CHAPTER 8

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INNOVATIVE ECOBIOTECHNOLOGY TO MAKE WATER CLEAN: THEORY OF ENERGY-SAVING, CARBON EMISSION-REDUCING BIOMACHINERY OF WATER SELF-PURIFICATION

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Abstract. *In order to develop the scientific basis for an innovative ecological biotechnology to improve water quality, to remediate polluted aquatic systems, to treat waste water, the author originated a novel theory of ecosystem driven water self-purification. Fundamental elements are formulated by the author for a qualitative theory of the polyfunctional (multifunctional) 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 aquatic filter-feeders (namely, the bivalve mollusks Unio sp., Mytilus galloprovincialis, Mytilus edulis, Crassostrea gigas, rotifers, and crustaceans). Aquatic plants are another example of organism which are of key importance in water purification. This theory is useful to create an innovative biotechnology which has important advantages: it is (1) energy-saving and (2) carbon emission reducing technology.*

Keywords: *Water self-purification, Ecological biotechnology, Aquatic ecosystems, Pollution control, Water quality, Filter-feeders, Aquatic plants, Biomachinery.*

INTRODUCTION

Currently, the role of water self-purification increases due to the deterioration of natural water quality (Moiseenko, 1999) and increased anthropogenic load of pollutants on water bodies and streams (Moiseenko, 1999; Ostroumov, 2004a). The self-purification of aquatic ecosystems and water quality formation is controlled by many factors and processes (Ostroumov, 2004a; 2004d).

The objective of this study is to systematize the knowledge about the polyfunctional (multifunctional) role of aquatic biota (aquatic animals, plants, microorganisms) 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 structurization of material was made here at the conceptual level on the basis of (Ostroumov, 2004d), without detailed reviews of works.

MAJOR PROCESSES AND FACTORS THAT CONTRIBUTE TO WATER SELF-PURIFICATION IN AQUATIC ECOSYSTEMS

The formation of water quality and its purification in aquatic ecosystems is governed by physical, chemical, and biotic (Ostroumov, 2003, 2003b, 2004a, 2004d) processes (Table 1). 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 hydrogen peroxide (H_2O_2) released by microalgae in the light (Ostroumov, 2004a), is of importance for a decrease in the toxic effect of some pollutants. The amount of hydrogen peroxide released into the aquatic environment was estimated at 10^{-5} mol/(l day).

The concentration of hydrogen peroxide 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 (Ostroumov, 2004a). An important process is gravitational sedimentation of suspended particles both of biotic and abiotic nature. The sedimentation of phytoplankton sedimentation 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 giant pond snail (Lymnaea stagnalis) pellets varies from 0.6 to 1.4 cm/s with a mean value of 0.82 cm/s (at T = 22-24°C) (Ostroumov, 2004a). Experiments with traps for suspended particles showed that suspended matter precipitates onto the bed of the Moskva River 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 Corg (organic carbon) in these sediments is 64.5% (Ostroumov et al., 2001). Organic matter oxidation and water filtration by aquatic animals are among the biotic processes contributing to 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 Schrödinger 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, but it can be even greater in some water bodies. For example, the Schrodinger ratio is 17.0 in Lake Lyubevoe in Leningrad province and 33.8 in Lake Zun-Torei east of Lake Baikal. 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 animals contribute to organic matter oxidation, but particular role in this oxidation belongs to bacteria (Ostroumov, 2003). The total population of heterotrophic bacterioplankton in the Mozhaisk Reservoir in June and July amounted to $(1.36–5.9) \times 10^9$ (samples were taken at a depth of 0.1–1 m), and the population of hydrocarbon-oxidizing bacteria was $(0.4–5) \times 10^6$ cell/ml. The rates of water filtration by some aquatic animals (bivalve mollusks, barnacles, ascidians, Tunicata, Polychaeta, sponges, echinoderms, and other groups of filter-feeders (suspension feeders) commonly amount to 1-9 l/h per 1 g of de-ashed dry mass (AFDM, ash-free dry mass) of their body (Ostroumov, 2004a). The dependence of filtration rate FR (units: l/h), on the mass of the aquatic animal DW (units: g), can be described by the power function (Ostroumov, 2004a): FR = aDWb, (1) were DW is the dry weight of soft tissues (units: g).

The values of coefficient a for some mollusk species vary from 6.8 to 11.6, and the value of coefficient b is between 0.66 and 0.92 (Ostroumov, 2004a). The rate of water filtration by five mollusk species converted to the area of their gills is about 1.2–1.9 ml/min per 1 cm^2 (Ostroumov, 2004a). The total rate of water filtration by populations of macroinvertebrates (mollusks, polychaetes, and others) was estimated at 1–10 m^3 per 1 m^2 of the bed of the aquatic ecosystem per 1 day (Ostroumov, 2004a).

Additional data on the filtration activity of aquatic invertebrate animals is given in Tables 2 and 3 in another paper (published by the author in the journal "Water Resources".

It is useful to summarize and put into a system the current knowledge on a diversity of factors and processes involved in water self-purification in aquatic ecosystems in the form of three tables:

(1) on physical and physico-chemical factors;

(2) on chemical factors;

(3) on biological factors.

It is interesting that when we made these tables, we observed that the first two groups of factors depend on biological factors. The resulting tables are presented below.

Table 1. Physical and physicochemical factors that are relevant to water self-purification.

Physical and physicochemical factors	Comments on dependence on biological factors
1. Dissolution and dilution of pollutants.	Mechanical transfer of water masses can depend on the abundance of macrophytes;
2. Transfer of pollutants to the shore	The same as above
3. Transfer of pollutants to neighboring water bodies and streams	The same as above
4. Sorption of pollutants by suspended particles with subsequent sedimentation	Depends on the concentration of suspended particles of biogenic nature in water
5. Sorption of pollutants by bottom sediments	Depends of the concentration of organic matter of biogenic nature in bottom sediments
6. Evaporation of pollutants	May depend on the surface film, the properties of which depend on the composition of DOM (dissolved organic matter)

This is an original table, it is based on (Ostroumov, 2004a, 2004d), and also on some other our publications, as well as many publications and materials of other authors, including those online.

The next table is on chemical factors, processes and phenomena.

Table 2. Chemical factors and processes that are relevant to water self-purification.

Chemical factors	Comments on dependence on biological factors
1. Hydrolysis	May depend on pH which changes during planktonic photosynthesis
2. Photochemical transformations	Depends on the concentration of photosensitizers of biogenic nature and water transparency, which, in its turn, depends on plankton

3. Redox–catalytic transformations	Concentration of catalytically active form of metal ion depends on the pH of the environment, which, in its turn, depends on the photosynthetic activity of plankton
4. Transformations involving free radicals.	Depend on the concentration of hydrogen peroxide (H_2O_2) that forms with the participation of aquatic animals (photosensitized transformation of DOM, release by microalgae)
5. Decrease in toxicity of pollutants as a result of binding with DOM.	Depends on DOM of biogenic nature; roles of humic acids are possible
6. Chemical oxidation of pollutant with the participation of oxygen	Depends on oxygen (O_2) release into water during photosynthesis
7. Decrease in toxicity of pollutants as a result of binding with particulate organic, mineral or organomineral matter	Depends on suspended particles of biogenic nature

This is an original table, it is based on (Ostroumov, 2004a, 2004d), and also on some other our publications, as well as many publications and materials of other authors, including those online. DOM is dissolved organic matter.

The next table is on biological factors, processes and phenomena.

Table 3. Biological factors and processes that are relevant to water self-purification

Biological factors	Comments
1. Release of O_2 from higher plants, algae and cyanobacteria; the oxygen takes part in many reactions of pollutant oxidation	O_2 release into water takes place during photosynthesis
2. Sorption and accumulation of pollutants and nutrients by aquatic animals	Depends on the populations and activity of aquatic animals
3. Biotransformation (redox–reactions, destruction, conjugation)	The same as above
4. Extracellular enzymatic transformation of pollutants.	Depends on the populations and activity of aquatic organisms
5. Removal of suspended particles and pollutants from water column as a result of water filtration by aquatic animals.	Is inhibited under the effect of some pollutants (according to the author's data: surfactants, synthetic detergents)

6. Removal of pollutants from water as a result of sorption by pellets excreted by aquatic animals	Pellet formation is reduced when feeding of aquatic animals is inhibited, as it was shown by the author
7. Release into water of organic matter, which can be used by bacteria or exert a regulatory effect on them	—
8. Organic matter release by phytoplankton was recorded.	Higher aquatic plants also release exometabolites
9. Release into water of organic matter that serves as a photosensitizer of pollutant photolysis or predecessors of photosensitizers	Depends on the population and functional activity of aquatic organisms
10. Release into water of organic matter (or predecessors of such matter), which will bind with pollutants with the formation of less toxic complexes	The same as above
11. Release into water of organic matter (or predecessors of such matter), which participate in free-radical and redox–catalytic mechanisms of pollutant destruction	—
12. Microalgae release hydrogen peroxide to water.	hydrogen peroxide may influence chemical reactions and processes in water
13. Release into water of vitamins, which are necessary for the vital activity of some aquatic animals, participating in self-purification of aquatic ecosystems	Water of lakes and pools contains, µg/l: vitamin B12 (0.001–0.85), thiamine (0.001–12), biotin (0.0001–0.1), niacin (up to 3.3), pantothenic acid (up to 0.26), and others vitamins
14. Removal or inactivation of some of bacteria, including pathogenic strains	Takes place at filtration activity of aquatic animals. Inactivation can take place under the effect of metabolites of aquatic organisms.
15. Prevention or slow-down of the release of nutrients and pollutants from bottom sediments into water; accumulation and binding of nutrients and pollutants by benthic organisms	Depends on the populations and functional activity of benthos.

16. Biotransformation and sorption of pollutants in soil during soil watering by wastewaters	Depends on the soil biocenoses (biological communities).
17. Regulation of the populations and activity of organisms participating in the processes of water purification as a result of organism-to-organism interaction	Depends on the preservation of intact community.

This is an original table, it is based on (Ostroumov, 2004a, 2004d), and also on some other our publications, as well as many publications and materials of other authors, including those online.

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

The hydrobiological self-purification mechanism of aquatic ecosystems incorporates four types of components (Ostroumov, 2004, 2004a, 2004d):

Type 1: Filters as functional components of the machinery for water self-purification; filtration activity of organisms ("filters") (Ostroumov, 1998);

Type 2: Pumps as functional components of the machinery for ecosystem water self-purification; the mechanisms of transfer of chemicals from one ecological compartment into another (from one medium into another);

Type 3: Mills as functional components of the ecosystem machinery for water self-purification; splitting pollutant molecules.

Type 4: Sorbents as functional components of the machinery for water self-purification; sorption of ecotoxicants, pollutants on biogenic sorbents – both biomass and non-alive biogenic material.

FILTERS AS FUNCTIONAL COMPONENTS OF ECOSYSTEM MACHINERY FOR ECOLOGICAL WATER SELF-PURIFICATION

The processes and aquatic animals that serve as filters (not only suspension feeders) (Ostroumov, 2004d), namely:

(1) invertebrate filter-feeders (suspension feeders);

(2) coastal macrophytes, which retain some nutrients and pollutants delivered into water from neighboring areas;

(3) benthos, which retains and absorbs part of nutrients and pollutants at the water–bottom sediment interface;

(4) microorganisms that are 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 (Ostroumov, 1998). Sedimentation (precipitation) of suspended particles, that is, their movement in the surrounding water enhances oxygen (O_2) exchange between the adsorbed bacteria and the aquatic medium.

PUMPS AS FUNCTIONAL COMPONENTS OF THE MACHINERY FOR ECOSYSTEM WATER SELF-PURIFICATION

The processes and aquatic animals that serve as pumps (Ostroumov, 2004d), namely:

(1) facilitating the transfer of part of pollutant from the water column into bottom sediments (e.g., sedimentation, sorption);

(2) transferring part of pollutant from the water column into the atmosphere (evaporation);

(3) transferring part of nutrients from water into the territory of neighboring terrestrial ecosystems because of the emergence of imago of aquatic insects;

(4) transfer of part of nutrients from water onto the territory of neighboring terrestrial ecosystems through fish-eating birds, which withdraw fish biomass from water.

MILLS AS FUNCTIONAL COMPONENTS OF ECOSYSTEM MACHINERY FOR WATER SELF-PURIFICATION; SPLITTING, DESTRUCTION OF POLLUTANT MOLECULES.

The processes and aquatic animals that serve as mills and split pollutants (Ostroumov, 2004d), namely:

(1) intracellular enzymatic processes;

(2) processes catalyzed by extracellular enzymes;

(3) decomposition of pollutants by photolysis: photochemical processes, sensitized by nutrients;

(4) destruction of pollutants in the free-radical processes with the participation of biogenic ligands.

SORBENTS AS FUNCTIONAL COMPONENTS OF THE MACHINERY FOR WATER SELF-PURIFICATION.

In a series of other publications the author described his experiments on studying sorption and biosorption of a number of toxic chemicals by biogenic sorbents. The author considered and discussed roles of biosorbents (including both biomass and non-alive biogenic materials) in removal and immobilization of toxic chemical components.

We demonstrated the removal of some amount of heavy metals from water as a result of interaction of them with biomass of aquatic plants (macrophytes). This result is in accord with experiments of other researchers.

In several publications, the author coined, explained and justified a new terminology which is useful to identify and analyze the extremely relevant role of non-alive biogenic material to remove toxic chemicals from the environment. The author introduced the new expression, namely ‘ex-living matter’ (E.L.M.). This functional type of matter includes several kinds of biogenic material which contribute to detoxification of the environment (including aquatic environment). By performing sorption, ex-living matter removes ecotoxicants from water and makes aquatic habitats safer for aquatic organisms. Functionally, this result is equivalent to water quality improvement and water self-purification.

ENERGY SOURCES FOR BIOTIC SELF-PURIFICATION MECHANISMS OF AQUATIC ECOSYSTEMS.

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 (Ostroumov, 1998). 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 methane CH_4), and anoxygenic phototrophic community (with the formation of S, H_2S, H_2, and methane CH_4).

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 (knellgasbacteria), methane CH_4 (methanotrophs), NH_3 (nitrifiers), H_2S (thiobacteria), thiosulfate (thionic bacteria) .

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 (Wetzel, 2001).

CONTRIBUTION OF MAJOR TAXA TO SELF-PURIFICATION PROCESSES IN AQUATIC ECOSYSTEMS.

Practically all major groups of organisms contribute to self-purification of aquatic ecosystems and formation of water quality (Zavarzin, Kolotilova, 2001; Ostroumov, 2002b, 2002c, 2003a, 2003b, 2004a).

Significant roles belong to microorganisms (Table 4), phytoplankton, higher plants, protozoa, zooplankton, benthic invertebrates, and fish. All these groups contribute largely to the self-purification of aquatic ecosystems, each group taking part in several processes. 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.

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

An important process of water self-purification is water filtration by organisms of many taxa. A detailed list of taxa, including planktonic and benthic filterers in aquatic ecosystems, is given in (Ostroumov, 2002).

Table 4. Role of bacterial (microbial) communities in the self-purification of aquatic ecosystems

Types of microbial (bacterial) community	Substrates which are being transformed (consumed) by the bacteria
Methanogenic community	Decompose biopolymers, form acetate, volatile fatty acids (VFA), hydrogen, methane CH_4
Sulfidogenic community	Decompose biopolymers, produce volatile fatty acids (VFA), hydrogen, acetate, lactate, H_2S, methane (CH_4)
Anoxigenic phototrophic community (oxidation anoxic phototrophic filter)	Consume volatile fatty acids (VFA), hydrogen, lactate, acetate, H_2S; produce hydrogen, acetate, H_2S, methane CH4 , SO_4^{2-}
Oxidation aerobic filter (gasotrophs)	Consume (oxidize) hydrogen, methane CH_4 , volatile fatty acids (VFA), thiosulfate, H_2S

(part of examples is given; some microbial groups are involved in the functioning of bacterial communities of several types (Zavarzin, Kolotilova, 2001; Ostroumov, 2004a) and others; VFA are volatile fatty acids)

The contributions of different groups of organisms to carbon (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.

Virtually all groups of organisms belonging to procaryotes and eucaryotes are necessary for water self-purification.

Some additional information on the roles of some communities of microorganisms is given in Table 4.

THE RELIABILITY OF WATER SELF-PURIFICATION SYSTEM

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.

Additionally, benthos duplicates the activity of planktonic organisms permanently inhabiting the pelagic zone, since the larvae of many benthic filterers follow the planktonic pattern. Plankton incorporates two large groups of many-celled invertebrate filter-feeders (suspension feeders), i.e., crustaceans and rotifers, both of which implement water filtration. One more large group of organisms (protozoa), which has somewhat different type of nutrition, also duplicates the filtration activity of multicellular filter-feeders (crustaceans and rotifers).

The oxidative decomposition of pollutants is partially duplicated by the activity of bacteria and fungi. Almost all aquatic animals, which are, in some way or another, capable of consuming and oxidizing organic matter, perform this function.

Self-regulation of the 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 of organisms of both lower and higher trophic levels in the food chain. The regulating role of organisms can be effectively studied with the use of the author's method of inhibitory analysis of regulatory interactions or trophic interactions in trophic chains (Ostroumov, 2002b). It could be noted that the publication (Ostroumov, 2000) is the first paper on using inhibitory analysis in ecology, in trophic chains, in trophic webs.

Various forms of signaling, including information-bearing chemicals (the author coined the special terminology: ecological chemoregulators and ecological chemomediators (Ostroumov, 2003a)). These new terms identified new classes of molecules which play important roles in regulation of ecosystems. Water self-purification and restoration of its quality is an important component of ecosystem self-stabilization and self-organization. This enables the restoration of the normal state of habitats for aquatic species in ecosystems.

Such restoration and maintenance of water quality is necessary for ecosystem stability. The causes for that are many. First, all types of anthropogenic pollution of water. Second, because autochthonous and allochthonous organic matter and nutrients are permanently delivered into water both from land and by water of tributaries, as well as by atmospheric precipitation, and solid particles carried by air.

Therefore, water self-purification is as important for aquatic ecosystems as the DNA repair is for the heredity system. This allows us to consider water self-purification as an ecological repair in aquatic ecosystems.

The wide range of the water filtration activity of invertebrates suggests the need to regulate this activity of filter feeders (suspension feeders). The volume of water filtered within an hour and measured in body volumes of the filter-feeders amounts to 5×10^6 for nanoflagellates and 5×10^5 for ciliates.

Cladocerans filter up to 4-14 ml per one organism per day. Copepods and rotifers filter 2-27 and 0.07-0.3 ml/day per animal, respectively.

All these aquatic animals and other filter-feeders (suspension-feeders) remove various types of suspension from water. Thus, all forms of regulation and communication of organisms within community are of importance for maintaining the reliability of ecosystem functioning.

An important role in the regulation and communication in aquatic communities belongs to some dissolved substances produced by organisms, namely, ecological chemoregulators and ecological chemo-mediators (Ostroumov, 2003a).

ON THE CONNECTION BETWEEN THE RELIABILITY OF WATER SELF-PURIFICATION SYSTEM AND AQUATIC ECOSYSTEM STABILITY

Filtration activity is not only a part of water self-purification process and water quality repair, but also it is a part of processes that maintain the stability of the aquatic ecosystem. The stability is performed through the conditioning of water, which serves as a habitat for many aquatic species, and through what we call "the ecological tax for the environmental stability" that filter-feeders pay in the form of removing suspended particles from water and producing pellets of organic and organomineral material.

These pellets form in the organisms that are filter-feeders (e.g., mollusks) from particulate organic matter (plankton, seston). These organisms filter the organic particles (plankton, seston) from water and then release this organic material into the aquatic environment in the form of pellets.

Pellets sediment onto the bottom of water bodies or streams. They are used as food by many other aquatic organims, including zoobenthos and bacteria.

The "ecological tax" is surprisingly high as compared with the share of carbon (C) of the organic matter which goes to assimilation and production. In some cases, it can be >100%, when calculated as the ratio of the amount of carbon not assimilated from the food (that is, carbon in fecal and pseudofecal pellets) to the amount of carbon consumed and assimilated for production.

The formation of pseudofeces by mollusks which are filter-feeders (that is, the process in which a part of the filtered seston does not pass through the digestive tract of the mollusk but is prepared to the release into the aquatic environment in the form of pellets) begins at low seston concentrations.

Thus, at the concentration of seston as low as 2.6 mg/l (the concentration of seston can be much greater), marine mussels Mytilus edulis (shell size of 1.7 cm) started releasing pseudofecal pellets (Ostroumov, 2004a).

Therefore, the formation of pseudofeces is not the result of excessive concentration of organic matter in the aquatic environment. The high “ecological tax” is justified because the filter-feeders (suspension 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 vital regulators of global geochemical cycles (e.g., of water and of carbon C), the stability of which withstands and counteract the modern hazard of global disturbances. Therefore, the reliability of water self-purification system is of importance for the global stability in the biosphere (Ostroumov, 2003).

RESPONSE OF THE ENTIRE SYSTEM OF WATER SELF-PURIFICATION TO EXTERNAL (ANTHROPOGENIC) IMPACTS ON AQUATIC ECOSYSTEM (WATER BODY OR STREAM)

The author has found an essential lability (changeability, vulnerability) of one of the processes involved in water self-purification, namely, water filtration by aquatic animals (as exemplified by bivalve mollusks and rotifers) (Ostroumov, 1998, 2002b, 2002c, 2003b).

Table 5. Effect of various chemical pollutants on suspension withdrawal from water by filter-feeders (suspension feeders) (Ostroumov, 2004, 2004a; Ostroumov et al., 1997; and others).

Substances (ecotoxicants, chemical pollutants, xenobiotics)	Aquatic Organisms	Concentrations, mg/l
SDS (anionic surfactant)	*Daphnia magna* (zooplankton)	-
TX-100 (non-ionic surfactant)	*Unio tumidus* (freshwater bivalve mollusk, freshwater mussel)	5
TDTMA (cationic surfactant)	*Crassostrea gigas* (aquatic bivalve mollusk)	0.5
SDS (anionic surfactant)	*M. edulis, M. galloprovincialis* (aquatic bivalve mollusks)	>1

The same as above	C. gigas (aquatic bivalve mollusk)	0.5
Copper sulfate (salt of copper, Cu)	*M. galloprovincialis* (aquatic bivalve mollusk)	2
Lead nitrate (salt of lead, Pb)	*M. galloprovincialis* (aquatic bivalve mollusk)	20
LD E (liquid detergent)	*C. gigas* (aquatic bivalve mollusk)	2
LD Fairy (liquid detergent)	*C. gigas* (aquatic bivalve mollusk)	2
TMOC	*Dreissena polymorpha* (freshwater bivalve mollusk, zebra mussel)	0.01–10
TDTMA (cationic surfactant)	*Brachionus angularis* (rotifer, zooplankton)	0.5
The same as above	*B. plicatilis* (rotifer, zooplankton)	0.5
The same as above	*B. calyciflorus* (rotifer, zooplankton)	0.5

Author's experimental data, some of them in co-authorship. LD is liquid detergent, SDS is sodium dodecyl sulfate (an anionic surfactant), TDTMA is tetradecyl trimethyl ammonium bromide (a cationic surfactant), TMOC is trimethyltinchloride.

Water filtration was inhibited – as it was shown in our experiments - by sublethal concentrations of anthropogenic pollutants, such as synthetic surfactants, surfactant-containing mixed preparations, and heavy metals (Table 5). Other pollutants were found to have similar effect on mollusks and zooplanktonic filter-feeders (suspension feeders) (Ostroumov, 2004a; Donkin et al., 1997). The population biomass of filter-feeders in polluted aquatic ecosystems decreases, the result of which is an additional slow-down of the total filtration activity in such ecosystems.

Therefore, the system of water self-purification processes and its quality formation is labile and vulnerable. The obtained data demonstrate the hazard of a decrease in the efficiency of water self-purification system in aquatic ecosystems which are under effect of anthropogenic impacts (chemical pollution of water bodies and streams) (Ostroumov et al., 1997; Ostroumov, 1998, 2002b, 2002c, 2003b).

RELATIONSHIP BETWEEN THIS THEORY AND FUNDAMENTAL ECOLOGICAL CONCEPTS

An important 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 filterers for removing suspension from water, during which the amount of suspended organic matter extracted from water is much greater than it is required for the filterer's organism.

The environmental significance of suspension removal from water and pellet formation is analyzed in detail in (Ostroumov, 2004a). The assimilability of food by filterers in laboratory experiments was ~50–60%, however it can be much lower in nature. Thus, bivalve mollusks marine mussels Mytilus galloprovincialis (with a biomass of 2 g) featured the assimilability that varied within the year from 4.8 to 51% (Ostroumov, 2004a), that is, in some cases >95% of filtered out material was released by the mussels in the form of pellets.

Thus, the synecological cooperation is one of the functional principles of the biotic system of water self-purification. Purification of aquatic ecosystems is accompanied by transfer of chemical substances and their constituents from one point of 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 exists in aquatic ecosystems" (Ostroumov, 2002a).

Confirmations were also obtained for the assumption that "competitive unity and biological-matter-controlled regulation of cyclic and noncyclic paths of chemical elements, representing chains of successive transitions of chemical elements from one phase into another (interphase transfer) and from one organism into another (organism-to-organism transfers) take place in aquatic ecosystems (Ostroumov, 2002a).

The author emphasized that the regulation of many processes of transfer of chemical elements in aquatic ecosystems is biologically controlled, and the roles of both components - biotic and abiotic - are equally important.

HOW THE ABOVEMENTIONED ECOLOGICAL THEORY HELPS TOWARDS ENERGY-SAVING

It should be noted that the traditional methods to treat polluted water – even the so called biological treatment – are using a substantial amount of electrical energy. In case of traditional biological treatment of wastewater a significant amount of energy is used to provide compressed air to the tanks of the treated water in order to aerate water and to facilitate activity of aerobic microorganisms which oxidize and mineralize organic pollutants in the waste water. Much energy is used for other processes and for pumping water.

Therefore it is a very important fact that if the abovementioned theory and ecosystem approach is to be used for creation of innovative green ecological biotechnology to improve water quality, the main actors in this technology are living organisms, especially green higher plants (aquatic macrophytes). The main source of energy for these organisms is sunlight. In this case, there is no need to use the colossal amount of electric energy which is necessary in traditional technologies for wastewater treatment.

HOW THE ABOVEMENTIONED THEORY HELPS TOWARDS DECREASING CARBON EMISSIONS

Using the abovementioned approach and theory as a scientific basis for creation of innovative ecotechnology for improving water quality has an additional advantage. This advantage is connected with the fact that the presence of living green plants in the ecosystem that is involved in improving water quality has a great effect of reduction of carbon emission as compared with traditional technologies.

As it was stated above, the traditional technologies use electric energy. The most popular methods of generation of electric energy are coupled with fuel burning, with carbon emission as a result.

By contrast, in case of creation or active use of ecosystems with green plants to involve them in improving water quality the result is active functioning green plants which consume carbon dioxide in the normal process of photosynthesis. By doing so, the green plants do not make carbon emissions but vice versa, uptake carbon from the atmosphere.

As a result, the innovative technology which is based on using green ecosystems has additional great advantage: removal of carbon (carbon dioxide) from the atmosphere.

FROM THEORY OF BIOMACHINERY OF WATER SELF-PURIFICATION TO INNOVATIVE ENERGY-SAVING, CARBON EMISSION-REDUCING ECOBIOTECHNOLOGY

At the beginning of this article, we started with developing the theory of ecosystem-driven water self-purification. This theory provides a new conceptualization of aquatic ecosystem function. It puts into a new system a broad range of facts, observations and experiments. It demonstrates valuable, indispensable and useful roles and functions of many species of aquatic organisms towards performing vital activity of aquatic ecosystem related to self-maintaining, self-organization, self-repairing, all of these functions are connected with improving or maintaining water quality, water self-purification.

We discovered an impressing analogy between functioning of ecosystem and functioning of a high technological level machinery, which led us to coining a new terminology, namely, the new ecological term, biomachinery ((Ostroumov, 2017) and several earlier publications of ours).

We suggest considering the function of aquatic ecosystem towards water self-purification as an example of biomachinery. It gives us the following: (1) a new angle for better vision of multitude of facts on aquatic ecosystem, (2) an opportunity to use the sharp tool for logical analysis and search for previously unnoticed or underestimated links among facts and phenomena; (3) an opportunity to use the precise language of technical sciences , (4) an opportunity to translate the knowledge of facts on ecology and life science into building artificial ecosystems, into creation of efficient biotechnology and ecotechnology to make water clean and clear.

Useful role of the theory of ecosystem-driven biomachinery of water self-purification is in providing a list of components of the future constructed ecosystem which are needed to be included in the constructed ecosystem if we want to have a really efficient ecobiotechnology for water quality improvement. This list must include: 1) filters, 2) pumps, 3) mills, 4) sorbents. Another useful thing which the theory provides is the crystal clear understanding that the almost all groups of species of aquatic biodiversity are useful and sometimes indispensable to reach a full-scale operation of the water self-purification machinery.

As we explained and emphasized in the previous sections of this article/chapter, the prospective biotechnology is really unique as it provides a powerful key to answer the most intimidating modern challenges: how to protect safety of sources of water supply, how to save energy, and how to reduce carbon emissions.

RESPONSE OF THE INTERNATIONAL SCIENTIFIC COMMUNITY TO THE ABOVEMENTIONED ECOLOGICAL THEORY

The publications that formulated and presented the abovementioned theory of ecosystem-driven water self-purification got a favorable citation in scientific literature. Some examples of use and mention of these publications are provided in Table 6 below.

Table 6. Use and mention of the publications that formed the theory of ecosystem-driven water self-purification

Who cited, the references: these papers cited the publications that presented the theory of water self-purification	**Countries and institutions whose scientists made these citations**
Lynch et al. (2023), cited (Ostroumov, 2004c)	1 U.S. Geological Survey, National Climate Adaptation Science Center, Reston, Virginia, USA; 2 Institute of Environmental and Interdisciplinary Science and Department of Biology, Carleton University, Ottawa, Canada; 3 Australian Rivers Institute, Griffith University, Nathan, Australia; 4 Institute of Environmental Research and Engineering, National University of San Martin, San Martín, Argentina; 5 iES Landau, Institute for Environmental Sciences, University of Koblenz-Landau, Landau, Germany; 6 International Water Management Institute, Colombo, Sri Lanka; 7 Conservation International, Arlington, Virginia, USA; 8 Free-Flowing Rivers Lab, School of Earth & Sustainability, Northern Arizona University, Flagstaff, Arizona, USA; 9 Tanzania Fisheries Research Institute (TAFIRI), Dar es Salaam, Tanzania; 10 Department of Chemistry and Bioscience, Aalborg University, Aalborg, Denmark; 11 Daniel P. Haerther Center for Conservation and Research, John G. Shedd Aquarium, Chicago, Illinois, USA; 12 School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington, USA; 13 Department of Wildlife, Fish & Environmental Studies, Swedish University of Agricultural Sciences, Umeå, Sweden; 14 Water Research Institute, Cardiff School of Biosciences, Cardiff, UK; 15 Freshwater Biological Association, The Ferry Landing, Cumbria, UK;

	16 Wyss Academy for Nature at the University of Bern, Bern, Switzerland; 17 Institute of Ecology and Evolution, University of Bern, Bern, Switzerland; 18 Department of Hydrology & Aquatic Sciences, South Eastern Kenya University, Kitui, Kenya; 19 Department of Fisheries Resource Management, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, India; 20 Department of Conservation Ecology and Entomology, Stellenbosch University, Matieland, South Africa; 21 Department of Landscape, Spatial and Infrastructure Sciences, Institute of Landscape Development, Recreation and Conservation Planning, University of Natural Resources and Life Sciences, Vienna, Austria; 22 Aquatic Ecology Centre, School of Science, Kathmandu University, Dhulikhel, Nepal; 23 Department of Life Sciences, School of Science, Kathmandu University, Dhulikhel, Nepal; 24 WWF-UK, Living Planet Centre, Woking, UK; 25 South African Institute for Aquatic Biodiversity, Makhanda, South Africa; 26 School of Sociological and Anthropological Studies, University of Ottawa, Ottawa, Ontario, Canada; 27 Leibniz Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany; 28 Geography Department, Humboldt-Universität zu Berlin, Berlin, Germany;
Yang et al. (2019) cited (Ostroumov, 2004b)	1 State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing, China; 2 Beijing Engineering Research Center for Watershed Environmental Restoration & Integrated Ecological Regulation, Beijing, China; 3 University of Naples 'Parthenope', Department of Engineering, Centro Direzionale, Naples, Italy; 4 Post-graduation Program in Production Engineering, Paulista University, Brazil;
Powell et al. (2022) cited (Ostroumov, 2017)	1 UK Centre for Ecology and Hydrology, Wallingford, UK; 2 School of Biological Sciences, University of Reading, Reading, UK; 3 Environment Agency, Wallingford, UK;

((Ostroumov, 2004b, 2004c, 2017) and other closely related publications by the same author).

CONCLUSIONS

When improving the methods and processes of wastewater treatment and the methods and processes of water treatment, one should take into account and use the natural principles of water purification under natural conditions. The preservation of water-purification potential of water bodies and streams is an important prerequisite of sustainable use of water–biological and water resources (an essential condition for sustainable economic development and growth).

Practically all the biodiversity participates in the processes that lead to water quality stability or improvement, to self-purification of aquatic ecosystems or regulation of these processes. This demonstrates the need to preserve the biodiversity in aquatic ecosystems. Onshore ecosystems and habitats actively participate in water purification processes.

Therefore, it is necessary to preserve the biodiversity of these onshore ecosystems as well. The concept of preservation of virtually all biodiversity now adds a vital addition to the previous approach based on the preservation of the gene pool of species.

The nature protection objectives and the regime in the land and water area of the territory to be preserved should include the preservation of not only gene pool and populations of species, but also the level of functional activity of these populations (we mean the functional activity that contributes to the maintaining of water quality and, thus, the stability of the entire aquatic ecosystem)

We can expect the appearance of new pollutants, which may cause a hazardous decrease in the self-purification capacity of aquatic ecosystems (water bodies and streams).

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