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BIOLOGICAL FACTORS IN CONTROL OF WATER QUALITY

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Ostroumov S.A. BIOLOGICAL FACTORS IN CONTROL OF WATER QUALITY

Generalizations presented in this paper represent, in a systematized form, the basic elements of the qualitative theory of biotic control of water quality and water self-purification in freshwater and marine ecosystems. The theory contributes to a better understanding of the issues of stability and regulation in the biosphere. The theory is supported by the results of the author's experimental studies of the effects exerted by surfactants, detergents and other pollutants on aquatic organisms.

Key words: water quality, aquatic ecosystems, surfactants, detergents, shellfish, bivalves, surfactants, heavy metals, water filtration, self-purification, xenobiotics, pollutants, assessment, environmental risks and hazards, pollution, marine systems, filter-feeders, Triton X-100, inhibitory effects, TDTMA, mussels, rotifers, inhibition of feeding, TX100, SDS, detergents, sublethal concentrations, *Mytilus edulis, Mytilus galloprovincialis, Unio tumidus, Lymnaea stagnalis*

Остроумов С.А. БИОЛОГИЧЕСКИЕ ФАКТОРЫ КОНТРОЛЯ КАЧЕСТВА ВОДЫ.

В статье в систематизированном виде представлены обобщения, которые содержат основные элементы качественной теории биотического контроля качества воды и самоочищения воды в пресноводных и морских экосистем. Теория способствует лучшему пониманию вопросов стабильности и регуляции процессов, происходящих в биосфере. Теория подтверждается результатами экспериментальных исследований автора, в которых изучались биологические эффекты при воздействии поверхностно-активных веществ (ПАВ), детергентов и других загрязняющих веществ на водные организмы.

INTRODUCTION

In 2000, A.F. Alimov developed some elements of the theory of the functioning of aquatic ecosystems [1]. However, this theory did not cover in detail the role of aquatic biota in the control of water quality. The latter depends on the activities of many aquatic organisms [2-19].

The role of the ecological factors and processes that contribute to improving water quality (water self-purification) increases due to the deterioration of natural water quality [3, 4, 14, 20] and increased anthropogenic impact on water bodies and streams [3, 14, 21-

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41]. The self-purification of aquatic ecosystems and water quality formation is controlled by many factors [8, 15, 17, 20-33, 36–38, 42-50].

The aim of this study is to systematize the knowledge about the polyfunctional role of aquatic biota (aquatic organisms) in the self-purification of water bodies and streams and briefly present the qualitative theory of the self-purification mechanism of aquatic ecosystems. The synthesis and system-based organization of the material was made at the conceptual level without detailed review of extensive literature.

This paper is substantially based on the string of our previous publications, including [18, 19, 24, 32] and others.

MAJOR PROCESSES CONTRIBUTING TO WATER SELF-PURIFICATION IN AQUATIC ECOSYSTEMS

The formation of water quality and its purification in aquatic ecosystems is governed by physical, chemical [42], and biotic [1, 2, 8, 15, 17, 20, 22, 23, 25, 26, 28, 30, 31, 33, 36–38, 42, 46, 49, 50] processes.

The physical and chemical processes of water self-purification are often controlled by biological factors or strongly dependent on them. Thus, the redox state of the aquatic environment, which forms with the participation of H_2O_2 released by microalgae in the light [23, 42], is of importance for a decrease in the toxic effect of some pollutants. The concentration of H_2O_2 in the Volga was found to equal up to 10^{-6}–10^{-5} mol/l, which was supported by measurements made by Dr. E.V. Shtamm and other authors [23, 42].

An important process is gravitational sedimentation of suspended particles both of biotic and abiotic nature. The sedimentation of phytoplankton depends on water temperature T. It is equal to 0.3–1.5, 0.4–1.7, and 0.4–2.0 m/day at T = 15, 20, and 25°C, respectively. According to our data, the sedimentation velocity of the pellets of *Lymnaea stagnalis* varies from 0.6 to 1.4 cm/s with a mean value of 0.82 cm/s (at T = 22–24°C) [23] .

Experiments with the traps for suspended particles showed that the suspended matter precipitates onto the bed of the River Moskva with a mean rate of 2.3 mg per 1 cm^2 of the bed surface per day, that is, 23.1 g per 1 m^2 of the bed surface per day; the proportion of C_{org} in these sediments is 64.5% [40].

Organic matter oxidation and water filtration by aquatic invertebrate animals (filter-feeders) are among the major biotic processes contributing to improving water quality and water purification.

The overall oxidation of organic matter by the entire community can be expressed either in absolute or in relative units, for example, as the ratio of energy expenditure to the exchange (total respiration R) by aquatic animals to their total biomass B. This ratio $(R/B)_e$ is referred to as Schroedinger ratio. The subscript "e" is introduced to show that the estimation is made for the ecosystem as a whole. In the water bodies where primary production exceeds the total respiration of the community, this ratio averages 2.99–6.1 [1], but it can be even greater in some water bodies. For example, the Schroedinger ratio is 17.0 in Lake Lyubevoe in the Leningrad province and 33.8 in Lake Zun-Torei east of Lake Baikal [1]. It is believed that the primary production in these lakes is much less than the total respiration and a large amount of organic matter delivered from outside is oxidized here.

Many aquatic organisms contribute to organic matter oxidation, but particular role in this oxidation belongs to bacteria [31]. The total population of heterotrophic bacterioplankton in the Mozhaisk Reservoir in June and July amounted to (1.36–5.9) × 10^9 (samples were taken at a depth of 0.1–1 m), and the population of hydrocarbon-oxidizing bacteria was (0.4–5) × 10^6 cell/ml [8].

The rate of water filtration by some aquatic animals (e.g., zooplankton, barnacles, some echinoderms, bivalves, polychaetes, sponges and many others) commonly amount to 1–9 l/h per 1 g of ash - free dry mass of their body [22, 23]. The dependence of filtration rate FR, l/h, on the mass of the aquatic animal DW, g, can be described by the power function [2, 23].

$$FR = a\,DW^b, \quad (1)$$

where DW is the dry weight of soft tissues, g.

The values of coefficient a for some bivalve mollusk species vary from 6.8 to 11.6, and those of coefficient b lie between 0.66 and 0.92 [23].

The rate of water filtration by five bivalve mollusk species converted to the area of their gills is about 1.2–1.9 ml/min per 1 cm^2 [23].

The total rate of water filtration by populations of macroinvertebrates (e.g., bivalve mollusks, polychaetes) was estimated at 1–10 m^3 per 1 m^2 of the bed of the aquatic ecosystem per 1 day [20, 23]. Additional data on the filtration activity of aquatic animals is given in [32] (see Tables 2 and 3 in [32]).

THE MAJOR COMPONENTS OF THE SELF-PURIFICATION MECHANISM OF AQUATIC ECOSYSTEMS

According to a series of our previous publications, the biological self-purification mechanism of aquatic ecosystems incorporates three main types of major functional components [22, 23]: filtration activity of organisms (“filters”) [21]; the mechanisms of transfer of chemicals from one ecological compartment into another, from one medium into another (“pumps”); and splitting pollutant molecules (“mills”).

The processes and aquatic organisms that serve as filters [21, 22, 23]:the invertebrate filter-feeders [2, 44]; the coastal macrophytes, which retain some nutrients and pollutants delivered into water from neighboring areas; the benthos, which retains and absorbs part of nutrients and pollutants at the water–bottom sediment interface; the microorganisms adsorbed on particulates that move within water column due to sedimentation of particles under the effect of gravity; as a result, the water mass and microorganisms moves relative to one another, which is equivalent to the situation when water moves through a porous substrate with microorganisms attached to walls [21]. Precipitation of a suspended particle, that is, its movement relative to water, enhances O_2 exchange between the adsorbed bacteria and the aquatic medium [50].

The processes and aquatic organisms that serve as pumps [22, 23] : the transfer of part of pollutants from the water column to bottom sediments (e.g., sedimentation, sorption); the transfer of part of pollutants from the water column into the atmosphere (evaporation); the transfer of part of nutrients from water onto the territory of neighboring terrestrial ecosystems because of the emergence of imago of aquatic insects; the transfer of part of nutrients from water onto the territory of neighboring terrestrial ecosystems through fish-eating birds, which withdraw some fish biomass from water.

The processes and aquatic organisms that serve as mills and split the molecules of many pollutants [22, 23]: the intracellular enzymatic processes; the processes catalyzed by extracellular enzymes; the decomposition of pollutants by photolysis: the photochemical processes, sensitized by organic matter; the destruction of pollutants in the free-radical processes with the participation of biogenic ligands [42].

ENERGY SOURCES FOR BIOTIC SELF-PURIFICATION MECHANISMS OF AQUATIC ECOSYSTEMS

As all types of machinery, the biomachinery for water self-purification needs some reliable sources of energy.

The processes of biotic self-purification of water take energy from the following sources: photosynthesis, oxidation of autochthonous and allochthonous organic matter; other redox reactions. Thus, practically all available energy sources are used. A part of the energy is supplied through oxidation of the components (dissolved and particulate organic matter) which the system gets rid of [34].

Water self-purification is commonly associated with organic matter oxidation by aerobic microorganisms. Equally important are anaerobic processes which receive energy from the transfer of electrons to acceptors other than oxygen. Anaerobic energetics feeds the metabolism of microorganisms of methanogenic community (decomposition of organic matter results in the production of H_2S, H_2, and CH_4), and anoxygenic phototrophic community (with the formation of SO_4^{2-}, H_2S, H_2, and CH_4) [50]. The products produced by organisms of these communities are used as oxidation substrates by organisms of other communities, including the organisms that form the group referred to as a bacterial oxidation filter. The latter filter functions under aerobic conditions and oxidizes H_2, CH_4 (methanotrophs), NH_3(nitrifiers), H_2S (thiobacteria), thiosulfate (thionic bacteria) [50].

For example, in Lake Mirror (USA), 19.1 g C/m^2 of lake surface is oxidized annually due to phytoplankton respiration, 12.0 due to zooplankton respiration, 1.0 due to macrophytes, 1.16 due to attached plants, 2.8 due to benthic invertebrates, and 0.2 g C/m^2 due to fish. Oxidation by bacteria in bottom sediments and by bacterioplankton accounts for 17.3 and 4.9 g C/m^2 of lake surface [49].

INVOLVEMENT OF MAJOR TAXA IN SELF-PURIFICATION PROCESSES IN AQUATIC ECOSYSTEMS

Analysis of facts demonstrated how practically all major groups of organisms contribute to self-purification of aquatic ecosystems and formation of water quality [11, 17, 20, 22, 23, 25–29, 31, 33–38, 49, 50].

A significant role belongs to microorganisms [8, 46, 50, 44], phytoplankton [22, 23], higher plants [22, 23], protozoa [11], zooplankton [22, 23, 49], benthic invertebrates [22, 23, 49], and fish. All these groups contribute largely to the self-purification of aquatic ecosystems, each group taking part in several processes.

Additional data on the role of aquatic plants were obtained by E.V. Lazareva and S.A. Ostroumov in their experiments with microcosms [12]. In those experiments it was shown that aquatic plants accelerated the decrease in concentration of a synthetic surfactant, sodium dodecyl sulphate (SDS), that was added to water [12]). This result is of interest, as synthetic surfactants are an important group of chemical pollutants of aquatic environment.

Microbial processes of water self-purification are associated basically with the activity of heterotrophic aerobic bacteria; however, representatives of practically all major bacterial groups (>30) participate in the key processes of organic matter destruction and self-purification of water bodies [50].

It is worth mentioning that the microorganisms participating in the destruction of biopolymers and in water self-purification system feature wide taxonomic diversity [50]. An important role in organic matter destruction and self-purification of aquatic ecosystems belongs also to eucaryotic microorganisms (protists), in particular, euglenes, ameboflagellates, dinoflagellates, infusoria, heteroflagellates, cryptomonades, choanoflagellates, metamonads, chitrids, and other organisms ([50] and others).

An important process of water self purification is water filtration by organisms of many taxa [2, 15, 22, 23, 44]. A detailed list of taxa, including planktonic and benthic filter-feeders in aquatic ecosystems, is given in [37]. The contributions of different groups of organisms to C removal from water of eutrophic Lake Esrum (Denmark) in percent of the total C withdrawn from water are as follows: 24.4% by respiration of producers, 20.9% by bacterial respiration, 30.7% by respiration of consumers, 4.5% (appears to be determined not completely) by the respiration of microorganisms in sediments, 0.14% by the emergence of aquatic insects [49].

The results of the analysis of roles of organisms in aquatic ecosystems made us conclude that virtually all groups of organisms belonging to procaryotes and eucaryotes are involved in water self-purification.

THE RELIABILITY OF WATER SELF-PURIFICATION BIOMACHINERY

The reliability of a technical system often relies on the presence of back-up components. Analysis of aquatic ecosystems shows a similar principle to govern their functioning. For example, the filtration activity of aquatic animals is doubled so that it is implemented by two large groups of organisms, i.e., plankton and benthos. Both groups filter water with a considerable rate [2, 15, 20, 44]. Additionally, benthos duplicates the activity of the planktonic organisms permanently inhabiting the pelagic zone, since the larvae of many benthic filter-feeders follow the planktonic way of life. Plankton incorporates two large groups of the multicellular invertebrate filter-feeders, i.e., crustaceans [44] and rotifers [15], both of which implement water filtration. One more large group of the organisms (protozoa), which have somewhat different type of feeding, also duplicates the filtration activity of multicellular filter-feeders (crustaceans and rotifers).

The enzymatic decomposition of pollutants is partially duplicated by the activities of bacteria and fungi. Almost all aquatic organisms, which are, in someway or another, capable of consuming and oxidizing dissolved organic matter, perform this function.

Self-regulation of biota is an important component of the reliability of water self-purification mechanism. The organisms that took active part in water self-purification are subject to control by other organisms of both lower and higher trophic levels in the food web. The regulating role of organisms can be effectively studied with the use of the author's method of the inhibitor analysis of regulatory interactions in trophic chains [26, 27].

Various forms of signaling, including the information-carrying chemicals (ecological chemoregulators and chemomediators [28, 29, 31]) play important roles in the regulation of ecosystems.

Self-control of water quality, water purification and permanent restoration of its quality is an important component for ecosystem self-stabilization. The restoration of the water quality is vital for ecosystem stability, because the autochthonous and allochthonous organic matter and nutrients permanently go into water from the surrounding land, by water of tributaries, atmospheric precipitation, and the solid particles carried by air [49]. Therefore, water self-purification is as important for an aquatic ecosystem as DNA repair is for the heredity system. This allows us to regard water self-purification as an ecological repair in aquatic ecosystems.

The wide range of variations in the filtration activity rates suggests the need to regulate this activity. The volume of water filtered within one hour and measured in the body volumes of the filter-feeders amounts to 5×10^6 for nanoflagellates and 5×10^5 for ciliates [49]. Cladocerans filter up to 4–14 ml per one organism per day [49] (according to [44], 20–130 ml). Copepods and rotifers filter 2–27 [49] and 0.07–0.3 ml/day per animal, respectively [15]. All these aquatic animals and other filter-feeders remove suspensions from water.

Thus, all forms of regulation and communication of organisms within community are of importance for maintaining the reliability of ecosystem functioning. Some important role in the regulation and communication in aquatic communities belongs to dissolved substances, ecological chemoregulators and chemomediators [28, 29, 31].

THE RELATIONSHIP BETWEEN THE RELIABILITY OF WATER SELF-PURIFICATION BIOMACHINERY AND AQUATIC ECOSYSTEM STABILITY

In our opinion, filtration activity of filter-feeders is not only a part of water self-purification process and water quality repair, but also a part of processes that maintain the stability of the aquatic ecosystem. The latter is performed through the conditioning of water, which serves as a habitat for many other aquatic species, and "the environmental tax for the environmental stability" that filter-feeders pay in the form of pellets of organic material. These pellets form in the organisms of filter-feeders (e.g., bivalve mollusks) from particulate organic matter they filter out from water and release into the environment in the form of 'lumps'. Pellets precipitate onto the bed of water bodies or streams. The pellets are used as food by many other aquatic organisms, including zoobenthos and bacteria. The "environmental tax" is surprisingly high as compared with the share of C of the organic matter included in production. In some cases, it can be >100%, when calculated as the ratio of the amount of C not assimilated from the food (that is, C from fecal and pseudofecal pellets) to the amount of C consumed and assimilated for production.

The formation of pseudofeces by filter-feeding bivalves (that is, the process in which part of the filtered seston does not pass through the digestive tract of the mollusk but is prepared to the release into the environment in the form of pellets) begins at rather low seston concentration. Thus, at the concentration of seston as low as 2.6 mg/l (the concentration of seston is commonly much greater), mollusks *Mytilus edulis* (shell size of 1.7 cm) started releasing pseudofecal pellets [23]. Therefore, the formation of pseudofeces is not the result of excessive concentration of organic matter in the aquatic environment.

The high "environmental tax" is justified because the filter-feeders will eventually benefit from the high level of stability of water quality characteristics. The entire system of water self-purification also benefits from this, because it requires the wide diversity of aquatic species to maintain its stability.

Aquatic ecosystems serve as one of the most important regulators of global geochemical cycles (e.g., of water and C), the stability of which withstands the hazard of global disturbances. Therefore, the reliability of water self-purification biomachinery is of key importance for the global stability in the biosphere [31].

RESPONSE OF THE ENTIRE BIOMACHINERY OF WATER SELF-PURIFICATION TO EXTERNAL (ANTHROPOGENIC) IMPACTS ON THE AQUATIC ECOSYSTEM

Is the rate of functional activity of the biomachinery of water self-purification a certain constant?

The author has found an essential element of lability in one of the processes involved in water self-purification, i.e., water filtration by aquatic animals (mollusks and rotifers) [17, 20–23, 25–27, 29–31, 33–39]. In a series of our experiments, water filtration was inhibited by sublethal concentrations of many anthropogenic pollutants, such as synthetic surfactants, surfactant-containing mixed preparations, and heavy metals (Table). Other pollutants were found to have similar effect on mollusks and planktonic filter-feeders [5, 23].

Table

Inhibitory effect of various pollutants on suspension withdrawal from water by filter-feeders. (TX-100 is the non-ionic surfactant Triton X-100; LD is liquid detergent, SDS is the anionic surfactant, sodium dodecyl sulfate, TDTMA is the cationic surfactant, tetradecyl trimethyl ammonium bromide ([23] and other publications by the author; the data on *Daphnia magna* from [47])

Substances	Organism s	Concentration, mg/l
TX-100	*Unio tumidus*	5
TDTMA	*Crassostrea gigas*	0.5
SDS	*Mytilus edulis* and *M. galloprovincialis*	>1
SDS	*C. gigas*	0.5
Copper sulfate	*M. galloprovincialis*	2
Lead nitrate	*M. galloprovincialis*	20
LD “E”	*C. gigas*	2
LD “Fairy”	*C. gigas*	2
TDTMA	*Brachionus angularis*	0.5
TDTMA	*B. plicatilis*	0.5
TDTMA	*B. calyciflorus*	0.5
SDS	*Daphnia magna*	0.5-10

Recently I.M. Vorozhun and S.A. Ostroumov have shown that the synthetic surfactant dodecyl sulphate (SDS) has an inhibitory effect on the ability of the planktonic filter-feeders *Daphnia magna* to remove phytoplankton from water during their filtration activity [47].

The population biomass of filter-feeders in polluted aquatic ecosystems decreases, the result of which is an additional drop in the total filtration activity in such ecosystems [23].

Therefore, the biomachinery of water self-purification processes and its quality formation is labile [22, 23, 38], and quickly rearranges to adjust to changes in the environment. The obtained data demonstrate the hazard of a decrease in the efficiency of water self-purification system in aquatic ecosystems subject to anthropogenic impacts (chemical pollution of water bodies and streams) [17, 20–23, 25–27, 29, 31, 33–36, 38, 39].

RELATIONSHIP BETWEEN THIS THEORY AND FUNDAMENTAL ECOLOGICAL CONCEPTS

A key principle in the organization of ecosystems is the interdependence and mutual usefulness of the organisms involved. This principle is confirmed so often that it has almost become an axiom and does not attract particular attention. However, its significance manifests itself in a new way in the analysis of water self-purification processes in aquatic ecosystems. The cooperative functioning of procaryote communities is one example. Another example is the high activity of filter-feeders in removing suspension from water, during which the amount of suspended organic matter extracted from water is much greater than it is required for the organism of the filter-feeder [2, 22, 23]. The environmental significance of suspension removal from water and pellet formation is analyzed in detail in [23]. The assimilation of food by filter-feeders in the laboratory experiments was ~50–60% [15], however it can be much lower in nature. Thus, bivalve mollusks *Mytilus galloprovincialis* (with a biomass of 2 g) featured the assimilation that varied within the year from 4.8 to 51% [23], that is, in some cases >95% of filtered out material was finally released by the mussels in the form of pellets.

In our opinion, the synecological cooperation is one of the functional principles of the biomachinery of water self-purification.

Biocontrol of water quality (the purification of aquatic ecosystem) is accompanied by transfer of chemical substances and their constituents from one location within the aquatic ecosystem into another. The results of data analysis support the earlier formulated proposition that “a competitive unity of vector and stochastic motion of chemical elements and the regulation of these processes based on biological matter exist in aquatic ecosystems” [33]. Confirmations were also obtained for the assumption that the following phenomena take place in aquatic ecosystems: “a competitive unity”; biological-matter-controlled regulation of cyclic and noncyclic paths of chemical elements; as well as the regulation of the transfer of chemical elements from one phase into another (inter-phase transfer) and from one organism into another (organism-to-organism transfers) [33]. Suggesting the term “a competitive unity” we mean that it is a unity, a union that embraces the components that compete against each other. The author emphasizes that the regulation of many processes of transfer of chemical elements in aquatic ecosystems is biologically and abiotically controlled, and the roles of both components of that control — biotic and abiotic — are equally important and integrated with each other. We suggested a special term that underlines the integrity of both types (biotic and abiotic) of that control of the transfer of matter – in Russian language this term is “biokosnyj control” [33].

FROM STUDYING THE BIOMACHINERY OF WATER PURIFICATION TO ECOTECHNOLOGIES

We consider the elements of the theory on biotic mechanisms of water purification, which were present above, as a scientific basis for better control of water pollution [51]. Among new ecotechnologies, the use of aquatic plants is of special interests. To develop phytotechnologies, we conducted experiments with 5 species of aquatic plants. Some new results were reported in a series of publications, including those by E.A.Solomonova and S.A. Ostroumov [43] and by E.V. Lazareva and S.A. Ostroumov 2009 [12]. E.g., some previously unknown quantitative parameters of the tolerance of the aquatic macrophyte *Potamogeton crispus* L. to the surfactant sodium dodecyl sulphate were determined [43]. Aquatic plants *Ceratophyllum demersum* induced a removal of the heavy metals Cu, Zn, Cd, and Pb from water [52, 53].

RELEVANCE OF THE CONCEPTS OF BIOTIC SELF-PURIFICATION OF WATER TO ISSUES OF WATER QUALITY IN VARIOUS REGIONS

Some of the elements of the theory of involvement of biota in self-purification of water that were formulated above were used in the analysis of issues of water quality in various regions of the world, including Canada [6] ; China [9]; Greece [16], Russia [13], Spain [7] , and U.S.A. [45].

The theory of biotic self-purification of water got a positive evaluation by other experts, e.g. [10].

We predict that the pressure for having good quality of water and increasing scarcity of water will lead to finding new examples of relevance of the concepts of biotic and biocoenotic control of water quality. We predict that new aspects of the key role of organisms in the control and improvement of water quality both in freshwater and marine ecosystems will be found, and new methods of applying organisms and new usages of them in water decontamination (remediation) will be described.

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REFERENCES

1. **Alimov A.F.** Elements of the theory of the functioning of aquatic ecosystems (= *Elementy teorii funktsionirovaniya vodnykh ekosistem*), St. Petersburg: Nauka, 2000.

2. **Alimov A.F.** Functional Ecology of Freshwater Bivalves (= *Funktsional'naya ekologiya presnovodnykh dvustvorchatykh mollyuskov*), Leningrad: Nauka, 1981.

3. **Danilov-Danil'yan V.I.** Sostoyanie I problemy okhrany okruzhayushchei sredy v Rossiiskoi Federatsii. *Nauch. I Tekhn. Aspekty Okhrany Okruzhayushchei Sredy,* 1995, no. 10, pp. 60–67.

4. **Dolgonosov B.M.** Problemy obespecheniya kachestva vody v prirodno-tekhnologicheskom komplekse vodosnabzheniya, - *Inzh. Ekologiya*, 2003, no. 5, pp. 2–14.

5. **Donkin P., Widdows J., Evans, S.V**. et al., Effects of Neurotoxic Pesticides on the

Feeding Rate of Marine Mussels *Mytilus edulis*, - Pestic. Sci., 1997, vol. 49, pp. 196–209.

6. **Fisenko A.I.** Natural purification of rivers and creeks through froth (foam) formation process // Research Journal of Chemistry and Environment, 2006. 10 (1), March, pp. 24-29.

7. **Hernandez I., Fernandez-Engo M.A., Perez-Llorens J.L., Vergara J.J.** Integrated outdoor culture of two estuarine macroalgae as biofilters for dissolved nutrients from *Sparus aurata* waste waters. – Journal of Applied Phycology, 2005, V.17. No.6, p. 557-567.

8. **Il'inskii V.V.** Mikrobiologicheskii monitoring neftyanogo zagryazneniya vodnykh ekosistem, in: *Neftyanye zagryazneniya: kontrol' i reabilitatsiya ekosistem* , Moscow: FIAN, 2003, pp. 4–47.

9. **Jiang J.-G., Shen Y.-F.** Estimation of the natural purification rate of a eutrophic lake after pollutant removal. - Ecological Engineering. 2006, Vol. 28, No. 2, P. 166-173.

10. **Kapitsa A.P.** Review of the book: S.A.Ostroumov. Biological Effects of Surfactants (2006). - Ecologica, 2008. т.15, No. 51, p. 71-72. (YU ISSN 0354-3285; Belgrade; in English).

11. **Khlebovich T.V.** Rol' infuzorii v protsesse samoochishcheniya vod, in: Gidrobiologicheskie osnovy samoochishcheniya vod , Leningrad: Nauka, 1976, pp. 25–29.

12. **Lazareva E.V., Ostroumov S.A.** Accelerated decrease in surfactant concentration in the water of a microcosm in the presence of plants: innovations for phytotechnology. - Doklady Biological Sciences, 2009, Vol. 425, pp. 180–182.

13. *Makushkin E.O., Korsunov V.M.* Self-Purification of Water Current and the Role of Microbiological Transformation of Organic Matter in the System of the Selenga River and Its Delta // Doklady Biological Sciences, 2005, Volume 404, Numbers 1-6, P. 372-374.

14. **Moiseenko T.I.** The Fate of Metals in Arctic Surface Waters. Method for Defining Critical Levels, Sci. Total Environ., 1999, vol. 236, pp. 19–39.

15. **Monakov A.V.** Feeding of freshwater invertebrates (= *Pitanie presnovodnykh bespozvonochnykh*), Moscow: IPEE RAN, 1998.

16. **Neofitou C., Dimitriadis A., Pantazis P., Psilovikos A., Neofitou N., Paleokostas A.** Self-purification of a long-stretched gully affects the restoration of an alpine-type lake in northern Greece. Fresenius Environmental Bulletin. 2005. V.14 (12 A), p. 1141-1149.

17. **Ostroumov S.A.** An aquatic ecosystem: a large-scale diversified bioreactor with a water self-purification function (= Vodnaya ekosistema: krupnorazmernyi diversifitsirovannyi bioreaktor s funktsiei samoochishcheniya vody). Doklady Akademii Nauk, 2000, vol. 374, no. 3, pp. 427–429 [English translation: Doklady Biological Sciences, 2000. Vol. 374, P. 514-516].

18. **Ostroumov S.A.** Aquatic organisms in water self-purification and biogenic migration of elements. Moscow. MAX Press. 2008. 200 p.

19. **Ostroumov S.A.** Biological Effects of Surfactants. CRC Press. Taylor & Francis. Boca Raton, London, New York. 2006. 279 p.

20. **Ostroumov S.A.** Biological Effects of Surfactants on Organisms (= Biologicheskie effekty pri vozdeistvii poverkhnostno-aktivnykh veshchestv na organizmy), Moscow: MAX-Press, 2001. 334 p.

21. **Ostroumov S.A.** Biological Filtering and Ecological Machinery for Self-Purification and Bioremediation in Aquatic Ecosystems: Towards a Holistic View. Rivista di Biologia/Biology Forum, 1998, vol. 91, pp. 221–232.

22. **Ostroumov S.A.** Biological mechanism of self-purification in natural water bodies and streams: theory and applications (= Biologicheskii mekhanizm samoochishcheniya v prirodnykh vodoemakh i vodotokakh: teoriya i praktika), Advances of Modern Biology (= Uspekhi Sovremennoi Biologii), 2004, vol. 124, no. 5, pp. 429–442.

23. **Ostroumov S.A.** Biotic mechanism of self-purification of freshwater and marine water. Elements of theory and applications (= Bioticheskii mekhanizm samoochish-cheniya presnykh i morskikh vod. Elementy teorii i prilozheniya), Moscow: MAX- Press, 2004. 96 p.

24. **Ostroumov S.A.** Biotic self-purification of aquatic ecosystems: from the theory to ecotechnologies // Ecologica. 2007, vol. 15, No. 50, p. 15-21.

25. **Ostroumov S.A.** Developing Fundamental Concepts in Aquatic and General Ecology:

from Aquatic and Ecological Research To Applications Relevant To Sustainability. - Ecological Studies, Problems, Solutions, 2003, vol. 6, pp. 28–33.

26. **Ostroumov S.A.** Inhibitory analysis of the regulatory interactions in food webs (= Ingibitornyi analiz regulyatornykh vzaimodeistvii v troficheskikh tsepyakh). - Doklady Akademii Nauk, 2000, vol. 375, no. 6, pp. 847–849 [English translation: Doklady Biological Sciences, Vol. 377, 2001, pp. 139–141. DOI 10.1023/A:1019218026198].

27. **Ostroumov S.A.** Inhibitory Analysis of Top-Down Control: New Keys To Studying Eutrophication, Algal Blooms, and Water Self-Purification. - Hydrobiologia, 2002, vol. 469, pp. 117–129.

28. **Ostroumov S.A.** Introduction to biochemical ecology (= *Vvedenie v biokhimicheskuyu ekologiyu*), Moscow: Moscow University Press, 1986. 176 p.

29. **Ostroumov S.A.** Concepts of biochemical ecology: ecological chemomediators, ecological chemoregulators, ecological chemoeffectors (= Kontseptsii biokhimicheskoi ekologii: ekologicheskie khemomediatory, ekologicheskie khemoregulyatory, ekologicheskie khemoeffektory). Aquatic Ecosystems and Organisms (= Vodnye Ekosistemy i Organizmy, 2003, vol. 6, pp. 105–107.

30. **Ostroumov S.A.** Method of biotesting: the method of assessing the potential hazards from chemical substances (= Metodika biotestirovaniya: metodika otsenki potentsial'noi opasnosti khimicheskikh veshchestv). – Aquatic Ecosystems and Organisms (=Vodnye Ekosistemy i Organizmy), 2001, vol. 5, pp. 137–138.

31. **Ostroumov S.A.** The functions of the living matter in the biosphere // Vestnik RAN (Herald of the Russian Academy of Sciences). 2003. V. 73. No. 3. P. 232-238. [= O funktsiyakh zhivogo veshchestva v biosfere. Vestnik Rossijskoj Akademii Nauk, 2003, vol. 73, no. 3, pp. 232–238].

32. **Ostroumov S.A.** On some issues of maintaining water quality and self-purification // Water Resources, 2005, Vol. 32, No. 3, pp. 305–313.

33. **Ostroumov S.A.** On the role of aquatic organisms in the regulation of flows of matter and migration of chemical elements (= O roli gidrobiontov v regulyatsii potokov veshchestva i migratsii elementov v vodnykh ekosistemakh), - Vestnik RAEN, 2002, vol. 2, no. 3, pp. 50–54.

34. **Ostroumov S.A.** Polyfunctional Role of Biodiversity in Processes Leading To Water Purification: Current Conceptualizations and Concluding Remarks. - Hydrobiologia, 2002, vol. 469, pp. 203–204.

35. **Ostroumov S.A.** Synecological basis of solving the problem of eutrophycation (= Sinekologicheskie osnovy resheniya problemy evtrofirovaniya), - *Doklady Akademii Nauk,* 2001, vol. 381, no. 5, pp. 709–712 [English translation: The Synecological Approach to the Problem of Eutrophication. - Doklady Biological Sciences, Vol. 381, 2001, p. 559–562. DOI 10.1023/A:1013378505630].

36. **Ostroumov S.A.** System of principles for protection of the biogeochemicalo function and biodiversity of filter-feeders (= Sistema printsipov dlya sokhraneniya biogeotsenoticheskoi funktsii i bioraznoobraziya fil'tratorov), - *Doklady Akademii Nauk,* 2002, vol. 383, no. 5, pp. 710–713 [English translation: System of principles for conservation of the biogeocenotic function and the biodiversity of filter-feeders. Doklady Biological Sciences. 2002. Vol. 383: 147-150. DOI 10.1023/A:1015398125876].

37. **Ostroumov S.A.** Protection of biodiversity and water quality : the role of feedbacks in ecosystems (= Sokhranenie bioraznoobraziya i kachestvo vody: rol' obratnykh svyazei v ekosistemakh), - *Doklady Akademii Nauk,* 2002, vol. 382, no. 1, pp. 138–141 [(English translation): Biodiversity protection and quality of water: the role of feedbacks in ecosystems.- Doklady Biological Sciences. 2002. Volume 382, Numbers 1-6, p.18-21.].

38. **Ostroumov S.A.** The concept of aquatic biota as a labile and vulnerable component of the water self-purification system (=Kontseptsiya vodnoi bioty kak labil'nogo i uyazvimogo zvena sistemy samoochishcheniya vody), - *Doklady Akademii Nauk,* 2000, vol. 372, no. 2, pp. 279–282 [English translation: Doklady Biological Sciences, Vol. 372, 2000, pp. 286–289].

39. **Ostroumov S.A. Donkin P., Staff F.** Inhibition by the anionic surfactant, sodium dodecyl sulphate, of the ability of mussels *Mytilus edulis* to filter and purify sea water (Ingibirovanie anionnym poverkhnostno-aktivnym veshchestvom sposobnosti midii *Mytilus edulis* fil'trovat' i ochishchat' morskuyu vodu), - Bulletin of Moscow University. Series Biology (Vestn. Mosk. Univ., Ser. 16. Biology), 1997, no. 3, pp. 30–36.

40. **Ostroumov S.A., Kolesnikov M.P., Rusanov A.G., Khromov V.M.** Studying Sedimented Matter in the Moscow River: Elemental Composition (C, N, P, Al, Si) and Geochemical Flow, Ecological Studies, Hazards, Solutions, 2001, vol. 5, pp. 23–24.

41. **Rand G.M.** (Editor) Fundamentals Of Aquatic Toxicology: Effects, Environmental Fate And Risk Assessment . CRC Press. 1995. 1148 p.

42. **Skurlatov Yu.I.** Osnovy upravleniya kachestvom prirodnykh vod, in: Ekologicheskaya khimiya vodnoi sredy , Moscow, 1988, vol. 1, pp. 230–255.

43. **Solomonova E.A., Ostroumov S.A.** Tolerance of an aquatic macrophyte *Potamogeton crispus* L. to sodium dodecyl sulphate. - Moscow University Biological Sciences Bulletin, 2007, 62 (4): 176-179.

44. **Sushchenya L.M.** Kolichestvennye zakonomernosti pitaniya rakoobraznykh, Minsk: Nauka i Tekhnika, 1975.

45. **Vaughn C.C., Nichols S.J., Spooner D.E.** Community and foodweb ecology of freshwater mussels // Journal of the North American Benthological Society. 2008. Vol. 27, Issue 2, P. 409-423.

46. **Vinogradov M.E., Shushkina E.A.** Funktsionirovanie planktonnykh soobshchestv epipelagiali okeana (Functionation of Planktonic Communities of the Epipelagic Zones of the Ocean), Moscow: Nauka, 1987.

47. **Vorozhun I.M. Ostroumov S.A.** On studying the hazards of pollution of the biosphere: effects of sodium dodecylsulfate (SDS) on planktonic filter-feeders. - Doklady Biological Sciences, 2009, Vol. 425, pp. 133–134.

48. **Wang X.Y. An, J. Zhang, X. Shi, C. Zhu, R. Li , M. Zhu, S. Chen.** Contribution of biological processes to self-purification of water with respect to petroleum hydrocarbon associated with No. 0 diesel in Changjiang Estuary and Jiaozhou Bay, China // Hydrobiologia, 2002. Volume 469, No. 1-3, P. 179-191.

49. **Wetzel R.G.** Limnology: Lake and River Ecosystems, San Diego: Academic, 2001.

50. **Zavarzin G.A., Kolotilova, N.N.** Introduction to Environmental Microbiology (= *Vvedenie v prirodovedcheskuyu mikrobiologiyu*), Moscow: Knizhnyi dom "Universitet," 2001.

51. **Ostroumov S.A.** Towards the general theory of ecosystem-depended control of water quality // Ecologica, 2009, vol. 16, No. 54, p. 25-32.

52. **Ostroumov S.A., Shestakova T.V.** Decreasing the measurable concentrations of Cu, Zn, Cd, and Pb in the water of the experimental systems containing *Ceratophyllum demersum*: The phytoremediation potential // Doklady Biological Sciences , 2009, vol. 428, no. 1, p. 444-447.

53. **Ostroumov S.A., Shestakova T.V., Kotelevtsev S.V., Solomonova E.A., Golovnya E.G., Poklonov V.A.** Presence of the macrophytes in aquatic system accelerated a decrease in concentrations of copper, lead and other heavy metals in water. // Water Sector of Russia: Problems, Technologies, Management (=Vodnoe Khozyaistvo Rossii). 2009. No. 2. p. 58 - 67.