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Anthropogenic Effects on the Biota: towards a New System of Principles and Criteria for Analysis of Ecological Hazards

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Abstract

The currently accepted system of criteria for evaluating environmental and ecological hazards of man-made chemicals (pollutants) is vulnerable to criticism. In this paper, a new concept of the system of approaches towards criteria for evaluating the ecological hazard from man-made impact is proposed. It is suggested to assess the man-made impacts (including effects of pollutants and xenobiotics) on the biota according to the following four levels of disturbance in biological and ecological systems: (1) the level of individual responses; (2) the level of aggregated responses of groups of organisms; (3) the level of stability and integrity of the ecosystem; (4) the level of contributions of the ecosystem to biospheric processes. On the basis of the author's experimental studies, an example is given of how to apply the proposed approach and the system of criteria to the analysis of concrete experimental data. To exemplify

the efficiency of the proposed approach, it is shown how to use it to analyze new data on effects of a synthetic surfactant on water filtering by bivalves. It is concluded that the proposed approach will be helpful in better assessing environmental and ecological hazards from anthropogenic effects on biota, including effects of man-made chemicals polluting ecosystems.

1.INTRODUCTION

One of the important tasks in preventing and mitigating changes in the biosphere is to perform an objective analysis of the hazards of a great many man-made impacts and disturbances on the state of the biota (the world-wide diversity of ecosystems, populations, and organisms). The multitude, diversity, and scale of anthropogenic effects has been described and analyzed in a number of publications (e.g., Yablokov & Ostroumov [1983], [1985], [1991]; Bezel' et al [1994]; Krivolutskii [1994]). This paper is based on such papers as well as on our previous publications (Ostroumov [2000a] [2000b], [2001]).

Studying the multiplicity of characteristics of anthropogenic factors affecting organisms and ecosystems (Flerov [1989]; Yablokov & Ostroumov [1991]; Bezel' et al [1994]; Alimov [2000]; Wetzel [2001]), researchers try to identify and analyze the most important parameters and criteria characterizing negative anthropogenic effects (Yablokov & Ostroumov [1991]; Krivolutskii [1994]), including the effects of chemicals (xenobiotics; pollutants) (Ostroumov [1986]; Filenko [1988]; Telitchenko & Ostroumov [1990]; Malakhov & Medvedeva, [1991]). Currently the development and systematization of these criteria are far from completion.

The aim of this paper is to contribute to developing approaches to improvement of a system of criteria of ecological hazards of anthropogenic effects on the biota and to consider some new experimental data on the effects of surfactant xenobiotics on living organisms.

2. THE TRADITIONAL APPROACH TO CLASSIFICATION OF CHEMICALS ACCORDING TO THEIR ENVIRONMENTAL HAZARDS

Approaches to establishing the criteria of ecological hazards of man-made chemicals have been developed in terms of the estimation of toxic contamination of ecosystems and assessment of effects of xenobiotics on organisms (e.g., Flerov [1989]; Yablokov & Ostroumov [1991]; Filenko [1988]; Telitchenko & Ostroumov [1990]; Malakhov & Medvedeva, [1991]. The classification of chemicals according to their environmental and ecological hazards now accepted in the European Union is based on the following three criteria (e.g., de Bruijin & Struijs, [1997]).

(1) Acute toxicity estimated from LC50 for the three groups of organisms: fish, algae, and daphnia.

(2) Susceptibility of the substance to biological decomposition in water. This is determined with the use of laboratory tests under aerobic conditions. Substances are decomposed by microorganisms, and their decomposition is accompanied by oxygen consumption. If a substance is quickly decomposed (oxidized) by microorganisms, it is not considered to be hazardous to the environment. Exceptions are compounds with a high acute toxicity (with an LC50 less than 10 mg/l) and a high bioaccumulation potential (see the next criterion).

(3) The substance's capacity for bioaccumulation. This capacity is considered to be hazardously high if the bioaccumulation factor (BCF) is higher than 100, or the logarithm of the distribution coefficient of the substance in the octanol–water system (logPow) is higher than 3.

A disadvantage of this set of criteria is an underestimation of other aspects of ecological hazards due to contamination of a water body with the given chemical, e.g., the hazard of a decrease in water O2 concentration due to oxygen consumption by microorganisms during oxidation of xenobiotics. Behavioral changes in living organisms because of interaction of the pollutant with their receptors (Flerov [1989]; Ostroumov, [1991]) is also beyond the scope of this system of criteria. Behavioral changes may occur in the absence of bioaccumulation (i.e., when the substance is not hazardous according to criterion 3). Changes in behavior may result in migration of certain species from the ecosystem (emigration) and, hence, to a decrease in biodiversity.

Therefore, more comprehensive sets of criteria should be developed.

3. A NEW APPROACH TO THE ANALYSIS OF HAZARDS OF ANTHROPOGENIC EFFECTS ON THE BIOTA

In some studies, anthropogenic effects on the natural environment were classified on the basis of the approach of considering the levels of biological organization (Yablokov & Ostroumov [1983]; Yablokov & Ostroumov [1985]; Yablokov & Ostroumov [1991]) . We suggest a new approach to developing a set of principles for the analysis of man-made effects (Table 1), in which anthropogenic effects on the biota are systematized based on the basis of a similar, but not identical approach (Ostroumov [2000a], [2000b], [2001]).

A characteristic feature of the system of principles and criteria shown in Table 1 is the division of the multiplicity of anthropogenic effects into orderly groups according to four levels of biota disturbance. Most of the traditionally studied toxic effects (an increased mortality, ontogenetic disturbances, organ pathology, etc.) fall in the group corresponding to the level of individual and population responses (level 1). Alterations in primary productivity, water concentration of chlorophyll, etc., correspond to the level of aggregated responses (level 2). Alterations at the level of ecosystem stability and integrity (level 3) are important but have not been sufficiently studied. These are, among others, disturbances in the self-purification capacity of water systems (Ostroumov et al. [1997]; Ostroumov, [1998]), i.e., their ability to sustain the parameters of the aquatic environment. The last group (level 4) comprises alterations in the contribution of ecosystems to biospheric processes, including biogeochemical flows of chemical elements (C, N, P, and S).

This approach agrees with the views of some other authors (Filenko [1988]; Stroganov [1976]) and is useful for developing a new, more adequate system of estimation and classification of anthropogenic effects, including environmental pollutants, with respect to ecological hazards.

An important constituent of the proposed system for analysis of ecological hazards is estimation of hazardous effects on the stability and integrity of an ecosystem, e.g., the hazard due to weakening the relationship between plankton and benthos. If an anthropogenic effect weakens this relationship in a given ecosystem, the consequences are expected to be unfavorable [13] (Ostroumov et al. [1997]). An example of such a situation is the decrease in the water filtration rate and elimination of seston by some filter-feeding organisms, such as bivalves, because their filtration activity is one of the important mechanisms for maintaining the plankton–benthos coupling. It would be important to estimate the possible effect of pollutants on the molluscan filtration activity.

Filtration of water and absorption of phyto- and bacterioplankton and other suspended matter by molluscs, as well as formation and excretion of fecal and pseudofecal pellets are important for processes occurring in an aquatic ecosystem [13] (Ostroumov et al. [1997]; Ostroumov [2001]). Inhibition of filtration by pollutants (xenobiotics) may, in turn, induce other disturbances at several organizational levels (see Table 1) of the ecosystem. Examples of such disturbances are a decrease in water filtration by other hydrobionts, decrease in water transparency and the resultant decrease in penetration of photosynthetically active radiation and ultraviolet light, deterioration of the conditions for phytobenthos, excessive growth of phyto- and bacterioplankton, disturbances in the regulation of the composition of the algal–bacterial community, increase in detritus formation and siltage of benthic habitats, imbalance of the food web of phytoplankton consumers, decrease in the population growth of filter feeding organisms, decrease in the number of planktophagous larvae and deformation of the food web, and decrease in organic carbon deposition and concentration in bottom sediments (Ostroumov et al. [1997]; Ostroumov [2001]).

4. EXAMPLE OF APPLYING THE NEW APPROACH TO THE ANALYSIS OF ENVIRONMENTAL AND ECOLOGICAL HAZARDS

An important question is whether surfactants, which heavily contaminate environment and have not been sufficiently studied with respect to possible effects on organisms, may suppress filtration (Ostroumov [1986]); Telitchenko, Ostroumov [1990]; Ostroumov [1998]).

Data obtained in experiments on *Mytilus edulis, M. galloprovincialis* and some other marine and freshwater molluscs indicate that synthetic surfactants may disturb the plankton–benthos coupling

(Ostroumov [1998], [2000a], [2000b], [2001]). Some surfactants, such as a nonionic surfactant Triton X-100 (TX100; an alkylphenol derivative), decrease the rates of water filtration and elimination of algae from water by mussels *Mytilus edulis* (Table 2). In the presence of 0.5 mg/l TX100, the concentration of algal cells after 90 min of filtration was 1092 cells per 0.5 ml of water versus 532 cells per 0.5 ml of water in the control sample (Table 2). In other words, an excess of algae as a result of filtration suppression was more than twofold (205%). If the TX100 concentration was increased to 2 mg/l, the concentration of algae after filtration was 2635 cells per 0.5 ml versus 556 cells per 0.5 ml in the control sample, i.e., the excess was almost fivefold (474 %). Thus, the inhibition increased with an increase in the surfactant concentration. These results are in excellent agreement with the data on the effects of other chemical compounds [13], including various surfactants, detergents, and other pollutants (Ostroumov et al. [1997]; Ostroumov [2000a], [2000b], [2001]). Recently new similar results were discovered while studying effects of the cationic surfactant tetradecyltrimetyhylammonium bromide on marine mussels (Ostroumov, Widdows, in preparation).

The system of criteria shown in Table 1 simplifies and systematizes the analysis of the ecological role and consequences of man-made disturbances of a given physiological function (in this case, disturbance of water filtration by molluscs). If we go sequentially from level to level, the suggested system will make it possible to follow the range of ecological consequences of a primary man-made disturbance at an individual level that manifests itself at higher levels of biological or ecological organization in an ecologically hazardous form.

In the given example, the change in the organism's physiological activity (water filtration) is the directly observable effect of the xenobiotic (surfactant). However, we can estimate the ecological hazards more accurately if we consider the processes occurring at level 3 (a decrease in the seston elimination from water and a decrease in the plankton–benthos coupling) and at level 4 (a decrease in the formation and excretion of the pellets formed from the algal cells that have been removed from water).

Many other examples (Filenko [1988]; Flerov [1989]; Telitchenko & Ostroumov [1990]; Malakhov & Medvedeva, [1991]; Yablokov & Ostroumov [1991]; Bezel' et al [1994]) confirm the usefulness and effectiveness of the approach proposed (Table 1) for the analysis of ecological hazards of anthropogenic effects on the biota. More detail is given in our books recently published (Ostroumov [2000a], [2001]) as well as in the experimental article (Ostroumov [2002]).

5. CONCLUSION

The proposed level–block approach to the analysis of ecological hazards of anthropogenic alterations in ecosystems allows the multiplicity of anthropogenic effects on the biota to be efficiently systematized. This approach may be used to develop new objective criteria for estimation and classification of ecological and environmental hazards produced by anthropogenic effects on the biota, including the hazards produced by man-made chemicals that pollute the biosphere.

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Table 1. The level–block approach to the analysis of ecological hazards of anthropogenic effects on the biota . (After Ostroumov [2000a], [2000b], [2001], with some modifications)

No.	Disturbance level	Examples of disturbances and their consequences (some of them may be assigned to different levels)
1	Individual responses	Toxic effects on individual species (increased mortality, decreased fertility, ontogenetic disturbances, diseases, etc.), changes in morphological and physiological variability, and behavioral changes
2	Aggregated (summarized) responses of a group of organisms	Changes in primary productivity, aggregated parameters of biomass, water chlorophyll, and dissolved O2 concentrations
3	Ecosystem stability and integrity	Rearrangements and/or weakening of plankton–benthos connections (coupling); rearrangements and/or weakening of links in the food web; changes in the level of bacterial destruction; decrease in the elimination of particles (seston) from water; decrease in water self-purification; decrease in some regulatory effects because of the loss, migration, or trophic inertness of organisms belonging to higher trophic levels

4	Ecosystem contribution to biospheric processes	Changes in C flows (e.g., sedimentation of pellets formed by filter-feeding organisms) and N flows (e.g., nitrogen fixation), as well as in flows and cycles of other elements, including S and P; changes in energy (heat etc.) flows

Table 2. Amount of algae Isochrysis galbana in flasks containing mussels *Mytilus edulis* after 90 min of water filtration by the molluscs in the presence or absence of Triton X-100 (TX100, 0.5 mg/l). (After Ostroumov [2000b], with some changes).

No. of the flask	Presence or absence of TX100 (0.5 mg/l)	Number of algal cells in 0.5 ml of the medium	The average number of algal cells in 0.5 ml of the medium
1	+	427; 451; 468	449
3	+	335; 338; 362	345
5	+	795; 766; 819	793
7	+	2806; 2743; 2793	2781
	The average number of the algal cells in 0.5 ml for four flasks with TX100- containing medium (flasks 1, 3, 5, 7)		1092 (standard error, 298)
2	–	727; 684; 716	709
4	–	347; 337; 348	344
6	–	359; 398; 456	404
8	–	638; 659; 716	671
	The average number of the algal cells in 0.5 ml for four control flasks (flasks 2, 4, 6, 8)		532 (standard error, 49)

Note: The differences between experimental and control values were significant at the 95% significance level according to Student's t-test ($p = 0.04$). Conditions: the average initial concentration of cells, 13372 per 0.5 ml; temperature, 16 °C. Cells were counted using the Coulter counter. The average reading of the counter in sea water was 674. Sixteen mussels weighing 7.2 to 9.2 g (wet weight with a shell) were used.