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## **AQUATIC ECOSYSTEM AS A BIOREACTOR: WATER PURIFICATION AND SOME OTHER FUNCTIONS**

Short title: AQUATIC ECOSYSTEM AS A BIOREACTOR

- 1 Introduction
- 2 Methods
- 3 Role of the main groups of organisms in the biological processes of water purification
- 4 Aquatic ecosystem as a bioreactor with some features
5. Man-made effects and the effects of some xenobiotics
6. Aquatic ecosystems as part of the apparatus of the biosphere
7. Conclusions.

**Abstract.** A fundamental concept is proposed of aquatic ecosystem as a bioreactor that carries out the function of water purification in natural water bodies and streams. The ecosystem as a bioreactor has the following characteristic attributes: (1) it is a large-scale (large-volume) bioreactor; (2) it is a diversified (in terms of the number of taxa and the scope of functional activities) bioreactor; (3) it possesses a broad range of biocatalytic (chemical-transforming and degrading) capabilities. New experimental data on xenobiotics-induced inhibition of the functioning of the molluscs *Unio tumidus*, *U. pictorum*, *M. galloprovincialis* and *Limnaea stagnalis* emphasize the potential ecological hazard from sublethal concentrations of pollutants (including those exemplified by synthetic surfactants and detergents).

**Keywords:** environmental hazards, man-made impacts, anthropogenic effects, pollutants, xenobiotics, aquatic ecosystems, water purification, water filtration, bivalves, surfactants, detergents, biosphere

**Abbreviations:** SDS, sodium dodecylsulfate; TX100, Triton X-100; TDTMA, tetradecyltrimethylammonium bromide;

## 1. INTRODUCTION

Priorities of ecological research include the further studies of ecosystem functioning (Ostroumov et al., [2003]) that include functioning towards water purification (the self-purification of water) in natural water bodies and streams.

The self-purification of water in natural ecosystems is a complex group of processes which includes physical, chemical, and biological components (Sushchenya, [1975]; Alimov [1981], [2000]; Skurlatov, [1988]; Uhlmann, [1988]; Izrael, and Tsyban, [1989]; Ostroumov [1998], [2001], [2002b]; Wetzel [2001]). Although biological aspects of water self-purification are generally attributed to heterotrophic microorganisms, the other groups of organisms are also known to play a significant role in this process (Sushchenya, [1975]; Konstantinov [1979], Alimov [1981], [2000], Wallace, and Starkweather, [1985]; Vymazal, [1988]; Walz, [1995]; Monakov [1998]; Wetzel [2001]; also, Vinberg, [1973]; Bul'on, Nikulina, [1976]; Ivanova, [1976]; Khlebovich, [1976]; - cit. in Ostroumov, [2001]).

The goal of this work was to analyze some data from the literature and our own experimental data on water self-purification under natural conditions and to formulate a fundamental concept of the aquatic ecosystem as an analog of a bioreactor (in a broad sense) that contributes to water self-purification mediated by main groups of aquatic organisms.

This paper is based on some previous publications of the author (Ostroumov [2000c], [2001], [2002a]).

## 2. METHODS

The rate of water purification by macrozoobenthic filter feeders was measured experimentally as described earlier (Ostroumov [2001]). After the water sample had been kept with filter feeders for a certain time, the water filtration efficiency was monitored by the measuring the optical density of the suspension of unfiltered single - cell organisms that remained in the water column. The control samples of water were subjected to the same procedure of filtration, but without the contaminant (chemical) tested. Some other methods of the studies of the effects of contaminants on aquatic organisms are described in (Waterbury & Ostroumov [1994], Ostroumov et al. [1997]).

## 3. ROLE OF THE MAIN GROUPS OF ORGANISMS IN THE BIOLOGICAL PROCESSES OF WATER PURIFICATION

Self-purification of water includes the following biological processes: (1) biodegradation of contaminants; (2) accumulation and sequestration of toxicants in aquatic organisms and the resultant removal of the toxicants from the water column (e.g. Vymazal, [1988]); (3) generation and emission of oxygen required for oxidative degradation of contaminants; (4) uptake of biogenic substances (including N and P) and organic substances from the aquatic environment; (5) production of exometabolites; (6) water filtration (Sushchenya, [1975]; Alimov [1981]; Wallace, and Starkweather, [1985]; Monakov [1998]); and (7) formation of pellet and detritus particles (e.g., Wotton et al. [1998]); and their sedimentation to the bottom (for review, see e.g., Konstantinov, [1979]; Ostroumov [1986], [1998], [2001], [2002b]; Skurlatov, [1988]). This list is far from complete, and some other biological phenomena simultaneously contribute to several processes listed above. Analysis of the relative contributions of individual groups of aquatic organisms to water self-purification as an integral function of an ecosystem (Table 1) shows that the main groups of organisms simultaneously contribute to several processes of the system of water self-purification. None of the main groups of aquatic organisms can be regarded as being insignificant in terms of water purification. The role of each group of aquatic organisms in these processes can be summarized as an integral ecological rating, which is calculated as the sum of the number of pluses in the corresponding row of Table 1. It is seen from Table 1 that this rating is sufficiently high in all groups of organisms.

Thus, the whole range of biological diversity of aquatic organisms is an important factor in water self-purification (Sushchenya, [1975]; Alimov [1981, 2000], Wallace, and Starkweather, [1985]; Wotton et al. [1998]; Ostroumov [2001], Wetzel [2001]). The biota representatives of the water column, the entire ecosystem volume, the boundary regions of the ecosystem, and zones of contact between the ecosystem and its environment are involved in water purification. Activities of unicellular organisms (including those freely suspended in water, immobilized, and attached to various particles, surfaces, and substrates) (e.g., Inkina, [1988]) as well as of other aquatic organisms (e.g., Ostroumov [2001], Wetzel [2001]) suggest that an aquatic ecosystem may be regarded as a bioreactor (in a metaphorically broad sense; i.e., including biological, physical, and chemical aspects). However, unlike industrial bioreactors, such a broad-sense bioreactor has the following important features.

#### 4. AQUATIC ECOSYSTEM AS A BIOREACTOR WITH SOME FEATURES

The first feature is a fundamental difference in the bioreactor size. The volume of technological bioreactors does not exceed a few hundred cubic meters, whereas the volume of natural ecosystems is significantly larger. For example, the volumes of lake and estuary ecosystems reach thousands of cubic kilometers: Lake Baikal, 22995 km<sup>3</sup>; Lake Superior, 12221 km<sup>3</sup>; Lake Michigan, 4871 km<sup>3</sup>; Lake Issyk-Kul, 1730 km<sup>3</sup>; Lake Ladoga, 908 km<sup>3</sup>; Lake Onega, 280 km<sup>3</sup>; Lake Balkhash, 112 km<sup>3</sup>;

and Lake Sevan,  $38 \text{ km}^3$ ; ( $1 \text{ km}^3 = 10^9 \text{ m}^3$ ). This increases the biospheric role of ecological, biochemical, and biofiltration processes in these systems. Therefore, the physical size and volume of the system within which water self-purification take place should be taken into consideration. Thus, natural ecosystems can be regarded as large-size (large-scale) analogues of bioreactors.

The second feature is the differences (in terms of size and diversity) between the gene-pool of organisms inhabiting natural ecosystems and the genetic pool of organisms grown in technological bioreactors. This difference leads to a significantly larger diversity of functional activities of organisms in natural ecosystems. Technological bioreactors are usually inoculated with monocultures or, less frequently, mixed cultures with a small number of constituting species. In contrast to technological bioreactors, the biological diversity of natural ecosystems is substantially broader. According to some incomplete estimates, the number of species in natural ecosystems is as many as several hundred to several thousand (e.g., Konstantinov, [1979]). These estimates were obtained without regard to the number of strains of individual microbial species. If the prokaryote strains are taken into account, the quantitative estimates of the biological diversity of taxa in natural ecosystems may increase by several orders of magnitude.

Third, an aquatic ecosystem is characterized by a higher degree of autonomy (including energy autonomy) than technological bioreactors. This autonomy is based on the presence of autotrophic organisms. Thus we suggest that natural ecosystems should be regarded as multispecies and diversified (i.e., based on the diversity of organisms and their functions) analogs of bioreactors, implementing a broad spectrum of catalytic functions (including transformation and degradation of contaminants).

## 5. MAN-MADE EFFECTS AND THE EFFECTS OF SOME XENOBIOTICS

Anthropogenic sublethal effects (including the inhibition of physiological activities) and behavioral changes in virtually any group or taxon of aquatic organisms may decrease the bioreactor efficiency. Some sublethal effects should be regarded as a potential hazard to the purification function (Ostroumov [1998], [2000a ], [2000b], [2002a]; Ostroumov et al. [1997], [1999 ] ). Because the main groups of macroorganisms and microorganisms play a substantial role in self-purification of ecosystems, it is very important to compare the sensitivities of the organisms to various contaminants. In some cases, macroorganisms are at least as sensitive (or even more sensitive) to contaminants as microorganisms (Table 2).

According to the presently adopted regulation of ecological monitoring and bioassaying, the ability of chemical compounds to damage the self-purification potential of ecosystems is being tested using heterotrophic bacteria alone. However, it follows from Table 2 that this approach may result in an underestimation of the effects of contaminants on more sensitive biological components of self-purified ecosystems (e.g., some macroorganisms).

We obtained new data on the ability of xenobiotics to inhibit water filtration by marine and freshwater organisms and on the hygienic function of pulmonary mollusks associated with elimination of organic matter (the removal of phytomass) from the water column in aquatic ecosystems (Table 3).

Some sublethal concentrations of contaminants may inhibit vital activities of other organisms involved in the functioning of the ecosystem as an analog of a bioreactor (e.g., Ostroumov [2001], [2002a], Ostroumov et al. [1999]).

## 6. AQUATIC ECOSYSTEMS AS PART OF THE APPARATUS OF THE BIOSPHERE

V.I. Vernadsky considered the biota as the apparatus of the biosphere (Vernadsky, [2001]). To continue and develop his thought, we could consider aquatic ecosystems and aquatic biota as a key part of that apparatus. In that capacity, aquatic ecosystem carries a number of functions, not only the one function discussed above (water purification). Among those biospherically important functions are the following: (1) production of organic matter; (2) removing the excess organic matter; ( 3 ) mediating, catalyzing, and regulating biogeochemical flows and cycles; ( 4 ) harboring biodiversity and by doing so harboring the genetic pool of biodiversity; (5) providing links among various parts of the biosphere; ( 6 ) contributing to stability of the biosphere.

## 7. CONCLUSIONS

The fundamental concept put forward in this work emphasizes that both the biological diversity of aquatic organisms and their normal level of physiological activities are required to provide the effective functioning of an ecosystem as an analog of a bioreactor. That bioreactor carries a number of biospherically important functions and processes (we call them 'microbiospheric processes') including those of water purification (environmental remediation, ecological repair). This may lead to a deeper insight into the mechanisms of aquatic ecosystems and to better understanding of hazards of the anthropogenic impact on the biosphere (Yablokov, Ostroumov [1983], [1985], [1991]; Ostroumov [1986]; [Wetzel, 2001]).

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**Table 1.** Contribution of aquatic organisms to some processes important for water self-purification in ecosystem (some examples; a simplified model)

Group of organisms	Biodegradation	Uptake of xenobiotics	Uptake of biogenic and/or organic substances	Production of exometabolites	Oxygen emission	Water filtration	Production of detritus	Regulation of organisms of the previous trophic level
Heterotrophic bacteria	+	+	+	+	–	–	–/+	–/+
Fungi	+	+	+	+	–	–	+	–/+
Cyanobacteria and microalgae	+	+	+	+	+	–	+	–
Protozoans	+	+	+	+	+/-	+/-	+	+
Higher plants	+	+	+	+	+	–/+	+	–
Invertebrates	+	+	+	+	–	+	+	+
Fish and amphibians	+	+	data insufficient	+	–	–/+	+	+

**Table 2.** Effect of Triton X-100 (TX) and tetradecyltrimethylammonium bromide (TDTMA) on biological organisms

Organisms	Biological effects	Substance	Concentration, mg/l	Reference
Bacteria <i>Hyphomonas</i> sp. MHS-3	Insignificant inhibition of growth (4–20%)	TX	5	New data
Bacteria <i>Hyphomonas</i> sp. VP-6	Slight inhibition of growth (7–16%)	TX	5–10	New data
Cyanobacteria <i>Synechococcus</i> sp. 8103	Growth stimulation (47–50.5%)	TX	5	Waterbury, Ostroumov [1994]
Marine bivalves <i>Mytilus edulis</i>	Significant decrease in water filtration efficiency (about 80% within 60 min)	TX	4	Ostroumov [2001]
Marine bivalves <i>Mytilus galloprovincialis</i>	Significant decrease in water filtration efficiency (78.3% within 50 min)	TDTMA	1	New data
Freshwater bivalves <i>Unio tumidus</i>	Significant decrease in water filtration efficiency (45.8% within 85 min)	TX	5	New data

**Table 3.** Inhibition of some functions of molluscs important for water self-purification under exposure to sublethal concentrations of contaminants (new data)

Substances	Organisms	functions inhibited	Marine (m) or freshwater (f) systems
TX100 (1–5 mg/l)	<i>Unio tumidus</i>	Water filtration of water	f
TDMA (1–2 mg/l)	<i>Unio pictorum</i>	filtration of water	f
TDMA (1 mg/l), SDS (1.7 mg/l), synthetic detergents (Lotos-Extra, Losk-Universal, and Tide-Lemon; 6.7–50 mg/l), Avon Hair Care (shampoo) (5–60 mg/l)	<i>Mytilus galloprovincialis</i>	filtration of water	m
TX100, TDMA (2 mg/l), Tide-Lemon (75 mg/l)	<i>Lymnaea stagnalis</i>	Elimination of phytomass from the upper layers of the water column	f

Note: SDS, sodium dodecylsulfate; TX100, Triton X-100;

TDMA, tetradecyltrimethylammonium bromide;

### Addendum (written in 2010):

After preparing this paper for publication, a number of other articles and some books were published, which supported the main conclusions of this paper. Among those more recent publications were the following:

1. Ostroumov S. A. Biological Effects of Surfactants. CRC Press. Taylor & Francis. Boca Raton, London, New York. 2006. 279 p. ISBN 0-8493-2526-9 [new facts and concepts on assessment of hazards from chemicals, new look on the factors important to water quality, to sustainability; new priorities in environmental safety];
2. Ostroumov S. A. On the biotic self-purification of aquatic ecosystems: elements of the theory. - Doklady Biological Sciences, 2004, Vol. 396, Numbers 1-6, p. 206-211. [https://www.researchgate.net/file/FileLoader.html?key=60f338228d6f3c5114d223ab81e15d3b](https://www.researchgate.net/file/FileLoader.html?key=60f338228d6f3c5114d223ab81e15d3b;); [https://www.researchgate.net/profile/Sergei\\_Ostroumov/blog/348\\_Useful\\_theory\\_of\\_natural\\_mechanisms\\_of\\_improving\\_water\\_quality](https://www.researchgate.net/profile/Sergei_Ostroumov/blog/348_Useful_theory_of_natural_mechanisms_of_improving_water_quality)
3. Ostroumov S. A. Suspension-feeders as factors influencing water quality in aquatic ecosystems. - In: The Comparative Roles of Suspension-Feeders in Ecosystems, R.F. Dame, S. Olenin (Eds), Springer, Dordrecht, 2004. p. 147-164.
4. Ostroumov S. A. Some aspects of water filtering activity of filter-feeders // Hydrobiologia, 2005. Vol. 542, No. 1. P. 275 – 286. <http://scipeople.com/uploads/materials/4389/5Hydr542p275water.filt.doc>
5. Ostroumov S. A. On some issues of maintaining water quality and self-purification. - Water Resources. 2005, Volume 32, Number 3, p. 305-313.
6. Ostroumov S. A. On the multifunctional role of the biota in the self-purification of aquatic ecosystems // Russian Journal of Ecology, Vol. 36, No. 6, 2005, p. 414–420.
7. Ostroumov S. A. Biomachinery for maintaining water quality and natural water self-purification in marine and estuarine systems: elements of a qualitative theory // International Journal of Oceans and Oceanography. 2006. Volume 1, No.1. p.111-118. [ISSN 0973-2667]. Publisher: Research India Publications, Dehli]. Basic elements are formulated for a qualitative theory of the polyfunctional role of the biota in maintaining self-purification and water quality in aquatic ecosystems. The elements of the theory covers the following: (1) sources of energy for the mechanisms of self-purification; (2) the main functional blocks of the system of self-purification; (3) the list of the main processes that are involved; (4) analysis of the degree of participation of the main large taxa; (5) degree of reliability and the main mechanisms providing the reliability; (6) regulation of the processes; (7) the response of the system towards the external influences (man-made impacts); (8) the analogy between ecosystems and a bioreactor; and (9) conclusions relevant to the practice of biodiversity conservation. In support of the theory, results are given of the author's experiments which demonstrated the ability of some pollutants (surfactants, detergents, and some others) to inhibit the water filtration activity of marine filter-feeders (namely, the bivalve mollusks *Mytilus galloprovincialis*, *Mytilus edulis*, and *Crassostrea gigas*).
8. Ostroumov S. A., Widdows J. Inhibition of mussel suspension feeding by surfactants of three classes. // Hydrobiologia. 2006. Vol. 556, No. 1. Pages: 381 – 386. 3 Tables. Bibliogr. 37 refs. [For the first time the negative effects of the three surfactants on the filtration rates by marine mussels were presented in one paper. The xenobiotics tested represented anionic, cationic and non-ionic surfactants (tetradecyltrimethylammonium bromide, TDTMA, a representative of a class of cationic surfactants; sodium dodecyl sulphate, SDS, a representative of anionic alkyl sulfates; and Triton X-100, a representative of non-ionic hydroxyethylated alkyl phenols). Negative effects of SDS, TDTMA, and Triton X-100 on the filtration activity of marine mussels *M. edulis* and *M. edulis* / *M. galloprovincialis*

- were discovered. All three surfactants inhibited the clearance rates. This is the first publication of the negative effects of a cationic surfactant on Atlantic mussels *Mytilus*. The significance of the results for the ecology of marine ecosystems is discussed]. DOI 10.1007/s10750-005-1200-7; <http://sites.google.com/site/ostroumovsergei/publications-1/hydrobiologia2006ostwidd>; <http://sites.google.com/site/3surfactantsfiltrationmytilus/>; [http://scipeople.ru/uploads/materials/4389/\\_Hydrobiologia2006%20vol%20556%20No.1%20pages381-386.pdf](http://scipeople.ru/uploads/materials/4389/_Hydrobiologia2006%20vol%20556%20No.1%20pages381-386.pdf); <http://www.springerlink.com/content/7166067538534421/>
9. Ostroumov S. A. Biotic self-purification of aquatic ecosystems: from the theory to ecotechnologies. - *Ecologica*, 2007. vol. 15 (50), p.15-23. (ISSN 0354-3285; Belgrade). Some basic elements of a new theory for the biological mechanism for water self-purification are presented. Hydrobionts (aquatic organisms) are actively involved in various processes leading to water purification. Not only microorganisms (bacteria, cyanobacteria and fungi), but also algae, plants, invertebrates, and many other groups of organisms are involved, which is discussed and analyzed in the paper. Results of the author's experiments that study the effects of various pollutants on aquatic organisms (freshwater and marine bivalves) are given. The theory is an innovative basis for developing ecological technologies to clean water and to upgrade its quality by using organisms and ecosystems [<http://scindeks.nb.rs/article.aspx?artid=0354-328507500150>].
  10. Ostroumov S. A. Basics of the molecular-ecological mechanism of water quality formation and water self-purification.- *Contemporary Problems of Ecology*, 2008, Vol. 1, No. 1, p. 147-152. [MAIK Nauka/Interperiodica; distributed by Springer Science+Business Media LLC; ISSN 1995-4255 (Print) 1995-4263 (Online); DOI 10.1134/S1995425508010177;
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  14. 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.
  15. 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. <http://sites.google.com/site/9dbs444/>; <https://www.researchgate.net/file/FileLoader.html?key=8fd8998627b86102db72c9b237c25054>;
  16. Biotic Mechanism of Self-purification of Freshwater and Marine Water. (Ecological Studies, Hazards, Solutions, vol. 9) Moscow: MAX Press. 2004. IV. 96 p., Abstract in English. Section in English: p.53-58; ISBN 5-317-01120-5. [Diploma of the Academy of Aquatic Sciences, awarded in 2006; another Diploma to the book was awarded at the 7th International Conference 'Aquatic Ecosystems, Organisms, Innovations' (2005)].
  17. Pollution, Self-purification and Restoration of Aquatic Ecosystems. Moscow: MAX Press. 2005. 100 p., tab. ISBN 5-317-01213-9. (Diploma of the Academy of Aquatic Sciences, awarded in 2006).
  18. Ostroumov S. A. Basics of the molecular-ecological mechanism of water quality formation and water self-purification. - *Contemporary Problems of Ecology*, 2008 (Feb), Vol. 1, No. 1, p. 147-152. [ISSN 1995-4255(Print) 1995-4263 (Online); DOI 10.1134/S1995425508010177;

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[http://scipeople.com/uploads/materials/4389/CPEC2008BasicsMolEcol.Mech.WaterQuali\(0147\).pdf;](http://scipeople.com/uploads/materials/4389/CPEC2008BasicsMolEcol.Mech.WaterQuali(0147).pdf)

19. Aquatic organisms in water self-purification and biogenic migration of elements. Moscow. MAX Press. 2008. 200 p. ISBN 978-5-317-02625-7.
20. Ostroumov S.A. Towards the general theory of ecosystem-depended control of water quality. - *Ecologica*, 2009, vol. 16, No. 54, p. 25-32. (Faculty of Biology, Moscow State University, Leninskie Gory, Moscow, 119991 Russia). Abstract: A new set of ecological generalizations formulated 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. <http://sites.google.com/site/9enecological16p25theory/>
21. Biocontrol of Water Quality: Multifunctional Role of Biota in Water Self-Purification.- *Russian Journal of General Chemistry*, 2010, 80 (13): 2754–2761. DOI: 10.1134/S1070363210130086; The full text see: <http://www.scribd.com/doc/49131150/10Rus-J-gen-Chem-biocon-water-Q-inen-Fulltext>;  
<http://www.scribd.com/doc/49131150>; <http://www.springerlink.com/content/y27060285142j5j1>;

**Some of the publications above [1-42] and the results in them won some awards and Diplomas, including:**

Diploma at the 1st International Forum on Conservancy of Nature (Moscow, 7-9th September 2005), signed by Co-Chairs of the Forum, Deputy Minister of Natural Resources of Russian Federation and Vice-President of the Trade Chamber of Russian Federation).

Diploma of the journal 'Ecology and Life' (awarded 15 October 2005).

Diploma of the competition 'Sustainable use of natural resources and environmental protection – strategy of sustainable development of Russia in the 21st century' at the international conference 'Sustainable Development: Nature-Society-Man' (organized in 2006, Moscow, by the Ministry of Natural Resources) for the paper by Ostroumov S.A. and Solomonova E.A. "On studies of water self-purification and interactions between pollutants (surfactants) and biota: searching approaches to issues relevant to sustainable use of water resources " (Directive of the Ministry of Natural Resources No.126 of 2 June 2006; the Diploma was signed by the Minister).

Diploma to the book 'Biotic Mechanism of Self-purification of Freshwater and Marine Water' by Dr. S. A. Ostroumov, awarded at the 7th International Conference 'Aquatic Ecosystems, Organisms, Innovations' (2005). Diploma of the Academy of Aquatic Sciences for the series of innovative publications on aquatic ecology, interactions between chemicals and organisms, and water self-purification, including the books 'Biological Effects of Surfactants in Connection with the Anthropogenic Impact on the Biosphere'; 'Biological Effects of Surfactants on Organisms'; 'Biotic Mechanism of Self-Purification of Freshwater and Marine

Water'; 'Pollution, Self-Purification and Restoration of Aquatic Ecosystems'; 'Biological Effects of Surfactants', (awarded in 2006).

Diploma of the Academy of Aquatic Sciences 'for his innovative contribution to improvement of environmental and ecological education', including the book 'Ecology and Hydrobiology. Curricula of Lecture Courses' (awarded in 2006).

Diploma of the Moscow Society of the Researchers of Nature (awarded in 2007).

**Positive evaluations of some of the results in the publications above see in:**

Petrosyan V.S. Review of the book: Biological Effects of Surfactants. CRC Press. Taylor & Francis. - Ecological Studies, Hazards, Solutions, 2007. vol. 12, p. 117-119 (in English).

Review of the book: Ostroumov S.A. Biological Effects of Surfactants. CRC Press. Taylor & Francis. Boca Raton, London, New York. 2006. 279 p. – Bulletin Samarskaya Luka. - 2007. - V. 16, № 4(22). - P. 864-867. Bibliogr. 10 refs. [http://www.ssc.smr.ru/media/journals/samluka/2007/16\\_4\\_22.pdf](http://www.ssc.smr.ru/media/journals/samluka/2007/16_4_22.pdf)

Review of the book: Biological Effects of Surfactants. CRC Press. Taylor & Francis. Boca Raton, London, New York. 2006. 279 p. // Problems of Biogeochemistry and Geochemical Ecology. 2007. № 2 (4). p.108.

Review of the book: S.A.Ostroumov. Biological Effects of Surfactants (2006). - Ecologica, 2008. v.15, No. 51, p. 71-72. (ISSN 0354-3285; in English).

Ermakov V.V. Review of the book: Ostroumov S.A. Biological Effects of Surfactants. CRC Press. Taylor & Francis. Boca Raton, London, New York. 2006. 279 p. – Toxicological Review [Toksikologicheskij Vestnik], 2009, No. 2, p. 40.

**ADDITIONAL USEFUL MATERIALS:**

1. <http://www.scribd.com/doc/51414359>; - Ecology. Key Innovations, Discoveries. NEW FACTS, and NEW CONCEPTS. The material is a brief summary of innovations in the publications authored and coauthored by Dr. S.A. Ostroumov: ecology, environmental science, biology, ecotoxicology, biogeochemistry;

2. Citation: World-wide and international citing of the publications authored and co-authored by Dr. S.A. O.:

[http://www.researchgate.net/profile/Sergei\\_Ostroumov/blog/10030\\_Ecologyciting\\_of\\_the\\_publications\\_authored\\_by\\_DrSAOstroumov](http://www.researchgate.net/profile/Sergei_Ostroumov/blog/10030_Ecologyciting_of_the_publications_authored_by_DrSAOstroumov);  
<http://www.scribd.com/doc/50443283/Table-WorldWideCiting-March10>;