Doklady Biological Sciences, Vol. 377, 2001, pp. 139–141. Translated from Doklady Akademii Nauk, Vol. 375, No. 6, 2000, pp. 847–849.

GENERAL BIOLOGY

Inhibitory Analysis of Regulatory Interactions in Trophic Webs

S. A. Ostroumov

Presented by Academician V.N. Bol'shakov January 25, 2000

Received February 16, 2000

All aspects of regulatory interactions between organisms are of significant importance for ecosystem structure and functions. Certain aspects of regulatory interactions were considered in the preceding works [1, 2]. Regulatory interactions in trophic chains, including the regulation of lower links by higher links (the top–down control), are of cardinal importance [3, 4]. The ecosystem regulation disturbances caused by anthropogenic impact are dangerous in terms of conservation of biological diversity [5–7].

The goal of this work was to formulate the concept of the inhibitory analysis of regulatory interactions in trophic webs, taking into consideration our own experimental findings and information available from the literature. According to this concept, the inhibitory analysis of regulatory interactions in trophic networks is considered as a tool for testing the ecosystem regulatory apparatus. Another goal of this work was to demonstrate the ability of the concept to provide a sufficiently deep insight into mechanisms of ecological systems, using aquatic systems as an example.

The efficiency of the top–down control was demonstrated by many researchers in both natural and artificial (laboratory) systems. This control is certainly extended to the regulation of algal population states [3, 4]. A sufficiently deep insight into the factors of the regulation of algal populations is required to solve the problem of eutrophication and prevention of algal blooms (including toxic algal blooms).

The purpose of our experiments was to study the effects of certain substances on the trophic activity of aquatic invertebrates. The invertebrates normally fed on plankton organisms, including algae.

It was shown in our experiments that xenobiotics induced a decrease in the trophic activity of invertebrates. The xenobiotics tested in this work inhibited the regulation of organisms of lower levels of trophic chains by organisms of higher levels of these chains (Tables 1–3) [8–12]. Our experiments revealed that the xenobiotic-induced inhibition of trophic-chain regulation occurred in both freshwater (Table 1) and marine (Tables 1–3) organisms. Not only individual substances, but also mixed preparations (e.g., synthetic surfactants), were shown to exert inhibitory effects when added to water (Table 3).

It should be emphasized that inhibitory effects were observed at sublethal concentrations of contaminants, i.e., neither invertebrates nor their food objects (unicellular planktonic organisms) were killed at these concentrations. The substances tested in this work were found to induce a partial or even complete inhibition of the top–down control of unicellular planktonic populations by organisms belonging to higher links of the trophic chain (invertebrates). The ecological hazard of this inhibition of the phytoplankton control by higher links of the trophic chain may be aggravated by phytoplankton growth facilitated by chemical environmental pollution. The phytoplankton-growth stimulation by chemical pollutants was observed in our studies on Triton X-100 (TX100) effects on marine plankton cyanobacteria *Synechococcus* sp. [13] and surfactant-induced effects on the growth of phytoplankton organisms (unpublished data obtained in collaboration with N.N. Kolotilova).

Analysis of a system of interacting species treated with chemical inhibitors provides important information about the degree of the regulatory effect of higher trophic chains. This approach is based on the addition of chemical inhibitors. Therefore, it is similar to the conventional method of inhibitory analysis widely used in biochemistry for studying individual enzymes and multienzyme complexes. In my opinion, this approach to ecological problems may prove to be as effective as in biochemistry.

The experimental results of this work are summarized in Table 1. These data provide new information, which is consistent with our theoretical concept and previous experimental findings.

It was found in systems containing Cladocera species (*Daphnia magna*, *D. longispina*, *Simocephalus vetulus*, and *Ceriodaphnia dubia*) and phytoplankton species (*Chlorella* sp., *Raphidocelis subcapitata*, etc.) that the algal population control by daphnia is sensitive to chemical agents added to the experimental system. The following chemical agents were shown to suppress the algal population control: heavy metals (Cd, Cu, and potassium bichromate), fluoranthene, dimethoate, and

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

0012-4966/01/0304-0139$25.00 © 2001 MAIK "Nauka / Interperiodica"

Table 1. New data on the inhibitory effects of various chemical compounds on the top–down control of plankton organisms

Species of a higher trophic level exerting a regulatory effect	Species of a lower trophic level	Chemical inhibitors of regulatory effects	Concentration, mg/l
Brachionus angularis	Chlorella sp.	TDTMA	0.5
B. plicatilis	Chlorella sp.	TDTMA	0.5
Unio tumidus	Scenedesmus quadricauda, Synechocystis sp. 6803	TX100	5
U. tumidus	Synechocystis sp. 6803	TX100	1
U. pictorum	Synechocystis sp. 6803	TDTMA	1–2
U. pictorum	Saccharomyces cerevisiae	TDTMA	1–2
Mytilus galloprovincialis	Dunaliella viridis	SDS	1.7
M. galloprovincialis	Monochrysis lutheri	TDTMA	1
M. galloprovincialis	Monochrysis lutheri	AHC	5–60
M. galloprovincialis	Monochrysis lutheri	SS	6.7–50
M. edulis	Isochrysis galbana	SDS	1–5
M. edulis	Isochrysis galbana	TX100	0.5–5

Note: TDTMA, tetradecyltrimethylammonium bromide; SDS, sodium dodecylsulfate; AHC, Avon Hair Care (a hair shampoo, Avon Cosmetics); SS, synthetic surfactants (Lotos-Ekstra, Losk-Universal, and Tide-Lemon). Experiments were performed with the expert assistance of Dr. P. Donkin, F. Staff, N.N. Kolotilova, N.V. Kartasheva, and N.E. Zurabova. In some experiments, *S. cerevisiae* was used as a model planktonic unicellular organism. New experimental findings and materials of preceding publications [8–12] are included.

dichloroaniline. These results were reported by M. Scholten (the Head of the Project), R. Jak, B. Clement, E. Foekema, P. Hernandez, K. Kaag, H. van Dokkum, M. Smit, and others (Institute of Applied Research, Den Helder) at the Workshop on Problems of Eutrophication (The Netherlands, December 9–12, 1999).

It should be noted that many chemical agents suppress the trophic activity of daphnia even at concentrations having no negative effect on the phytoplankton algal populations. This is true for many pesticides (endosulfan, diazinon, methylparathion, atrazin, lindan, dichlobenyl, etc.). These data were also reported at

Table 2. Tetradecyltrimethylammonium bromide (TDTMA) reduces the ability of *Mytilus galloprovincialis* to control the cell population of *Monochrystis lutheri*

Monitoring period	Incubation time, min	Optical density at 650 nm		B/A, %
		Variant A (+TDTMA)	Variant B (–TDTMA)	
1	10	–	0.088	65.19
	11	0.135	–	
2	14	–	0.061	47.66
	15	0.128	–	
3	26	–	0.039	31.20
	27	0.125	–	
4	41	–	0.030	25.86
	42	0.116	–	
5	45	–	0.027	23.68
	46	0.114	–	
6	50	–	0.023	21.70
	51	0.106	–	

Note: Experimental tanks contained 500 juvenile (two-month-old) mollusks each (a total of 0.5 g raw weight including shells). Incubation temperature, 25.8°C. Optical density was measured using an SF-26 spectrophotometer (LOMO, Russia) at an optical path length of 10 mm. Water incubation medium volume, 50 ml.

Table 3. Synthetic surfactants (SS) reduces the ability of *Mytilus galloprovincialis* to control the cell population of *Monochrystis lutheri*

Monitoring period	Incubation time, min	Optical density at 650 nm			B/A, %
		Variant A (+SS)	Variant B (–SS)	Variant C (only algae without mollusks and –SS)	
1	9	–	0.128	–	76.65
	10	0.167	–	–	
	13	–	–	0.173	
2	15	–	0.095	–	55.23
	17	0.172	–	–	
	18	–	–	0.166	
3	47	–	0.029	–	18.13
	48	0.160	–	–	
	49	–	–	0.167	

Note: The incubation temperature was 27.8°C. In variant A (+SS), the mollusks were preincubated for 20 min in the presence of 13.3 mg/l SS. The other experimental details were as in Table 2.

the Workshop on Problems of Eutrophication (The Netherlands, December 9–12, 1999). Similarly, it was shown in our experiments that, although certain concentrations of xenobiotics are able to inhibit the trophic activity of invertebrate consumers of unicellular aquatic planktonic organisms (including bacterial plankton), these concentrations of xenobiotics exert significantly lower inhibitory effects on bacterial growth. This was demonstrated using the effect of TX100 on marine prostecobacteria *Hyphomonas* MHS-3 as an example [14]. These findings indicate that it is the regulatory function of higher links of trophic chains that is the most vulnerable to chemical pollution.

The results of our experiments (Tables 1–3) are consistent with the data obtained in the framework of the project headed by Dr. M. Scholten. The practical significance of these findings is that they provide new insight into the possible causes and detrimental mechanisms of water eutrophication and algal blooms (including these processes in estuary and coastal sea waters). The results of these experiments show that the anthropogenic pollution of water may cause disbalances in the natural mechanisms of algal phytoplankton population control. In addition to regulation of phytoplankton, this conclusion seems to be true for unicellular plankton control in general.

In my opinion, this factor provides a deeper insight into the causes and mechanisms of (1) eutrophication of freshwater, estuary, and seawater basins and (2) algal blooms, algal bloom models, and methods of algal bloom prevention. Full-scale regulatory interactions in trophic webs of aquatic ecosystems are also required to provide effective self-purification of water [8–10, 12]. Regulatory interaction disturbances caused by the chemical contamination of water should be regarded as a potential hazard to the sustainable use of aquatic [15] and living [5–7] resources.

ACKNOWLEDGMENTS

I am grateful to M.E. Vinogradov, A.F. Alimov, V.V. Malakhov, V.D. Fedorov and other researchers from the Department of Hydrobiology (Moscow State University), V.N. Maksimov, A.S. Konstantinov, A.O. Kasumyan, E.A. Kriksunov, S.V. Kotelevtsev, Prof. H. Dumont, Dr. M. Scholten, Prof. Nico M. van Straalen, and other colleagues for stimulating discussion.

This study was supported by the MacArthur Foundation (the program for individual research grants and the Program on Global Security and Sustainability). This work was also partly supported by RSS, Open Society Foundation (project no. 1306/1999).

I am grateful to colleagues from the Institute of Biology of Southern Seas, National Academy of Sciences of Ukraine, Dr. P. Donkin, N.N. Kolotilova, N.V. Kartasheva, M.P. Kolesnikov, and N.E. Zurabova for expert assistance in some experiments.

REFERENCES

1. Ostroumov, S.A., *Vvedenie v biokhimicheskuyu ekologiyu* (Introduction to Biochemical Ecology), Moscow: Mosk. Gos. Univ., 1986.
2. Telitchenko, M.M. and Ostroumov, S.A., *Vvedenie v problemy biokhimicheskoi ekologii* (Introduction to the Problems of Biochemical Ecology), Moscow: Nauka, 1991.
3. Wootton, J., *Ecology*, 1992, vol. 73, pp. 981–991.
4. Wurtsbaugh, W., *Oecologia*, 1992, vol. 89, pp. 168–175.
5. Yablokov, A.V. and Ostroumov, S.A., *Okhrana zhivoi prirody: problemy i perspektivy* (Protection of Living Nature: Problems and Prospects), Moscow: Lespromizdat, 1983.
6. Yablokov, A.V. and Ostroumov, S.A., *Urovni okhrany zhivoi prirody* (Levels of Nature Conservation), Moscow: Nauka, 1985.
7. Yablokov, A.V. and Ostroumov, S.A., *Conservation of Living Nature and Resources: Problems, Trends and Prospects*, Berlin: Springer, 1991.
8. Ostroumov, S.A., Donkin, P., and Staff, F., *Dokl. Akad. Nauk*, 1998, vol. 362, no. 4, pp. 574–576.
9. Ostroumov, S.A., *River. Biol.*, 1998, vol. 91, pp. 221–232.
10. Ostroumov, S.A. and Fedorov, V.D., *Vestn. Mosk. Gos. Univ., Ser. 16: Biol.*, 1999, no. 1, pp. 24–32.
11. Kartasheva, N.V. and Ostroumov, S.A., *Toksikol. Vestn.*, 1998, no. 5, pp. 30–32.
12. Ostroumov, S.A., Donkin, P., and Staff, F., *Vestn. Mosk. Gos. Univ., Ser. 16: Biol.*, 1997, no. 3, pp. 30–36.
13. Uoterberi, Dzh. and Ostroumov, S.A., *Mikrobiologiya*, 1994, vol. 63, no. 2, pp. 258–262.
14. Vainer, R. and Ostroumov, S.A., *Toksikol. Vestn.*, 1998, no. 4, pp. 42–43.
15. Ostroumov, S.A., *Aquatic Ecosystems*, Moscow: Dialog, 1999, pp. 13–14.