Volume 27, Number 3 May-June 1996
ISSN: 1067-4136 CODEN: RJOEEW

RUSSIAN JOURNAL OF ECOLOGY

Official English Translation of *Ekologiya*

Editor-in-Chief
Vladimir N. Bolshakov

Member of the Russian Academy of Sciences
Director of the Institute of Plant and Animal Ecology,
Ural Division of the Russian Academy of Sciences

Translated and Published by
МАИК НАУКА/INTERPERIODICA PUBLISHING

Distributed worldwide by PLENUM/CONSULTANTS BUREAU

Russian Journal of Ecology, Vol. 27, No. 3, 1996, pp. 155–160. Translated from Ekologiya, Vol. 27, No. 3, 1996, pp. 165–170.

Problems of the Comprehension of the Basic Notions of Ecological Science by Contemporary Society

V. N. Bol'shakov*, S. V. Krinitsin*, F. V. Kryazhimskii*, and J. P. Martinez Rica**

* *Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences, ul. Vos'mogo Marta 202, Yekaterinburg, 620144 Russia*

** *Pyrenean Institute of Ecology, Saragossa, Spain*

Received January 12, 1996

Abstract—The basic concepts of ecology as a biological science are inadequately reflected in public awareness despite the apparent indispensability of their application in the interaction between human society and living nature. This stems not only from ecological ignorance on the part of even the most well-educated and active segments of the population, but also from a continuously anthropogenic worldview. Science and education face the problem of changing this mentality and introducing basic ecological concepts into public awareness.

The word "ecology" has become very popular; however, it is understood in different ways. For scientists, it is a certain branch related to biological sciences, whereas nonprofessionals evision something else, at best, studying only the sanitational aspect of environmental quality and often nothing more than the level of its anthropogenic pollution. There arises a discrepancy between the common understanding of ecology and the results achieved by the science of ecology. Since the reconciliation of science with common sense is achieved through education in its broad sense, this problem can be largely treated as educational.

The article attempts to estimate the intensity and negative consequences of the discrepancy between scientific knowledge and its comprehension by society and formulate a number of tasks to be solved by scientists and educators in order to bridge this gap. This analysis was performed by using several basic concepts recognized in contemporary scientific circles. This article elucidates the background of these concepts, their main point, and the level of their comprehension in society.

DEVELOPMENT OF ECOLOGY AS A HISTORICAL PROCESS

The development of science, like many other processes of historical development in human society, has a cyclic character and manifests itself as a change in paradigms (Kun, 1977). In general, the first stage of the cycle is characterized by the accumulation and classification of data; at the second stage, the reduction of data is performed, as well as the empirical verification of hypotheses; at the third and final stage, synthetic theories of a holistic character prevail, giving rise to a new paradigm. This is the pattern, but, in reality, the aforementioned stages considerably interact and coexist, disguising the cyclic character of the development of science. Therefore, in the last century, for instance, the majority of scientists treated the development of science as a linear process, reduced to continual increments in knowledge. It should be noted that the ancient dispute on the nature of the development of science is fairly senseless. The most descriptive pattern of science was offered even in the 13th century by the Spanish philosopher Ramon Llull, who represented human knowledge as "the tree of science" (*Arbor Scientiae*). Such a depiction is static rather than dynamic (the latter was hardly possible in the Middle Ages), but it emphasizes the evolution of science, comparing the branching of science with that of a tree. Moreover, it reflects the cyclic character of science, because the processes of the growth of new branches are similar to those that emerged before. Furthermore, "the tree of science" allows the linear development from the trunk to the tip of any branch to be traced: linear development coexists with the cyclic one and does not contradict it.

Tracing the history of ecology, we notice an apparent tendency toward synthesis and generalization. An entirely holistic approach, however, displaces neither a reductional nor a mechanical way of thinking; it occupies its own peculiar place in the specific branch of ecology, where only simple deterministic formulations prevailed before.

The first stage of ecological development began with the works by Haeckel (1866), who was the first to give a description of the science based on the paradigm of evolution.

Subsequently, ecologists were favorably disposed toward either a descriptive (Warming, 1895; Cowels, 1899) or an experimental approach (Clements, 1905), although they had already made important generalizations concerning the tendency of natural ecological communities toward a "mature" state or balance.

The outlined tendencies toward quantitative consideration of studied phenomena and processes were

1067-4136/96/2703-0155$15.00 © 1996 МАИК Наука/Interperiodica Publishing

related to the names of Volterra (1926) and Lotka (1925). Even at that time, Lotka tried to realize his program of transforming biology into a strictly quantitative science. In so doing, Lotka turned primarily to ecological objects: the dynamics of populations, interspecific interaction, and biochemical cycles. His approach was notably mechanistic; biology represented only a section of physics. Despite the fact that Lotka did not even use the term "ecology," his attempts to apply the laws of physics to biological objects illustrate most clearly the tendency to widen the field of investigation carried out under the slogan of ecology. The best known result of those attempts was the so-called "Lotka energy principle."

Tendencies toward quantitative description in ecological studies were seen throughout the entire 20th century, giving rise to new concepts and laws of ecology as a science. For example, G. Gause (1934) proclaimed his famous principle of competitive exclusion, emphasizing the importance of trophic connections as the primary energy flows through natural communities, which contributed to the rise of the concept of ecology offered by A. Tansley (1935). Tansley took a considerable step forward in successfully integrating the biocenosis with the biotope at the level of a new functional unit—the ecosystem. As R. Lindemann showed later (1942), the connecting links here were the flows of matter and energy.

The generalization stage in ecology also originated in the 1920s, though generalizations at that time were mostly of an approximate character. The idea of an integrated, interrelated world of living matter that forms a certain sphere around the Earth was put forward in the works (though many of them were not published until now) by V.I. Vernadsky (1945; 1978) and P. Teilhard de Chardin (1955). These authors approached the formulation of the notions of "biosphere" and "noosphere" from points of view not formally connected with classical ecology. Their philosophical (and even mystical in the latter case) syntheses had no scientific support at the time of their creation and were neglected by ecologists until recently, when many of their assumptions proved to be valid (Lovelock, 1979; Gorshkov, 1988; Gorshkov and Kondrat'ev, 1990).

After World War II, ecology began to develop rather intensively, which was largely determined by the introduction of ideas originating outside this field of science. For instance, the founding of cybernetics by N. Wiener (1948) promoted the synthesis of biology and engineering and gave impetus to the use of a systemic approach and the ideas of the self-regulation and self-organization of ecological systems. Studies on the theory of information, particularly its thermodynamic interpretation (Shannon and Weaver, 1949), also had a profound effect on ecological science. The concept of natural systems as open dissipative thermodynamic systems formulated by E. Bauer (1937) and E. Schroedinger (1945) was further developed in the works by I. Prigogine and his group (Prigogine and Wiame, 1946).

The theory of insular biogeography worked out by R. MacArthur and E. Wilson in the 1960s (MacArthur and Wilson, 1967) contributed significantly to the promotion of an ecological mentality. This theory, synthesizing evolutionary ways of thinking with models of populational dynamics, gave tremendous impetus to functional ecology despite its apparent limitation (Hengeveld, 1990). The emergence of this theory marked the transition of classical ecology from mechanistic grounds to more general, synthetic ones. The identification of natural (ecological) systems with chemical mechanisms ignored not only the peculiarities of the thermodynamics of open systems, but also such features as the capacity for self-reproduction and transformation (evolution).

This must have prompted R. Margalef (1957) in the late 1950s to work out the concept of diversity, which became the most popular field of investigation in the past two decades. This approach, arising from thermodynamics and the theory of information, finds application in studying numerous ecosystem characteristics, from production and stability to the mechanisms of the colonization of new territories.

A tendency toward forming a new paradigm is traced from the late 1970s into the 1980s. At that time, Bertalanffy's general theory of systems (Bertalanffy, 1968), as an approach transversing the barriers between different branches of science, was already in place. Moreover, the arsenal of ecology as a science was enriched by new mathematic and computational devices: multivariable statistic analysis, the modeling of epigenetic landscapes, game theory, catastrophe theory, and the construction of complex computer models on the basis of standard algorithmic languages (Forrester, 1961; Odum, 1971; Jones, 1977; May, 1986; Svirezhev, 1987). The emergence of such scientific trends as nonequilibrium thermodynamics, synergetics, etc. revolutionized ecological science. The behavior of natural systems is no longer described by deterministic (linear) laws; their dynamics are largely determined by chaotic behavior shifts, sudden changes, catastrophes, and other nonlinear (and often unpredictable) effects (Bol'shakov *et al.*, 1993).

REGULARITIES OF POPULATION DYNAMICS

The concept of population is one of the keystones of ecology; it is during the study of populations that ecology is integrated to a large extent with evolution (Shvarts, 1967, 1971; Shilov, 1981). Studies in population dynamics have a long history. Now, regularities of its formation can be inferred from a number of basic assumptions. Below, we provide a rough idea of some of the most essential ones.

One of the basic concepts of population ecology is the idea of self-regulation, that populations have a feedback mechanism, and the impact of the environment is reflected in the dynamics of populations through those mechanisms. They are rather diverse and have different origins: behavioral, physiological, genetic, etc.; however, they eventually lead to changes in the demographic characteristics of a population (birth and death rate, migration flows) in response to a change in a population's structure and numbers. In this case, the response of populations to such changes depends on external (in relation to a population) parameters of the environment.

Inasmuch as population dynamics are determined by the interaction of the birth and death rates, two ways are theoretically possible for maintaining stable numbers (when the birth and death rates are equal): a high death rate (and, consequently, a short lifespan) with a high birth rate, or a low death rate (with a long lifespan) with a low birth rate. These tendencies were called "*r*-strategy" and "*K*-strategy," respectively (MacArthur and Wilson, 1967). These designations go back to Ferhulst and Pearl's generally accepted logistical equation of population growth ("*r*" is a Malthusian parameter or the instant initial growth rate of the population observed at very low densities; "*K*" is the capacity of the environment, i.e., stable numbers that the population is tending towards under the given conditions). In conformity with current notions, *r*-strategists have a selective advantage under unstable conditions, when the death rate insignificantly depends on the density of the population, whereas *K*-strategists are better adapted to stable conditions (Stearns, 1976).

As for population laws, direct parallels between human and animal populations are rather difficult to draw. The classical notion of a population obtained in the course of studying species is applicable to human society with certain modifications. Without going into the details of the dispute on the origin of humankind and its manifestation as a separate species, it is worth noting that, during a relatively short span of time, humans have practically settled over the entire inhabitable surface of the planet, and numerous human groups living separately (populations) during documented times differ to a greater extent than many related species of animals due to the considerable pressure of social mechanisms. The relations between those groupings more closely resemble drastic interspecific competition.

Humankind has passed the stage of spatial separateness surprisingly quickly (however, with great sacrifice) and is rapidly advancing toward complete unification. Nevertheless, it seems that a unified society would be constantly falling into groups, this time not only territorial, but also social (strata). With primary crossing of individuals within one group (and, less probably, with outside groups) taken as the main characteristic of a population, the separation of human society into diverse, more or less isolated groups (social populations) is evident. The difficulty of applying the results obtained by classical ecology is that different and complex combinations of natural populational mechanisms act within those various groupings.

However, it is superficial, even dangerous, to ignore the role of populational regularities in the society of people. S. Shvarts (1976) wrote about this in the 1970s, claiming that there is no one better than an ecologist to know how many population phenomena have become apparent in human behavior. Imprinting manifests itself in the behavior of all of us. There are also many transformed manifestations of the "group effect" in the social life of people. The psychology of the "populational dominant" shows itself more often than we can imagine .... Interrelation of the dynamics of the territorial structure of populations with the dynamics of its genetic structure deserves detailed consideration by sociologists and demographers.

Many facts accumulated to date are indicative of the objective character of regular processes that occur in human populations. For instance, developed countries (with a maximal impact on natural complexes and a high standard of living) are known to face a socially conditioned decrease in birth rate and a change in the demographic situation of the population (Meadows *et al.*, 1994) that are in a certain sense similar to a transfer from an *r*-strategy to a *K*-strategy. Social mechanisms allow every population to shift from an *r*- to a *K*-strategy, and, if we know how this occurs, it will allow more effective development. However, despite the apparent necessity to apply the ideas of population ecology to analysis of the processes that occur in human society (taking into account the interaction of humans and the environment), even scientists hesitate to devote themselves to this, choosing to adhere to an anthropocentric view, which pits humans against nature. Ignoring the ideas of classic population ecology in analyzing the demographic situation of human society (which, in our opinion, stems from ecological ignorance on the part of even the most well-educated segments of the population) evokes an illusion of the possibility of overcoming critical situations in ways that in reality lead to objectively undesirable retardation of natural processes.

NONLINEAR EFFECTS IN THE DYNAMICS OF ECOLOGICAL SYSTEMS

Mechanisms of self-regulation play a stabilizing role; however, the actual dynamics of natural populations and communities (particularly, fluctuations in numbers) cannot be described only in terms of self-regulation (Stenseth, 1985). At the population level, the interrelation of the mechanisms of self-regulation with environmental factors is expressed in terms of the population growth curve, which reflects the dependence of the specific increment in numbers on the density of the population. In many cases, such an interchange results in a nonmonotonic curve (with local maxima and minima). The nonmonotonic character of the population growth curve is a prerequisite for nonlinear effects consisting in a sudden change in the numbers and structure of a population and/or the character of its dynamics. Such effects are formally described in terms of mathematical theories: bifurcation and catastrophe theories. The disjointed behavior of populations is responsible, to some extent, for its impredictability. Other sources include the time lag of demographic responses to environmental impacts and the temporal discreteness of populational phenomena (May, 1975). Since ecosystems (biotic communities) represent systems of interacting populations (Shvarts, 1971), similar effects occur (and are even intensified) at the level of ecosystems.

The possibility of sudden (trigger) transfers of ecological systems of different classes from one more-or-less steady state (pattern) to another was reflected in the concepts of elastic stability (Holling, 1973) and the stability of mobile ecological systems (Isaev and Khlebopros, 1973). One of the most important consequences of the behavior of ecological systems is the existence of particularly stressed and very unstable states, which often fall within the limits of the variations in their characteristics observed in nature.

The study of the functioning of natural ecological systems clearly shows that it is incorrect to assume that an ecological system (including human society) can develop as a linear unidirectional progressive process. Nevertheless, such hopes prevail in the contemporary ideology of nature conservation (see below). Moreover, present-day ecological education is oriented, voluntarily or otherwise, toward this very concept. Few can seriously understand that, in the contemporary world, humans and uncertainty have to coexist (*Ecological Systems*, 1981) and that long-term social modeling, performed even with good intentions, cannot in principle provide the expected results.

ENERGETICS AND THERMODYNAMICS OF ECOLOGICAL SYSTEMS

One of the main features of any natural system is its dynamic state involving constant synthesis and decomposition. To maintain such a state, free energy as well as spatial and temporal organization are required (Broda, 1978). In terms of thermodynamics, ecological systems of any kind are open dissipative systems that are far from thermodynamic equilibrium (heat chaos). Thermodynamic nonequilibrium, as one of the essential characteristics of organic substances distinguishing them from inorganic ones, was noted as early as the 1930s by E. Bauer (1937, p. 43), who suggested the "principle of stable nonequilibrium," stating that all living systems, and only living systems, are never in equilibrium and are constantly performing, at the cost of their free energy, work to counteract the equilibrium required by the laws of physics and chemistry under existing external conditions.

Ecological energetics based on fundamental natural scientific laws (the first and second principles of thermodynamics) is one of the most important branches of ecological science, showing that any changes in the structure and volume of ecological systems are connected with changes in the energy flows through these systems, and that additional energy consumption inevitably entails an increase in its expenditure (or, in terms of thermodynamics, an increase in the production of entropy and its outflow into the environment). Figuratively speaking, energy is money in the functioning of nature, and a graphic definition of ecology as the "economy of nature" is true exactly in this sense, because, in nature, as in human society, there are no free lunches.

One and the same error occurs in human awareness of both economics and ecology: money is taken at face value, i.e., as a means of payment, but not a universal means of exchange. Such a fallacy (along with the mechanistic notion of development as a linear translational motion) was one of the reasons for the outwardly appealing idea of sustainable (self-supporting) development that prevails in political programs of different countries (*Agenda 21*, 1992). However, from a scientific standpoint, the concept of sustainable development contradicts the second law of thermodynamics for open systems under stationary conditions, since the production of entropy, which is increasing with the development of technological civilization, should be counterbalanced by its outflow into the environment (resulting in its degradation), and the stability of development (in terms of development progressing against a background of conservation) is possible only locally (Svirezhev, 1995). The term "stable development" is contradictory in essence; it is suspected that its advancement as the main social aim was the result of consensus among politicians (because such a vague notion can be filled with a diverse sense) rather than the result of thorough scientific analysis of the ecological situation on the planet (Vranckx, 1995).

CONCLUSION

When considering the human community as a component of the biosphere and, consequently, a nexus of ecological dependences, it should be emphasized that this subject was prohibited in the course of the formation and development of the structure of human society. This prohibition is quite understandable from the point of view of moral standards, i.e., the system of the regulation of interrelations within groups of any rank. This naturally unique structure of a particularly informational character allowed humankind to somewhat mitigate their direct impact on nature, if not outright escape the control of population mechanisms.

Against the background of rapidly evolving society, the effect of natural mechanisms is misinterpreted, if it is accepted at all. Furthermore, the basic notions and concepts of ecology are not actually comprehended by even the most active part of society that takes the ecological crisis seriously. Ecological education is often reduced to nothing more than demonstration of the negative impacts of human activity accompanied by either appeals to reduce this activity (ignoring its connection with the standard of living and, consequently, the demographic and social responses of the population) or creation of the illusion of the possible solution of delicate ecological problems by purely technical means (low waste techniques, purification plants, etc.), which is woefully incorrect. It might be well to note that some researchers have recently proposed the improvement of this situation via the formation and development of educational centers on human ecology, which is considered a synthetic multidisciplinary branch based on notions of classical ecology (see the article by L. Hens in this issue).

However, this is largely bandwagoning on nature management by politicians (even with the best intentions) and public figures, who have no scientific knowledge to rely on. The role of science is to answer questions and make diagnoses. But, in the face of the current crisis, society is still afraid of answers that will shake its foundations, favoring self-diagnostics and self-treatment, and makes science sign, but not write, prescriptions. Scientific knowledge, of course, is not available in advance. Its accumulation is the result of conflicting historical development, and, as any other development, the gain of knowledge requires investment (ever greater as science advances) on the part of society.

Mutual mistrust between science and society is simultaneously a reason and a result of the development and intensification of the ecological crisis. In this respect, scientists, as a part of society, should adopt a more active role in overcoming ecological ignorance. The significance attached to professional ecologists in the general education of people at different levels is strategically advantageous for science itself: until society can appreciate the proper place of science in its structure, distrust of science (which is not a giving tree) will impede their mutual development.

ACKNOWLEDGMENT

The work was carried out within the framework of the INTAS project no. 94-4377.

REFERENCES

Adaptive Enviromental Assessment and Management, Holling, C., Ed., Chichester: Wiley, 1978. Translated under the title *Ekologicheskie sistemy,* Moscow: Mir, 1981.

Agenda 21: Programme of Action for Sustainable Development, New York: UNCED, 1992.

Bauer, E.S., *Teoreticheskaya biologiya* (Theoretical Biology), Moscow: Vses. Inst. Ekolog. Manadzh., 1937.

Bol'shakov, V.N., Kryazhimskii, F.V., Pavlov, D.S., Prospective Trends in the Development of Ecological Investigations in Russia, *Ekologiya* (Ekaterinburg), 1993, no. 3, pp. 3–16.

Broda, E., *Evolution of the Bioenergetic Processes,* Oxford: Pergamon, 1975. Translated under the title *Evolutsiya bioenergeticheskikh protsessov,* Moscow: Mir, 1978.

Clements, F.E., *Research Methods in Ecology,* Lincoln (NB), 1905.

Cowels, H.C., *The Ecological Relations of the Vegetation of the Sand Dunes of Lake Michigan,* Chicago: Chicago Univ. Press, 1899.

Forrester, J.M., *Industrial Dynamics,* Cambridge (MA): MIT Press, 1961.

Gause, G.F., *The Struggle for Existence,* Baltimore, 1934.

Gorshkov, V.G., *Predely ustoichivosti okruzhayushchei sredy* (Limits of the Stability of the Environment), *Dokl. Akad. Nauk SSSR,* 1988, vol. 301, no. 4, pp. 1015–1019.

Gorshkov, V.G. and Kondrat'ev, K.Ya., Le Chatelier's Principle As Applied to Biosphere, *Ekologiya,* 1990, no. 1, pp. 7–16.

Haeckel, E., *Generelle Morphologie der Organismen,* Berlin, 1866, vol. 1.

Hengeveld, R., *Dynamic Biogeography,* Cambridge: Cambridge Univ. Press, 1990.

Holling, C.S., Resilience and Stability of Ecological Systems, *Ann. Rev. Ecol. System.,* 1973, vol. 4, pp. 1–23.

Isaev, A.S. and Khlebopros, R.G., *Printsip stabil'nosti v dinamike chislennosti lesnykh nasekomykh* (Principle of Stability in the Dynamics of the Numbers of Forest Insects), *Dokl. Akad. Nauk SSSR,* 1973, vol. 208, no. 1, pp. 225–227.

Jones, D.D., The Application of Catastrophe Theory to Ecological Systems, *Simulation,* 1977, no. 1, pp. 1–15.

Kun, T., *Struktura nauchnykh revolyutsii* (Structure of Scientific Revolutions), Moscow: Progress, 1977.

Lindemann, R.L., The Trophic–Dynamic Aspect of Ecology, *Ecology,* 1942, vol. 33, no. 2, pp. 399–418.

Lotka, A.J., *Elements of Physical Biology,* Baltimore: Williams & Wilkins, 1925.

Lovelock, J.E., *Gaia: A New Look at the Life on Earth,* New York: Oxford Univ. Press, 1979.

MacArthur, R.H. and Wilson, E.O., *The Theory of Island Biogeography,* Princeton: Princeton Univ. Press, 1967.

Margalef, R., La Teoria de la Informacion en Ecologia, *Mem. R. Acad. Cienc. Artes Barcelona,* 1957, vol. 32, pp. 373–449.

May, R.M., Biologial Populations Obeying Difference Equations: Stable Points, Cycles, and Chaos, *J. Theor. Biol.,* 1975, vol. 51, no. 2, pp. 511–524.

May, R.M., When Two and Two Do Not Make Four: Nonlinear Phenomena in Ecology, *Proc. R. Soc.,* 1986, no. 228, pp. 241–266.

Meadows, D.H., Meadows, D.L., and Randers, J., *Za predelami rosta* (Limits to Growth), Moscow: Progress, Pangeya, 1994.

Odum, H.T., *Environment, Power, and Society,* New York: Wiley, 1971.

Prigogine, I. and Wiame, J.M., Biologie et Thermodynamique des Phenomenes Irreversibles, *Experimentia,* 1946, no. 2, pp. 451–453.

Schroedinger, E., *What is Life?* Cambridge: Cambridge Univ. Press, 1945.

Shannon, C.E. and Wiever, W., *The Mathematical Theory of Communication,* Urbana: Univ. of Illinois Press, 1949.

Shilov, I.A., Biosphere, the Levels of Life Structure and Ecological Problems, *Ekologiya*, 1981, no.1, pp. 5–11.

Shvarts, S.S., Populational Structure of a Species, *Zool. Zh.*, 1967, vol. 46, no. 10, pp. 1456–1469.

Shvarts, S.S., Populational Structure of Biocenosis, *Izv. Akad. Nauk SSSR, Ser.: Biol.*, 1971, vol. 28, no. 4, pp. 485–493.

Shvarts, S.S., Problems of Human Ecology, *Vestn. Akad. Nauk SSSR*, 1976, no. 12, pp. 80–84.

Stearns, S.C., Life History Tactics: A Review of the Ideas, *Quart. Rev. Biol.*, 1976, vol. 51, no. 1, pp. 3–47.

Stenseth, N.C., Mathematical Models of Microtine Cycles: Models and the Real World, *Acta Zool. Fennica*, 1985, no. 173, pp. 7–12.

Svirezhev, Yu.M., *Nelineinye volny, dissipativnye struktury i katastrofy v ekologii* (Nonlinear Waves, Dissipative Structures, and Catastrophes in Ecology), Moscow: Nauka, 1987.

Svirezhev, Y.M., Thermodynamics and Ecology: The Myth of Sustainable Development, *Environmental Pollution and Ecological Safety: First Practical Conf. (Dnepropetrovsk, December 4–8, 1995)*, 1995, vol. 1, pp. 52–53.

Tansley, A.G., The Use and Abuse of Vegetational Concepts and Terms, *Ecology*, 1935, vol. 16, no. 1, pp. 284–307.

Teilhard de Chardin, P., *Le phenomene humaine*, Paris: Editiones de Seuls, 1955.

Vernadsky, V.I., *Zhivoe veshchestvo* (Living Matter), Moscow: Nauka, 1978.

Vernadsky, W.I., The Biosphere and the Noosphere, *Am. Sci.*, 1945, vol. 33, no. 1, pp. 1–12.

Volterra, V., Fluctuations in the Abundance of a Species Considered Mathematically, *Nature*, 1926, vol. 188, pp. 558–560.

Vrankcx, A., A Brief Semantic Consideration of the Current Debate, *Is Sustainable Development a Controversy of Terms?* Brussels: Br. Council & Vrije Univ. Brussel, 1995, pp. 44–48.

Wiener, N., *Cybernetics*, New York: Wiley, 1948.