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SHORT COMMUNICATIONS

# Elementary Structural Units of the Biosphere

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A hundred years have passed since the birthday of N.V. Timofeeff-Ressovsky, an eminent Russian biologist and geneticist. In 1996, a book was published in which A.N. Tyuryukanov (Timofeeff-Ressovsky's disciple) and V.M. Fedorov compiled some unknown works by Timofeeff-Ressovsky and his unexpected and nontrivial notes about ecological problems and relationships between the biosphere and humans. This book is a good illustration of this outstanding scientist's strong intuition, whose ideas anticipated some modern developments in these fields. Timofeeff-Ressovsky's ideas concerning the elementary structural units of the biosphere proved to be in striking consistency with the theory of biotic regulation (Gorshkov *et al.*, 1999).

As noted by Gorshkov *et al.* (1999), traditional views on the species of the earth's natural biota "virtually ignore the ecological restrictions imposed on the population sizes of biological species, causes of the formation of natural species communities, and stability of these communities and their environment." However, practical biologists and geographers have been distinguishing stable biospheric and geographic structural units (ecosystems and landscapes) for a long time. They also distinguish elementary, indivisible structural units of ecosystems and landscapes. Biologist and ecologists call these unit biogeocenoses, and geographers, facies. V.N. Sukachev's definition of the term "biogeocenosis" (*Okhrana landshaftov,* 1982) eliminates the distinction between these terms.

The numerous definitions of the terms "biogeocenosis" and "facies" neither refer to the main function of the indivisible structural units nor determine their sizes and borders. It remains unclear what determines the indivisibility of biogeocenoses and facies. These difficulties are easy to overcome in terms of the theory of biotic regulation of the environment, which postulates that the main property of life is the ability of species to perform certain work aimed at maintaining optimal environmental conditions. Complex interactions with the environment inevitably result in the formation of communities with specific sets of species concordantly interacting with one another and their environment. This concordance resembles the concordance between cells and organs within a multicellular organism.

The maintenance of environmental stability is ensured by the cycle of biogens, which closes within an elementary structural unit with a high precision. The precision is determined by the statistical law of large numbers, which postulates that the relative fluctuation in a system of independent elements is proportional to $1/\sqrt{N}$, where $N$ is the number of the parts of the system that are not correlated with one another. Indeed, in an elementary structural unit, such as a tree and the area of ground equal to the projection of its crown, synthesis is performed by a large number of independent elements, leaves (a broadleaf tree has more than 200000 of them, and needles of conifers are even more numerous), which even compete with one another for the flow of solar radiation. Huge numbers of microorganisms and fungal hyphae are responsible for decay and mineralization of organic matter in the soil. A soil layer 30 cm thick and 1 $m^2$ in area contains more than one trillion microorganisms (*Okruzhayushchaya sreda*, 1993). If an environmental perturbation occurs, the energy and matter cycles in a biogeocenoses open to compensate for it. Thus, an elementary unit of the biosphere is also an elementary unit of the biogeochemical cycle and possesses an elementary mechanism of regulation of the environment. This is its main function.

Timofeeff-Ressovsky wrote in 1968 (p. 62), "V.N. Sukachev was absolutely right to discern more or less discrete subdivisions in the Earth's biosphere, namely, biogeocenoses separated from one another by various borders. Biogeocenoses are both structural subdivisions of the biosphere and elementary units of the biological cycle, i.e., the biogeochemical activity that occurs in the biosphere" (hereinafter, cited from Tyuryukanov and Fedorov, 1996).

The following statement by Timofeeff-Ressovsky (1968, pp. 57–58) is quite in line with the theory of biotic regulation: "…Our Earth is always and everywhere populated by more or less complex sets of numerous species of living organisms, by complex communities or biogeocenoses as biologists call them. Now, we still do not know why such complex communities can remain in a state of equilibrium between the constituent species for a long time (many generations of living organisms) provided that humans do not disturb, deteriorate, or alter them." Here, the equilibrium and stability of biogeocenoses, as well as the correlation between the constituent species (limitations on their numbers), are emphasized. This follows from the requirements of biotic regulation of the environment.

The mutually correlated species in the community must maintain the optimal abundance and produce an optimal number of offspring. Apparently, these species must preserve genetic constancy and stability during geological periods of time without adaptation to any environmental fluctuations (according to paleontological data, the average life span of a species is 3.5 million years). They must have a mechanism for stabilizing the genetic program and preventing the accumulation of mutational substitutions, which erase the genetic information. This mechanism is intraspecific competition, which ensures elimination of individuals with disturbed genetic programs.

Correlated species of the elementary structural unit of the biosphere retain the stability of their general genetic program on the basis of competition between the populations of biogeocenoses. These populations, which appear as areas with homogeneous vegetation, are usually called ecosystems. The biogeocenoses whose activity in stabilizing the environment is insufficient are eliminated from the ecosystem.

The correlation between the species constituting a biogeocenosis is ensured by exchange of matter and energy flows, which decay as the distance between organisms increases; therefore, the strongest correlation is ensured by the smallest possible elementary structural units. According to indirect estimations, the minimum size of these units is within the range from several centimeters to several dozens of meters and does not exceed the sizes of higher plants. The distance at which the number of the species consuming the greater part of energy flows in the community is saturated may serve as an indirect characteristic of the size (or border) of a given biogeocenosis. The length of species saturation is usually calculated without taking into account the proportion of energy consumed by each species, which results in a considerable overestimation of the parameter. The borders may be experimentally determined by measuring the circulation of radioactive labels of nonvolatile elements introduced into biogeocenoses without disturbing their natural structure. In the simplest biogeocenoses (epilithic lichens), the border is easy to discern visually (Gorshkov, 1995).

It follows from the definition of the main function of the elementary biospheric unit as an elementary unit of the biogeochemical cycle (an elementary unit of biotic regulation) that it is indivisible. Indeed, if the elementary unit is divided in any way, its main function is lost.

Thus, the ideas of Timofeeff-Ressovsky are very close to the main postulates of the theory of biotic regulation of the environment and make it possible to unambiguously define the terms "biogeocenosis" and "ecosystem." It also becomes clear that the facies and landscape in the science of landscapes are identical to the biogeocenosis and ecosystem; the difference is that the former are considered in geographical terms. Therefore, this approach requires considerable revision taking into account the main function of the elementary structure of the biosphere (the geographic constituent).

Timofeeff-Ressovsky's views on the biosphere were far ahead of their time. He wrote in 1968 (p. 64), "A normally functioning Earth biosphere not only provides humankind with food and valuable organic raw materials, but also maintains the equilibrium of the gas composition of atmosphere and the solutions of natural waters. Therefore, if man undermines the activity of the biosphere (either quantitative or qualitative aspects of it), not only will the production of organic matter on Earth decrease, but also the chemical equilibrium in the atmosphere and natural waters will be disturbed." This is what we observe now, when more than 60% of natural terrestrial ecosystems are either destroyed or have considerably deteriorated. Another of Timofeeff-Ressovsky's ideas (1968, pp. 59–60) is of primary importance for this problem: "… I would like to note the following: we habitually regard the biological productivity of Earth from the viewpoint of food resources for ourselves. However, the Earth's biosphere is a giant living factory transforming energy and matter on the surface of our planet; it forms both the equilibrium composition of the atmosphere, the composition of solutions in natural waters, and, via the atmosphere, the energetics of the planet. It also affects the climate. Remember the decisive role of water evaporated by vegetation, the plant cover of the Earth, in the global water cycle. Therefore, Earth's biosphere forms the entire environment of humankind. A negligent attitude to it and undermining its regular activity would mean undermining not only the supply of food and various industrial raw materials necessary for us, but also the gas and water environment of humans. Ultimately, humans would be unable to exists on Earth at all without the biosphere or with a biosphere that does not operate well."

These brief notes succinctly formulate the theory of biotic regulation of the environment. It follows from them that the biosphere and the system controlling it (the biota) is the basis rather than a resource of life; there is a limit to its anthropogenic perturbation (the carrying capacity, as it is often called); the biota as a controlling system forms its own environment and the environment for man; and, finally, above-threshold perturbation may put a limit to the very existence of humankind.

Timofeeff-Ressovsky addressed the problem of studying the elementary units of control and regulation of the environment, because most biocenoses that have been in dynamic equilibrium for a relatively long time are complex self-regulating systems. Therefore, studying the causes, mechanisms, and conditions of the maintenance of this dynamic equilibrium in biogeocenoses is an extremely important problem. It can be solved in terms of biotic regulation of the environment.

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