# FUNDAMENTALS OF BIOLOGICAL SCIENCE: AN EVOLUTIONARY APPROACH

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**Contents**



**Summary**

In this article, the interrelationships between general biology and special biological disciplines, dealing with the specificity of various groups of organisms at different levels of their structural organization, are considered in connection with their history and methodology. Special attention is paid to evolutionary theory and evolutionary synthesis, starting from the time of Darwin and covering the punctuated equilibrium theory, structuralism, and cladistics. The structural levels of biosphere organization are analyzed from their hierarchical position and specificity of expression. This is connected with the problems of life's origin and its evolution on earth (palaeontological, molecular, and other data concerning stages and factors of life's evolution). As a topic, the evolutionary problem of the formation of biological and taxonomic diversity is considered. This is based on various life sciences, and on the ratios between stability and plasticity of different biological systems (the principle of dynamic stability). Biology is considered, first, as a productive force that is able to increase the biological resources, and second, as a scientific basis of the relationships between *Homo sapiens* and nature on the international, national, and social levels. In general it is a main aim of fundamental and applied biology.

## 1. Introduction

> The main task of biology is to gradually discover the structures and related possibilities of living organisms
>
> (Niels Bohr, 1961)

Modern society often faces Hamlet's question, "To be or not to be?" An army of researchers all over the world tenaciously works in various fields of theoretical and applied biology in order to answer this question affirmatively. Whether or not they will succeed primarily depends on understanding the general laws and mechanisms of the origin and development of life on earth; the correct estimation of the importance of the interaction between biotic and abiotic factors for the development of species diversity and communities; a valid classification of organisms, which is required for estimation of their numbers and the protection of nature; and the history of biology itself, which is necessary in order to predict its future development.

Fundamental biology deals with general laws of the origin and evolution of living organisms, and an explanation of general capacities which have a different expression on the different levels of their structural organization: from molecules and organelles to the organism–environment interaction at the population, biocenotic, and biospheric levels (Figure 1). The general problems of the evolution of life on earth are the subject of evolutionary biology, which is based on the synthesis of evolutionary knowledge accumulated by various branches of fundamental biology, and special biological disciplines dealing with the specificity of various groups of organisms at different levels of their organization.

The knowledge accumulated by individual branches of biology is determined by their history, including changes in their interrelations and methodology. The most important trend in modern biology is the development of the evolutionary concept, which now unites almost all branches of biology. This field of their interaction is sometimes referred to as "evolutionism," and deals with the causes, factors, laws, and mechanisms of evolution. Evolutionary theory focuses on general biological problems:

- How life originated and developed.
- How the diversity of organisms arose, and how it changes.
- Why, along with complex higher organisms, very simple ones, such as bacteria and protozoans, also exist.
- What determines species similarities and dissimilarities.
- What the causes and mechanisms are of organisms' transformation, structural elaboration, perfection, and extinction, how organisms' miraculous adaptations to environment are formed, and what the limits are of their diversity.
- What the destiny is of biological evolution on earth.

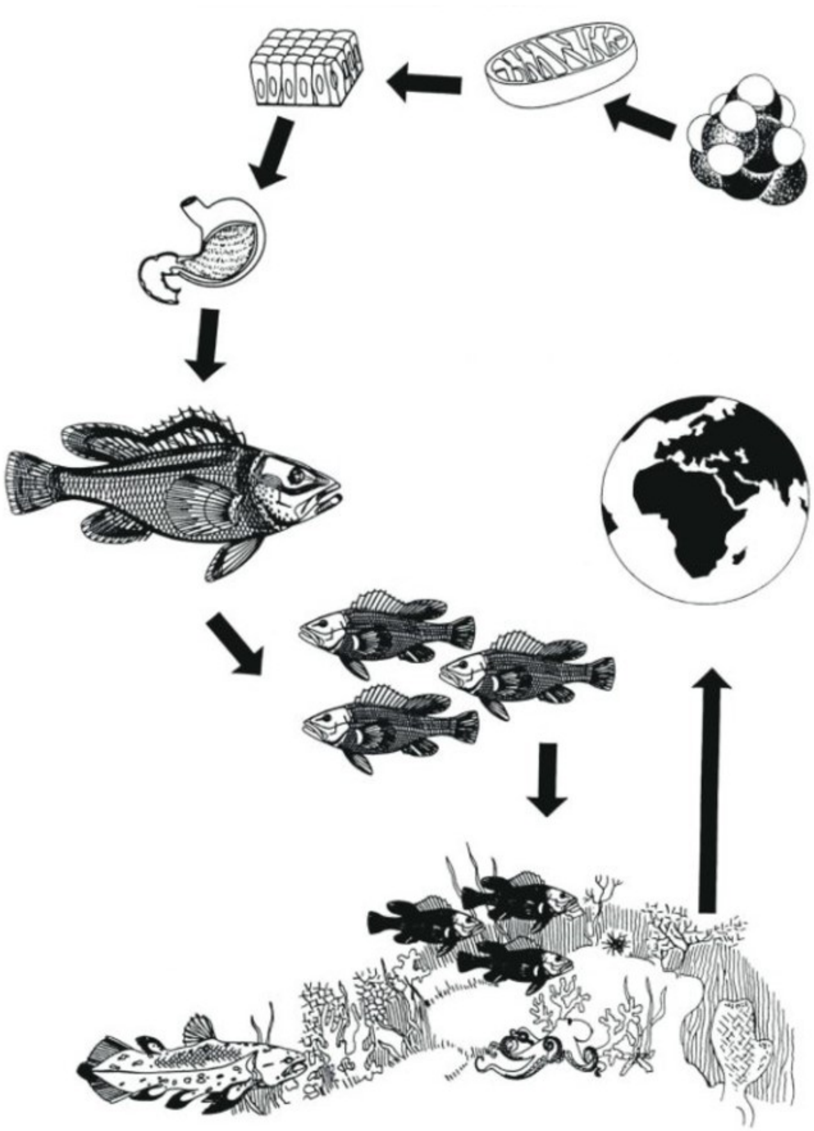

Figure 1: Hierarchy of Life and different levels of its structural organization: from molecules to organelles, cell and tissue, organ, obiocenosis and biosphere.

Evolutionary biology can already answer some of these questions, whereas others must be the subjects of future research. Each branch of biology makes a contribution to the general evolutionary theory. This contribution depends on the given discipline's "experience in evolution" and the possibilities determined by the relevant biological organizational level. For example, molecular biology deals with the submolecular and molecular levels (related to the biochemical and physicochemical levels); genetics deals with the genetic level; morphology, with the organ and organism levels; histology and cytology, with the cell and tissue levels; and ecology, with populations, species, and biocenosis levels. Each of these levels has its specificity. At the same time, they are hierarchically interrelated, showing both a certain degree of independence and compensatory relationships. Accumulation of data clarifying the mechanisms of interaction between structural levels (from molecular to biospheric), and the search for ways of evolutionary synthesis between branches of biology dealing with these levels, are among the main goals of modern theoretical biology. To carry out this synthesis, researchers should primarily know the history of the evolutionary concept in biology. The idea of evolution dates back to antiquity (the fifth to first centuries B.C.); it was originally put forward by the outstanding philosophers Heraclitus, Democritus, Empedocles, and Lucretius Carus, and eventually developed into the concept of historical development of life that was first formulated by the famous British naturalist Charles Darwin.

## 2. Evolutionary Theory and Evolutionary Synthesis

The theory developed by Darwin is now considered the first evolutionary synthesis of biological data. It was based on the notion of a common origin and historical development of all living organisms, and was confirmed by gathering a vast volume of evidence, including botanical, zoological, and paleontological collections, anatomical and embryological data, and experience from plant and animal domestication. The formation of the evolutionary views of the young Darwin was greatly affected by his round-the-world voyage aboard the *Beagle* (1831–6), when he happened to visit the Galapagos Islands, now generally known as a unique natural laboratory of evolution. As we can judge from his notes of 1836–8, this visit caused Darwin's views to change fundamentally from saltationism and creationism to gradualism, that is, the notion that organisms gradually change in the course of their evolutionary development (phylogeny).

Darwin published the basics of his theory in *On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Species in the Struggle for Life* (1859). The British botanist A. Wallace, who had independently come to similar conclusions, stimulated publication of this book, which took many years of assiduous collection of evidence. In July 1858, Wallace's work and Darwin's letter stating the principles of his theory were reported at London's Linnaean Society. After the session, Wallace admitted the priority of Darwin, whose theory was more fundamental and comprehensive than his own. The main idea of Darwin's theory was that natural selection is the main factor and mechanism of the adaptation of organisms to their environment in the course of gradual divergent evolution. The material and conditions for transformations are indeterminate variation, alternation of adaptations, and struggle for existence, leading to survival of the fittest and elimination of the unfit. Darwin's theory was the first to explain the essence, causes, and factors of the development of life. This was its main difference from the theory proposed by Darwin's predecessor, the famous French scientist Jean Baptist Pierre Lamarck.

In 1809, Lamarck published the book *Philosophie Zoologique* (Zoological Philosophy), where he postulated the idea of evolution. Lamarck's concept was rather a speculative metaphysical theory, postulating that organisms change (transform) with time by means of self-development (autogenesis), impelled by "nature's striving for progress." Many researchers accepted the theory of autogenesis over the next few decades, including some outstanding scientists. The entire subsequent history of biology is marked by the controversy between the so-called neo-Lamarckists and neo-Darwinists. Creationists, too, have always been ardent opponents of Darwinian theory, which they consider discredits the idea of mankind as God's creation when postulating that apes are the nearest human ancestors. These reproaches are entirely unfair. Darwin included humans in his scheme of evolution long after he published his basic work, namely in 1871, when his *Descent of Man and Selection in Relation to Sex* was published. Darwin gently noted in this book that superciliousness urges humans to deify themselves, while to connect their origin to animals would be both more modest and more reasonable.

Modern evolutionary theory is still based on Darwinism. However, changes and logical deviations have occurred during its development. These transformations were related to the discovery of new facts indicating that the rate of evolution is uneven and speciation processes are discrete; therefore, some species, superspecific taxa, and individual characters of plants and animals might have emerged by saltations. The development of genetics allowed the nature of the Darwinian "indeterminate variation" to be revealed. It was explained as a hereditary intraspecies variation. Numerous data on pre-Cambrian micro-organisms (bacteria) required the revision of the patterns and factors of the evolution of the prokaryotic biosphere. The so-called synthetic theory of evolution (STE) was developed in the 1930s and 1940s. This theory was an important stage in the development of biology, and is considered a second evolutionary synthesis. Generally, this was a combination of classical Darwinian ideas with the data accumulated in genetics, paleontology, and taxonomy. The main initiators of this synthesis were T.Dobrzhansky, E. Mayr, B. Rensch, G. Simpson, and J.Huxley. Many other scientists also participated in the foundation and further development of the STE. These included S. S. Chetverikov, A. Weismann, I. I. Schmalhausen, N. V. Timofeff-Ressovsky, and N. P. Dubinin.

The STE, in the narrow sense, is a synthesis of the Darwinian theory and population genetics. As a result, researchers began to interpret all evolutionary events in terms of changes in gene frequencies within populations. It is believed that mutations and natural selection are sufficient to explain biologic diversity, and macroevolution (at the super-specific level) is reducible to microevolution (at the intra-specific level). Specialists in many branches of biology, including morphology, physiology, ecology, molecular biology, and microbiology, are not satisfied with this oversimplified approach. The STE is often accused of reductionism. A so-called punctuated equilibrium theory of evolution (punctuated evolution or punctualism) was put forward as an alternative to the STE in the 1970s. It was originated by N. Eldridge and S. Gould, who published, in 1972, a paper entitled *Punctuated Equilibrium: An Alternative to Phyletic Gradualism.* The model of punctuated evolution suggested by them was based on the assumption that species are stable for long periods (the evolutionary stasis), which alternate with outbursts of speciation related to macromutations. Therefore, the intermittent series of fossil forms is regarded as a natural phenomenon, rather than the result of incomplete fossil records. Punctualists also deny the STE's postulate that macroevolution is reducible to microevolution. Their model considers the problem of species stability, which is very important, and yet poorly studied in modern evolutionary theory. Essentially, the main controversy between the STE and punctualism is that they estimate differently the determination of speciation, as well as the extent and rates of the processes involved in it; hence, the two theories are complementary.

Structuralism also opposes both Darwinism and the STE. This theory became especially popular in Japan and the United Kingdom in the 1980s, when structuralists formed the Osaka group. The originators and followers of this theory (A. Sibatani, M. Ho, P. Saunders, and B. Goodwin) focused on the epigenesis and dynamics of structural transformations at different levels, from the molecular to the morphological and species ones, and concluded that many characteristics of living organisms may emerge and exist without natural selection. Structuralism attaches special importance to epigenetic evolutionary mechanisms, such as morphogenesis and the species "lifestyle" (including morphological and physiological adaptations, behavior, and habitats), which are regarded as specific properties of organisms. Structuralists‘ views are eclectic, preconceived, and autogenetic. However, they raised some unsolved or poorly studied problems, for example, the origin of biological forms, patterns of organisms' development as related to their internal structural rearrangements, and the pattern and importance of intra- and interspecies competition. At present, problems of structural evolution seem intricate. It is obvious that new strategies and approaches are necessary to unite the evolutionary views of researchers in various fields. A comprehensive analysis of stability and specificity of the levels of structural organization, together with clarifying the hierarchical links between these levels that ensure the biosphere integrity, is one of such strategies aimed at a new evolutionary synthesis.

## 3. Structural Levels of Biosphere Organization

Biologists study structures and processes in living organisms in ascending order: from simple to complex structures, or from small particles (molecules and cell components) to interactions between hundreds to thousands of species living in the same or different regions. Therefore, it is convenient to consider the hierarchy of the structural organization of life from lower to higher levels, that is, from organic molecules (the subcellular level) to cells, tissues, organs, organisms, populations, ecological communications, biocenoses, biomes (large territorial zones), and the biosphere as a whole (see Figure 1). Molecules serve as the cell's building material, while ensuring the functions of cellular components. All organisms are known to consist of the same types of organic macromolecules, namely, carbohydrates, proteins, lipids, and nucleic acids. These molecules form organelles, cells, tissues, and organs of various organisms. The origin of organic molecules, primarily nucleic acids, which are closely connected with the origin of life, is in the realm of molecular biology and biochemistry or, to be more precise, chemistry, because there was no life before cells and organisms emerged.

The cell is generally assumed to be the fundamental element of life. Cells are the basis of tissues in multicellular organisms (Figure 2). Tissues are groups of cells with the same co-ordinated functions. Different tissues form different organs, which are united into organ systems. Both of them fulfill certain vital functions in organisms. The integration of all these systems characterizes individual organisms (individuals). The organism is the focus of many branches of general biology, including morphology (anatomy and embryology), developmental biology, physiology, genetics, microbiology, paleontology, and autecology. At higher hierarchical levels, organisms form social systems. The population, that is, a group of genetically related organisms living in the same area and capable of inter-breeding, is an elementary unit of these systems, as well as of speciation. A reproductively isolated group of populations actually or potentially capable of crossing comprises a species. Populations and species are the main objects of research in autecology and speciation. Individuals of different species who live in the same biotope form ecological communities, spatially grouping into biocenoses and biomes, which, in turn, are components of the biosphere (Figure 3).

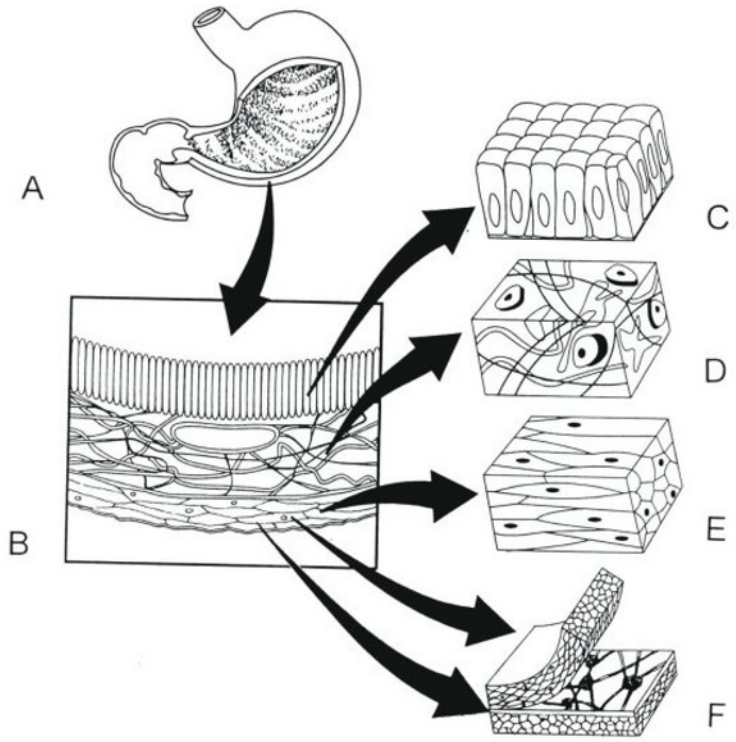


Figure 2: Interrelationships between four tissues types on the organ level. A-stomach, B-itz section, C-epitelial tissue, D- connective tissue, E-muscle tissue, F- muscle and nervous tissues (Modified after W.K.Pures et al., 1999)

Each level of the structural organization of life has characteristic features that determine its difference from other levels. Higher levels accumulate the characteristics of lower ones and acquire fundamentally new properties as compared to the lower levels. For example, cells and tissues have processes and functions that are lacking in their molecular components. The potentiality of an organism is considerably wider, and more diverse, than those of the cells from which it develops. On the other hand, the organism's possibilities are determined by the complex interaction between organ systems, which is reflected in various senses, feelings, and properties, such as the senses of touch and smell, as well as memory and, at least in humans, fear and love. Memory is ensured, for example, in humans by interaction between $10^{12}$ brain cells connected with one another by $10^{15}$ links. Finally, the possibilities inherent in the social levels are collective and are absent in individuals. For example, a population is characterized by density, rate of expansion, and extinction rate, although the latter characteristic also depends on individual birth and death rates.

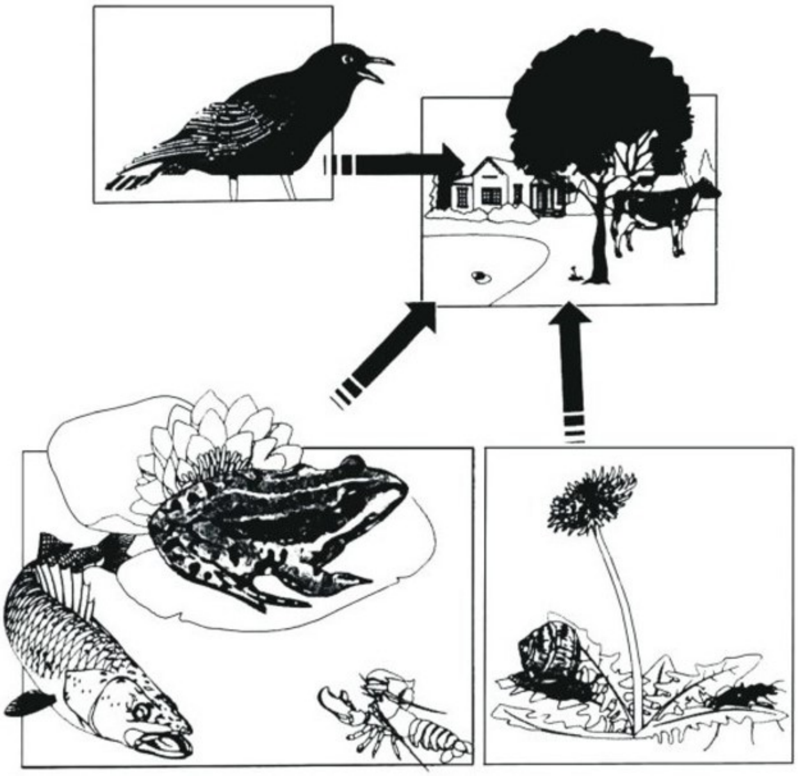

Figure 3: Ecological communications of the organism groups living in antropogenic ecosystems (Orginal reconstruction by N.V.Panteleev).

The possibilities of ecological communications are determined by species diversity. The possibilities of higher levels are certainly related to those of lower levels. However, merely studying these lower levels cannot identify them. For example, biologists will never discover the essence of human emotions by studying nerve cells, although they can explain emotions in terms of interactions between large numbers of cells. Similarly, the evolutionary formation of morphological characters is not reducible to the genetic level: morphological development cannot be explained by interaction between homeoboxes (Hox-genes), although homeoboxes do govern this process. However, the study of genomes in groups of organisms belonging to different evolutionary levels makes it possible to develop new evolutionary theories. In recent years, genomes of not only a simple eukaryote (yeast), but also of a multicellular organism (the roundworm, or nematode, *Caenorhabditis elegans*) were deciphered. Besides, it was found that humans have only four to five times more genes that the nematode has, and that many of the nematode genes that account for its difference from yeast are most likely related to intercellular interactions. This emphasizes the main role of functional genomics in the genomics of humans and other organisms, and the importance of interaction between structural levels, beginning from the lowest level (i.e. molecular). There are at least two ways to clarify the hierarchy and specificity of expression of different structural levels: first, to trace the formation of these levels in the course of the development of life on the earth, which is related to the problem of the origin of life, and second, to analyze their stability, which is inseparably linked with their plasticity, or dynamism.

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### Biographical Sketches

**Rem Viktorovich Petrov** was born in 1930. He is a Doctor of Sciences, an Academician, immunologist, and a university professor. He was educated (1947–53) in Voronezh Medical University. In 1953–62 he was a junior, then senior research staff member, and during 1962–83 was Head of Laboratory, Institute of Biophysics, USSR Ministry of Health. In 1956–91 and in 1983-–8 he was Director, Institute of Immunology, USSR Ministry of Health. In 1974 he began working as holder of the Chair of Immunology, Second Moscow N. I. Pirogov Institute of Medicine. In 1983 he was elected President of the All-Union (now Russian) Immunology Scientific Society. In 1984 he was elected a full member of the Academy of Sciences of the USSR (as from 1991, Russian Academy of Sciences). In 1988–91 he was Head of the Department of Immunology, M. M. Shemyakin, Y.A. Ovchinnikov Bioorganic Chemistry Institute, Academy of Sciences of the USSR.

In the Academy of Sciences, his studies include molecular and cellular immunology, immunogenctics, and the creation of artificial vaccines. He is an author of more than 300 scientific publications. Petrov's textbook *Immunology* was republished twice in Russian and once in Spanish. Two of his scientific books (*Immunology of Acute Radiation Sickess*, and *Transplant Immunity and Radiation Chimeras*) have been published in the United States. He is a member of the editorial boards of the following international scientific magazines: *Myelopeptide, Allergology and Clinical Immunology, Herald of the Russian Academy of Sciences*) and editor in chief of *Science in Russia,* published in Russian and English. His popular science book, *Me or Not Me* has been published in fourteen languages around the world, including the countries of England, France, Japan, and China.

Rem Viktorovich Petrov is a member of the Council of the International Union of Immunological Societies and the board of the World Academy of Art and Science. He was an organizer and chairman of many international conferences, symposiums, and so on. With more than ten years' involvement in UNESCO activity, he is a member of the ISAB (International Scientific Advisory Board), vice-chairman of the MCBN (Molecular Cell Biology Network of UNESCO), and a member of the UNESCO Bioethics Committee.

He holds the following awards: I. I. Mechnikov Gold Medal, Academy of Sciences (1987); Order of the October Revolution; Hero of Labour (1990); 0rder of Lenin (1990). He holds the following Honorary Degrees: Bar-Ilan University, Israel (1990); Madrid Polytechnic University, Spain (1994); Academy of Medical Sciences (since 1978); Russian Academy of Sciences (since 1984); World Academy of Art and Science (since 1989); Russian Academy of Agricultural Sciences (since 1991); Russian Academy of Natural Sciences (since 1991); Washington Academy of Sciences (since 1993); and Norwegian Academy of Science (1999).

**Emilia Ivanovna Vorobyeva** was born in 1934, in Slobodskoj, in the Kirov region of Russia. She was a student of the Biology Department at Moscow State University, from 1954 to 1957, and from 1957 to 1960 a postgraduate of the Palaeontological Institute RAS, Moscow. She became a Doctor of Biological Science in 1972. In 1990 she became a correspondent member of the Russian Academy of Science; and in 1994, Professor of Zoology.

In 1957–87 she was Scientist, Head of Laboratory and Senior Scientist of the Palaeontological Institute, RAS (Moscow) (Laboratory of Fossil Fishes), and in 1987–2002 Head of the Evolutionary Morphology Laboratory at the Institute of Ecology and Evolution, of which she was Deputy Director in 1977–81. In 1997–2002 she has also been Senior Scientist of the Palaeontological Institute RAS.

From 1967 to 2001 she attended twenty-five international meetings on the subjects of palaeontology, the origin and evolution of life, vertebrate morphology, developmental biology, the history of biology, the methodology and theory of evolutionary biology. She was organizer of four meetings in evolutionary biology (1978–90) in Praha, Pilzen, and Moscow; a member of the International Committee of the Fourth Congress of Vertebrate Morphology (1993, Chicago); and organizer of the INTAS Development Biology Symposium (1994, Moscow).

She holds the following awards: Silver medal by G. J. Mendel, International Medal by K. Purkinye, Prize by acad. I. I. Schmalhausen of RAS and prize by acad. A. N. Severtzov of RAS; Prize of the Moscow Society of Nature.

She is a permanent member of the International Committee of Russian Biologists (UNESCO), and a member of the Russian Herpetological and Palaeontological Societies. Her professional interests are in paleontology, evolutionary morphology, zoology, ichthyology, the theory of evolution, and the methodology of biology. Her field experience has been undertaken on the Main Devonian Field; Central Devonian Field of Russia; the Devonian of Mongolia; the Triassic of Middle Asia; and Devonian-Carboniferous of Siberia (Jacutia). She has also received a number of international grants.