Doklady Biological Sciences, Vol. 381, 2001, pp. 559–562. Translated from Doklady Akademii Nauk, Vol. 381, No. 5, 2001, pp. 709–712.

GENERAL BIOLOGY

The Synecological Approach to the Problem of Eutrophication

S. A. Ostroumov

Presented by Academician M.E. Vinogradov July 9, 2001

Received July 11, 2001

In recent years, the importance of the problem of eutrophication of various aquatic ecosystems has been progressively increasing [1–3]. According to the survey of the trophic status of inland waters in 23 states performed by the United States Environment Protection Agency (EPA), eutrophic, mesotrophic, and oligotrophic lakes account for 45, 26, and 12% of the total number of lakes, respectively (the trophic status of 17% lakes was identified as "uncertain") [3]. The eutrophication index of inland waters in some European countries (e.g., the Netherlands) is about 300, which is substantially higher than the desired level (about 100) and the level of stability (about 80) [2]. Eutrophication aggravates the problem of insufficient availability of water to people worldwide. According to the Global Accord estimates [4], the availability of water is expected to decline significantly in the foreseeable future in many countries. For example, from 1990 to 2025, the availability of water (m^3 per capita) in Algeria will decline from 750 to 380; in Kenya, from 590 to 190; in Libya, from 160 to 60; in Israel, from 470 to 310; and in Jordan, from 260 to 80.

The current knowledge on the anthropogenic impact on aquatic organisms should be used to solve the problem of eutrophication. The role of nutrient substances in water eutrophication and possible approaches to reduction of the inflow of nutrient substances to water have been the main subjects of ecological studies on eutrophication thus far [1, 2]. Although these aspects of water eutrophication remain very important, they do not cover the entire spectrum of approaches to the problem.

The goal of this work was to consider analytical approaches to the problem of eutrophication and to formulate a dualistic (two-component) approach to its solution.

Based on the current ecological knowledge (including our own data and their analysis reported in [5–11]), a two-component solution of the problem of eutrophication is thought to be valid if two factors of phytoplankton abundance in water are taken into account. These factors are the availability of nutrient substances and phytoplankton elimination by organisms of the next trophic level. The two factors provide a methodological basis of the two-component approach to the problem of eutrophication. According to this approach, these factors can be used to control the ecological situation in water.

The first component is the availability of nutrient substances in water. Reducing the rate of the inflow of biogenic substances to water can change the ecological state of the system. This well-understood method is widely used in practice [1, 2].

The second component of this approach concerns biological mechanisms of elimination of phytoplankton cells from water. These mechanisms include the filtration activity of zooplankton and benthic filter-feeders. Although the second component is quite obvious and easily understandable, it is insufficiently used in practice. Below, I will consider this component in more detail using previously obtained data on inhibitors of natural mechanisms of biological filtration, i.e., the compounds that reduce the rate of elimination of phytoplankton cells from water.

The experimental data considered in this work were obtained during the studies on the biological effects of the liquid washing mixture (LWM) Fairy (Procter and Gamble). This preparation is a mixture of several compounds, including surfactants.

The marine bivalve mollusk mussel (*Mytilus galloprovincialis* Lamarck) was used in biotesting experiments. The mussel specimens were collected in the Black Sea. The yeast (*Saccharomyces cerevisiae*) cell suspension in water was used to measure the efficiency of water filtration [5, 7, 9, 11]. The rate of the water-turbidity decrease was taken as a quantitative measure of the efficiency of water filtration. It was shown in special experiments that the process of elimination of the *S. cerevisiae* suspension from water is an adequate model of elimination of cells of marine algae. Bivalve mollusks were grown in an aquaculture farm (I am grateful to V.I. Kholodov and other colleagues for providing me with the mussels). Experiments were performed as described in [9, 11]. The following experimental conditions were used. Each experimental tank contained 20 mollusk specimens. The mollusk biomass (fresh weight together with the shell) in tanks A and B was 158.4 and 141.0 g, respectively. The water temper-

Moscow State University, Vorob'evy gory, Moscow, 119899 Russia

0012-4966/01/1112-0559$25.00 © 2001 MAIK "Nauka / Interperiodica"

Table 1. Effect of the LWM Fairy (2 mg/l) on the optical density (OD_{550}) changes in the S. cerevisiae suspension during filtration by Mytilus galloprovincialis

Period of measurement	Incubation time, min	Experiment (+LWM) A	Control (with mussels, without LWM) B	Control (without mussels, without LWM) C	A/B, %
1	2	0.282	0.233	0.302	121.0
2	23	0.048	0.024	0.290	200.0

Table 2. Chemical compounds inhibiting the activity of filter-feeders

Compound	Class of chemical compounds	Reference
Individual chemical compounds		
Sodium dodecylsulfate	Anionic surfactants	Ostroumov *et al.*, 1997, cited from [5, 6]
Triton X-100	Nonionic surfactants	[5] and unpublished data of Ostroumov
Tetradecylcetyltrimethylammonium bromide	Cationic surfactants	[5]
Pesticides	Organic substances	Donkin *et al.*, 1997, cited from [14], see also [6] and references therein
Trimethylstannate	Organometallic compounds	Mitin, 1984, cited from [14]
Tributylstannate, dibutylstannate	Organometallic compounds	Widdows, Page, 1993, cited from [14]
Cd, Cu, Cr	Heavy metals	Cited from [6]
Potassium cations	Cations of alkaline-earth metals	[15]
Mixed preparations		
OMO	SWM	[5, 9] and unpublished data of Ostroumov
Tide-Lemon	SWM	[5, 6] and unpublished data of Ostroumov
Losk-Universal	SWM	[5, 6, 10] and unpublished data of Ostroumov
Lotos-Extra	SWM	[5, 6] and unpublished data of Ostroumov
IXI	SWM	[10, 11] and unpublished data of Ostroumov
Deni-Automat	SWM	The same
Lanza	SWM	"
Avon Herbal Care	SWM	[5, 6, 11] and unpublished data of Ostroumov
Preparation E	SWM	[9, 11]
Preparation Mila	SWM	[11]
Fairy	SWM	Table 1 of this work (column A/B)

ature was 22.5°C. The initial concentration of *S. cerevisiae* in the cell suspension was 100 mg/l. Each tank contained 500 ml of water. Optical density was measured using a LOMO SF-26 spectrophotometer.

The LWM tested in our experiments (Fairy) inhibited the filtration activity of mollusks (Table 1). A similar inhibition of the filtration activity of other species of bivalves was observed in our experiments with other LWMs (IXI, Lanza, Deni, Vesna, OMO, etc.).

It follows from Tables 1 and 2 that the potential filtration capacity of filter-feeders is reduced as a result of exposure to various compounds that are generally regarded as chemical pollutants. Therefore, these pollutants reduce the ability of the ecosystem to eliminate various types of seston, phytoplankton cells, and other types of suspended particles.

It follows from these data that the natural ability of aquatic ecosystems to eliminate phytoplankton from bulk water is seriously endangered. Complex multicomponent pollution of water with a variety of chemicals may be aggravated by summation of detrimental effects. For example, two types of chemicals may enter water ecosystems: potential nutrient substances and inhibitors of filter-feeders. The effects of the two types of pollutants are summed and lead to the same final result, an increase in phytoplankton biomass. This phenomenon can be called two-level synecological summation or synergistic summation of individual effects of pollutants on aquatic organisms.

Because the range of chemical pollutants causing inhibition of filter-feeders is very broad (Table 2), these

Table 3. Filter-feeders whose activity is inhibited by pollutants

Organism	Component of ecosystem	Reference
Mytilus galloprovincialis	Benthos	[5–7, 10, 11] and Table 1 of this work (column A/B)
Mytilus edulis	"	[5, 11, 12]; unpublished data of Ostroumov; Donkin *et al.*, 1997, cited from [14]
Crassostrea gigas	"	[7, 11]
Unio tumidus	"	[9, 11]
Dreissena polymorpha, Crenomytilus grayanus	"	Mitin, 1984, cited from [14]
Brachionus angularis	Zooplankton	[13]
Brachionus plicatilis	"	Kartasheva, Ostroumov, 2000, cited from [5]
Daphnia magna	"	Day, Kaushik, 1987, cited from [14]
Daphnia magna, D. longispina	"	Scholten *et al.*, cited from [6]
Simocephalus vetulus, Ceriodaphnia dubia	"	Scholten *et al*., cited from [6]

phenomena may aggravate the hazard of the eutrophication syndrome.

The activity of benthic filter-feeders is inhibited by surfactants and synthetic detergents (Table 2). The inhibitory activities of three surfactants and ten commercially available washing mixtures (containing both surfactants and phosphorus-containing chemical compounds) were tested in the preceding works [9, 10] and in this study (Table 2).

In addition, it was shown that some other types of chemical agents also inhibit the filtration activity of bivalves ([12], [14] and references therein).

Many zooplankton species are also important representatives of filter-feeders. The filtration activity of zooplankton was also shown to be inhibited by pollutants. In experiments performed together with N.V. Kartasheva, we found that tetradecylcetyltrimethylammonium bromide, a surfactant, inhibits the filtration activity of rotifers [13]. Experimental studies performed by Filenko (1988) provided additional support to this conclusion ([14] and references therein). Some pesticides exert toxic effects on zooplankton, the inhibition of zooplankton being observed at lower concentrations of pesticides than the inhibition of phytoplankton was. Many examples of toxic effects of pesticides on aquatic ecosystems were reported at the ecological seminar held at Den Helder (the Netherlands) on December 9–12, 1999 (organizer, Dr. M. Scholten). Interesting results on this subject were reported by Dr. M. Scholten and co-workers (see [6] for more detail). Some species of filter-feeders subjected to the detrimental effects of pollutants are listed in Table 3.

The following aspects of the antieutrophication activity of filter-feeders should be considered in more detail. Filter-feeders excrete large amounts of rapidly sedimenting fecal and pseudofecal pellets. As a result, filter-feeders ensure rapid removal of C, P, and N from bulk water and transfer of these elements to deep water layers and bottom deposits. Therefore, filter-feeders facilitate the removal of a fraction of nutrient substances from the upper layer of bulk water.

Note that, in this work, phytoplankton is regarded as a component of the trophic chain. In this chain, phytoplankton interacts with a population of consumers (filter-feeders). Therefore, the concept of eutrophication suggested in this work is based on the synecological approach. A practical two-component solution of the problem of eutrophication of ecosystems can be recommended on the basis of this approach. We believe that two components of the antieutrophication activity are equally important. First, the rate of the inflow of biogenic compounds to the ecosystem should be decreased. The importance and practical applications of this approach are considered in more detail in [1, 2]. Second, the pollution of aquatic ecosystems with the chemicals capable of inhibiting the biofiltration activity of ecosystems (i.e., the ability of filter-feeders to eliminate phytoplankton biomass) should be decreased. It should be noted that our second recommendation has not been implemented so far. The pollutants capable of inhibiting the biofiltration activity of ecosystems include surfactants, detergents [5–10], and some other compounds and preparations. In my opinion, in certain aquatic ecosystems, only the sum of the two components would have a pronounced antieutrophication effect, whereas none of them taken alone is active. Because synecology is the cornerstone of the concept of the antieutrophication measures suggested in this work, this approach can be considered to be a synecological solution of the problem of eutrophication. In my opinion, the list of chemical agents exerting similar detrimental effects (the risk of emergence of eutrophication symptoms caused by inhibition of the filtration activity of filter-feeders) will be supplemented, in the foreseeable future, by new inhibitors of filter-feeders.

Thus, the results obtained in this work are expected to contribute to optimization of the antieutrophication priority measures and development of an effective strategy of eutrophication prevention in freshwater, estuary, and marine ecosystems.

ACKNOWLEDGMENTS

I am grateful to V.D. Fedorov, A.F. Alimov, V.L. Kas'yanov, L.A. Sirenko, A.G. Dmitrieva, R. Newell, M. Scholten, and other participants of the ecological seminar at Den Helder (the Netherlands) for stimulating discussion. I am also grateful to the colleagues from the Institute of Biology of Southern Seas, National Academy of Sciences of Ukraine, G.E. Shul'man, G.A. Finenko, V.I. Kholodov, A.V. Pirkova, A.Ya. Stolbov, and A.A. Soldatov for providing me with marine mollusks and technical assistance. I also thank O.A. Kurochkina and P. Wangersky for the expert assistance and consultations and J. Widdows and N.A. Eysedyecher for reprints.

This study was supported by the Open Society Foundation (RSS project no. 1306/1999).

REFERENCES

1. *World Resources 1996–1997*, New York: Oxford Univ. Press, 1996.
2. *World Resources 1994–1995*, New York: Oxford Univ. Press, 1994.
3. Mason, R. and Mattson, M., *Atlas of United States Environmental Issues*, New York: Macmillan, 1990.
4. *Global Accord*, Choucri, N., Ed., Cambridge: MIT, 1993.
5. Ostroumov, S.A., *Biologicheskie effekty poverkhnostno-aktivnykh veshchestv v svyazi s antropogennymi vozdeistviyami na biosferu* (Biological Effects of Surfactants as Related to the Anthropogenic Impact on the Biosphere), Moscow: MAKS, 2000.
6. Ostroumov, S.A., *Dokl. Akad. Nauk*, 2000, vol. 375, no. 6, pp. 847–849.
7. Ostroumov, S.A., *Dokl. Akad. Nauk*, 2001, vol. 378, no. 2, pp. 283–285.
8. Ostroumov, S.A., *Izv. Akad. Nauk, Ser. Biol.*, 2001, no. 1, pp. 108–116.
9. Ostroumov, S.A., *Dokl. Akad. Nauk*, 2001, vol. 380, no. 5, pp. 714–717.
10. Ostroumov, S.A., *Dokl. Akad. Nauk*, 2001, vol. 379, no. 1, pp. 136–138.
11. Ostroumov, S.A., Biological Effects of Surfactants as Related to the Anthropogenic Impact on Organisms, *Doctoral (Biol.) Dissertation*, Moscow: Mosk. Gos. Univ., 2000.
12. Ostroumov, S.A., Donkin, P., and Staff, F., *Dokl. Akad. Nauk*, 1998, vol. 362, no. 4, pp. 547–576.
13. Kartasheva, N.V. and Ostroumov, S.A., *Toksikol. Vestn.*, 1998, no. 5, pp. 30–32.
14. Ostroumov, S.A. and Fedorov, V.D., *Vestn. Mosk. Univ.*, 1999, no. 1, pp. 24–32.
15. Wildridge, P., Werner, R., Doherty, F., and Neuhauser, E., *J. Great Lakes Res.*, 1998, vol. 24, pp. 629–636.