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IMPACT OF THE WORKS OF V. G. GORSHKOV ON THE DEVELOPMENT OF MATHEMATICAL MODELS OF ECOSYSTEMS

N. V. Belotelov

FIC IM CC RAS named by A. A. Dorodnicyn, 40 Vavilova street, Moscow, 119333, Russia
E-mail: belotel@mail.ru

Abstract. This paper discusses the latest article by V. G. Gorshkov and A. M. Makarieva *Fundamental ecological parameters of stationary and moving life*. The main theoretical results obtained by V. G. Gorshkov over the past 40 years are reviewed. The problem of combining population and mass energy approaches in ecosystem modeling is analyzed. It is suggested that in the course of study of ecological systems, it is necessary to make use of the methodological developments of modern physics, and at the same time systematically and carefully coordinate the conceptual framework developed in physics and biology using the language of mathematical modeling.

Keywords: mathematical modeling, population models, biogenic element cycle models, size spectrum.

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ВЛИЯНИЕ РАБОТ В. Г. ГОРШКОВА НА РАЗВИТИЕ МАТЕМАТИЧЕСКИХ МОДЕЛЕЙ ЭКОСИСТЕМ

Н. В. Белотелов

ФИЦ ИУ РАН Вычислительный Центр им. А. А. Дородницына, Россия, 119333, г. Москва, ул. Вавилова, 40
E-mail: belotel@mail.ru

Аннотация. В работе обсуждается последняя статья В. Г. Горшкова и А. М. Макарьевой «Фундаментальные экологические параметры неподвижной и передвигающейся жизни». Проводится обзор основных теоретических результатов, полученных В. Г. Горшковым за последние 40 лет. Анализируется проблема совместного использования при моделировании экосистем популяционного и масс-энергетического подходов. Высказывается мнение о том, что при исследовании экологических систем необходимо заимствовать методологические разработки современной физики, но при этом системно и тщательно согласовывать системы понятий, разработанных в физике и биологии, используя язык математического моделирования.

Ключевые слова: математическое моделирование, популяционные модели, модели круговорота биогенных элементов, размерный спектр.

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This article was prompted by the last paper [1] of Viktor Gorshkov, the outstanding scientist who made a significant contribution to the theory of quantitative physicomathematical description of ecological systems. Over almost 40 years of persistent research in the field of quantitative ecology, he created an original holistic theory that gave a new perspective to biosphere processes. Since initially Viktor Gorshkov focused on theoretical physics, his theoretical constructions were based on physical approaches. The main provisions of its concept were described in the monograph [2]. From my point of view, the article under discussion [1] elaborates on and clarifies some of the ideas brought up in the monograph.

Listed below are the main initial theoretical and experimental hypotheses underlying the concept of V. G. Gorshkov:

- Constant flow of solar energy;
- "Living organisms should not use the substances the concentrations of which cannot be regulated by biota";
- Equality between biota-generated flows of synthesis and destruction of organic matter. Moreover, the power of these flows is so great that misalignment can lead to the destruction of biota over a period of 10–100 years;
- Competitive interactions in biota maintain genetic programs ensuring the maximum closure of the biogenic element cycle.

These hypotheses, with a number of assumptions, lead Gorshkov to the following conclusions. First of all, the biosphere can exist in its current state only if the rates of biological synthesis and decomposition are exactly equal, i.e. the biochemical cycles of substances are highly closed. The enormous power of synthesis and decomposition of the Earth's biota is necessary to quickly offset all occurring external fluctuations. A random set of viable organisms will not be able to ensure environmental sustainability. Life uses solar radiation as a source of energy and facilitates transformation of the environment on the basis of dynamically closed cycles of matter, the flows of which are many orders of magnitude higher than the external flows of environmental destruction by external forces.

I would especially like to emphasize the following results obtained by Viktor Gorshkov: proof of existence of a stable so-called size spectrum of primary product consumption [2]; analysis of the velocities of information flows in the biosphere and their comparison with information flows in the human civilization [2]; and, of course, crystallizing the "biotic pump" principle, which links evapotranspiration by vegetation with atmospheric precipitation [3]. It is the biotic pump that ensures the transfer of the moisture evaporated over the ocean deep inland.

In the late 1980s, the works by Viktor Gorshkov provoked fierce debate among the specialists engaged in mathematical modeling of ecological systems. To put it mildly, Viktor Gorshkov was not a fan of mathematical modeling in ecology at all because of two fundamental propositions. The first was that in ecology, the measurements of phase variables included in the model are usually inaccurate. Another objection was that the functional relationships between the flow rates of changes in the model's phase variables and the values of the phase variables themselves were unknown. This stance is also seen in the text of the article under discussion: "...the issue of ecosystem instability in the presence of large animals has not been considered in the environmental literature. One of the reasons for this is that mathematical equations used in population dynamics such as various modifications of the Lotka-Volterra equations do not allow for a possibility of animal extinction. This problem is called the atto-fox problem, where atto means multiplication by 10^{-18} (Sary, Lobry 2016; Mollison 1991). In these models, even if the population of a species reaches an infinitesimal number – for instance, up to 10^{-18} individuals of foxes per square kilometer, as in the paper of Mollison (1991), it can possibly be restored to realistic observable values. Therefore, the extinction scenario does not exist mathematically; it must be set manually. If you do not make sure there is an extinction, the population will exist forever, wobbling between the infinitesimal and the ordinary population numbers. Infinitely small populations can also be excluded artificially. For example, in the model of Pleistocene steppes, when the population of large animals fell below one individual per thousand square kilometers, it automatically increased to this value (Zhu et al. 2018). (Note that many large animals have an individual feeding area of about a thousand square kilometers (Makarieva et al. 2005b), therefore for large animals, the population density of 10^{-3} individuals/km^2 is rather normal than low.) It is obvious that this way, it is impossible to look into the ecosystem sustainability" [1].

The above fragment clearly shows his attitude to mathematical modeling in ecology, and this attitude, like I said, has a long history. It might partly be a reasonable approach, but there are some points that I would like to dwell on.

When V. G. Gorshkov presented his concept in the Mathematical Ecology laboratory of the Computing Center of the USSR Academy of Sciences, he was greeted by boos and hisses. On the one hand, physical analogies and estimates provided results not shown by simulation models. On the other hand, it was clear that he was not interested in the very problem of mathematical modeling. Now, thirty years later, there is more awareness that many of the problems were related to language.

We live in a language. All a person understands and explains of himself and the surrounding world mysteriously fits into language constructs that form a person's understanding of the world around. When we say that we understand how the surrounding world works, it means that we use certain concepts and, in accordance with the generally accepted ideas at a given time in the history of human development, build from these concepts some logically consistent constructions that, as we think, explain the phenomena observed in the surrounding world. Surprisingly, yesterday we were satisfied with one explanation of the observed phenomena, today with another, and tomorrow…who knows? And a language is the combination of the code and history.

N. N. Moiseev was very well aware of this problem. In his first book [4], where he analyzed of the possibility of studying poorly formalized and poorly measurable processes using mathematical and computer modeling, he wrote: "Mathematics is also a language, and like any language, it is a form of thinking. The stage of mathematization of a branch of science begins when the natural language with which it began its formation is not enough for the branch of science, when the possibilities of this language for the advance of science are exhausted. Physics crossed this crucial milestone in the days of Newton: it is impossible to describe classical mechanics without resorting to the language of mathematical models. The introduction of a new language, however, always requires a major transformation of the branch of science".

Let us get back to the origins of physics for a short time. The concept of energy, which is the main concept of V. G. Gorshkov, appears as a natural science category in Lagrange's *Analytical mechanics*. It arises from mathematics: mechanical work is the scalar product of force and displacement vectors. And in the 19th century energy turns from mechanical energy, the invariant of mechanical motion, to the foundation for describing inanimate matter. In 1937 in his *Thermodynamics* textbook, E. Fermi wrote when introducing the concept of "internal energy of a body": "If we want to remain within the framework of the conservation-of-energy principle, then...". In this sense, the physical categories used by V. G. Gorshkov, generally speaking, are based on mathematical models.

"Every natural scientist constantly faces the problem of objective description of experience, which means an unambiguous report or verbal message. Every new piece of knowledge appears to us in a shell of old concepts adapted to explain previous experience, and any such shell may be too tight to include new experience. Expanding the concept system not only restores order within the relevant area of knowledge, but also reveals analogies in other areas.

...When talking about a system of concepts, we mean simply an unambiguous logical representation of the relationship between experimental data… Mathematics, which has so strongly contributed to the development of logical thinking, plays a special role; with its well-defined abstractions, it provides invaluable help in the expression of coherent logical dependencies… We will consider it (pure mathematics) rather an improvement on the general language for displaying dependencies for which a normal verbal expression would be inaccurate or too complex. In this regard, it can be emphasized that the necessary unambiguity of definitions for an objective description is achieved when using mathematical symbols namely because in this way references to the conscious subject, which permeate everyday language, are avoided" [5].

The stage of mathematization of ecology, as well as other descriptive sciences, began in the mid-20th century, when the scientific community was overwhelmed by the advent of physics, a system of concepts about inanimate matter. Another factor contributing to the rapid penetration of mathematical methods into descriptive sciences was the appearance and development of electronic computing machines [6].

Just when electronic computing machines began to become widely available (machines of the third generation) a strong interest in mathematical modeling in ecology, economics, sociology, and other humanities was registered.

At present, "mathematical biology" even turned into a scientific field, an interdisciplinary field of science, where the object of research are biological systems of different levels of organization, and the goal of research is closely linked to the solution of certain specific mathematical problems that make up the subject of research. A mathematical proof is the criterion of truth there. The main mathematical apparatus of mathematical biology is the theory of differential equations and mathematical statistics" [7]. Although it is true that a mathematical proof in itself cannot provide additional knowledge, it can only provide a new perspective on pre-existing concepts used by biologists. Moreover, it is clear that the existing physicomathematical languages at the current level of development can not fully satisfy biologists. "The events occurring in the physical world are based on fundamental constants that have stable numerical values. In this sense, this world is stationary. In the world of life, of course, there are constants, but they do not rise to the rank of fundamental constants. These are the same non-fundamental constants as, say, in physics, the half-life of an atom or the melting point of a metal. Their numerical values are not critical for the existence of the world itself. This explains the failures of modeling ecosystems using the language of differential equations (this has already been discussed in the work of V. V. Nalimov 1983, *Analysis of the foundations of the ecological forecast*. Problems of philosophy. No. 1. P. 198–217)" [8].

The main issue related to the development of science is the creation and development of a conceptual framework, that is, a system of concepts that objectively, ideally without the influence of the internal state of the observer, describe these very phenomena and processes and establish cause-and-effect relationships between concepts [6].

Director of the Computing Center of the USSR Academy of Sciences academician A. A. Dorodnicyn wrote: "Building a mathematical model is, first of all, defining the structure of the operator, and there are no algorithms for this…

A "Modeler" is in the grip of existing mathematics and tries to describe phenomena in new fields using known mathematical structures: mainly differential equations, sometimes additionally introducing finite-difference relations.... only the advent of new mathematics (differential and integral calculus) made it possible to create a mathematical model of movement... I believe the task of introducing informatics into "descriptive" sciences to be one of the crucial, perhaps the most important problem of the near future" [9].

It follows from the above that mathematical models in ecology are certainly appropriate, only they should be created not for the sake of mathematics, but for the sake of solving and discussing certain environmental problems. Of course, it is up to specialists in biology and ecology to formulate the problems themselves. Or at least the results of mathematical modeling must be understandable to biologists.

In this sense, I really like the idea of V. G. Gorshkov about the existence of a stable size spectrum of consumption, which I mentioned above. The point is that we can discern two approaches to describing ecosystems in ecology. The first is associated with mass-energy and the idea of a cycle of biogenic elements created by living systems that interact with the abiotic environment, using the energy of the Sun. The second is population-based and the main variables used in this description are concentrations or populations. These two approaches are not reducible to each other, and the size spectrum of consumption, drawing an analogy with quantum mechanics, in a way, plays the role of the Bohr complementarity principle or the Heisenberg uncertainty principle. And it would be very interesting, returning to the article [1], to estimate not the maximum rate consumed by "mobile" biota, but the distribution by size and to link this distribution to the distribution of "stationary" biota products. And it would be wonderful to take into account evapotranspiration.

It seems that rough estimates of the power of large phytophages, which are given in the article [1], do not allow us to fully assess the complex dynamics, and in particular, the stability of undisturbed ecosystems and the role of animals in this dynamics. The point is that large phytophages naturally have a strong impact on the turnover rate of the forest mosaic [10], which affects the local hydrologic cycle, the same is true of the beaver complex mentioned in the article [1]. It is possible that the activity of these animals, who increase the moisture content of the territory under certain conditions, increases the productivity of forest and pasture systems, and the estimates given in the paper as an example are not quite correct. At least this is what some works on data analysis in the ecosystems that have not been actively transformed by humans suggest.

I would like to make another minor comment on definitions. The terms "mobile and stationary life" are unsatisfactory. Life, in its essence, is always a movement in space and time, certainly on its correspondent scale. This point would benefit from discussion, so that readers, especially those with a degree in biology, do not feel the terminological dissonance.

Conclusion

In his monograph [2], V. G. Gorshkov wrote: "The purpose of the work is to demonstrate the existence of natural biological regulation of the environment and to prove that it is impossible to preserve a stable environment suitable for human life in the current trends of transformation of the modern biosphere".

Currently, humanity is in the middle of a very tough crisis. Apparently, the main difficulty is the lack of understanding what is happening. This lack of understanding is primarily due to the fact that this is a new situation in history, therefore, it is not "described" in terms of existing natural languages.

Modern information technologies – statistical data processing (big data), neural networks, deep learning and other approaches that allow for efficiently process, visualize, and analyze (if we know what for) huge sets of information, do not help us to improve our understanding of the studied phenomena. "We see what we understand" (A. Einstein), that is, we collect data based on certain theoretical concepts that have historically shaped our modern understanding of the world. Of course, this is an important area of scientific activity, but it is not fully clear, whether it will lead to an improvement in our understanding of the leading processes that shape the dynamics of the system under study.

On the other hand, it is clear that the task of restoring the anthropogenically disturbed environment in the near future will become the top priority. But it is impossible to deal with restoration without a more or less reliable tool in the form of formalized representations, i.e. mathematical models of biosystems of different spatial and temporal levels. And artificial intelligence is unlikely to help here.

Critical analysis of the concepts used in describing cause-effect relationships in ecology is needed, primarily from the point of view of measurement procedures during experimental work. This seems to be a necessary prerequisite that, hopefully, will make mathematical ecology a truly predictive science in the future, to some extent similar to the well-defined structure of mathematical physics. To solve these problems, it is necessary to intensify the systematic interdisciplinary scientific study of biosphere processes based on biological and physical descriptions of ecosystems. In this interdisciplinary approach, mathematical models will play a crucial role. Certainly the works of V. G. Gorshkov will be an important stage in this activity.

Библиографический список

1. Горшков, В. Г. Фундаментальные экологические параметры неподвижной и передвигающейся жизни / В. Г. Горшков, А. М. Макарьева // Russian Journal of Ecosystem Ecology. – 2020. – Vol. 5 (1).
2. Горшков, В. Г. Физические и биологические основы устойчивости жизни / В. Г. Горшков. – Москва : ВИНИТИ, 1995.
3. Gorshkov, V. G. Biotic pump of atmospheric moisture as driver of the hydrological cycle on land / V. G. Gorshkov, A. M. Makarieva // Hydrology and Earth System Sciences. – 2007. – Vol. 11. – P. 1013–1033.
4. Моисеев, Н. Н. Математика ставит эксперимент / Н. Н. Моисеев. – Москва : Наука, 1979.
5. Бор, Н. Единство знаний. Избранные научные труды / Н. Бор. – Москва : Наука, 1971. – Т. 2. – С. 481–497.
6. Белотелов, Н. В. О возможных направлениях развития математической экологии / Н. В. Белотелов // Russian Journal of Ecosystem Ecology. – 2018. – Vol. 3 (4).
7. URL: https://ru.wikipedia.org/wiki/Математическая_биология
8. Налимов, В. В. Разбрасываю мысли. В пути и на перепутье / В. В. Налимов. – Москва : Прогресс-Традиция, 2000.
9. Дородницин, А. А. Информатика: предмет и задачи / А. А. Дородницин // Кибернетика. Становление информатики. – Москва : Наука, 1984.
10. Smirnova, O. V. Natural zonality of the forest belt of Northern eurasia: myth or reality? Part 1 (literature review) / O. V. Smirnova, A. P. Geraskina, V. N. Korotkov // Russian Journal of Ecosystem Ecology. – 2020. – Vol. 5 (1). – DOI 10.21685/2500-0578-2020-1-2.

References

1. Gorshkov V. G., Makar'eva A. M. *Russian Journal of Ecosystem Ecology*. 2020, vol. 5 (1). [In Russian]
2. Gorshkov V. G. *Fizicheskie i biologicheskie osnovy ustoychivosti zhizni* [Physical and biological principles of sustainability of life]. Moscow: VINITI, 1995. [In Russian]
3. Gorshkov V. G., Makarieva A. M. *Hydrology and Earth System Sciences*. 2007, vol. 11, pp. 1013–1033.
4. Moiseev N. N. *Matematika stavit eksperiment* [Mathematics conducts an experiment]. Moscow: Nauka, 1979. [In Russian]
5. Bor N. *Edinstvo znaniy. Izbrannye nauchnye trudy* [Consistency of knowledge. Selected research articles]. Moscow: Nauka, 1971, vol. 2, pp. 481–497. [In Russian]
6. Belotelov N. V. *Russian Journal of Ecosystem Ecology*. 2018, vol. 3 (4). [In Russian]
7. Available at: https://ru.wikipedia.org/wiki/Matematicheskaya_biologiya
8. Nalimov V. V. *Razbrasyvayu mysli. V puti i na pereput'e* [I am dissipating ideas. On the way and at a crossroads]. Moscow: Progress-Traditsiya, 2000. [In Russian]
9. Dorodnitsin A. A. *Kibernetika. Stanovlenie informatiki* [Cybernetics. Origin of informatics]. Moscow: Nauka, 1984. [In Russian]
10. Smirnova O. V., Geraskina A. P., Korotkov V. N. *Russian Journal of Ecosystem Ecology*. 2020, vol. 5 (1). DOI 10.21685/2500-0578-2020-1-2. [In Russian]

Belotelov, N. V.

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