Ecosystem Transformation
Трансформация экосистем

ISSN 2619-094X Print
ISSN 2619-0931 Online
www.ecosysttrans.com

Review

Paradigm shift in technical hydrobiology: from local impact, to a new techno-ecosystem concept for thermal and nuclear plant water

Alexandr A. Protasov

Institute of Hydrobiology, National Academy of Sciences of Ukraine, pr. Geroev Stalingrada 12, Kiev, 04210 Ukraine

alexalexpr7@gmail.com

Received: 22.10.2020
Revised: 08.12.2020
Accepted: 29.12.2020
Published online: 26.01.21

DOI: 10.23859/estr-201022
UDC 574.63:621

Translated by S.V. Nikolaeva

Abstract. Based on analysis of F.D. Mordukhai-Boltovskoy's publications, this paper examines the history of studies of the impact of thermal and nuclear power plants, which were originally performed under the classical "Haeckelian" ecological paradigm: the external effect of technogenic factors on aquatic ecosystems and biota. The decline in interest in the problem was not associated with a decrease in the technogenic impact or changes in the energy industry. However, the paradigm itself is changing in association with the emergence of the concept of a technoecosystem. The cooling ponds of thermal power plants (TPPs) and nuclear power plants (NPPs) can be used as models of climate change, particularly climate warming. The materials obtained in studies of the effects of technogenic temperature rise are still underused by hydrobiologists studying climate change and its potential consequences.

Keywords: F.D. Mordukhai-Boltovskoy, thermal power plants, nuclear power plants, power structure, climate change.

To cite this article. Protasov, A.A., 2021. Paradigm shift in technical hydrobiology: from local impact, to a new techno-ecosystem concept for thermal and nuclear plant water. *Ecosystem Transformation* **4** (1), 3–9. https://doi.org/10.23859/estr-201022

Dedicated to the 100th anniversary of the birth of F.D. Mordukhai-Boltovskoy

Introduction

More than half a century ago, Filaret Dmitrievich Mordukhai-Boltovskoy became one of the founders of a new direction in applied hydrobiology in the USSR, i.e., studies of the impact of anthropogenic factors on aquatic ecosystems associated with the operation of thermal and nuclear power plants. In the mid-1970s, an extensive review was published (Mordukhai-Boltovskoy, 1975), in which he not only summed up some of the results of research in this area, but also outlined the main directions for further work. This publication made a big impact on research into this problem in the USSR.

The study of the problem was based on the principle of external technogenic impact on the hydroecosystem, similar to the principles of the classical Haeckelian ecology. The hydrobiological paradigm of the functioning of communities and ecosystems was similar to that prevailing in ecology: an organism (population, community, ecosystem) exists and performs its functions in a certain field of environmental factors, which in one way or another affect a given object. It was within this paradigm that studies of the effect of power plants on aquatic ecosystems were developed. Thus, on the Volga reservoirs, the effect of direct-flow cooling systems of thermal power plants was studied, i.e., of the discharge of heated water into large water bodies. In such cases, the condenser cooling water is used once. Further studies of TPP systems, and then

NPPs with a circulating cooling system (in particular, with cooling ponds) led to the development of ideas about the biotopic unity of natural and technogenic elements of ecosystems and then to the formulation of a new concept of a techno-ecosystem. In this case, the study of techno-ecosystems is based on a different approach, namely, on the principle of the unity of direct and inverse relationships between natural and anthropogenic elements of techno-ecosystems. Such a paradigm shift in technical hydrobiology and applied ecology as a whole, leads to the emergence of a different view of the system of interaction in relations between humans and water bodies, the problem of protecting ecosystems, and obtaining ecosystem services.

A fundamental review of the problem of the impact of heated wastewater from power plants on aquatic ecosystems made by F.D. Mordukhai-Boltovskoy almost half a century ago, was of great importance for hydrobiologists in Russia, not only because access to foreign literature was then limited and difficult, but also because the review summarized some of the research results and set tasks for the future. That review largely determined the development of a whole area of applied hydrobiology and was published in the collective volume appropriately titled "The ecology of organisms in cooling water reservoirs". The collection included works only on objects in the Volga basin, but this problem had been developed for more than 10 years in other regions of the USSR, in particular, in Lithuania, Transbaikalia, and Ukraine. Priority was rightly given to Ukrainian scientists who worked under the leadership of A.V. Topachevsky, M.L. Pidgayko, and O.G. Kaftannikov. However, it was with the active participation of F.D. Mordukhai-Boltovskoy that the research in this field was properly coordinated and several fruitful scientific meetings and conferences were organized.

In that review, the author considered the impact of fundamental hydrobiological factors such as the water temperature and hydrodynamics. However, in that case the focus was on their origin and impact. The author emphasized that this introduced new aspects to seemingly traditional problems: it was about the flow of additional heat into the reservoir, moreover, all year round, as well as a significant excess of the absolute temperature in comparison with natural conditions. In addition, a new phenomenon has appeared, i.e., the passage of huge masses of water with their population through heat exchanger systems, which is especially important in closed cooling ponds, where this can happen many times. It was also essential to analyze the problem of threshold temperatures not only at the physiological, organismic, but also at the cenotic levels. It turned out that purely academic physiological research related to "unnaturally" high temperatures has a very real ecological application. By the mid-1970s, considerable material has been accumulated on the impact of power plants on aquatic organisms and their communities of different ecological groups; a very different response of plankton, benthos, periphyton, and fish population to technogenic factors was shown. That, publication, was certainly a milestone, it played a significant role in the subsequent development of the problem under study, it set important tasks for further work. F.D. Mordukhai-Boltovskoy also provided extensive bibliography as by that time, world literature had already numbered many hundreds of publications, including monographic works.

The nature of the impact

It seems important to note that in F.D. Mordukhai-Boltovskoy's research, the object of study determined the approach and the basic concept of the paradigm of applied hydrobiology. The scientist and his colleagues dealt with areas of large reservoirs affected by thermal power plants, so the approaches were limited to the following research model: the aquatic ecosystem is under an exclusively external technogenic impact. The task of the study was considered within the framework of the classical ecological paradigm: an ecological object is located and functions in the field of certain environmental factors, the main of which in this case were thermal and hydrodynamic, determined by the operations of a power plant.

F.D. Mordukhai-Boltovskoy divided the problem into two aspects: the effect of a technogenic rise in temperature, often up to threshold ecological values, and the involvement of huge masses of water in the technical and circulation water supply systems. Based on considerable material, it was shown that in natural conditions, almost the same as in physiological studies, there are threshold temperature values ("enchanted 30"). For most aquatic organisms of the temperate zone, it was the threshold of 30° C that was shown to be critical for development and survival. Studies at the community level have shown that a regular change of dominant complexes occurs in the temperature gradient: in particular, in phytoplankton, whole sections of algae can fall out of the composition of communities. It was very important to compare the response to an increase in temperature and other technogenic factors by representatives of various ecotopic groups of hydrobionts (plankton, benthos, and periphyton). Nevertheless, on the scale of a large reservoir and a direct-flow cooling system, the impact of power plants appeared rather local, and most importantly, one-sided, since the consequences of discharges did not affect the "disturbing" object.

The relationship between technical systems and the aquatic ecosystem looks significantly different with a circulating water supply and cooling scheme for TPPs and NPPs: with closed cooling ponds, cooling towers, etc. (Protasov et al., 1991; Techno-Ecosystem of AES, 2011). In such cases, a kind of techno-ecosystem is formed, including natural and technogenic biotopes, in which biocenoses are formed under the effect of both natural and technogenic factors. Strictly speaking, the reservoir is also a techno-ecosystem, since it has an anthropogenic nature and its main functions are determined by human agency, but natural components can also dominate here.

Attention to the problem of the scientific community

In his review, F.D. Mordukhai-Boltovskoy noted the presence of many publications and the breadth of geography of research in the field of impact of power plants on aquatic ecosystems, but in recent decades, interest in the problem has significantly dropped. For example, in Ukraine in 1960–1990, such studies were carried out at all large cooling ponds of TPPs, at the coolers of the Chernobyl and South-Ukrainian NPPs (Protasov et al., 1991), while currently, hydrobiological studies are constantly being conducted only at the reservoir of the Khmelnitsky NPP. Research on “thermal pollution” in Belarus has effectively been curtailed. In Russia, hydrobiologists are working on Kenon Lake in Transbaikalia (Tsybekmitova, 2017); some special work is carried out in the regions of the Leningrad NPP (Makushenko et al., 2014), on one of the cooling ponds of the TPP in Tyumen (Sharapova et al., 2020). However, no comprehensive studies of techno-ecosystems are being conducted.

What are the reasons for the decline in interest in this problem? There is probably a factor in the popularity of the problem, if not the fashion for the problem. In a certain initial period, problems are solved rather quickly, which seem to lie on the surface. The main financial and organizational support of research is directed at the solution of these “superficial” issues. Then comes the period of solving more particular, but also deeper problems, studying specific features, and individual and rare varieties of the phenomena in question. In a sense, there is “fatigue” from the problem. Let us recall at least the history of the study of eutrophication, “water bloom,” the introduction of zebra mussels into water bodies, etc. Here one parallel comes to mind, connected with the work of F.D. Mordukhai-Boltovskoy (1960), which dealt with the dynamics of the invasion process: a new problem can be compared with an initially aggressive invasive species, sharply increasing its numbers, but gradually its population decreases, and it occupies a less prominent position, if not entirely disappears from the ecosystem.

Another reason for the decline in interest in the problem of “thermal pollution” may be changes in the energy structure. There is a widespread opinion that replacement of traditional energy sources is imminent, and the growth of the so-called ‘green energy’. Since the 1970s, thermal energy from fossil fuels has been largely supplanted by nuclear power all over the world, which has turned out to be quite dangerous not only for ecosystems, but also directly for humans. However, the very problem of thermal discharges and other related factors has not disappeared and cannot disappear in principle as long as there is electricity generation in thermal or nuclear power plants, and as long as the turbine is rotated by steam obtained from the combustion of fossil or nuclear fuel. The structure of the world energy sector has not fundamentally changed over the past 20–25 years (Ten, 2012), as recent statistical studies show (BP Statistical Review..., 2020). Although the proportion of so-called ‘green energy’ in 2019 for the first time slightly exceeded that of nuclear power plants, and the production of electricity from solar power plants is growing extremely rapidly (Fig. 1), the bulk of the world’s electricity (90% or more) is produced and will continue producing over many years in power plants that use water for cooling and technical needs. So far, there are no global, sustainable trends in the reduction of electricity production at nuclear power plants, except for in some European countries. However, according to Ten (2012), the decommissioning of nuclear power plants, for example, in Germany, will lead to the use of replacement capacities and the combustion of $35.2 \cdot 10^9$ m^3 of natural gas per year.

Techno-ecosystem concept

The existence and functioning of the biosphere is associated exclusively with natural processes in natural ecosystems. Anthropogenic ecosystems are energetically dependent on natural ones, just like the people that create them. The biosphere is being transformed due to the increasing expansion of techno-ecosystems. The latter can be defined as a set of biotopes (natural and of a techno-anthropogenic nature) and their living population, united by a system of matter and energy flows that change in space and time.

The origins of the concept of a techno-ecosystem are laid in the initial concepts of ecosystems. The author of the term and concept of the ecosystem, A. Tansley (1935) recognized the existence of both purely natural ecosystems, and ecosystems depending to varying extents on humans. The study of the impact of power plants began with the traditional question: how do the discharges of heated water from thermal power plants, that is, a certain set of technogenic factors, affect aquatic ecosystems? However, over time, two additional aspects became apparent:

1) the water supply systems of TPPs and NPPs are a single whole with the biotopes of the actual cooling reservoir;

2) the efficiency and reliability of technical systems operation significantly depends on environmental factors.

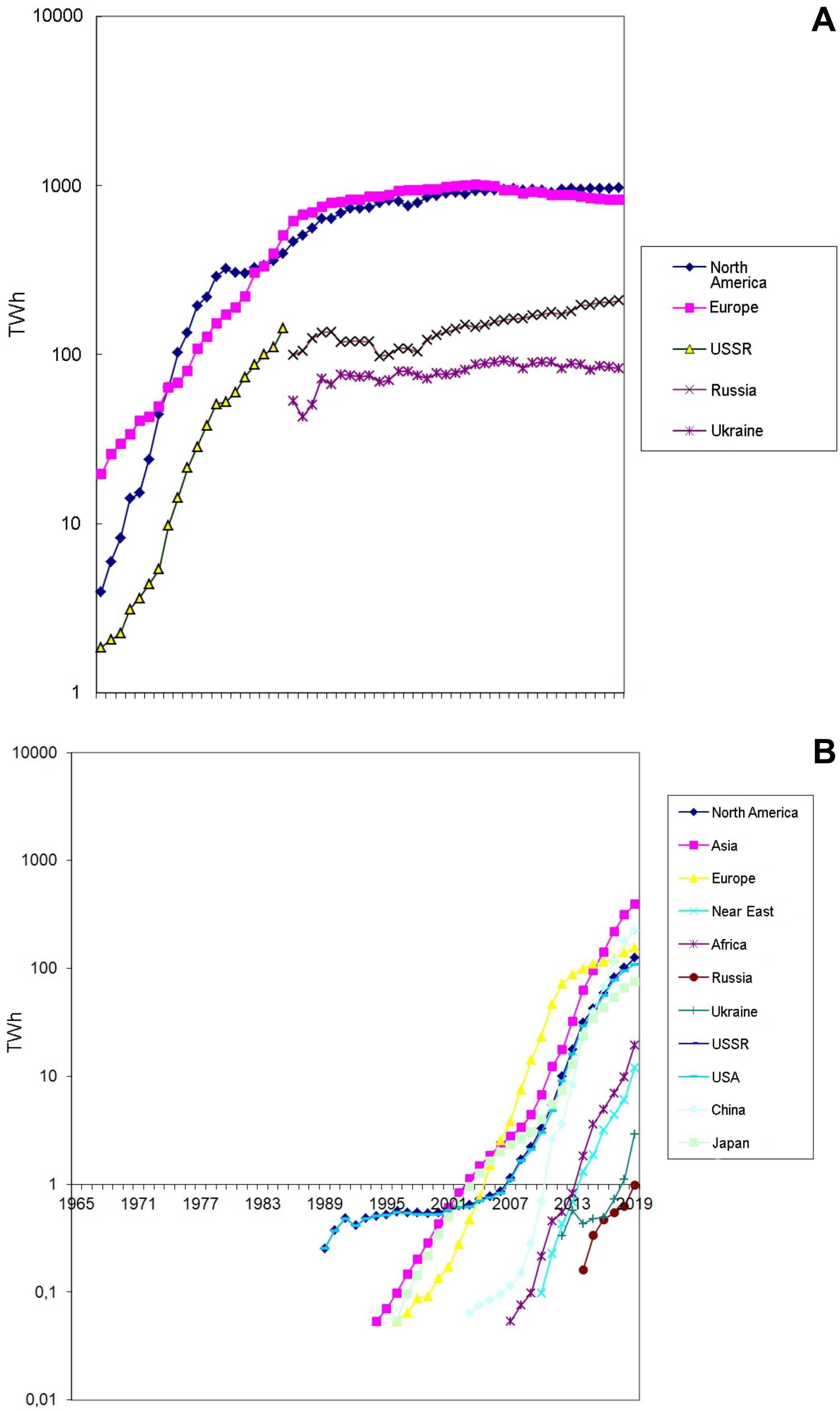

Fig. 1. Electricity production at nuclear (**A**) and solar (**B**) power plants, terawatt-hour (According to BP Statistical review..., 2020).

Thus, the next the question is, what are the relationships and interactions in the system of relations between ecological and technical objects (that is, in the techno-ecosystem), and how do techno-ecosystems and the surrounding natural ecosystems affect each other?

The uniqueness of techno-ecosystems lies in the fact that they do not have any "biotopic, ecological logic", as is justified in the concepts of river (Vannote et al., 1980) and/or lacustrine (Protasov, 2008) continua. The significant popularity of the concept of a river continuum (CRC) (Baturina, 2019) precisely for potamology has in a certain way reduced its importance for hydrobiology and ecology in general. The provisions expressed by V. Zhadin (1948) decades before the appearance of CRC, which can be considered an anticipation of it, in our opinion, are much broader and more universal. We are talking about the model proposed by Zhadin for the transformation of biocenoses downstream of the river and when it comes into contact with the lentian reservoir, for example, when creating a reservoir. The concept of continuity can be used as the basis for biogeomic structuring of the hydrospheric part of the biosphere (Protasov, 2016, 2017).

At the same time, in techno-ecosystems, the change of biotopic elements is associated with their design and the nature of their operation. For each techno-ecosystem, there are unique combinations and proportions of biotopes, as well as the communities of aquatic organisms inhabiting them. The concept of a techno-ecosystem considers not only the direct effects of technogenic factors on biota, environmental conditions, but also the reverse effect of biotic factors on technical devices, aggregates and systems as the most important. The resulting problem of biological interference is considered one of the key problems in technical hydrobiology. Biological hindrances are complex interactions between different aquatic organisms, their populations and communities, on the one hand, and technical objects, on the other. In thermal and nuclear power engineering, one of the important variants of biological interference is fouling, the formation of periphyton communities on various technical surfaces (Protasov et al., 1991)

Consequences of the new paradigm

From the standpoint of environmental protection, we should consider not so much the direct impact of technogenic factors as the relationship between the techno-ecosystem and the surrounding natural ecosystems. This approach should significantly change the principles of environmental and hydrobiological monitoring, in particular, in the energy sector. It should be based not on the control of "permissible" discharges, but on a holistic assessment of the ecological and technical state of the technological ecosystem of TPPs or NPPs. It should be noted here that after the notorious disasters at the Chernobyl nuclear power plant and the Fukushima-1 nuclear power plant, attention is quite rightly focused on the radiation impact of these power plants on humans. However, non-radiation factors also play a significant role, not only from the point of view of the impact on the environment, but also in terms of ensuring the reliability of the equipment of the stations themselves. The biogeographic issue of the invasive process is shifting into a completely practical plane: the techno-ecosystem should constantly monitor the appearance of invaders, primarily those organisms that can cause biological interference in the operation of the equipment and lead to a decrease in its reliability.

In F.D. Mordukhai-Boltovskoy's review, some hypotheses were put forward regarding the development of the problem. The assumption was shown to be correct that even with the establishment of a subtropical thermal regime, ecosystems of a subtropical or tropical composition and type will not form in the coolers. The point, apparently, is that when the thermal regime changes, other environmental factors remain unchanged, for example, the illumination mode, seasonal periodicity. However, at present, the invasive process is proceeding so intensively that there are already examples when the dominant complex of aquatic organisms in coolers located in the temperate zone is of tropical or subtropical origin (Novoselova et al., 2020).

Like other scientists who were then dealing with this problem, F.D. Mordukhai-Boltovskoy could not have foreseen that in three decades the problem of local "thermal pollution" would develop into a problem of "global warming". The development of power engineering did not lead to global warming of water bodies, although the capacity of nuclear power plants alone in Europe and the United States by 2019 have increased more than five times relative to the 1970s! Nevertheless, considering observed thermal weather anomalies, local impacts of power plants can have catastrophic consequences.

Technical hydrobiology and global climate problems

In the 1970s there was an idea that studies in the field of the effect of high temperatures, which usually do not occur in nature, are of a purely academic nature, associated with the physiology of extreme conditions, or refer to particular problems of local impact of thermal power plants and nuclear power plants on water bodies. However, climate change has posed this problem on a completely different, global scale. The need arose to predict the behavior of aquatic ecosystems with an increase in temperature in natural conditions. Techno-ecosystems of TPPs and NPPs have become extremely important models of climate change. However, in our opinion, the experience of research in this area of technical hydrobiology is very insufficiently used. An illustrative example can be works (e.g., Lazareva et al., 2016; Shcherbak, 2019) in which the issues of the response of different groups of aquatic organisms to abnormally high natural temperatures are considered without any reference to studies of the effect of technogenic temperature rise.

One way or another, the problem of thermal pollution itself under the influence of power plants has now significantly narrowed (or in any case, the interest of scientists in it has declined), but new important aspects have appeared, i.e., climatic change and patterns in the function of the techno-ecosystems of TPPs and NPPs, as well as other techno-ecosystems, and assessment of their condition.

Prospects for studying technoecosystems

As for the development of the concept of the technoecosystem itself, it is broader than the problem of the impact of thermal power plants and nuclear power plants on water bodies and the life in them. This effect is a particular issue, and the effect of temperature increase is considered in combination with other factors: hydrodynamic as well as changes in the hydrochemical regime. The problem is changed from monocentric to bicentric: the effect of technical factors on biotic systems acquires the same importance as the issues of reliability of technical systems under the influence of environmental, including biotic, factors.

Techno-ecosystems of TPPs and NPPs are only a part of the growing anthropogenic component in the biosphere. It seems that the movement towards the noosphere, about which V.I. Vernadsky writes, is the process of to one degree or another, replacing natural ecosystems with natural-anthropogenic ones. This is a global problem of the formation of a new structure of the biosphere; the problem of noospherogenesis.

The nature of science is such that it has the property of diversity. Some representations completely replace old paradigms, and they disappear into history, while in other cases new paradigms coexist with old ones, absorb their experience and supplement it with new approaches, ideas, and principles. That is why the scientific heritage of F.D. Mordukhai-Boltovskoy is relevant now. Research initiated by F.D. Mordukhai-Boltovskoy, A.V. Topachevsky and others continue to this day in Russia and Ukraine. Several years ago, a scientific and practical conference was held in Chita dedicated to the study of cooling ponds (Tsybekmitova, 2017). There is no doubt that the study of aquatic techno-ecosystems, both of power plants and of other origins, their role in individual regions and the entire biosphere will become one of the main tasks of technical hydrobiology.

ORCID

Alexandr A. Protasov 0000-0002-0204-2007

References

Baturina, N.S., 2019. Zakonomernosti organizatsii rechnyih ekosistem: retrospektiva stanovleniya sovremennyih kontseptsiy (obzor) [Regularities of the organization of river ecosystems: a retrospective of the formation of modern concepts (review)]. *Biologiya vnutrennikh vod [Biology of inland waters]* **1**, 3–11. (In Russian).

BP Statistical review of World Energy, 2020. Web page. URL: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html (accessed 24.06.2020)

Lazareva, V.I., Pryanichnikova, E.G., Tsvetkov, A.I., 2016. Otklik vodohranilisch Verhney Volgi na poteplenie klimata: izmenenie kislorodnogo rezhima i ego vliyanie na gidrobiontov [Response of Upper Volga reservoirs to climate warming: changes in oxygen regime and its effect on aquatic organisms]. *Materialy V Mezhdunarodnoy nauchnoy konferentsii “Ozyornye ekosistemy: biologicheskie protsessy, antropogennaya transformatsiya, kachestvo vody” [Materials of the International scientisic conference “Lake ecosystems: biological processes, anthropogenic transformation, water quality”]*, 12–17 September 2016, Minsk – Naroch. Publishing Centre of Belarusian State University, Minsk, Belarus, 85–87. (In Russian).

Makushenko, M.Ye., Kulakov, D.V., Vereshchagina, Ye.A., 2014. Zooplankton of Koporskaya Bay of the Gulf of Finland in the Zone of the Influence of the Leningrad NPS. *Hydrobiological Journal* **50** (4), 3–14. https://doi.org/10.1615/HydrobJ.v50.i4.10

Mordukhai-Boltovskoy, F. D., 1960. Kaspiyskaya fauna v Azovo-Chernomorskom basseyne [Caspian fauna in the Azov-Black Sea basin]. Nauka, Moscow – Leningrad, USSR, 286 p. (In Russian).

Mordukhai-Boltovskoy, F. D., 1975. Problema vliyaniya teplovykh i atomnykh elektrostantsiy na gidrobiologicheskiy rezhim vodoyemov [The problem of the influence of thermal and nuclear power plants on the hydrobiological regime of reservoirs]. In: Devyatkin, V.G. (ed.), *Ekologiya organizmov vodokhranilishch-okhladiteley [Ecology of organisms of water reservoirs-coolers] (Proceedings of IBIW AS USSR, Is. 27 (30)).* Nauka, Leningrad, USSR, 7–69. (In Russian).

Novoselova, T.N., Sylaieva, A.A., Gromova, Yu.F., Menshova, T.I., Morozovskaya, I.A., Protasov, A.A., 2020. Technoecosystem of the cooling pond of the South Ukrainian Nuclear Power Plant: group dynamics and transformation. *Ecosystem Transformation* **3** (1), 40–54. https://doi.org/10.23859/estr-191112

Protasov, A.A., 2008. River and Lake Continua: An Attempt at Analysis and Synthesis. *Inland Water Biology* **1** (2), 105–113.

Protasov, A.A,. 2016. Biogeomes of hydrosphere and land as elements of the biosphere structure. *Ecology and Noospherology* **27** (1–2), 5–15.

Protasov, A.A., Sergeeva, O.A., Kosheleva, S.I., Kaftannikova, O.G., Lenchina, L.G. et al., 1991. Gidrobiologiya vodoemov-ohladiteley teplovyih i atomnyih elektrostantsiy Ukrainy [Hydrobiology of cooling ponds of thermal and nuclear power plants in Ukraine]. Naukova Dumka, Kiev, Ukraine, 192 p. (In Russian).

Protasov, O.O, 2017. Bioheomika. Ekosystemy svitu u strukturi biosfery [Biogeomics. Ecosystems of the world in the structure of the biosphere]. Academperiodica, Kiev, Ukraine, 382 p. (In Ukrainian).

Sharapova, T.A., Gerasimov, A.G., Gerasimova, A.A., 2020. Invasive Tropical Crustacean *Stenocypris* sp. (Ostracoda) in Periphyton of a Cooling Pond (the Western Siberia). *Hydrobiological Journal* **56** (3), 62–68. https://doi.org/10.1615/HydrobJ.v56.i3.50

Shcherbak, V. I., 2019. Response of phytoplankton of the Kiev Reservoir to the increase in summer temperatures. *Hydrobiological Journal* **55** (1), 18–35. https://doi.org/10.1615/HydrobJ.v55.i1.20

Tansley, A.D., 1935. The use and abuse of vegetational concepts and terms. *Ecology* **16** (4), 284–307.

Tehno-ekosistema AES. Gidrobiologiya, abioticheskie faktoryi, ekologicheskie otsenki [NPP technoecosystem. Hydrobiology, abiotic factors, environmental assessments], 2011. Protasov, A.A. (ed.). Institute of Hydrobiology, National Academy of Sciences of Ukraine, Kiev, Ukraine, 234 p. (In Russian).

Ten, M.G.,2012. Mirovaya energetika: sovremennoye sostoyaniye i prognoz razvitiya [World energy: current state and development forecast]. *Territoriya novykh vozmozhnostey. Vestnik VGUES [Territory of new opportunities. The Herald of Vladivostok State University of Economics and Service]* **1**, 7–13. (In Russian).

Tsybekmitova, G.Ts. (ed.), 2017. Sbornik materialov Vserossiyskoy nauchno-prakticheskoy konferentsii s mezhdunarodnym uchastiem “Ekologiya vodoyemov-okhladiteley energeticheskikh stantsiy” [Materials of all-Russian scientific-practical conference with international participation “Ecology of reservoirs-coolers of power plants”]. Transbaikal State University, Chita, Russia, 278 p. (In Russian).

Vannote, R.L., Minchall, G.W., Cummins, K.W., Sedell, J.R., Cushing, C.E., 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Science*s **37** (1), 130–137.

Zhadin, V.I., 1948. Donnaya fauna Volgi ot Sviyagi do Zhiguley i ee vozmozhnyie izmeneniya [The bottom fauna of the Volga from Sviyaga to Zhiguli and its possible changes]. In: Zhadin, V.I. (ed.), *Sbornic rabot po problem rekonstruktsii fauny Volgi [Collection of works on the problem of reconstruction of the Volga fauna] (Proceedings of ZIN AS USSR. V. 8. Is. 3).* Academy of Sciences USSR Publishing House, Moscow – Leningrad, USSR, 413–466. (In Russian).