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PROSPECTIVE DIRECTIONS OF DEVELOPMENT OF ECOLOGICAL RESEARCH IN RUSSIA

V. N. Bol'shakov, F. V. Kryazhimskii, and D. S. Pavlov

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On the basis of analysis of general properties of ecological systems, the main directions of development of natural sciences, historical experience, and world trends of ecological research, taking into account the specific situation in Russia, a number of directions are distinguished which seem most promising for development of domestic ecology. In this case, study of biological systems will remain the core of ecology.

Determination of the prospective directions of any branch of science is a very complex task, even if it has fairly clearly defined boundaries, i.e., a specific subject of investigation and its own method. The task of distinguishing prospective directions in such a field as ecology is many times harder, since, at present, this scientific discipline does not have distinct boundaries, merging with geography, geology, economics, and politics. At the same time, it is urgently necessary to resolve this task, since ecological problems are extremely acute for the world community as a whole, and for Russia in particular. Therefore, within the framework of the State Scientific and Technical Program "Ecology of Russia," a special project was included to determine the prospects of ecological research in our country, in which the authors took part. We clearly understand that various researchers may and should have different ideas about the prospects of the science's development, and we do not claim to announce the final word on this subject, but we believe that it is useful to set forth our point of view on this important question. A large contribution to formulation of the ideas presented below was also made by corresponding member of the Russian Academy of Science Yu. I. Chernov and doctor of biological sciences Yu. G. Puzachenko, to whom the authors express their sincere thanks.

APPROACHES TO DETERMINING PROSPECTIVE DIRECTIONS OF ECOLOGY

The task of determining priorities in the development of any branch of science is complicated by the fact that it has more than one level of resolution. The first level is determination of the immediate prospects of the science's development, i.e., using T. Kuhn's terminology (1977), prediction of the development of a "normal science" within the scope of the existing paradigm (conceptual framework of the science), based on fundamental ideas set forth in textbooks, elementary or advanced. At this level, it is possible, in principle, to find a solution proceeding from existing theoretical developments and urgent practical (technological, economic, social) problems. Another level is determination of long-term prospects of the science's development, which is connected with prediction of discoveries leading to formation of a new paradigm. At this level, prediction is much more complicated.

A rise in interest in "anomalies," i.e., facts that do not fit within the framework of prevailing theories, can be considered a sign of a critical situation in a science preceding a change in the paradigm. To determine the direction of a probable "breakthrough" in the science, it is necessary to keep in mind the inseparable connection of various fields of science, and also the dependence of science's development on technological and social progress (Kapitsa, 1981; Kuhn, 1977).

Proceeding from what has been set forth above, and also from a number of general considerations, we can distinguish several possible approaches to determining the prospective directions of ecology.

Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences. M. V. Lomonosov Moscow State University. Translated from Ékologiya, No. 3, pp. 3-16, May-June, 1993. Original article submitted January 27, 1993.

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First, there is systemization of current ideas about ecological systems and identification of the most urgent practical and theoretical problems stemming from these general properties. Moreover, for correct determination of a science's most important directions it is necessary to turn to the accumulated historical experience of the science's development. Another very important point in solving such a problem is study of the trends of development of other branches of science, especially those that deal with complex systems. And finally, determination of the prospects of any scientific direction is impossible without specific analysis of world trends in the development of that direction.

All of these approaches are interrelated and supplement each other. Therefore, a number of prospective directions of development of ecology are distinguished below on the basis of all of these approaches together.

ECOLOGY AS A BIOLOGICAL SCIENCE

It seems that no one disputes the statement that ecology deals with the natural environment on Earth. Nonetheless, there are contradictory interpretations of the subject and methodology of this scientific direction. More and more often (especially in the mass media, and also in the pronouncements of politicians), we hear a vulgarized interpretation of ecology as the study of only hygienic aspects of the state of the enviroment, and frequently simply as the level of its technogenic pollution. The popularity of such interpretations is quite understandable, since they are readily comprehended at the level of ordinary consciousness; at the same time, we cannot ignore the danger of extending such a simplified approach to one of the most important and complex scientific problems of our time. Such an approach creates an illusion of the possibility of resolving delicate ecological problems by purely technical means (waste-free technologies, treatment facilities, etc.), which is fundamentally untrue. Unquestionably, it is impossible to solve ecological problems without employing new technologies, but they are by no means the whole solution.

On the other hand, there is a "broad" interpretation of ecology as some vast complex of scientific directions, including economics, sociology, medicine, geography, geology, and a number of technological disciplines. In spite of the fact that the development of any scientific direction requires interaction with other fields of knowledge, the interpretation of ecology as such a grandiose conglomerate of various scientific directions completely blurs its boundaries and deprives it of its own subject and methodology.

The two points of view of ecology as a branch of knowledge mentioned above have in common an underestimation of its core component: the study of living matter as the main component of any natural complex. Besides the fact that ecology was historically established as a biological science about interrelations and interaction between various living objects and their environment (Alimov, 1989; Andersen, 1985; Odum, 1975, 1986; Pianka, 1981; Riklefs, 1979; Shilov, 1981; Clarke, 1954; Clements and Shelford, 1939; Shelford, 1929), there is a fundamental basis for such a claim, starting from the concept of the planetary role of living matter developed by V. I. Vernadskii back in the 1920's (Vernadskii, 1978). In our time, these ideas have received further development and quantitative confirmation: the biosphere as a whole is seen as a self-regulating system in which living matter, in all of its diversity, provides the narrow physical conditions (gas composition of the atmosphere, temperature conditions, etc.) for its existence with high accuracy (Gorshkov, 1988; Gorshkov and Kondrat'ev, 1990; Lovelock, 1979). Precisely for this reason, *the central component of ecological research must be biological systems of different levels of organization.*

It is obvious that, in the development of applied directions of ecology, as well as new theoretical concepts, a fundamental point is the impossibility of advancing without the progress of investigations continuing and elaborating historically established scientific directions. These directions reflect the structural and functional organization of the biosphere and are the foundation on which formation of new divisions of ecology is based. Among the basic traditional directions of ecology, in accordance with current ideas about its structure as a biological science, we can mention *physiological ecology*, which studies the reaction of an entire organism to changes in its environment, *population ecology*, which studies patterns of ecological processes occurring at the population, or group level of organization of living matter, and also the *ecology of communities and biogeocenology*, which study patterns of formation of ecosystems. These directions are the basis for development of comparatively new branches of ecology in the formational stage, such as *global ecology*, which tries to solve problems of the biosphere as a whole, and *socioecology*, i.e., the discipline studying the interaction of nature and human society (Alimov, 1989). Each of these divisions includes a large number of specific directions. The boundaries between the directions and divisions are blurred; at present, investigations are emerging at the junction of such fields of ecology as population ecology and biocenology (Dobrinskii et al., 1983), or physiological and population ecology (Shvarts et al., 1964; Shilov, 1977). All of these directions are closely related with classical branches of biology, such as botany, zoology, and physiology, the basic methodology of which is *naturalism*. We can safely say that neglect of traditional (naturalistic) directions of ecology, a tendency toward which is fairly clearly evident at present, is fraught with a lag in all other fields of ecology, including applied ecology. In particular, in the present stage of the science's development and taking into account the complex economic situation, evaluation of the condition of ecosystems and prediction of their dynamics are frequently possible only at the level of expert evaluations. Only those researchers can act as experts who have enough experience in conducting traditional ecological studies; they are the only ones who possess sufficient knowledge and intuition.

BRIEF CHARACTERISTICS OF BASIC PROPERTIES OF ECOLOGICAL SYSTEMS

From the standpoint of a systematic hierarchy, ecological systems include biosystems of the organism and supraorganism levels of organization, from individuals to the biosphere (Shilov, 1981), although ecological systems are more often understood as supraorganism systems: from species populations to ecological communities (Odum, 1986). The population level occupies a special place in the system of organization of living matter. On the one hand, a population is the elementary unit of the evolutionary process (Timofeev-Resovskii et al., 1973; Shvarts, 1971). Of the basic properties of ecological systems, we must particularly single out the fact that they are not static, but are in a state of constant change, which significantly affects the systems' structural and functional organization, productivity, biotic diversity, and stability ("Ecological Systems," 1981).

The main difficulty in investigating ecological systems is that experimentation with them (in the classical natural-science understanding of the process) is practically impossible, for a number of objective reasons (first of all, because human society is an integral part of the bioshpere as a whole). In such cases, observation (monitoring) and experimentation with models, i.e., an advanced form of an imaginary experiment, remain practicable ways of studying the behavior of ecological systems.

Natural ecological systems belong to the class of extremely complex systems (sometimes called "supersystems"), the behavior of which, under the action of disturbing factors on them, is not subject to exact prediction at the current level of the science's development. The reason for this is significant nonlinearity, as a consequence of which analytic solution of equations modeling the dynamics of ecological systems is impossible. For numerical modeling, it is necessary to have sufficiently precise data on the controlling parameters and variables. Hence follows the importance of collecting and systematizing ecological data. Besides that, distinguishing the controlling parameters proper and variables is an almost insoluble problem in conditions of a shortage of information.

Moreover, a typical property of complex systems is large variability of indices of their behavior, which is determined not by random fluctuations, but by the structure of the system itself. And finally, a remarkable property of complex systems is the presence of memory in them; the system's behavior depends on its history, so that description of the system's state at a given moment in time, however detailed, is insufficient for predicting its behavior (Nicholis and Prigogine, 1978). The excessive complexity of ecological systems' structural, functional, and dynamic organization significantly hampers practical analysis of their condition, viability, stability, reserve possibilities, and rehabilitation prospects. Therefore, the main methodological problem is to seek ways of such analysis. To a significant extent, the welfare of modern mankind and its future depend on the successful resolution of this problem.

TASKS STEMMING FROM GENERAL PROPERTIES OF ECOLOGICAL SYSTEMS

According to the current view of the biosphere already mentioned above, one of the main guarantees of preservation of stable conditions of the existence of life on Earth is preservation of the maximum biological diversity on a planetary scale and in all of its aspects: intraspecific, species, syntaxonomic, and ecosystem. Therefore, *study of biological diversity and the mechanisms maintaining it* should be one of the highest-priority directions of ecology.

At present, an important task stemming from the general properties of ecological systems, and also from practical problems of the use of natural resources, which we do not yet know how to solve, is *development of a general theory of the stability of ecological systems and determination of the boundaries of specific ecological systems' stability*. The very concept of stability, as applied to ecosystems, is not yet adequately developed; for example, the relationship of stability and complexity, for which biological diversity can serve as a measure, remains an important question (Svirezhev and Logofet, 1978; May, 1973). Theoretical developments in this field usually rely on mathematical determination of the stability of dynamic systems (according to Poincaré, Lyapunov, and Lagrange) and take into account the nonlinear nature of interrelations in ecological systems and the temporal discreteness of ecological processes (Bazykin, 1985; Svirezhev, 1987; May, 1975, 1986). Here, the ideas of the mathematical theory of bifurcations and its applications mentioned below, such as, for example, catastrophe theory (Jones, 1977) prove useful. These developments are of a qualitative, intuitive nature: such, for example, are the concepts of stability of mobile ecosystems (Isaev and Khlebopros, 1973), or the resilience of ecological systems (Holling, 1974). A related problem that remains urgent is that of the so-called "minimum viable population," the essence of which consists in determining the minimum size of a population that would guarantee its existence over the course of some fairly long period ("Viability of Populations," 1989).

Like the solution of many other urgent problems of ecology, resolution of the question of the limits of stability, i.e., finding the critical values of external factors and internal characteristics of ecological systems for specific populations or biocenoses, requires systemization of collected data and is practically unavoidably connected with construction of computer simulation models. Simulation modeling itself conceals a number of difficult methodological problems (Shannon, 1978). It is obviously fundamentally impossible to consider all of a system's characteristics, and some of the parameters left unconsidered in constructing a model may prove to be extremely important in an altered environment; thus, the search for the boundaries of stability will always be conducted in conditions of incomplete information and definite, fundamental unpredictability ("Ecological Systems...," 1981). Development of scientific approaches that take into account this objectively existing indeterminacy is an important theoretical and practical problem.

The excessive complexity of ecological systems and the indeterminacy stemming from it partially explain the shortage, noted below, of formalized, logically consistent theories in modern ecology. Nonetheless, ideas about the general properties of complex systems do make it possible at least to outline some ways of creating theories of this sort, which are confirmed by analysis of achievements in certain other fields of natural science and world trends in the development of ecology. One of the likely directions apparently can be deduction of certain *extremum principles* of the functioning of ecological systems of different ranks. Based on the general properties of complex systems, we can expect that a characteristic feature of such principles will be their multiple orientation: optimization must occur with respect to many parameters simultaneously (Arnold, 1981).

It is commonly known that, in the modern world, the activity of human society has become the most powerful environment-forming factor. A science that would make it possible to harmonize the interests of development of modern society with maintenance of the optimum natural environment is urgently needed (Shvarts, 1974; Barrett, 1984). On the strength of the complex nature of interactions of nature and society, purely ecological tasks are closely interwoven with economic, technological, medical-hygienic, and political problems. In this context, development of synthetic directions at the junction of ecology with other branches of knowledge is a strategically important task. For example, an urgent problem facing economic science, as well as ecology, is the formulation of theoretical principles of ecological and economic evaluations of anthropogenic influence on natural complexes of different scales and on the biosphere as a whole. There is an indisputable need for further development of the interdisciplinary complex of *applied ecology*, which includes *ecological diagnosis, ecological toxicology*, development of scientific principles of *ecological normalization* of anthropogenic actions on the environment, *ecological expertise* in basic forms of current and planned use of natural resources, *ecological monitoring* (current and retrospective), *ecological prediction*, and also *ecological engineering and systems engineering* (Bol'shakov et al., 1987, 1991; Bezel et al., 1992; Sokolov and Bocharov, 1988).

In analyzing the dynamics of ecological systems, it is hard to avoid an anthropocentric view of problems that arise; the consequences of human action important for mankind are the first to be considered. A basic shortcoming of such an outlook is the fact that, explicitly or implicitly, human society is considered separately from natural systems as existing outside of them. Therefore, in formulating and solving ecological problems the feedback between the natural environment and human society is practically not taken into account: consideration of mankind's interrelations with natural complexes is usually limited to investigation of anthropogenic changes in the latter, while study of the environment's reciprocal influence on mankind is mainly concerned with medical-hygienic aspects. Meanwhile, mankind is an integral part of the biosphere and undoubtedly experiences its regulating influence not only at the physiological level, but also at other, higher levels of organization. Thus, it is well known that in industrially developed countries (i.e., where the action on natural complexes is maximum) a socially determined reduction in the birth rate and changes in the demographic structure of the population are occurring. Another example concerns industrial emissions of carbon dioxide, which are stabilizing in developed countries, so that the main contribution to the expected accumulation of carbon dioxide in the Earth's atmosphere, according to predictions, will come from developing countries ("International Energy Workshop," 1989). Therefore, in the long term, it seems strategically inevitable that our world outlook has to change on the basis of *developments at the junction of ecology and social sciences that will consider human society as part of the biosphere*, and not separately from it.

To provide for successful development of basic, as well as applied ecological research, it is necessary to organize presently available and newly obtained information in the form of computerized information systems and data banks. The task of constructing such systems in Russia and setting up their communications with international data banks is one of the most urgent in the current stage, since without its resolution it will be extremely difficult to integrate Russian science with the rest of the world and, accordingly, impossible to solve most global and regional ecological problems. Moreover, many theoretical problems of ecology, on the strength of the complexity of ecological systems, can be solved at the current level only by drawing on a large amount of accumulated and newly obtained data. This is true, first of all, of modeling of processes occurring in natural complexes, for the purpose of seeking patterns of their functioning and predicting their development; that is not all, however. Another necessary organizational task that is closely related to this is to set up systems for monitoring natural ecological systems and enter the information obtained into data banks.

HISTORICAL EXPERIENCE AND DETERMINATION OF THE PROSPECTS OF DEVELOPMENT OF ECOLOGY

The historical experience of science's development shows that promising directions most often are, by nature, a certain synthesis arising at the junction of various diciplines. Thus, 20 years ago, S. S. Shvarts (1972) wrote that ecology should follow the path of conceptual synthesis of population ecology and biogeocenology, which has been confirmed, for the most part, by the subsequent development of ecological research. The benefit of an "outside view" is also commonly known, i.e., the introduction into some specialization of ideas arising within another scientific specialization or another science (Kuhn, 1977). As an example, we will give the stimulating effect of thoughts expressed in the late 1940s by the physicist E. Schrödinger (1972) on development of a number of new directions of biology, including uncovering of the genetic code.

A brief statement of the history of ideas about the mechanisms of formation of animals' population dynamics can serve as an example illustrating the connection of ecological concepts with ideas arising in other branches of the natural sciences, and also formation of new views on the basis of previously expressed ideas that did not receive general acceptance.

In the 1920s-1930s, the emphasis in collecting empirical data was on the relation of population density with such environmental factors as food provision and climatic conditions (Vinogradov, 1934; Sviridenko, 1934; Formozov, 1935; Elton, 1924, 1927). Within the framework of this outlook, a great deal of factual information was accumulated, confirming the role of external factors in animals' population dynamics. The concepts of biotic potential and the environment's resistance emerged (Severtsov, 1937; Chapman, 1931). At the same time, in another field of science, which later came to be called biomathematics, or mathematical biophysics, analytic models were developed that included ideas about intrapopulation regulation formulated back in the nineteenth century (Lotka, 1925; Pearl, 1927; Verhulst, 1838); however, they did not actually influence the practice of research zoologists. An exception was Nicholson's experimental work performed on flesh flies (1933), which was then included in many textbooks.

In the late 1940s-early 1950s, new directions of science began to develop rapidly, primarily cybernetics (Weiner, 1948) and general systems theory (Bertalanffy, 1950, 1956). At the center of attention of these directions was control with the help of feedback, or self-regulation. At that time, the ideas of self-regulation attracted the concentrated attention of ecologists working on animals' population dynamics. As a mechanism of formation of animals' population dynamics, J. Christian (1950) suggested the concept of adreno-pituitary regulation in response to the action of stressors, among which one of the main places was assigned to increased population density.

In the 1950s-1960s, other concepts of ecological self-regulation of animals' numbers emerged, at the population level (Wynne-Edwards, 1959, 1965), as well as at the level of ecological communities (Schultz, 1964). This period was also characterized by blossoming of the synthetic theory of evolution and increased interest in processes of microevolution. Under the influence of general interest in changes in the genetic structure of populations, Chitty's well-kown hypothesis emerged (1958, 1960), which played an important stimulating role in population-ecological investigations. Hypotheses of self-regulation were not self-sufficient for explaining and predicting changes in population size; in particular, they could not explain sharp fluctuations in numbers (Stenseth, 1985). Ideas about populations as open complex systems led to confirmation of the concepts of multivariate regulation of animals' population dynamics (Viktorov, 1971, 1973; Lidiker, 1978).

In the 1970s, mathematical catastrophe theory, which is a generalization of the theory of singularities of smooth mapping and Poincaré's and Andronov's theory of bifurcations (Thom, 1977; Thom and Zeeman, 1975) were very popular. The ideas on which these mathematical theories were based found reflection in corresponding concepts of population dynamics (Isaev and Khlebopros, 1973; Clark et al., 1979), which include internal, as well as external factors in relation to the population and explain sharp changes in the levels of animals' numbers.

Thus, a brief history of the study of animals' population dynamics over the course of the Twentieth Century shows the constant action on development of this particular direction of ecology of ideas, approaches, and concepts introduced from other fields of science. An analogous conclusion could be drawn, for example, from tracing the history of introduction of the tropho-dynamic approach (Lindemann, 1942) and many other contemporary directions into ecology.

GENERAL TRENDS IN NATURAL SCIENCE CONNECTED WITH STUDY OF COMPLEX SYSTEMS

A feature of the second half of the twentieth century is the development of information technologies that have opened new prospects for accumulation, transmission, and analysis of information, which makes it possible to solve previously insoluble scientific problems, and also to set new tasks. Therefore, in our time, directions connected with analysis of complex systems have become popular, such as the thermodynamics of open systems, or synergetics. Ecology is one of a number of such directions; therefore, to determine its prospects it is useful to look, first of all, at trends of development of scientific fields of this sort.

Until the middle of the present century, researchers' primary attention was focused on steady states; motion was also most often considered as a steady process (by analogy with uniform translational motion in mechanics). Deviations from this uniformity were conveniently seen as some random fluctuations of a probability nature.

Approximately by the middle of the twentieth century, a great many facts had been accumulated in the practical study of physical and chemical systems that forced researchers to reconsider these views. The need arose to interpret disruptions of a steady state not from a probability standpoint, but from a deterministic one, and to show the significance and objective existence of extremely unlikely events from the traditional probability point of view. Among the theoretical generalizations of this sort, we should mention, first of all, nonequilibrium thermodynamics of open systems (Nicholis and Prigogine, 1978; Prigogine, 1978). Primary attention began to be focused on nonlinear effects determining systems' complex, nonequilibrium behavior. Such an approach quickly produced important results; ideas about self-organization of nonequilibrium systems were developed. In particular, from a selectionistic standpoint, the inevitability of maximization of the rate of replication for a system of evolving self-replicating structures was shown (Eigen, 1973), from which stems Fisher's well-known evolutionary criterion of adaptation.

New directions of mathematics developed in parallel, which were applicable to description of nonlinear systems and the complex behavior of dynamic systems, such as the already mentioned catastrophe theory (Thom, 1977; Thom and Zeeman, 1975). In this field of knowledge, an intensive search is underway for new directions (for example, solutions of problems of control with incomplete information, problems for systems with different characteristic times, etc.). Attention to nonequilibrium processes will lead to a search for other extremum principles than equilibrium.

Different directions of natural science dealing with complex systems are sometimes joined under the arbitrary common name synergetics (Hocken, 1980), although this field of knowledge is still far from forming itself into an independent scientific discipline. We can expect the emergence of a number of new approaches and disciplines. It is noteworthy that, in the development of these new methodologies, they have been applied primarily to description of biological processes and phenomena (Prigogine, 1972; Prigogine and Wiame, 1946; Thom, 1969; Zeeman, 1974).

As a prediction, we can state that *researchers who are aware of these changes in world outlook and accordingly transform their methodology will have great advantages in the immediate future.*

WORLD TRENDS IN THE DEVELOPMENT OF ECOLOGY

Since the middle of the twentieth century, systems ideas began to prevail in ecology, which has served as the basis for creation of such theoretical constructions as ecosystem concepts of the dynamics of populations and ecological communities

(Leslie, 1945; Levins, 1968; Odum, 1968; Whittaker, 1970), the theory of island biogeography (MacArthur and Wilson, 1967), and the concept of ecological niches (Hutchinson, 1957). Methodologically, these constructions are based on an equilibrium paradigm and are, as a rule, of an inductive nature.

At the same time, there is an appreciable shortage of deductive theories, which was noted as far back as almost 20 years ago at the First International Ecological Congress (Riger, 1974). Since that time, the situation has changed little, in spite of the fact that a number of directions intended to fill this gap have appeared. If we are talking about mathematized deductive theories (close in form to what is called a "theory" in other natural sciences), then, for example, the so-called "theory of optimal foraging" (Pyke, 1984; Pyke et al., 1977) has won great popularity among them. It is one of a number of theories based on the principle of optimality of energy and time expenditures, the application of which in biology was begun by the works of D'Arcy Thompson (1942), proceeding from a general selectionistic standpoint (Rosen, 1969). However, on the whole, deductive constructions even now remain the prerogative of mathematical biophysics (including mathematical biophysics of populations and communities), originating from the works of Volterra (1926), which, as before, is developing with a certain detachment from empirical ecology. Therefore, as before, bringing together the mathematical biophysics of ecological systems and traditional ecological investigations (mathematization of ecology) is an important goal.

The current set of most popular directions of ecology is fairly fully represented, for example, by the subjects of reports presented at the Fifth International Ecological Congress, which was held in August, 1990, in Yokohama (Japan), under the motto "Development of Ecological Perspectives for the Twenty-First Century" (1990), and also at the Sixth European Ecological Congress, which was held in Marseille (France), in September, 1992 ("Sixth European Ecological Congress," 1992). Analysis of the reports' contents shows that, in international practice, attention to such traditional directions of ecology as the ecology of communities, population ecology, and physiological ecology has not weakened. A great deal of attention is given to mathematization of ecology. Thus, at the Fifth International Congress, there was a special section that considered questions of the application of statistical methods (16 reports) and microcomputers (9 reports) to ecology, and also problems of artificial intelligence and expert systems (5 reports). Increased interest was displayed in problems of global ecology and ecological safety in connection with technological progress. In their plenary sessions, European ecologists primarily discussed questions connected with the interrelations of mankind and natural ecological systems. In this regard, study of biological diversity is a priority direction. It must be noted that the importance of studying and preserving biological diversity was particularly emphasized at the very authoritative International Ecological Conference held in 1992 in Rio de Janeiro.

STATUS OF ECOLOGICAL RESEARCH IN RUSSIA

In the development of ecology, science in this country is practically on a par with world science, and even in front place in some directions. It is sufficient to note that the global ideas put forth by V. I. Vernadskii back in the 1920s were only recently assimilated by the world scientific community. The same can be said of the works of É. S. Bauér belonging to the same period, which largely anticipated new natural-science views on biological systems. Another example is the works of G. G. Gauze performed in the 1930s at Moscow University, which became a classic of world ecology.

Russian science has made a significant contribution to formation of the theory of functioning of ecosystems. The names of V. I. Sukachev, G. G. Vinberg, V. S. Ivlev, V. G. Karpov, A. A. Molchanov, N. I. Bazilevich, L. E. Rodin, N. P. Remezov, and many others are connected with this direction. Population research is largely connected with the names of S. S. Shvarts and N. P. Naumov; S. S. Shvarts's school had an evolutionary-ecological direction differing from more pragmatic foreign approaches (see Pianka, 1981; Shvarts, 1980).

In our country, an apparent breakthrough in the field of mathematical ecology is connected with the initiative of A. A. Lyapunov, supported by I. I. Shmal'gauzen. Several large schools have emerged that are working on ecological deductive (formalized) theoretical directions, based, for the most part, on certain qualitative results of a general nature. In connection with this, we must mention Yu. M. Svirezhev's school and its developments, which are undoubtedly advanced for the world level. In spite of the significant detachment of investigations of this sort from experimental and field ecology, ways of bringing these directions together have recently been outlined. For example, mathematical ideas about dynamic systems' loss of stability were applied in our country to analysis of population outbreaks of forest insects (Isaev and Khlebopros, 1973), simultaneously with similar works of C. S. Holling's group from the International Institute of Applied Systems Analysis.

On the whole, domestic ecology is at least equal to the world level in the field of theory. Therefore, an important task is to preserve and strengthen leading positions in the field of theoretical developments. At the same time, there is a noticeable lag in the field of widespread mastery of theoretical knowledge and use of it to solve applied problems. Therefore, decisive steps must be taken in this direction; however, for the reasons set forth above, in no case is it permissible for priority to be given to applied research to the detriment of basic research.

PROSPECTIVE DIRECTIONS OF DEVELOPMENT OF ECOLOGY IN RUSSIA

From the preceding section, it follows that ecology in Russia does not lag behind the world level, at least in the field of basic developments. Therefore, the most important task is to preserve and strengthen leading positions in this field. As was already noted, the fundamental point here is the impossibility of advancing without the leading development of investigations continuing and elaborating such traditional, historically established, scientific directions as study of patterns of the functioning of ecosystems (biogeocenoses), population ecology, and physiological ecology.

Of the basic directions, we should single out study of mechanisms of the bioproduction process at various levels of organization of ecological systems, the practical significance of which is development of approaches to controlling biological productivity, and also study of mechanisms of homeostasis and regulation of the dynamics of ecological systems. A very important problem that is receiving attention all over the world is study of biological diversity and ecological mechanisms of maintaining it. Among this class of problems, we must also single out study of population structure and population dynamics, taking into account the special nature of the population level of organization of living matter. These directions provide continuity in those divisions of ecology where Russian science has occupied leading positions.

A natural continuation of investigations of this sort, which is, moreover, urgently needed, is study of mechanisms of living systems' reaction to anthropogenic actions and development of a theory for management of bioresources in modern conditions.

As was already noted, development of a theory of stability of ecological systems is an important question, where Russian science has also occupied a leading position. Along with this, investigation of unstable (nonequilibrium, nonsteady-state) ecosystems, communities, and populations is very promising. In connection with this, the problem arises of seeking other extremum principles than equilibrium lying at the foundation of ecosystems' functioning, and also working out approaches to study of them, taking into account the complexity of ecological systems (including the objective indeterminacy of their dynamics). In the field of theoretical, and then applied developments, it is necessary to ensure the synthesis of mathematical biophysics of ecological systems with traditional ecological research, i.e., the mathematization of ecology. Solution of basic and applied ecological problems in the present stage is impossible without widespread computerization of data collection and analysis, including construction of computer simulation models, organization of presently available and newly obtained information in the form of information systems and data banks, and also establishment of systems for monitoring natural ecological systems and entering the information obtained into data banks. Besides that, improvement of methods of investigating ecological systems and the biosphere as a whole remains an important direction (ecological instrument making, satellite methods, geoecological information systems, etc.).

Development of a theory of the interaction of nature and society on the basis of a new view considering human society as an integral part of the biosphere is a strategic goal. In this regard, it is extremely important to develop synthetic directions at the junction of ecology with other branches of knowledge and to develop an interdisciplinary complex of applied ecology. Urgent applied problems that must be solved immediately, for example, are provision for the country's ecological safety on the basis of inexhaustible use of natural resources, development of ecological principles of industrial and agricultural production, devising social and economic mechanisms of resolving ecological problems, solution of organizational and legal problems of natural-resource management, and development of methods of ecological support for solution of problems of economic and social development of the country and its individual regions, taking into account the ecological situation.

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