognition with application of digital techniques and computational procedures give reasonable estimates. The complexity and hardness of research grows exponentially depending on the number of parameters and variables being analyzed. Then some idealized images of communities which are lesser dimension but significantly impoverished serve as an object of theoretical cognition of things and phenomena immanent to the communities. These images being some constituent parts of the real natural environment represent the communities.

Such examples are the research works concerning the population dynamics of forest insects [1,2,8]. The established modern concepts about the regularities of spatiotemporal development of “forest-insects” system and about the breeding grounds and pandemic irruptions of needle- and leaf-eating phytophagans and xylophages within this complex biological community were preceded by various theories of population dynamics. Let us mention some of them, those, which names allow understanding the essence of each theory: the weather theory, the trophic resilience theory; statical theory; synthetic theory; integral theory; biogeocenotic theory; theories based on the atmosphere circulation or solar activity and other [8]. The conclusion about the effects of the meteorological conditions and climate in the weathers upon the propagation of insects seems indisputable. All processes in the biosphere including the resistance of trees and that of the tree stand in general depend on these conditions. The physiological state of the woody plants determines the concentration of protective agents with insect-repellent and toxic properties which affects the population density and prevents insect epidemics [2]. The consumer eating the fodder changes its quality as the green mass accumulates the antibiotic active ingredients. The change of fodder quality and quantity makes some insects fall into dormancy, especially those faring on fruits and seeds. Population explosion is an endogenetic succession of biogeocenosis with age structure and composition of species typical for it [1].

We believe that all theories in total complement each other and do not contradict to the modern views upon the classification of the major factors of population dynamics.

We have empirically established the dependences between the density of differently resistant trees colonization with some species of insects in diverse forest types with their taxation characteristics in various geographic areas of Siberia and the most important parameters of population. The constant values and the functional dependences are taken into consideration when building various mathematical models (parametric, non-parametric, statistical, imitative, phenomenological and others) and phase portraits of the dynamics of the interacting populations [1,2,3].

The first most important fact with the far-reaching implications for estimating of the populations dynamics is that insects-xylophages have collective behavior when choosing their habitat and colonizing an individual
tree depending on their resistance. So, the density of the larch bark beetle colonies on the tree trunks is limited at the top and at the bottom, its value is within 0.3 to 6.5 families per 1 dm² of the trunk surface.

Each following nest of the bark beetle family on the tree trunk during the xylophages emergence period is built not closer than 2-3 cm and not farther than 40-50 cm from the previously built nests being placed with as little density as possible up to the minimal one. Thus, emergence of nests on the tree trunk resembles a “progressing” wave of density. Finally the correlation between the fodder supply and the number of insects determines 1) – spatial holding of the fodder base and 2) – density of the population.

Depending on the density of the colony the empirical correlations (linear and non-linear) were established with such characteristics of species’ activity (larch bark beetle, Monochamus sutor, Altaian larch borer, larch bud midge, line looper, gypsy moth, Siberian silk moth and other) as the amount of eggs laid by the female insects, survival of various stages of offspring, net reproduction, distance of insects departure from their hatch places, sex ratio and other.

When studying the location of breeding grounds of different insect species in the Siberian taiga forests which area equals hundreds of thousands hectares we defined landscape-ecological morphostructures with various risks of breeding grounds emergence. Such ecosystems, differing from each other, are seen on the aerospace photographs. Besides, hundreds of parameters and variables, causal relationships and functional dependences in the “forest-insects” system including those for particular landscapes, areas, stows, tree stands, trees colonized by the insects to a different extent and also having different physiological state reflecting their resistance to the insects were linked to the deciphering characteristics which made the basis of aerial photography materials produced at different scales. These indirect indicators were used to build the forecast system for the population dynamics of the most dangerous species for different lead time: very-long-term (for 10 years and longer), long-term (3 years minimum) and medium-term (annual). Thus, application of distance methods of forest areas sounding allowed passing from the real object to its image in the form of aerial or space image filled with various information. This information correlates to the population characteristics of forest insects, resistance of tree stands and individual trees, allows estimating the capacity of populations habitats and using for building mathematical models of breeding grounds in time and space.

The highest degree of the achieved understanding and knowledge of an object is its mathematical model including all causal relations. Although in practice even when building the imitational models the researchers leave behind many properties of the system or simplify them greatly [2]. All parametric models are simplified independently of whether they are built for one or several interacting populations.

Analysis of qualitative models is usually considered on a plane. But even under such significant limitation there are questions left concerning the amount of quasi-equilibrium states, type of critical points (node, focus, saddle, center or other critical point), mechanisms of bifurcation points emergence. In all cases an important question is at what times and places the structure of the community and its functions remain invariant within the activity of a higher living system [1, 8, 9].

3. Conclusion
When integrating or synthesizing the knowledge about the certain components of the community when the segregates and the studied components are united into a cohesive whole we face a difficult task to make a correct model of the whole community’s behavior with consideration not only to the mentioned above specific system particularities but also to the philosophical category of quality. A good model implies integrating new knowledge into it, allows calculating the consequences of such integration and estimating the quality of the original more precisely and forecast its behavior in various situations.

The biological communities are self-oscillating systems. They are able to oscillate with the frequency of the external periodic cyclic action. Synchronization of some interacting populations densities with or without a time shift is also possible.

Solving the problems of the population dynamics may become foundational when formulating rules, regularities, laws, principles and concepts of formation and development of many biological communities interacting with each other in a living system of any level. They can be used in the practices of planning and organizing environmental protection and reclaim.

References
[1] Isaev A S, Khlebopros R G, Kiselev V V, Kondakov Y P, Nedorezov L V and Soukhovolsky V G 2009 Eurasian Entomological Journal. 8(2) 3-115
[2] Isaev A S, Rozhkov A S and Kiselev V V 1988 Fir Sawyer Beetle (Novosibirsk:«Nauka» Publishing House Siberian Branch 271)
[3] Kiselev V V, Alexandrova I N and Tikhonova I N 2020 General ecology part 1 (Pyatigorsk: RIA «KMV» 184)
[4] Kashkarov D N 1944 Basics of animal ecology (Leningrad: Publishing House Commissariat RSFSR 384)
[5] Macfadyen A 1965 Animal ecology: Aims and Methods (London: sir Ysaac Pirman and Sons LTD 376)
[6] Larcher V 1978 Plant ecology (Moscow: «Mir» 384)
[7] Odum E P 1971 Fundamentals of Ecology (Philadelfia-London-Toronto: Third Edition W B Saunders Company 743)
[8] Population Dynamics of Forest Insects 2001 red. Isaev A S (Moscow: «Nauka» 374)
[9] Volterra V 1976 Mathematical Theory of the Struggle for Existence (Moscow: «Nauka» 287)