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GENERAL BIOLOGY

An Aquatic Ecosystem: A Large-Scale Diversified Bioreactor with a Water Self-Purification Function

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The self-purification of water is a complex process which includes physical, chemical, and biological components [1–4]. Although biological aspects of water self-purification are generally attributed to heterotrophic microorganisms, other groups of organisms are also known to play a significant role in this process [5–7].

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

The rate of water purification from suspended particles mediated by macrozoobenthic water filtrators was measured experimentally as described earlier [7]. After a water sample had been kept with filtrators for a certain time, the water filtration efficiency was measured by the optical density of a suspension of unfiltered single-cell organisms that remained in the bulk water. Control samples were subjected to the same procedure of filtration, but without the contaminant tested. Other methods of studies of the effects of contaminants on biological organisms are described in [6, 8].

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 bulk water; (3) generation of oxygen required for oxidative degradation of contaminants; (4) uptake of biogenic substances (including N and P) and organic substances from the environment; (5) production of exometabolites; (6) water filtration; and (7) formation of pellet and detritus particles and their gravimetric sedimentation to the bottom [1–5]. This list is far from complete, and some biological phenomena simultaneously contribute to several processes listed above. Analysis of the relative contributions of individual groups of hydrobionts 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 this 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 (no less than six) in all groups of organisms.

Thus, the whole range of biological diversity of hydrobionts is an important factor in water self-purification [1, 2]. The biota representatives of the bulk water, the entire ecosystem volume, all 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) suggests 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.

The first one is a fundamental difference in the bioreactor sizes. 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^3; Lake Superior, 12221 km^3; Lake Michigan, 4871 km^3; Lake Issyk-Kul, 1730 km^3; Lake Ladoga, 908 km^3; Lake Onega, 280 km^3; Lake Balkhash, 112 km^3; Lake Sevan, 38 km^3; and Lake Balaton, 2 km^3 ($1\ km^3 = 10^9\ m^3$). 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.

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Table 1. Examples of the contribution of aquatic organisms to some processes important for water self-purification in ecosystem (a simplified model)

Group of organisms	Biodegradation	Absorption of xenobiotics	Absorption of biogenic and/or organic substances	Production of exometabolites	Oxygen evolution	Water filtration	Formation of pellet and detritus	Regulation of subordinate trophic chains
Heterotrophic bacteria	+	+	+	+	–	–	–/+	–/+
Fungi	+	+	+	+	–	–	ICD	–/+
Cyanobacteria and microalgae	+	+	+	+	+	–	+	–
Protozoans	+	+	+	+	+/–	+/–	+	+
Higher plants	+	+	+	+	+	–/+	+	–
Invertebrates	+	+	+	+	–	+	+	+
Fish and amphibians	+	+	ICD	+	–	–/+	+	+

Note: (ICD) incomplete data.

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

Organisms	Biological effects	Substance and concentration	Reference
Bacteria Hyphomonas sp. MHS-3	Insignificant inhibition of growth (4–20%)	TX 5 mg/l	New data
Bacteria Hyphomonas sp. VP-6	Insignificant inhibition of growth (7–16%)	TX 5–10 mg/l	The same
Synechococcus sp. 8103	Growth stimulation (47–50.5%)	TX 5 mg/l	[6]
Mytilus edulis	Significant decrease in water filtration efficiency (about 80% within 60 min)	TX 4 mg/l	[3]
Mytilus galloprovincialis	Decrease in water filtration efficiency (78.3% within 50 min)	TDTMA 1 mg/l	New data
Unio tumidus	Decrease in water filtration efficiency (45.8% within 85 min)	TX 5 mg/l	The same

The second feature is the differences between the gene-pool sizes and biological diversities of organisms inhabiting natural ecosystems and grown in technological bioreactors. This difference causes 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 small number of constituting species. In contrast to technological bioreactors, the biological diversity of natural ecosystems is substantially broader. According to incomplete estimates, the number of species in natural ecosystems is as much as several thousand [1]. These estimates were obtained without regard to the number of strains of individual microbial species. If prokaryote strains are taken into account, the quantitative estimates of the biological diversity of taxa in natural ecosystems increases 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).

Anthropogenic sublethal disorders (including physiological activity dysfunctions) and behavioral changes in virtually any group or taxon of hydrobionts may decrease the bioreactor analog efficiency. Sublethal disorders should be regarded as a potential hazard to the purification function [2, 4]. 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 presently adopted regulations on ecological monitoring and biotesting, the ability of chemi-

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

Substance	Organism	Damaged functions	Marine (m) or freshwater (f) systems
TX100 (1–5 mg/l)	Unio tumidus	Water filtration	f
TDTMA (1–2 mg/l)	U. pictorum	"	f
TDTMA (1 mg/l), SDS (1.7 mg/l), SS (6.7–50 mg/l), AHC (5–60 mg/l)	Mytilus galloprovincialis	"	m
TX100, TDTMA (2 mg/l), Tide-Lemon (75 mg/l)	Lymnaea stagnalis	Elimination of phytobiomass from upper layers of bulk water	f

Note: SDS, sodium dodecylsulfate; SS, synthetic surfactants (Lotos-Ekstra, Losk-Universal, and Tide-Lemon); TX100, Triton X-100; TDTMA, tetradecyltrimethylammonium bromide; AHC, Avon Hair Care (hair shampoo).

cal compounds to damage the self-purification potential of ecosystems is 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 (phytobiomass removal) from water in aquatic ecosystems (Table 3).

Sublethal concentrations of contaminants may inhibit vital activities of other organisms involved in the function of an ecosystem as an analogue of a bioreactor [8–12]. This finding provides a deeper insight into the mechanisms of anthropogenic impact on biosphere [13–15]. The concept put forward in this work emphasizes that intactness of the whole range of biological diversity of hydrobionts is required to provide effective functioning of an ecosystem as an analog of a water self-purification bioreactor. Therefore, the cost estimates of ecosystems and biota should be increased.

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