Chapter 9
The Path to a Systemic Understanding of the Biosphere

Like a little worm chewing its way through its chosen apple, man has built his civilization within the biosphere at the cost of its partial destruction. But while the larval codling moth, reaching maturity, deserts its devoured fruit, humans lack the opportunity to do the same and, abandoning our "apple," settle other planets. It was not long ago at all that we as people began studying this most complicated of systems. The first attempts at a universal, holistic approach to the biosphere—long before the term itself appeared—arose when Alexander von Humboldt began his work. It was Humboldt (1769–1859) who counterposed the mosaic of independent organisms proposed by Karl Linnaeus with the concept of an interrelation of organisms between each other and the landscape, laying the basis of biogeography. Nonetheless, by the second half of the nineteenth century, Humboldt's views of a united earth system with a strong influence of climate upon the living world had made way for the historical descent of organisms (Phylogeny) as the lone scientific explanation for natural phenomena deserving of attention (Zavarzin 2004).

Alexander Humboldt

Charles Darwin used the history of descent, through a process of competitive natural selection on the basis of variability and persistence of successful mutations among offspring in response to tasks of adaptation to environmental conditions, to explain the linear diversification of species. Darwin's theory, convincing in its logic and freed of the necessity of appealing to external forces to explain biological diversity and the sustainability of species, became, however, less a theory of evolution and more a paradigm shift in world views. Within the bounds of its subsequent development, a reductionist approach came to prevail in biology—an explanation of the whole by way of the parts on the

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basis of acquired empirical material—which focused scientists' attention on the evolutionary fate of isolated species and individual specimens, gradually decompartmentalizing the biome. This tendency, taken to its extreme, seriously delayed the development of views on the biosphere as a unified system with all the rules of a whole. As a result, by the turn of the twentieth century, only a few minds hazarded to approach research of the biosphere from this point of view.

You might think that a systemic concept of the biosphere should have arisen as part of the then-emerging field of ecology, but, as it happened, everything happened differently. And the first to arrive at the modern understanding, by his own, independent path, was not a biologist but a mineralogist: the founder of geochemistry, prolific Russian scientist Vladimir Vernadsky (1863–1945). He, in turn, based his work upon that of his great predecessor, founder of soil sciences Vasily Dokuchaev (1846–1903). In a set of lectures published by Vernadsky under the title "*Biosfera*" (The Biosphere) and released 3 years later in French (*La Biosphere* 1929), he put forward the idea of a holistic world in which living material ("the membrane of life") is connected through a system of biogeochemical cycles in the atmosphere, hydrosphere and lithosphere. He proposed that we call this covering of the Earth, in which all biogeochemical processes run their course, the biosphere.

Vladimir Ivanovich Vernadsky

Vernadsky showed that the chemical state of the Earth's crust lies entirely under the influence of life and is determined by living organisms. His studies not only looked at the basic qualities of life materials and influences on them by chemical compounds, but also first explored the reverse influence of life upon the abiotic medium with the formation of such bio-inert natural bodies as, for example, soil. For the first time, Earth's covering was conceived as a single, complicated, and at once fragile entity. As he put it, the process of its evolution is expressed in the natural bio-inert bodies that play a foundational role in the biosphere—soils, surface and ground waters, anthracite and bitumen, limestone, nutrient minerals, etc. (Vernadsky 1998). In the monograph "The Chemical Construction of the Earth's Biosphere and its Surroundings," also published posthumously, he directly calls the biota an enormous geological force: "*Living organisms* are *functions of the biosphere* and connected to it tightly in both matter and energy, and are an enormous *geological force which determines it*" (Vernadsky 1987, p. 45).

Along with this, thinking on the paths of evolution of the biosphere and the special place that humans occupy within it, Vernadsky came to the idea of possibly governing the biosphere through the power of human reason. "We are presently living through an exceptional phenomenon of life in the biosphere, connected genetically to the appearance, hundreds of thousands of years ago, of *Homo Sapiens*, by this path creating a new geographical force, scientific thought, sharply increasing the influence of life material in the evolution of the biosphere. Completely overtaken by life material, the biosphere increases, clearly, its geological force to unlimited size and, processed by the scientific thought of Homo sapiens, transitions to a new state—the noosphere" (Vernadsky 1988, p. 32).

In this sense, Vernadsky was a man of his time and age, bound by hope in the future and the limitless, as it then seemed, possibilities of scientific progress. But we've already come to a different aspect of Vernadsky's legacy—his widely-known idea of the noosphere (the sphere of reason, the human "thinking membrane" of the planet), which we will settle on in more detail in Chap. 16.

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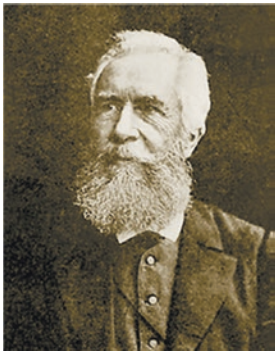
Vernadsky's ideas, coming far ahead of their time, could have long remained abandoned if not for a new field that was speedily developing at roughly the same time—ecology—which focused the attention of scientists on the structure and particular functions not of isolated organisms, but of the biological complexes they make up. Though ecology owed its establishment mainly to existing biologists, the two fields did not truly come to agreement until the second half of the twentieth century. And while a first understanding of ecology was proposed by the famous German naturalist, philosopher and Darwin-supporter Ernst Haeckel (1834–1919) to distinguish the area of biology which studies interaction of organisms with the environment (he called it "the economics of nature"), the term was hardly ever used in scientific circles until the early 1900s. Hydro-biologists made a particularly significant contribution to the establishment of this new branch of science, which is understandable: water ecosystems (especially reservoir ecosystems), as a rule, are easier to wall off. By their very nature, it seems, they are isolated from surrounding ecosystems.



Ernst von Haeckel

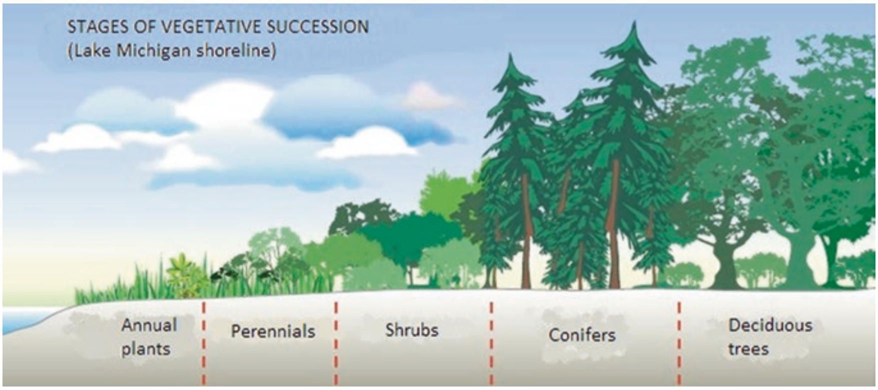
Among the first specialists in ecology stands German zoologist Karl Mobius (1825–1908). While studying mollusk reproduction in North Sea oyster beds, he confirmed the existence of an internally linked community of organisms inhabiting one or another identical portion of sea floor, which he called a biocenose (1877). At the same time, Mobius noted definite adaptations acquired through evolution, the attachment of given species not only to each other but also to specific conditions of the local abiotic environment—the *biotope*. As a result, the concept of biocenose was applied to freshwater communities as well—the biocenose in a pond or lake. Then, also to land—the biocenose of a birch forest, a riverine meadow, etc.

Karl August Mobius

But truly widespread study at the supra-organism level began in the early twentieth century, with biologists from many different backgrounds—botanists, zoologists, hydro-biologists, forestry specialists, etc.—each making their contribution. They considered it particularly important to discover a set of general rules, which would characterize the development of the most diverse organism complexes (communities, biocenoses) in the course of their interaction with the environment. That would include, for example, the process of *ecological succession*, the regular stage of development for the most diverse type of ecosystems.

The discovery of succession was the work of two American botanists. The first, Henry Cowles (1869–1939), conducted research of vegetation on the shores of Lake Michigan, which over a long historical period had slowed and retreated from the shoreline. He correctly hypothesized that the growth of a community should increase in proportion to its distance from the tide, and, in this way, was able to reconstruct a detailed scheme for the whole process. The youngest, just-formed sand dunes were seeded with perennial grasses that put down roots in shifting sands. Then taller grasses would appear in their place, followed by shrubs. Under this formed canopy, on the older and more established dunes, trees would start to grow, in a strictly determined order of succession: first pines, and after a generation, oaks and maples would replace them. Finally, furthest from the shore, there appear beech trees—the most shade-loving trees for that climate (Odum 1983).

Illustration: Journal "Nauka i zhizn" 2010, No. 3



In 1916, Cowles adherent Frederic Clements (1874–1945) published his classic work *Plant Succession*. Viewing the vegetation community as a single, holistic organism undergoing degrees of development from infancy to maturity, he showed the adaptability of biocenoses, their ability to adjust and evolve as the environment changes. While at the early steps various communities on the very same place may differ greatly from one another, at later stages they become more and more similar. It turns out in the end that for every area with a particular climate and soil, there is only one characteristic, mature, in Clements' terms *climax community*.

Ten years later, in England, zoologist Charles Elton (1900–1991) released the book *Animal Ecology* (1927), which established the field of population ecology and allowed zoologists to switch their attention from the isolated organism to the population as a whole, the independent unit level at which specific particularities of ecological adaptation and regulation appear. The author, who had recently been on two Arctic expeditions, took an interest in cyclical variations in the number of small rodents that occurred every 3–4 years. Having observed many years' worth of data from the North American fur trade, he came to the conclusion that hare and lynx also demonstrate cyclical variation, though their numbers peak roughly once in 10 years. In this work, also considered a classic, the structure and distribution of animal communities are first described, and, furthermore, Elton introduces the concept of an ecological niche and formulates the rules of an *ecological pyramid*—the consecutive lessening of the number of organisms from the lowest trophic levels to the highest (from plants to herbivores, from herbivores to predators and so on) (Elton 1946).

The 1920s and 30s were marked by the introduction of precise research methods into ecology, led by mathematicians American Alfred James Lotka (1880–1949) and Italian Vito Volterra (1860–1940). In Lotka's book, *Elements of Physical Biology*, released in 1925, the first attempt was made to use quantitative methods in the field of biology. In part, Lotka developed mathematical models for interaction between species (for example, a model showing the inter-connected trends in the numbers of predators and prey) as well as biogeochemical cycles. While Lotka never used the term "ecology," his attempts to apply the laws of physics to biological study clearly illustrates the tendency to expand the field of research conducted as part of ecology (Lotka 1925). In 1926, Volterra developed a mathematical model for competition between two species for one food source and showed the impossibility of their extended sustainable coexistence.

Charles Elton

Alfred Lotka

The theoretical research of Lokta and Volterra attracted the attention of young Soviet biologist Georgy Gause (1910–1986), who presented his own modification of the equation, more cogent to biologists, describing the processes of interspecies competition. His experimental tests of the models, conducted with laboratory cultures of bacteria and protozoans, showed that species coexistence is possible only if it is determined by distinguishing features of the environment, i.e., when the species occupy different ecological niches. Among competitors for the same niche, species inevitably push each other out (the competitive exclusion principle). Gause's work was published in the US in

1934 as *The Struggle for Existence*. It only saw the light of day in Russia seven decades later. In many ways, the book facilitated the emergence of population biology. The emphasis it placed on trophic connections as the basic path for the flow of energy through natural communities made a major contribution to the nascent concept of ecosystems.

The honor of introducing this concept, however, belongs by rights to English *botanist* Arthur Tansley (1871–1955). Of course, he had his own highly authoritative predecessors, of which we might name American hydro-biologist Edward Birge, who researched the role of lake organism communities in mineral cycles and transformation of energy, or his German colleague August Thienemann, who in the 1920s formulated such important concepts for ecology as biomass and biological production. But, nonetheless, it is 1935 that ecologists consider the year of birth for their field as an independent branch of science. Tansley's main achievement was to successfully integrate the biocenose and biotope into a new function unit—the *ecosystem*. And while other, more established sciences, such as physics, chemistry or cell biology had long possessed their own basic unit—atom, molecule, cell—now ecology had the ecosystem: A single natural complex limited in time and space, created by living organisms and their environment, where living and inert components are linked by mineral exchange and the distribution of energy flows.

Arthur Tansley

In 1942, independently of Tansley, Russian biologist Vladimir Sukachyov (1880–1967) developed the concept of biogeocenose based on forest communities. Generally analogous to an ecosystem (synonyms, really, and many ecologists use the similar term landscape), the biogeocenose is characterized by limited geographic extent and homogeneous natural and climactic conditions. On land this could be a small plot—a subsystem of the landscape (such as a riverine meadow with the soil beneath it and canopy above), including the biotic and abiotic components of the environment united by a mineral cycle and flow of energy. Both territorially and hierarchically biogeocenoses can be viewed as the units or "cells" of the biosphere, which, in turn, is itself an ecosystem of a higher level—the global ecosystem of Earth (Reymers 1990).

Vladimir Sukachyov

The appearance of the ecosystem as a concept sharply changed the situation in ecology, which had noticeably suffered from overextension over the various branches of science, and laid the groundwork for a wide arena of ecosystem research. As before, here hydro-biologists played a leading role. Their specialization—aquatic organisms often dwelling in closed reservoirs (ponds and lakes)—

being distinguished by the tightly weaved interconnection of physical, chemical and biological processes.

So the above-mentioned limnologist Edward Birge, studying the "breathing of lakes," through strict quantitative methods, was able to establish the seasonal trends of dissolved oxygen content, which depends not only on the agitation of water mass and oxygen diffusion from the air, but also on the activities of organisms that produce oxygen (plankton, algae) or use it (bacteria and animals). As a result, these ideas were developed in the works of Russian limnologists Leonid Rossolimo (1894–1977), Georgy Vinberg (1905–1987) and others. Vinberg developed the energy balance approach, allowing further research into the mineral cycle and transformation of energy in an ecosystem on the basis of purely quantitative indicators. According to his method, one used the unity of biochemical processes taking place in the various organisms—such as photosynthesis in algae or all plants in a forest—to add up the results of their activity according to the quantity of organic material and free oxygen formed thereby. In this way, the opportunity arose not only to place a quantitative value on biological production by forest or water ecosystems, but also to design theoretical mathematical models based on the energy approach.

Three years later in the US, George Hutchinson (1903–1991) established similar methods, collecting his own research and that of other scientists into his *Treatise on Limnology* (1957), which still represents the most complete summary of lake-borne life in the world. For this reason, his school of thought greatly influenced the development of ecology in many countries. First among his students worth noting is Raymond Lindeman (1915–1942), who sadly passed well before his time. His short work, *The Trophic-Dynamic Aspect of Ecology,* (Lindeman 1942), without exaggeration, brought about a new era in ecology. Scientists from all over the world still cite it to this day. In this work, Lindeman developed a general scheme for the transformation of energy in an ecosystem and laid out the basic methods for calculating the balance of energy. In part, he theoretically demonstrated that during the transfer of energy from one trophic level to another (from plants to herbivores or carnivores), the quantity of energy is reduced. Thus an organism of each consecutive level has access to only a small part of the energy, no more than 10%, which belonged to the organisms of the previous level.

Raymond Lindeman

Since that time, ecosystem research has become one of the main currents in ecology, and the quantitative determination of components in ecosystems—one of the principle methods that allow us to model biological processes.

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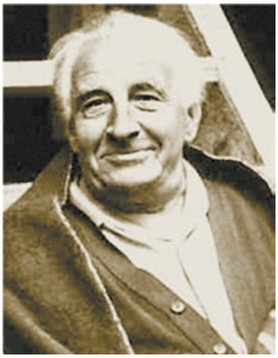
Thus, step by step, by the efforts of hundreds of scientists, ecology pieced together the incomplete fragments of the construction and occupied the structure whose vaults and contours Vernadsky had described in his works. However, the field had not yet risen to an understanding of the biosphere as a global system.

Vernadsky died in the final year of the Second World War, and his ideas remained undervalued in many ways by his contemporaries. Even his magnum opus, a type of scientific inheritance, “Chemical Composition of the Earth and Its Environs,” was only published 15 years after his death. It took still another decade for scientists to confirm his view of the biosphere as a single holistic system. General systems theory, associated with Austrian biologist Karl Ludwig von Bertalanffy(1901–1972) in the 1940s, played a role in this. Bertalanffy studied mathematical rules for different types of systems under the most general view. It was Bertalanffy who introduced the concept of an open system (as opposed to a closed one, whose many diverse variations are studied in theoretical physics), which distinguished the specifics of living organisms existing on a constant flow of matter from the environment. These provide themselves with additional energy, enabling a lowered level of entropy and creating the preconditions for sustainability of living systems in relation to the environment.

Among the number of Russian scientists who followed Vernadsky’s line, it’s worth mentioning first and foremost, the remarkable biologist Nikolay Timofeyev-Resovsky (1900–1981). Having made his mark during the interwar decades, when he conducted research into radiation genetics in Germany, in his later years Timofeyev-Resovsky focused on issues of global ecology. In many ways, he anticipated current understandings of a wide number of environmental problems which were then only just emerging. In the report, “Biosphere and Humanity,” that he made in 1968 at a division meeting of the Obninsk City Geographical Society, where he lived after release from the GULAG (Moscow, Leningrad and other large cities being closed to him), he compared the biosphere to a giant living factory, reshaping matter and energy on our planet’s surface.



Nikolay Timofeyev-Resovsky

The biosphere, according to the report, “forms the balanced makeup of our atmosphere, the diluted makeup of natural waters, and, through the atmosphere, the energy of our planet. It influences the climate. Recall the enormous role of water evaporation for vegetation and the moisture cycle on the Earth, the vegetative cover of Earth. Therefore, the Earth’s biosphere forms all of man’s surroundings…To sum up, without a biosphere or with a poorly working biosphere, people cannot exist on Earth” (Timofeyev-Resovsky 1996, pp. 59–60).

This report, in the form of an article by the same name, was printed in a collection of scientific works by the Obninsk Department of the Geographical Society. But given the specifics of this obscure publication, few read it. Fewer still, perhaps enough to count on one’s hands, could see the value of the scientist’s innovative ideas. As so often happens with Russian trailblazers, both report and article passed by nearly unnoticed. Nor did the Academy of Sciences at that time care to remark on the fallen scholar. But here Timofeyev-Resovsky had almost first expressed a very important idea about the environment's full-scale management of life on Earth.

Unfortunately, being on this side of the "iron curtain" often put Russian scientists in a notedly disadvantageous position, and the ideas that Timofeyev-Resovsky expressed remained truly beyond the field of vision for Western scholarship.[1] Instead, an unusual degree of interest in the scientific world was aroused by a different biospheric conception, put forward in the 1970s by English scientist James Lovelock (1919–). He called it "Gaia," after the Greek goddess of Earth.

James Lovelock

An engineer by education, Lovelock had previously worked at NASA, where he designed tools for the discovery of life on other planets in connection with future flights by automated stations to Mars and Venus. Even earlier, as a university student, he created a unique gas spectrophotometer for the measurement of minute concentrations of gases in the atmosphere. It was using precisely this tool that scientists managed to detect increasing quantities of chlorofluorocarbons destroying the Earth's ozone layer. This professional activity led Lovelock to the idea that the existence of life on a planet could theoretically be detected according to the makeup of its atmosphere as the most volatile environmental medium, the most sensitive to any biogeochemical changes. The atmosphere of a "living" planet, Lovelock proposed, should be distinguished by a thermodynamic disequilibrium supported by life activity. By the same token, a "non-living" planet has an atmosphere whose makeup is determined by the average chemical composition in a state of equilibrium. All of these considerations spurred the further formation of his hypothesis, best known as the Gaia Principle, which was first published in the form of an article, then developed into a number of books and monographs.

The image of Gaia, according to Lovelock, arises as one looks thoughtfully upon our planet from space, when it is seen as a complex, multi-level living organization. Or when mentally travelling from the macro-level to the micro: biosphere> biocenose> organism> organ> cell. The whole shape of the Earth, he writes, "The climate, the composition of the rocks, the air and the oceans, are not just given by geology; they are also the consequences of the presence of life. Through the ceaseless activity of living organisms, conditions on the planet have been kept favourable for life for the past 3.8 billion years. Any species that adversely affects the environ-

[1] Which, by the way, one might attribute to his not winning the Nobel Prize. He entirely could have shared the prize won by his younger colleague Max Delbruk, with whom, at one time in early 1930s Germany, he carried out the work of determining the size of a gene.

ment, making it less favourable for its progeny, will ultimately be cast out, just as will those members of a species who will fail to pass the fitness test" (Lovelock 1991, p. 25). Gaia is imagined as some kind of self-organizing system, like a "super-organism" possessed of self-regulating "geophysiological" properties and maintaining the global environmental parameters through homeostasis at levels favorable to life. Evolution of the biota is so closely linked to that of its physical environment that together they form a single self-perpetuating system, by its nature recalling in part the physiology of a living organism.

In his configuration, Lovelock gives particular attention to the Earth's bacterial community, whose role in the evolution of the biosphere from the first appearance of life to our time hardly requires proof. Bacteria, after all, for the course of two billion years was the only form of life on Earth, and, as the catalysts of biogeochemical cycles, formed the biosphere. Today they remain the primary biogeochemical engine of the planet. But while at one time the ancient prokaryotic bacterial communities reigned supreme, covering most of the Earth in a solid membrane as a kind of monopolistic power in the biosphere, over the course of evolution its autocatalytic units "migrated" and found themselves joined to more complex organisms, forming specialized organelles in nuclear cells—*mitochondria and chloroplasts*. Management of Gaia's "physiological" processes (restorative-oxidizing, binding oxygen to carbon, etc.) is conducted by both the direct heirs to these nucleus-free single cells such as soil bacteria, and their descendants in nuclear cells—*mitochondria* (oxydizers) and chloroplasts (deoxidizers). And this catalytic hypercycle, to use a term from Manfred Eigen, binds the smallest living organisms to the planetary macrosystem as part of maintaining the climactic and biogeochemical parameters of its environment (Eigen and Schuster 1979).

It's hard not to notice the striking similarity between Gaia and the modern representation of the biosphere in the vein of Vernadsky's ideas, of whose works Lovelock learned only in the 1980s (due to a lack of adequate translations of "The Biosphere" into English as well as, by his own admission, a "deafness" of anglophone writers to foreign languages). There are some distinctions, however. First of all, generally speaking, Gaia is not the biosphere but the Earth as a whole. Here Lovelock draws a picturesque comparison between Gaia and the cross-section of an old tree, where the living part (the biosphere) is only a thin layer of vascular tissue under the bark, and the main mass of dead timber is the product of extended activity by this layer. Second, the Gaia hypothesis takes a skeptical attitude toward the possibility of humans conquering nature and submitting it to their interests, in opposition to Vernadsky's postion.

But is it even possible to consider the "Gaia" concept, which Lovelock himself calls a hypothesis, science in the full sense of the word? And in this hypothesis, aside from grandiosely bold ideas and philosophical underpinnings, a more strictly scientific component? Here it's worth noting that several of Lovelock's "geo-physiological" hypotheses have received confirmation through scientific experimentation.

In 1981, Lovelock postulated that the global climate stabilizes itself by way of the carbon dioxide cycle's self-regulation through biogenic intensifications of the rock erosion process. In the terms of geo-physiology, carbon dioxide is a key metabolic gas of Gaia, influencing not only the climate, but also plant production, as well as production of oxygen in the atmosphere. The main abiotic source for this comes from volcanic activity. Carbon dioxide gas dissolved into rain and ground matter creates carbonic acid, which interacts with silicates and bicarbonates in a rock, resulting in the creation of bicarbonate ions (chemical erosion). The products of this interaction are carried off by streams to the World Ocean where plankton and coral use them to build their skeletons. After death, these tumble to the bottom of the ocean, forming a chalky residue.

The results of research by David Schwartzman and Tyler Volk, published in *Nature*, confirmed that micro-organisms and planets are able to speed the chemical erosion of rock by tens or hundreds of times (Schwartzman and Volk 1989). Also, the plants that swallow carbon dioxide from the air and transfer the carbon content into soil raise its local concentration by 10–40 times. The main mass of dead plants, undergoing bacterial oxidation, also turns into carbon dioxide at point of contact with calcium compounds, silicates and water. Thus, the biota, influencing the concentration of atmospheric CO_2, a greenhouse gas, participates in regulating the temperature setting of Earth.

One could produce other examples, proven today, of a closed chain of cyclical causation, the typical characteristic of geo-physiology (Gaia theory). Lovelock's central postulate with its idea of Gaia as a global correlated superorganism, however, does more poorly, having met with stern criticism from many famous evolutionary biologists (Ford Doolittle, Richard Dawkins, etc.). After all, the evolution of the biosphere according to the "Gaia" Concept is interpreted as the individual development (epigenesis) and improvement of its self-regulating properties. However, from the point of view of traditional scientific representations, strictly correlated and high-complexity systems (including Gaia) inevitably degrade and pull apart with time. Living organisms are also distinguished by highly complex organization, but this complexity and order is supported in nature by using a mechanism of competitive interaction by individuals. Those who have lost internal order and, as a result, become uncompetitive, are weeded out of the population. It is through this process of evolution that the unique complexity of living materials is reproduced and supported.

But Gaia exists in the singular, and therefore cannot reproduce. Thus, Dawkins notes, a natural selection of the most adaptive planets is impossible. And, therefore, there can be no discussion of any extended preservation of Gaia's self-regulating abilities without the ordering will of a Creator standing behind her. Or, Dawkins notes sarcastically, a committee of species that assembles annually for the purpose of deciding the climate and chemical makeup of the planet for the following year. Lovelock couldn't come up with anything to oppose this criticism, and the scientific community recognized the untenability of the theory as a whole (despite its undeniable beauty).

Further on we will tell of how St. Petersburg biophysicist Viktor Gorshkov attempted to resolve this problem. But now we will return to the already cited work of Nikolay Timofeyev-Resovsky, in which he, even before Lovelock, was able to find an approach to overcoming this contradiction. He called attention to the structural unit of the biosphere, within which the natural selection of populations occurs. These are biocenoses, he says, "the elementary units of the biological cycle, i.e. of the biogeochemical work taking place in the biosphere."

Timofeyev-Resovsky continues, "The majority of biocenoses are in a state of prolonged dynamic equilibrium, being very complex self-regulating systems. So the problem of studying the causes, mechanisms and support conditions for such a dynamic equilibrium in biocenoses is especially important." And without knowledge of these mechanisms, "it is impossible to understand and properly schematize the true occurrence of evolutionary processes in nature, constantly improving in dynamic biocenoses and their greater complexes—landscapes" (Timofeyev-Resovsky 1996, p. 63).

It's not hard to note how different this structured system of "biospheric cells" is from the concept of "Gaia." After all, if the work of supporting the biogeochemical cycle is performed not by the biota overall, or by some anthropomorphized "superorganism," but by separate biotic communities and their populations, it therefore leaves room for competitive interaction. That is the mechanism for weeding-out and replacing poorly working "cells" which protects the biosphere from degradation and collapse, preserving its capacity to support global biogeochemical balance for an indefinitely long period of time. But we will speak in more depth of this in the following chapter, in connection with Victor Gorshkov's concept of biotic regulation of the environment. For now, let us again conduct a mental overview of the path ecology has taken from the moment of its establishment as an independent branch of science.

When, in the late 1920s, Vernadsky came to the idea of the biosphere as a single holistic entity forming the face of our planet, and Tansley soon after introduced ecology's key understanding of the ecosystem, the majority of people still imagined the world to be open and nearly limitless, a place where man could do whatever he saw fit, and could adapt and remake according to his needs. What ecologists did within laboratory walls seemed far away from people's everyday business and worry. It would take more than half a century to make the connection obvious and to make terms like biosphere and ecosystem equal in usage to understandings such as energy and evolution. Nonetheless, that path has not yet come to its end. Between acknowledging human dependence upon the environment and understanding the full danger of its degradation lurking in the none-too-distant future as ecologists warn stands an enormous distance. But cross it we must, if the future is to come at all.

Table 9.1 Scientists who have made contributions to the formation of a systemic concept of the biosphere

Haeckel's line	Humboldt-Vernadsky line
Ernst Haeckel (1834–1919)—German evolutionary biologist, follower of Charles Darwin, first introduced the concept of ecology as an area of biology, studied interaction of organisms with environment. Karl Mobius (1825–1908)—German zoologist and hydro-biologist. Using the example of oyster beds on the North Sea, developed and proved theory of an internally created community of organisms populating one or another similar area of the sea floor, which he called biocenosis (1877). Henry Cowles (1869–1939)—American botanist. Studying vegetation on the shores of Lake Michigan, discovered regular stages in development in different types of ecosystems and first described the process of biological succession. Frederick Clements (1874–1945)—American botanist, developed concept of succession in detail. Introduced concept of climax communities as the ultimate stage of biological succession, showed adaptiveness of biocenoses, their ability to adapt and evolve as the environment changes. Charles Elton (1900–1991)—English zoologist. Laid groundwork for population ecology. Introduced understanding of ecological niches and formulated rules for ecological pyramid-reduced numbers of organisms from lower trophic levels to higher ones. Arthur Tansley (1871–1955)—English botanist. Introduced concept of ecosystem in 1935, considered founding year for ecology as independent branch of science. Tansley's main accomplishment was the successful attempt to integrate biocenose and biotope at level of new functioning unit—the ecosystem, which became for ecology what the atom is for physics, the molecule for chemistry or the cell for cellular biology. Vladimir Sukachyov (1880–1967)—Russian biologist, forest specialist. Using example of forest communities, developed concept of the biogeocenose (1940), analogous to the ecosystem, distinguished by limited scale and uniformity, natural and climatic conditions and including biotic and abiotic components of the environment.	Edward Suess (1831–1914)—Australian geologist, first used the term biosphere in the sense of one of Earth's coverings, alongside the atmosphere, hydrosphere and lithosphere. Vladimir Vernadsky (1863–1945)—Russian mineralogist and geochemist. Put forward and developed concept of the biosphere as a holistic and interconnected world of living material, united by a system of biogeochemical cycles with the abiotic spheres—atmosphere, hydrosphere, and lithosphere. Showed that the chemical state of our planet's crust is in large part under the influence of life and is determined by living organisms. Alfred Lotka (1880–1949)—American mathematician, author of the book *Elements of physical Biology* wherein he first made attempt to remake biology as a strictly quantitative science. Developed mathematical models for interspecies interaction (for example, a model describing the interconnected trends in numbers of predators and prey) as well as biogeochemical cycles. Nikolay Timofeyev-Resovsky (1900–1981)—Russian biologist, one of the founders of molecular genetics and radiobiology. In later life focused on global problems of biology. Compared biosphere to giant living factory forming Earth's environment. First pointed to the role of biocenoses as elementary cells in biological cycle and to the possibility of competitive relations between them, creating conditions for stabilizing evolutionary selection. James Lovelock (born 1919)—English scientist, electrical engineer by education. Put forward "Gala Hypothesis," an original concept of Earth as a holistic superorganism in which the evolution of living things is closely linked to changes in their physical and chemical surroundings. This concept enabled a new way of thinking about global mineral cycle processes. Many of Lovelock's theoretical predictions were confirmed through experimentation. However, Lovelock was unable to explain how this superorganism, a complex system of correlations, has avoided inevitable degradation and collapse for hundreds of millions of years, for which he suffered criticism from evolutionary biologists.

(continued)

Table 9.1 (continued)

Haeckel's line	Humboldt-Vernadsky line
Georgy Gause (1910–1986)—Russian biologist, modeled processes of interspecies competition in bacterial and protozoan cultures. Formulated the competitive exclusion principle, according to which, two species cannot occupy the same ecological niche: one of the species inevitably pushes out the other. Raymond Lindeman (1915–1942)—American ecologist. Developed general scheme for transformation of energy in an ecosystem and the basic methods for calculating its energy balance. Demonstrated the rule of trophic pyramids: As energy transfers from one trophic level to the next, the quantity reduces by an order of magnitude. Thus, an organism of a higher level has access to no more than ten percent the energy used by an organism of the previous level. Eugene Odum (1913–2002)—American biologist. Laid the basis for ecology as an independent scientific discipline. Known for his work in the area of ecosystem ecology, as well as the textbooks *Fundamentals of Ecology* (with Howard Odum) (1953), *Ecology* (1963) and others, which played a major role in establishing ecology as a university course. Odum brought together materials that had been scattered throughout journal articles and separate monographs, reassembling them into an omnibus of basic concepts for ecology. G. David Tilman (born 1949). American ecologist. A notable representative of a new branch of ecology focused on physiological mechanisms. Tilman's most famous works are in the research area of limiting resources based on diatom algae and grasses. Proved that ecologically similar species can coexist if they are limited by different resources (for example, the concentrations of various nutrients dissolved in water).	Viktor Gorshkov (born 1935)—Russian theoretical physicist. Developed concept of biotic regulation of the environment. Unlike Lovelock, Gorshkov linked the problem of supporting environmental parameters beneficial to life with the life activities of competing, independent biotic communities (biocenoses). Reacting to disruption of the environment with system change or destruction of organic material, the biota is able to absorb excesses of one or another nutrient in the environment or, contrarily, fill a deficit of it and thus regulate concentrations at a level suitable for life. According to Gorshkov's concept, the current global ecological crisis arises primarily from the destruction of ecosystems over an enormous swath of land, and a transition to sustainable development is possible only if a considerable portion of destroyed ecosystems are restored.

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