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Bygone Times

The Year of Science and Technology in the Russian Federation

Anniversary Dates of Russian Ecology in 2021: Toward an Ecosystem Approach

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Abstract—The idea of an ecosystem is one of the central concepts of modern ecology. Analysis of the structure and dynamics of ecosystems should underlie the scientific development and planning of environmental protection measures. How did systemic concepts in ecology originate and emerge? Hydrobiological studies of continental water bodies, especially lakes, have played an important role on this path. Due to their relative isolation, it was the lakes that served as a kind of testing ground for the formation of holistic principles in ecology. Using the example of several significant dates in 2021, this article analyzes how this happened in our country. In connection with the 150th anniversary of S.A. Zernov, a major organizer and, in essence, the founder of hydrobiological science and education in Russia, his efforts to organize a comprehensive study of water bodies, in particular, research at a biological station on Glubokoe Lake, are described. Particular attention is paid to Zernov's disciple V.I. Zhadin, the author of one of the first systems of views on the biological productivity of water bodies. In addition, the concept of the biotic balance of water bodies, which was first proposed 75 years ago, in 1946, by G.G. Vinberg is considered. The study of the energy relations of organisms, which is the basis of this concept, is the cornerstone of modern ideas about the functioning of ecosystems.

Keywords: hydrobiology, ecology, anniversary dates, G.G. Vinberg, V.I. Zhadin, S.A. Zernov, biological station on Glubokoe Lake, biotic balance, theory of biological productivity of reservoirs, ecosystem.

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Thanks to E. Haeckel, 155 years ago, biology was enriched by a new section—ecology. It was in 1866 that the name of the biological discipline was first given, the focus of which is the relationship and interaction of living organisms with each other and with the abiotic components of the environment [1]. One of the central concepts of ecology is the ecosystem, that is, a set of populations of living organisms connected by flows of energy, substances, and information. These flows are organized due to physiological functions—photosynthesis, respiration, and nutrition [2]. A significant contribution to the development of ecology was made by specialists of its "aquatic" branch—hydrobiology. Due to the closed nature of many water bodies (lakes, reservoirs, and seas), the formation of ecosystem principles proceeded faster and more productively in the depths of hydroecology (as hydrobiology is now increasingly called), as well as limnology [3]. Many names of Russian and foreign scientists have made up the golden fund of ecology and hydrobiology.

This jubilee article highlights some significant dates associated with both the biographies of scientists and organizational events in hydrobiological science, as well as with the emergence of new concepts. The names and events that have played a significant role in the development of world ecology are taken as a basis, while attention is paid to Russian scientists, since their contribution remains insufficiently illuminated and sometimes even undeservedly forgotten. Of course, almost every year there are jubilee dates of significant events in science. However, it so happened that it was in 2021, the year of the 155th anniversary of ecology, that we celebrated the anniversaries of many scientists and concepts that to a significant extent determined the appearance and development of this discipline throughout the entire 20th century and in the first quarter of the 21st century. Of course, the names and dates chosen do not exhaust the history of ecology in general and hydrobiology in particular, but their

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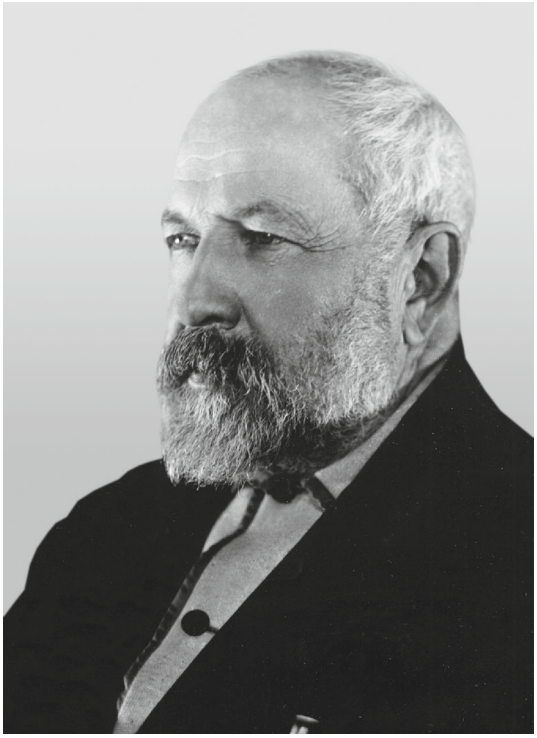


Sergei Alekseevich Zernov (1871–1945).

example can best illustrate the movement of thought on ecosystems.

Sergei A. Zernov (1871–1945), the foremost organizer of hydrobiological science and education in the Soviet Union, one of the founders of the biocenotic approach in ecology, and Academician of the USSR Academy of Sciences (1931), was born 150 years ago. Two other major anniversaries of the year are associated with the name of this scientist: the organization of the first freshwater hydrobiological station in the Russian Empire (and one of the first in Europe) on Glubokoe Lake in Moscow province in 1891 [4] and the creation of the Society for Researchers of Water and Its Life in 1921 [5], the permanent chairman of which was Zernov.

Note that the very idea of creating the Society for Researchers of Water and Its Life largely belonged to Arvid L. Behning (1890–1943), who at the time of its organization had been the head of the Volga Biological Station in Saratov for many years [6]. Behning was recognized in Europe as a specialist in river fauna and hydrobiology and the author of the well-known monograph *Study of the Bottom Life of the Volga River* (1924), which analyzed the biocenoses of the river. In the 1920s, along with Zernov, he became one of the main organizers of hydrobiological research. On the initiative of Behning, in 1921, the official organ of the Society for Researchers of Water and Its Life began to be published—*Russian Hydrobiological Journal*—the editor-in-chief of which was Behning. The journal was published at the Volga Biological Station and was not only the first but also the only specialized scientific publication on this topic at that time. Unfortunately, it ceased to exist in 1930, and soon Behning was illegally arrested. In 1931 the Society for the Researchers of Water and Its Life was transformed into the hydrobiological section of the Moscow Society of Naturalists [7].

Despite the setbacks and difficulties sometimes caused by opposition from the totalitarian government, many undertakings of our hydrobiologists, as well as the creation of the Department of Hydrobiology at Moscow State University by Zernov in 1924, played a decisive role in the development of ecological research in the country and even in the world. The international authority of Soviet hydrobiologists in the 1920s was eloquently evidenced by the fact that when the first congress of the International Association for Theoretical and Applied Limnology was convened in 1922, founded by two prominent European scientists A. Thienemann (Germany) and E. Naumann (Sweden), Zernov and N.K. Deksbakh were among the founders of this organization [8]. By the decision of the association, its third congress was held in 1925 in four Soviet cities at once—Moscow, Leningrad, Saratov, and Astrakhan. Many Soviet hydrobiologists and limnologists gave plenary reports there. The peculiarity of the congress was that it was the first international scientific event that took place in the Soviet Union after the revolution. Its holding in our country testified to the broad international contacts of domestic scientists and the high authority of our science in the world. The scientific achievements of Russian hydrobiology in the 1920s were so great that this gave Thienemann a reason to advise all specialists studying water bodies to learn Russian, unless they want to deprive themselves of colossal scientific knowledge [9]. Unfortunately, the flourishing of Soviet hydrobiology literally a few years later was rudely interrupted by rising Stalinism. However, scientists continued their research in the 1930s, despite the gradually emerging isolationism of Soviet science.

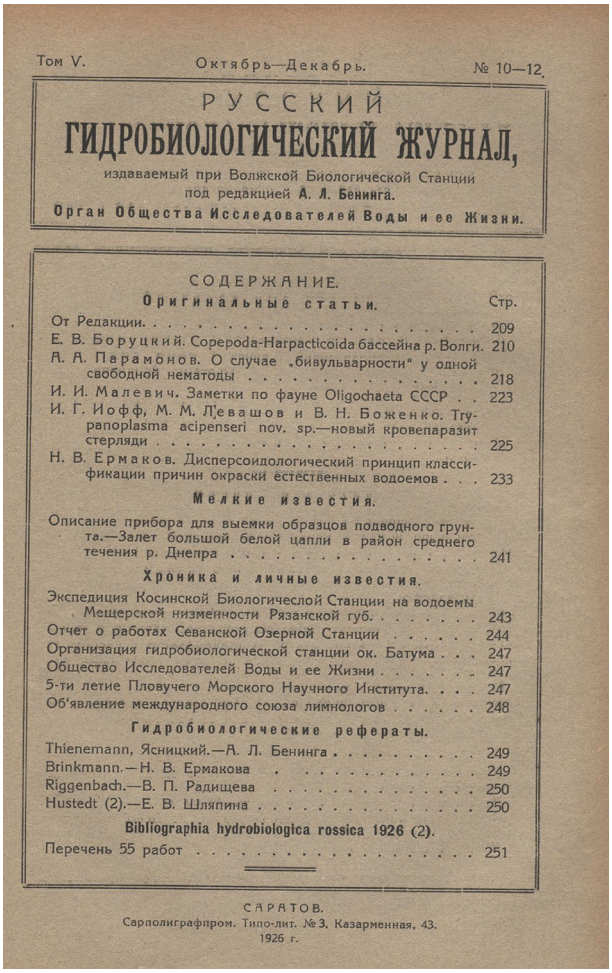
Zernov was appointed head of the station on Glubokoe Lake already in his student years [4]. The station was organized on the initiative of the famous Moscow zoologist N.Yu. Zograf, who at that time headed the Ichthyology Department of the Russian Society for the Acclimatization of Plants and Animals. This event was preceded by the work of the Commission for the Study of the Fauna of Moscow Province created in 1888 under the Imperial Society of Lovers of Natural Science, Anthropology, and Ethnography, which also included prominent figures in the fisheries sector. Among the purely scientific ones, a practical task was also set—to study local water bodies to organize the reproduction of fish. Zernov began work by taking plankton samples at Glubokoe Lake. This formulation of the question was in full accordance with the spirit of the times because hydrobiology at the end of the 19th century was mainly engaged in the study of

plankton. Subsequently, in his famous textbook *General Hydrobiology* (1934), Zernov noted that the creation of freshwater biological stations served as a leading factor in the development of hydrobiology as a science [10]. Indeed, it is difficult to overestimate the ever-expanding possibilities of year-round stationary research of one or several water bodies with the participation of a team of diverse specialists.

Many famous hydrobiologists and limnologists began their research on Glubokoe Lake: B.S. Greze, S.N. Duplakov, G.S. Karzinkin, S.I. Kuznetsov, S.D. Muraveiskiy, A.P. Shcherbakov, and others. In addition to the traditional purely faunistic and zoological work, the specialists of the Glubokoe Lake station paid great attention to the study of the relationship between the vital activity of aquatic organisms and the chemical composition of the water and bottom sediments of the lake. In this formulation of the research program, the influence of interest in the physicochemical foundations of life, so characteristic of the world biology of the 1920s, was noticeable: scientists hoped to understand the behavior and physiology of the whole organism, based on the chemical composition of its cells. The same was true in hydrobiology. For example, Kuznetsov, one of the founders of freshwater microbiology, wrote in 1925: "It seems to us that, by studying separately the activities of various groups of organisms, it will be easier to approach the physiology of the entire water body" [11, p. 49]. It is noteworthy that the water body at that time was often considered as a semblance of an organism; therefore, the phrase *physiology of a water body* was quite common.

The greatest attention in studies on Glubokoe Lake was paid to the influence of aquatic organisms (especially plankton and macrophytes) on the aquatic environment itself. Kuznetsov, in particular, established the role of bacteria in the oxygen regime of lakes. The method of direct determination of the number of bacteria in water, developed in 1931 by Kuznetsov together with Karzinkin, immediately became internationally famous [12]. Shcherbakov, who became the head of the Glubokoe Lake station after the war, drew attention to the influence of planktonic organisms on the pH regime in the 1920s [13]. Muraveiskiy raised the question of the effect of thickets of higher aquatic plants on the chemical composition of the littoral water, which could determine both the distribution and biological characteristics of plankton in it [14]. Rubinshtein established the chemical zoning of water in thickets, which, in turn, determines the biocenotic zoning [15].

Largely thanks to these works in the 1920s–1930s, the essential aspects of the cycle of substances in water bodies were clarified, especially the role of microorganisms in it. These studies, in fact, can rightfully be called ecosystem studies, although the corresponding term appeared only in 1935. Indeed, physicochemical processes were considered as the material basis for the interaction of organisms with the environment, which, ultimately, made it possible to speak of a water body as a whole.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РУССКИЙ
ГИДРОБИОЛОГИЧЕСКИЙ ЖУРНАЛ,
издаваемый при Волжской Биологической Станции
под редакцией А. Л. Бенинга.
Орган Общества Исследователей Воды и ее Жизни.

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САРАТОВ.
Саропечатграфпром. Типо-лит. № 3. Казарменная, 43.
1926 г.

The cover of one of the issues of the Russian Hydrobiological Journal, the first specialized periodical in the Soviet Union, published in 1921–1930 at the Volga Biological Station (Editor-in-Chief A.L. Behning). The official organ of the Society for Researchers of Water and Its Life, created in 1921.

The ecosystem (holistic) approach to the processes in the lake literally permeated the entire scientific activity of the station staff. Thus, back in the early 1920s, Duplakov, who met an untimely death, studied the periphyton communities, as well as the successions of water bodies, and Karzinkin studied the boundaries and stability of the biocenosis [4]. The hydrobiological station on Lake Glubokoe successfully operates to this day as part of the Severtsov Institute of Ecology and Evolution, RAS.

Zernov very consistently and zealously defended the independence of hydrobiology as a science and the need to study water bodies from the point of view of their integrity. Holistic ideas were inherent in Zernov

at the beginning of his scientific career. For example, they were clearly manifested in his work on the biocenoses of the Black Sea, carried out at the beginning of the 20th century [7]. Zernov pushed his enthusiasm for biocenoses further, describing in the 1920s a special community of ice organisms in an anabiotic state, called a "págon." At the same time, his textbook on hydrobiology [10] was quite classic for the beginning of the 20th-century style of presentation of the impact of various factors on an organism.

Zernov actively contributed to the development of an experimental approach in hydrobiology. One of his closest young collaborators was S.N. Skadovskii (at the same time a student of N.K. Kol'tsov), the founder of a separate trend in hydrobiology—hydrophysiology [16], within which the pH of the water column is considered as an indicator of the ratio of the intensity of assimilation and dissimilation processes in a reservoir. It is no coincidence that among the students of Zernov there was also the founder of the trophological branch in ecology, Nadezhda S. Gaevskaya [17], who was engaged in the nutrition of organisms, including the use of aquatic cultures, first in the Department of Fish Science of the Timiryazev Agricultural Academy, and then in the Moscow Institute of the Fishing Industry, created on its basis.

In 1930, Zernov became the head of the Zoological Museum of the USSR Academy of Sciences, which was almost immediately transformed into the Zoological Institute of the USSR Academy of Sciences (now the Zoological Institute of the RAS, ZIN RAS) [18]. Zernov became the head of a large institute at an extremely difficult time, when the authorities had begun to persecute scientists. 1929 was the year of the so-called Great Turning Point, followed by years of arrests, exiles, and executions. An ideological restructuring of the research program was required from science in general, academic institutions, and scientists. In particular, one of the main aspects of this restructuring was the need to serve economic tasks and provide practical assistance to the building of socialism. The work of the Zoological Museum–Institute also had to be revised under such conditions. Zernov decided to reorganize it in a way that the former purely systematic focus of research was replaced by topics focused on solving applied problems. For example, it was necessary to study the issues of combating pests in agriculture and forestry and pathogens of human diseases ("protecting the health of workers") [19]. As a result of the transformation carried out by Zernov, the structure of the Zoological Institute underwent changes, acquiring more of an ecological than a systematic character, which was previously inherent in the museum institution. In particular, a special hydrobiological department was created.

Sometimes one comes across the opinion that Zernov "spoiled" the structure of ZIN (see, for example, the statements of F.D. Mordukhay-Boltovskiy in [20]) and that his transformations had a negative impact on the research carried out by the Institute, as they infringed on the interests of zoologists in traditional taxonomy. However, one should not forget that this was a time when it was impossible not to obey the directive documents of the authorities: the alternative could only be dismissal from work (at the least), if not complete physical destruction. In addition, as often happened during the period of totalitarianism, some elements of the ideology turned out to be quite consonant with the objective attitudes of scientists. In particular, we are talking about one of the main Stalinist principles of "the unity of science and practice," which was by no means alien to the overwhelming majority of scientists at the turn of the 19th–20th centuries. For many of them, serving practical needs was not only quite sincere but also an essential aspect of everyday scientific activity [21]. This sincerity was the secret of a fairly effective strategy for finding a compromise with the authorities. In limnology, this was the path taken by Leonid L. Rossolimo (1894–1977), who in 1934, proceeding from the practical needs of using water bodies, proposed a balance principle for studying the circulation of substances in them. From this principle, a theoretical system of views developed that served as the basis for modern ecosystem studies of water bodies (the concept of biotic balance of water bodies by G.G. Vinberg, 1946) [22]. From 1923 to 1941, Rossolimo headed the Kosino limnological station near Moscow. The balance principle proposed by him for the study of water bodies became organizing in the activities of its employees, many of whom at different times worked at the Glubokoe Lake station. The essence of the balance principle is the idea of the dynamics of organic matter, which is closely related to the water exchange in the lake. Rossolimo considered the water balance and the associated balance of organic matter as a single origin of all phenomena and processes in the lake.

Regarding hydrobiology, the economic problems turned out to be largely associated with the construction of reservoirs that unfolded in the 1930s, in particular, with the Big Volga project. Under these conditions, a well-founded forecast of changes in the fauna and flora of the rivers and water quality during the construction of dams was required. These questions attracted a student of Zernov at the Timiryazev Academy, Vladimir I. Zhadin (1896–1974), the future Honored Scientist of the RSFSR, whose 125th birthday was celebrated in 2021.

Zernov invited Zhadin, then an employee of the Gorky Hydrological Institute, to make a report at the famous Faunistic Conference in 1932 [23] on the topic of changes in biocenoses and river fauna during hydraulic engineering. The conference was organized with the aim of preparing ZIN for reorganization. Subsequently, in 1934, Zhadin, with the direct assistance of Zernov, was invited to head the Division of Mollusks in the ZIN Hydrobiological Department

and soon the department itself. Undoubtedly, with his arrival, the Hydrobiological Department gradually took shape as a major center for research on relevant issues in the Soviet Union.

Zhadin did a lot to study the fauna and biological regime of rivers. First of all, to a wide circle of zoologists and hydrobiologists, he is known for his fundamental work *Mollusks of Fresh and Brackish Waters of the USSR* (1952), which has not lost its significance to this day, and he also published and edited the multivolume edition "Life of Fresh Waters of the USSR." However, hydrobiologists are much less aware that Zhadin, based on the results of studies of rivers and reservoirs, as well as his observations of the nature of the change of biocenoses in watercourses during the construction of dams, developed a theory of the biological productivity of water bodies [24]. This theory, as now firmly established and recognized, can be considered along with the concept of biotic balance by Vinberg as one of the first interpretations of the integrity of water bodies [9]. As our recent historical studies have shown, Zhadin's theory has similarities with the balance system of views of Vinberg, and especially with the trophodynamics of R. Lindeman; that is, in fact, it is a herald of modern ideas about the ecosystem.

Although the scientist considered the productivity of reservoirs from an economic, utilitarian point of view (as the output of the biomass of useful organisms), he was able to identify a process that united a reservoir not only with a catchment but also with parts of the reservoir [24]. This process turned out to be the so-called accumulation: the accumulation of organic compounds, leading to siltation in its extreme version. Accumulation has a decisive influence on the composition of benthic fauna since it simultaneously determines the food and respiratory conditions in the reservoir or in an area of it. The most important here is the amount and nature of the accumulated substances. The study of the ratio of the biomasses of primary aquatic organisms (as a rule, having gill respiration and therefore placing demands on the oxygen content) and secondary aquatic (capable of using oxygen from the air) organisms can shed light on the origin of fauna in a reservoir. In fact, Zhadin viewed accumulation as a global process that is a direct consequence of soil erosion in watersheds. However, he attached incomparably less importance to the phenomena inside the reservoir and the vital activity of aquatic organisms in the development of accumulation.

It is significant that Zhadin pointed out the need to study the unity of biological and hydrological processes, which, in his opinion, "merge" in a reservoir. He defended the independence of hydrobiology as a science and demonstrated its objectively complex nature, insisting on the organization of a specialized institution in this area [25]. Such an institution was supposed to be the Hydrobiological Institute, which was planned to be created on the basis of the ZIN Hydrobiological Department. In the development of this project, Zhadin was actively assisted by Zernov. Unfortunately, the project was never implemented for reasons that are not quite clear.

Vladimir Ivanovich Zhadin (1896–1974).

Towards the end of his life, in the 1960s, Zhadin became interested in the problems of self-purification of water bodies, as well as the introduction of radioisotope techniques in hydrobiological research [26]. In the ZIN Laboratory of Freshwater and Experimental Hydrobiology, which arose during the reorganization of the Hydrobiological Department, a special radioisotope room (laboratory) was created, which still exists today. It is difficult to underestimate the prospects of using the tagged atom technique in the study of biogeochemical fluxes in aquatic and terrestrial ecosystems, which is now widely accepted. Zhadin also outlined a research program in the field of sanitary hydrobiology. He was worried by the ever-increasing influence of industry and agriculture on the water quality of rivers and lakes, in particular, the Neva River.

It is significant that Zhadin always took the position of a comprehensive study of the processes and mechanisms of the circulation of substances in water

bodies. In the laboratory headed by him, microbiologists and hydrochemists worked along with "pure" zoologists, botanists, and hydrobiologists. It is this interdisciplinary approach that facilitated the most complete study of those processes that determine the level of biological productivity of rivers and lakes, that is, the rate of formation of organic matter in them.

Zhadin's scientific creativity was characterized by three main features, closely related to each other. First, from the very beginning of his scientific career, he was focused on solving practical issues of the economy [23, 26]. While still a student, he studied the distribution of mollusks—carriers of the parasitic disease fascioliasis. In the 1920s, the local authorities of Vladimir and Nizhny Novgorod provinces set the task of hydrobiological substantiation of the water supply to cities for the team of the Oka biological station headed by Zhadin in Murom. In the 1930s, the scientist solved the issues of pearl fishing in the rivers of the North. In the second half of the 1940s, he looked for effective ways to control the invasive mussel *Dreissena*. In the 1950s, he was engaged in theoretical substantiation and practice of pond fertilization. Second, Zhadin was inherent in a naturalistic style of thinking, thanks to which he knew the fauna and flora of water bodies well, giving preference not to quantitative calculations but to the perception of natural objects and phenomena in their qualitative originality and integrity. This is clearly manifested in his theory of productivity, where the mathematical apparatus is replaced by graphic constructions. According to the figurative expression of Zhadin's disciple, RAS Academician A.F. Alimov, his teacher was characterized by a "feeling of the river" [27]. Third, meeting economic needs in the spirit of the ideology of conquering nature, the scientist never forgot about the need to work on its protection [28]. Thus, even in 1932, at the dawn of the era proclaimed by the authorities of alteration of fauna and flora in the interests of building socialism, when nature needed to be turned into a factory, at the Faunistic conference in ZIN, Zhadin in his report stated the need to develop measures to combat the pollution of water bodies and preserve fish, the movement and reproduction of which was hampered by the construction of dams. Zhadin spoke these words in the presence of I.I. Prezent, at that time the main ideologizer of biology in Leningrad and the future associate of the notorious T.D. Lysenko. Of course, Zhadin showed great personal courage. Then he mentioned the ecologist V.V. Stanchinskiy, whose arrest was already brewing by that time, naming him among those who were part of the group ("brigade," as it was then customary to say) for the preparation of the report.

I would like to especially note Zhadin's attitude to the negative processes in biology that were taking place before his eyes, which would later be defined as Lysenkoism. He widely used in his publications, especially after the session of the All-Union Agricultural Academy in 1948, the rhetoric of Michurin biology, in particular, one of its main principles—the unity of the organism and the environment [9]. However, very skillfully and carefully he warned against overestimating the significance of some radical practical recommendations for transforming nature. In particular, Zhadin tried to convey the idea of the need for deep thinking over acclimatization measures and a comprehensive consideration of the interrelationships of organisms in biocenoses and biocenoses in water bodies. He also understood all the abnormality of the current situation in science, which can be read about in his memoirs [23]. From the analysis of his works and unpublished materials, one gets the impression that Zhadin was only outwardly loyal, skillfully using in his work general ideas and principles of Michurin's "doctrine" consonant with his views and at the same time conducting scientifically based research and recommendations.

It is also obvious that the scientist was well aware of the groundlessness of accusations and reprisals against his colleagues. He never forgot to mention in his publications and reports Behning, who was repressed and died in prison during the war years, but who back in 1912 had introduced a student of the Murom real school Vladimir Zhadin to the practice of hydrobiology [23]. In the late 1930s, when Skadovskiy faced problems in connection with his removal from the head of the Zvenigorod hydrophysiological station created by him, Zhadin, as evidenced by archival documents, planned to invite the scientist to the Hydrobiological Institute that he was designing [25].

Zhadin's organizational activity was extremely extensive. This side of his scientific biography is well described. Here it is worth touching on the scientist's work on the development and strengthening of international scientific contacts of Soviet science. Largely thanks to Zhadin, the Soviet Union in the 1950s, after a quarter of a century of isolation, was able to renew its membership in the International Association for Theoretical and Applied Limnology. In 1959, Zhadin was elected vice-president of this authoritative society, the president of which was the world-renowned American ecologist G.E. Hutchinson, and in 1965 they were awarded a prestigious international award—the E. Naumann medal [9]. The text of the diploma indicated that the medal was awarded for outstanding research on rivers, reservoirs, and mollusks. It is worth remembering that, in the creation of the society itself in the early 1920s, Soviet scientists also played an important role: Zernov, Deksbakh, V.M. Rylov, Skadovskii, and many others. As a result of the resumption of international relations in 1971, for the first time in many years (since 1925), the next International Limnological Congress was held in the Soviet Union, in Leningrad [8]. Unfortunately, Zhadin was no longer able to take part in it, apparently for health reasons. Three years later, the scientist died at the age of 78.

Zhadin also played a certain role in organizing studies of the energy balance of water bodies at ZIN. They became an essential part of the International Biological Program [29] and also determined the further fate of the ZIN Laboratory of Freshwater and Experimental Hydrobiology, making it the center of domestic aquatic ecology and one of the leading teams in this field at the international level.

The concept of the biotic balance of matter and energy in water bodies was developed by the outstanding Russian scientist Georgii G. Vinberg (1905–1987), a student of Skadovskii and Kol'tsov. In 1976 he was elected a Corresponding Member of the USSR Academy of Sciences. For the first time, the term *biotic balance* appeared in the title of Vinberg's doctoral dissertation, which he defended in 1946 at the Moscow Institute of the Fishing Industry (Mosrybvtuz) [30]. In it, the very concept of biotic balance was most fully described. In 1971, a complete calculation of the biotic balance was carried out by Vinberg and his students for the Belarusian Drivyaty Lake [31]. Thus, in 2021, we recognize that 75 years have passed since the introduction of the term *biotic balance* into scientific circulation and 50 years since the publication of the first scheme of the complete energy balance of the lake ecosystem. The first works in this direction began in 1932 at the Kosino Limnological Station with experiments to determine the intensity of photosynthesis and respiration (the method of dark and light bottles) in the water column of lakes near Moscow, which Vinberg conducted under the leadership of Rossolimo. As a result, Vinberg came to a revolutionary conclusion in the ecology of that time that the processes of the circulation of organic substances in the reservoir as a whole can be more fully and deeper characterized by the rate of consumption and release of oxygen in water, rather than by the taxonomic composition and biomass of aquatic organisms. Vinberg's subsequent experiments were related to the measurement of the respiration rate of various aquatic animals. As a result, it turned out to be possible to express quantitatively the share of participation of different groups of aquatic organisms in the total energy flow in the reservoir. The transition from the amount of oxygen to energy can be easily realized due to the simple stoichiometric relationship that exists between them in the equations of photosynthesis and respiration.

The idea of biotic balance at first consisted in correlating the amount of oxygen consumed during mineralization (destruction) of organic substances to the value of primary production, and the calculation was carried out in energy units. Thus, it is possible to establish the completeness of the use of primary organic substances and predict the possibility of deposition of excess organic compounds in the composition of bottom sediments. Subsequently, the calculation and analysis of the elements of the biotic balance began to expand and included not only primary production and destruction but also the diets of organisms, the amount of feces excreted by them, etc.

In addition, the very idea of studying the gas (oxygen) regime of water bodies turned out to be very fruitful for subsequent studies at the biospheric level of life organization. It is noteworthy that one of the articles by Vinberg was recommended for publication by V.I. Vernadsky [32]. In this work, Vinberg examined on a quantitative basis the rate of oxygen exchange between the reservoir and the atmosphere. Vinberg actively defended the idea of the large environment-transforming role of living organisms. In particular, in the article mentioned, he wrote that the gas equilibrium between reservoirs and the atmosphere is always violated due to the vital activity of organisms, that is, production and destruction in a reservoir. According to Vinberg's calculations, the rate of oxygen exchange between water and air is proportional to the net production of the reservoir, defined as the difference between the rate of photosynthesis and destruction. This follows from the fact that long-term supersaturation of water with oxygen is possible only due to its excessive (in comparison with respiration) production by phytoplankton. At the present level, the transition to calculations of the emission of not oxygen but carbon dioxide is closely related to the analysis of "greenhouse" processes in the biosphere. It is clear that Vinberg's ideas were ahead of their time.

Calculations of the biotic (energy) balance of water bodies formed the basis of the International Biological Program, within which research was especially intensive in the second half of the 1960s. Realizing the need to include Soviet scientists in these works, Zhadin contributed to the invitation to Vinberg to work at the Zoological Institute of the USSR Academy of Sciences [30]. Despite the difficult, as it is believed, personal relationship between the two major hydrobiologists, Zhadin actually handed over to Vinberg the leadership of the ZIN Laboratory of Freshwater and Experimental Hydrobiology, which he himself headed until 1967.

Many production studies were initiated by Zhadin and began in the laboratory even before Vinberg appeared in it. In particular, Zhadin initiated the use of radioisotope techniques to determine the primary production of phytoplankton [26]. These works were carried out by his team at one of the field bases of the Zoological Institute—on Krasavitsa Lake on the Karelian Isthmus in Leningrad oblast. He also organized an ecological and physiological study of some aquatic organisms, in particular, the study of the rate of their oxygen consumption. Zhadin was interested in the respiratory capabilities of organisms living on sediments of varying degrees of silting [9]. This aspect was part of the question he was considering about the ratio of primary and secondary water organisms and the origin of the faunas of water bodies within the theory of their biological productivity developed by the scien-

tist. However, these works were not widely presented by him; it is obvious that he was less attracted by ecological physiology. There is no doubt that Zhadin and Vinberg's theoretical and organizational basis of production research contributed to the most complete integration of Soviet hydrobiological and limnological work into the general international flow. As a result of the successful development of the production direction in hydrobiology in the 1950s–1960s in the Soviet Union and in the world, ecosystem research received a significant impetus and determined the logic of the development of ecology in general. Here it is necessary to note the great role in the development of the concept of the ecosystem, central to ecology, of domestic scientists, who in some respects were ahead of their foreign colleagues. Indeed, the theory of Zhadin was published in 1940, and the concept of biotic balance by Vinberg was formed in the late 1930s, although the author defended his doctoral dissertation on this topic only in 1946 (the first, incomplete balance scheme was published only in 1948). Vinberg's timely defense of his dissertation was prevented by his illegal arrest in 1940, as a result of which he ended up in a forced labor camp in the Komi ASSR, from where he was mobilized into the active army [30]. Only in 1944 did he manage to resume scientific work. If not for his arrest, the priority in the development of energy concepts of ecosystems would belong to Vinberg, and not to Lindeman, who in 1942 proposed the basic principles of the energy approach in the study of communities and ecosystems [29]. It so happened that it is Lindeman's work that is considered as a starting point for modern ecosystem research, and this, as we see, is not entirely fair.

It is obvious that ecosystem studies were fully based on the experimental approach of hydrobiologists, their desire to quantify the intensity of the vital activity of organisms, and the physiology primarily of photosynthesis and respiration. Only thanks to such an assessment was it possible to raise the question of the role of individuals and populations in the cycle of substances and the flow of energy in the reservoir in general. Here it is imperative to recall the place that the founder of ecology E. Haeckel identified for the new science he designated "the physiology of the relationship of organisms" [1]. The scientist, who practically did not engage in environmental research himself, showed amazing insight and brilliant foresight, highlighting a special section in biology and urging other naturalists to deal with the relationship of organisms with each other and with the inorganic environment. Throughout the second half of the 20th century, the logic of the development of biological thought repeatedly proved that the concept of an ecosystem could arise and successfully develop only in the depths of biology. The very existence of an ecosystem is unthinkable without the physiological functions of living organisms, which organize the flow of energy in it [2].

From the position of the first quarter of the 21st century, it is becoming more and more obvious that the infinitely broad interpretation of ecology as a science of environmental protection, which has spread on a huge scale, sometimes even among specialists, is absolutely wrong [33]. The historical cross section of this science, held after one of its jubilee years, allows us to turn again to the foundations of ecology and to reveal its essence. Ecology has been and remains a branch of biology, the main object of which is ecosystems. The successful solution of environmental problems should be entirely based on the theory of their functioning, which will be developed, obviously, in the near future, in which historical lessons will also help.

CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

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