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Some aspects of water filtering activity of filter-feeders

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Key words: filter-feeders, water purification, bivalves, pollution, filtering activity

Abbreviations: AFDW - ash-free dry weight; LD - liquid detergent; SD - synthetic detergent (laundry detergent in the form of powder); SDS - sodium dodecyl sulphate; TDTMA -tetradecyltrimethylammonium bromide

Abstract

On the basis of the previous publications, our new data and the existing scientific literature, we have formulated some fundamental principles that characterize the pivotal roles of the biodiversity of filter-feeders in ecosystems. Among those roles are: (1) the role of ecological repair of water quality, (2) the role of contributing to reliability and stability of the functioning of the ecosystem, (3) the role of contributing to creation of habitat heterogeneity, (4) the role of contributing to acceleration of migration of chemical elements. It is an important feature of the biomachinery of filter-feeders that it removes from water various particles of a very broad range of sizes. Another important principle is that the amount of the organic matter filtered out of water is larger than the amount assimilated so that a significant part of the removed material serves no useful function to the organism of the filter-feeder, but serves a beneficial function to some other species and to the ecosystem as a whole. The new experiments by the author additionally demonstrated a vulnerability of the filtration activity of filter feeders (e.g. bivalves and rotifers) to some xenobiotics (tetradecyltrymethylammonium bromide, heavy metals and some others).

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The text of the paper is below:

Introduction

Quantitative data on the filtering activity of various benthic filter- feeders have been obtained (e.g., Alimov, 1981; Gutelmaher, 1986; Newell 1988; Monakov 1998; and many other authors). A significant body of data on planktonic filter-feeders was produced (e.g., Sushchenya, 1975; Zankai, 1979, Starkweather & Bogdan,1980).We have found new evidence of the vulnerability of that activity of filter-feeders to some chemicals (Ostroumov, 1998, 2002 a,b; 2003a). In order to better understand the implications of those effects, it is worth analyzing the fundamental patterns in the data on the filtration activity of aquatic organisms.

The goal of this paper is to contribute to that analysis.

In the paper we address the following topics:

1. Some examples of the filtering activity and clearance time in some water bodies;
2. Diversity of filter-feeders: its role in reliability of the biomachinery involved in water filtration;
3. The concentration of particles: effects on filtration rates;
4. Production of pellets by filter-feeders. Role for the ecosystem;
5. Filter-feeders and regulation of the ecosystem;
6. Author's new experimental data on effects of chemicals on filter-feeders.

Examples of the filtering activity and clearance time in some water bodies

Among many examples of quantitative studies of various aquatic species, we mention here only a few examples. Thus, the filtration activity of *Eudiaptomus gracilis* (copepod) in Lake Balaton was in winter 0.11 ml animal^{-1} day^{-1} and in summer 1.44 ml animal^{-1} day^{-1} ; their maximal activity was as high as 3.27 ml animal^{-1} day^{-1} (Zankai, 1979). The filtration activity of *Keratella cochlearis* was 5-6 μl animal^{-1} h^{-1} (Starkweather & Bogdan, 1980). A higher activity (5-30 μl animal^{-1} h^{-1}) was reported for *Brachionus calyciflorus* when they were feeding in the laboratory on ciliates (*Coleps* sp.) (see: Ostroumov et al., 2003b). Some other examples are in Tables 1 and 2 below.

The filtration rate for a number of benthic organisms was as high as 4.7-10.2 l g^{-1} h^{-1} (dry body weight; see Dame et al., 2001).

In detailed studies it was shown that the filtration rate FR (l h^{-1}) increased with increasing body weight W (dry weight of the soft parts) according to the equation (Sushchenya, 1975; Alimov, 1981; Kryger & Riisgård, 1988):

$$FR = a\,W^{b}$$

The data for a and b for many species were determined (e.g. Alimov, 1981; Kryger & Riisgård, 1988).Thus, the *a* value for *Dreissena polymorpha* was 6.82 (feeding on *Chlorella vulgaris*), and for *Sphaerium corneum*, 2.14 (also feeding on *Chlorella vulgaris* (Kryger & Riisgård, 1988). As for b values, they are often within the range from 0.46 to 0.92 (Kryger & Riisgård, 1988).

Studies by many authors have shown that the total filtering activity of benthic populations of bivalves (e.g., Unionidae, Dreissenidae) is often within the range from 0.1 to 5 m^3 m^{-2} day^{-1} (see: Ostroumov, 2003a).

It is important that the filtering activity is so high that the total volume of many water bodies is filtered within a time period of from 1-2 days to some dozens of days. Even if only benthic filter-feeders are taken into account, that time period is from one day to several dozens of days (see Table 1). If only planktonic filter-feeders are considered, similar results were reported (Gutelmaher, 1986).

Diversity of filter-feeders and its role for reliability

The biodiversity of organisms that are involved in filter-feeding covers uni- and multicellular, planktonic and benthic, freshwater and marine organisms (Alimov, 1981; Krylova, 1997; Monakov, 1998; Dame et al., 2001; Shuntov, 2001). Here we consider only invertebrates and mainly benthic organisms. However, in order to indicate the broad biodiversity involved, some examples of vertebrates could be mentioned: filter-feeding is a way of trophic activity of some fish (Clupeidae and many others) and even birds (flamingo, Phoenicopteridae).

Filtration rate was measured for a number of taxons of invertebrates (Alimov, 1981; Kryger & Riisgård, 1988; and others). Some examples for benthic filter-feeders are given in table 2 . It is interesting that for a number of taxons the filtering rate is as high as up to 10 l g-1 h-1 (dry weight of the filter-feeder).

Such filter-feeders as brachiopods are important but the quantitative data on their filtration rates are not available. They are important in both shallow habitats (e.g., *Tythothyris rosimarginata*, 5-25 m) and deep bottom habitats – e.g., *Pelagodiscus atlanticus* (366-5530 m), *Multitentacula (Dentaria) amoena* (found at 5060 m), *Bathyneaera hadalis* (2970-8430 m) (Krylova, 1997).

The diversity of organisms involved in water filtration makes the entire ecosystem activity in water filtration and seston removal more reliable. It is interesting to note that each of the two main parts of the aquatic ecosystem (the pelagic and benthic parts) has several taxons of filter-feeders; it is noteworthy that many of the benthic filter feeders (e.g. bivalves) produce larvae that constitute another element of pelagic filter-feeders. The various taxons of filter feeders may have different food requirement and complement each other. However their ecological niches partially overlap, which increases the reliability of the entire water filtering activity of aquatic biota en bloc.

The concentration of particles: effects on filtration rates

Studies of filtering activities at various concentrations of particles were performed (e.g., Schulman & Finenko, 1990; Monakov, 1998). At relatively low concentration of particles, the dependence of the fitration rate on the concentration of particles is usually linear or almost linear. At the concentration of particles above certain threshold, a non-linear dependence of the filtering rate on the concentration of particles was found in many cases (Schulman & Finenko, 1990). One of many examples of studies of that type is illustrated by the data of Table 3.

In several studies it was shown that the higher the concentration of suspended particles (the cells of algae, etc.), the lower is the filtration activity and (in relative terms) the grazing pressure on seston.

That pattern of the filtering activity and consumption activity was reported in many other cases. Among them are *Mytilus galloprovincialis* (feeding on *Gymnodinium kowalevskii*) (Shulman & Finenko, 1990), *Brachionus calyciflorus* (feeding on *Langerheimia ciliata, Scenedesmus acuminatus*), *Daphnia magna, D. rosea, Diaphanosoma brachyurum* and other filter-feeders (Sushchenya, 1975; Monakov, 1998).

It means that when for some reason the concentration of phytoplankton increases above certain threshold, the grazing pressure on it - at least in some cases - might not be increased proportionately, which means that some relative decrease of the control of the phytoplankton takes place. It might open the way for further growth of the phytoplankton. That pattern of cause and effect is an exemplification of the system of positive feedbacks. A detailed discussion of the role of positive feedbacks was given in (Dame et al., 2001).

As a final result, the abovementioned might contribute to the local increase in the relative phytoplankton abundances in some parts of aquatic ecosystems. The relative increase in phytoplankton changes some other parameters of the local aquatic environment (transparency of water, amount of detritus etc.) so that the heterogeneity of the aquatic habitat increases.

The level of heterogeneity of the habitat is a very important parameter from the viewpoint of general ecology and it is necessary to take into consideration all possible mechanisms that contribute to its formation.

Production of pellets by filter-feeders. Role of the process for the ecosystem. Ecological taxation

The role of organic matter produced by filter-feeders as pellets and detritus is of so high an importance to the ecosystem that it can be viewed as a service done to ecosystem or a type of ecological tax paid by filter-feeders. To evaluate the amount of the tax or to make the picture more visible, it makes sense to compare the amount of pellets excreted and the productivity of populations of filter-feeders. That kind of comparison may be done by calculating the ratio F : P (F- excreted non-digested, non-assimilated organic material; P - productivity). It should be noted that the ratio gives only a rough (and perhaps indirect) estimate of that what might be considered the tax as the pellets are covered by a mucus layer. The mucus is a product of metabolism of invertebrates and some energy is spent on its synthesis. The formation of the mucus envelope for the pellets is another evidence of the special role of the function of pellet production. To pay the tax in an organized way, the organism sacrifices (or donates) valuable metabolic energy and effort to synthesize a special package for the material returned to the ecosystem. The mucus envelope contributes to better hydrodynamic attributes of the pellets so that they faster move downward to the deeper layers of water or to the bottom. The downward transfer of organic matter is important for the well-being and stability of the ecosystem.

What is said above generates interest in calculating the ratio F:P. An example of the calculation is given in Table 4, where the original data are part of the energy budget of the ecosystem of the central part of the Sea of Okhotsk in the summer time.

We may consider P (productivity) as an analogy of profit, and F might be viewed as an estimate of what the organism returns to the community as a tax towards some stability of environment.

Another way of calculating an estimate of ecological tax is the ratio F: (P + R), where P and R stands for productivity and respiration, respectively (Table 5). Again, we have to make some reservations and emphasize that this ratio is only a rough estimate as some metabolic energy was spent on the synthesis of the mucus envelope for the pellets.

Discussing the pellets, it is worth mentioning that the mucus that covers the pellets has several roles. It was shown that mucus binds various pollutants from water, including some metals (for discussion, see Ostroumov 2001c).

As a result of pellet production, some amount of the material is deposited on the bottom. The amount of the biosediment formed was measured in a number of studies. Some examples are given in Table 6.

Filter-feeders and regulation of the ecosystem

We would like to emphasize that another important role of filter-feeders in ecosystems is the regulation of abundance of some key players in the ecosystem including not only algae but also bacteria. By doing so, filter-feeders control an extremely active process of oxidation of organic matter in the ecosystem as the bacteria are sometimes the most active actors in performing the oxidation of organic matter in aquatic ecosystems (see, e.g., Table 7). Also, the table shows that filter-feeders themselves (zooplankton plus part of zoobenthos) are also an important part of the biomachinery for carbon oxidation in the ecosystem.

From the data of the Table 7, we clearly see the role of bacteria. Important are also the other organisms that help bacteria, e.g., by producing extracellular organic metabolites, recycling nutrients (excretion of various forms of nitrogen and phosphorus) that are available for bacteria. Moreover, the regulatory role of filter-feeders is also important towards some optimization of the rates of oxidation of organic molecules by bacteria and other small heterotrophic organisms.

Analyzing the role of filter-feeders in regulating the abundance of bacteria and therefore their oxidation activity, we should also underline another aspect of the influence of filter-feeders on heterotrophic bacteria. This aspect is the production by filter-feeders of the pellets rich in organic matter that provide the organic substrate for heterotrophic bacteria, and also provide the organic molecules that serve the function of electron acceptors for some anaerobic bacteria of sediments.

Author's new experimental data on the effects of chemicals on filter-feeders

It is important to better understand the implications of water pollution, including some potential effects of pollutants on filter-feeders and their functional activities. We have studied the effects of some chemicals (surfactants and others) on the filtering rate of invertebrates. The individual chemicals tested represented all three main classes of surfactants: anionic, cationic, non-ionic surfactants. The representatives of those that were tested were SDS, TDTMA, and Triton X-100, respectively. Some inhibition was found (Ostroumov et al., 1997; Kartasheva & Ostroumov, 1998; Ostroumov, 1998; 2000a,b,c; 2002a,b; Ostroumov et al., 2003 b). Surfactant SDS inhibited the filtration activity of *Mytilus* *edulis* (Ostroumov et al., 1997). Surfactants TDTMA and SDS (both at 0.5 mg l^{-1}) inhibited the filtration activity of *Crassostrea gigas* (Ostroumov, 2003a). TDTMA (0.5 mg l^{-1}) inhibited water filtration by rotifers (Kartasheva & Ostroumov, 1998; Ostroumov et al., 2003b). Quantitative data on the effects of some chemicals on filter-feeders are presented in table 8. To measure the effect of the chemicals, we used monitoring the amount of suspended matter that stayed in water after a certain period of filtration by invertebrates. As a result of the filtration, some suspended matter was removed from the water. If the filtration activity was inhibited by the chemical, the amount of the removed suspended matter was less than the amount of that removed in the control. Therefore the concentration of the non-removed suspended matter in water was higher in the system with the chemical tested than in the system with uninhibited activity of filter feeders. We calculated the ratio of the concentration of suspended matter in the system with the chemical inhibitor to that in the control system where the filtration activity was uninhibited. The ratio was presented in table 8. It is seen that both individual surfactants and the chemical products that are the mixtures of several chemicals including surfactants produced a significant effect on the filtration activity. The effect was concentration-dependent. Those data are in accord with previous studies by other authors who have found a similar inhibitory action of other chemicals or have used other organisms (e.g., Mitin, 1984; Widdows & Page 1993; Stuijfzand et al., 1995; Donkin et al., 1997).

It should be noted that the response of some species to specific pollutants may have a complex (e.g., bi-phasic) character and we have to be careful when interpreting our experiments. We have to avoid oversimplification of the situation when a pollutant affects aquatic organisms as it is known that some concentrations of toxicants might produce a stimulation of biological functions. We do not extend our conclusions on all types and all concentrations of pollutants and xenobiotics. However at least in case of surfactants we definitely observed the inhibition of the filtering activity both in marine and freshwater organisms.

It is interesting that the filtering activity can be inhibited not only by the man-made chemicals, but also by some natural ecological chemoeffectors (kairomones). Thus, the filtration activity of *Ceriodaphnia* cf. *dubia* was inhibited by kairomones exuded by eastern rainbowfish *Melanotaenia duboulayi* at fish densities 0.125 fish l^{-1} or higher, when the fish were placed in culture water for one hour (Rose et al., 2003).

All in all, the data shows that the filtering activity is a labile and vulnerable process.

From facts to some principles and general conclusions

The material above leads to formulation of some conclusions on fundamental features of filter-feeders. The logic of thoughts that start with facts and lead toward fundamental conclusions is presented in Table 9. Each line of the table starts with a summary of factual data in the left cell of the line. The factual data are commented in the middle cell of each line, which pave the way for the short formulation of a more general principle in the right cell of each line.

The analysis given above provides some basis for a new vision of the risk of man-made disturbances in biota and ecosystems. This vision was formulated by us in the papers (Ostroumov, 2000a, 2003 b) and is summarized in Table 10.

According to the approach presented in the table and discussed in more detail in (Ostroumov, 2003 b), the man-made inhibition of the water filtration rate is a significant disturbance to the ecosystem. The inhibition of the filtration activity of filter-feeders may lead to the situation previously described as that of ecological bomb of the second type (Ostroumov, 1999).

Conclusions

The studies of filter-feeders help to elucidate some important aspects of ecosystem stability and regulation, which are among the priorities in ecology (Ostroumov et al., 2003 a).

1. The filter-feeders perform some functions that are important services to ecosystem and are characterized by the following:

(a) Filter feeders participate in the large-scale repair of water quality;

(b) Filter feeders contribute to the reliability of the mechanism and stability of ecosystem;

(c) Filter feeders may potentially contribute to creating habitat heterogeneity;

(d) Filter feeders by removing seston and excreting pellets are involved in 'ecological taxation': filter-feeders pay some ecological tax to the ecosystem;

(e) Filter feeders contribute to acceleration (biocatalysis) of migration of elements;

(f) Filter feeders contribute to the regulation of the metabolism of ecosystem.

2. Using several species of filter-feeders as a model system for studies, we have shown that the filtration rate may be inhibited by some xenobiotics and pollutants.

3. On the basis of our studies of various chemicals and organisms, we predict that new examples of pollutants and xenobiotics that inhibit the filtration activity of aquatic organisms will be found in future.

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Literature

Achituv, Y. & M.L.Pedrotti, 1999. Costs and gains of porcelain crab suspension feeding in different flow conditions. Marine Ecology Progress Series. 184: 161-169.

Alimov, A. F., 1981. Functional Ecology of Freshwater Bivalves (Funktzionalnaja Ekologija Presnovodnykh Dvustvorchatykh Molluskov). Nauka press, Leningrad. 248 pp.

Asmus, R.M. & H. Asmus, 1991. Mussel beds: limiting or promoting phytoplankton? Journal

Experimental Marine Biology Ecology. 148: 215-232

Bacher, C., 1989. Capacité trophique du bassin de Marennes-Oléron: couplage d'un modele de transport particulaire et d'un modele de croissance de l'huitre *Crassosrea gigas*. Aquatic Living Resources. 48:199-214.

Ball, B., R.Raine & D.Douglas, 1997. Phytoplankton and particulate matter in Carlingford Lough, Ireland: an assessment of food availability and the impact of bivalve culture. Estuaries. 20: 430-440.

Bern, L., 1987. Zooplankton grazing on [methyl-3H] thymidine-labelled natural particle assemblages: determination of filtering rates and food selectivity. Freshwater Biology. 17: 151-159.

Cloern, J., 1982. Does the benthos control phytoplankton biomass in South San Francisco Bay? Marine Ecology Progress Series. 9: 191-202.

Dame, R., D. Bushek & T. Prins, 2001. Benthic suspension feeders as determinants of ecosystem structure and function in shallow coastal waters. Ecological Studies. 151: 11-37.

Dame, R., N. Dankers, T. Prins, H. Jongsma & A. Smaal, 1991. The influence of mussel beds on nutrients in the Western Wadden Sea and Eastern Scheldt estuaries. Estuaries. 14: 130-138.

Dame, R., R. Zingmark, H. Stevenson & D. Nelson, 1980. Filter feeding coupling between the water column and benthic systems. In: Kennedy V. (Editor) Estuarine perspectives. Academic Press, New York: 521-526.

Davies, B., V. Stuart & M. de Villiers, 1989. The filtration activity of a serpulid polychaete population (*Ficopomatus enigmaticus* (Fauvel) and its effects on water quality in a coastal marina. Estuary Coast Shelf Science. 29: 613-620.

Donkin, P., J. Widdows, S. V. Evans, F. Staff & T. Yan, 1997. Effects of neurotoxic pesticides on the feeding rate of marine mussels *Mytilus edulis*. Pesticide Science. 49: 196-209.

Frost, T. 1978. Impact of the freshwater sponge *Spongilla lacustris* on a *Sphagnum* bog-pond. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie. 20: 2368-2371.

Frost, T., 1980. Clearance rate determination for the freshwater sponge *Spongilla lacustris*: effects of temperature, particle type and concentration, and sponge size. Archiv für Hydrobiologie. 90: 330-356.

Gutelmaher, B. L., 1986. Metabolism of Plankton as the Whole (Metabolizm Planktona Kak Edinogo Tzelogo). Nauka, Leningrad. 156 pp.

Hily, C., 1991. Is the activity of benthic suspension feeders a factor controlling water quality in the Bay of Brest? Marine Ecology Progress Series, 69: 179-188.

Jaramillo E., Bertran C., Bravo A. 1992. Mussel biodeposition in an estuary in southern Chile. Marine Ecology Progress Series. 82: 85-94.

Kartasheva, N. V. & S. A. Ostroumov, 1998. Tetradecyltrimethylammonium bromide (tetradetziltrimetilammonij bromid). Toxicological Bulletin (Toksikologicheskii Vestnik). 5: 30-32.

Kautsky N., Evans S. 1987. Role of biodeposition by *Mytilus edulis* in the circulation of matter and nutrients in a Baltic coastal ecosystems. Marine Ecology Progress Series. 38: 201-212.

Krylova, E.M., 1997. Abyssal bivalves of the superfamily Cuspidarioidea (Septibranchia) from the Far-Eastern seas and the North-Western Pacific. In: Kuznetzov, A. P. & O. N. Zezina (eds) Composition and distribution of bottom invertebrate animals in the seas of Russia and adjacent waters. Institute of Oceanology, Moscow: 80-84

Kryger, J., & H.U. Riisgård, 1988. Filtration rate capacities in 6 species of European freshwater bivalves. Oecologia. 77: 34-38.

Kryuchkova, N.M. & V.H. Rybak, 1989. Patterns of feeding of *Moina rectirostris* Leydig on phytoplankton of a hypertrophic water body (osobennosti pitaniya *Moina rectirostris* Leydig fitoplanktonom gipertrofnogo vodoema. Hydrobiological Journal (Gidrobiologicheskiy Zhurnal) 25 (3): 28-31.

Migne, A. & D. Davoult, 2002. Experimental nutrition in the soft coral *Alcyonium digitatum* (Cnidaria: Octocorallia): removal rate of phytoplankton and zooplankton. Cahiers de Biologie Marine. 43 (1): 9-16.

Mitin, A., 1984. Effect of some environmental factors on the water-clearing activity of bivalves. Summary of Ph.D. Thesis, Moscow. 22 pp.

Monakov, A. V., 1998. Feeding of Freshwater Invertebrates (Pitanie Presnovodnykh Bespozonochnykh). Institute of Ecological and Evolutionary Problems, Moscow. 320 pp.

Newell, R., 1988. Ecological changes in Chesapeake Bay: are they the result of overharvesting the American oyster, *Crassostrea virginica*? Understanding the estuary: Advances in Chesapeake Bay Research. Proceedings of a Conference. 29-31 March 1988. Baltimore, Maryland.- Chesapeake Research Consortium Publication 129: 536-546.

Ogilvie, S. & S. Mitchell, 1995. A model of mussel filtration in a shallow New Zealand lake, with reference to eutrophication control. Archiv für Hydrobiologie. 133(4): 471-482.

Ostroumov, S. A., 1998. Biological filtering and ecological machinery for self-purification and bioremediation in aquatic ecosystems: towards a holistic view. Rivista di Biologia/ Biology Forum. 91: 247-258.

Ostroumov, S.A., 1999. Integrity-oriented approach to ecological biomachinery for self-purification and bioremediation in aquatic ecosystems: stopping an ecological time bomb. Limnology and Oceanography: Navigating into the Next Century. February 1-5, 1999, Santa Fe, New Mexico. ASLO, Waco, TX. Page 134.

Ostroumov, S. A., 2000a. Criteria of ecological hazards due to anthropogenic effects on the biota: searching for a system (Kriterii ekologhicheskoj opastnosti antropoghennykh vozdejstvij na biotu: poiski sistemy). Doklady Biological Sciences 371: 204-206 (the Russian edition: Doklady Akademii Nauk 371: 844-846).

Ostroumov, S. A., 2000b. The concept of aquatic biota as a labile and vulnerable component of the water self-purification system (Kontzeptzija vodnoi bioty kak labil'nogo i ujazvimogo zvena sistemy samoochishchenija vody). Doklady Biological Sciences 372: 286-289 (the Russian edition: Doklady Akademii Nauk 372: 279-282).

Ostroumov, S. A., 2000c. Aquatic ecosystem: a large-scale diversified bioreactor with a water self-purification function (Vodnaja ekosistema: krupnorazmernyj diversifitzirovannyj bioreaktor s funktzijej samoochishchenija vody). Doklady Biological Sciences 374: 514-516 (the Russian edition: Doklady Akademii Nauk 374: 427-429).

Ostroumov, S.A., 2001a . Responses of *Unio tumidus* to a mixture of chemicals and the hazard of synecological summation of anthropogenic effects (Reagirovanie *Unio tumidus* pri vozdeistvii smesevogo himicheskogo preparata i opasnost sinekologicheskogo summirovaniya antropogennyh vozdeistviy). Doklady Akademii Nauk. 380: 714-717. [Transl. into English and published: Responses of *Unio tumidus* to mixed chemical preparations and the hazard of synecological summation of anthropogenic effects. Dokl Biol Sci (Doklady Biological Sciences). 2001, 380: 492-495].

Ostroumov, S.A., 2001b. Synecological foundation for the solution of the problem of eutrophication (Sinekologicheskie osnovy resheniya problemy evtrofirovaniya). Doklady Akademii Nauk. 381:709-712. [Transl. into English and published: The synecological approach to the problem of eutrophication. Dokl Biol Sci (Doklady Biological Sciences). 2001, 381: 559-562].

Ostroumov S.A. 2001c. Amphiphilic chemical inhibits the ability of molluscs to filter water and to remove the cells of phytoplankton. Izvestia RAN. Seriya Biology (Bulletin of Russian Academy of Sciences, Biology Series). No.1: 108-116.

Ostroumov, S.A., 2002a. Inhibitory analysis of top-down control: new keys to studying eutrophication, algal blooms, and water self-purification. Hydrobiologia. 469: 117-129.

Ostroumov, S.A., 2002b. Polyfunctional role of biodiversity in processes leading to water purification: current conceptualizations and concluding remarks. Hydrobiologia. 469 (1-3): 203-204.

Ostroumov, S.A., 2002c. Biodiversity and water quality: the role of feed-backs (Sokhranenie bioraznoobrziya i kachestvo vody: rol obrantykh svyazej v ekosistemakh) Doklady Akademii Nauk. 382: 138-141. [Translated into English and published: Biodiversity protection and quality of water: the role of feedbacks in ecosystems. Dokl Biol Sci (Doklady Biological Sciences). 2002, 382: 18-21].

Ostroumov, S.A., 2003a. Studying effects of some surfactants and detergents on filter-feeding bivalves. Hydrobiology. 500: 341-344.

Ostroumov, S.A., 2003b. Anthropogenic effects on the biota: towards a new system of principles and criteria for analysis of ecological hazards. Rivista di Bilogia / Biology Forum. 96: 159-169.

Ostroumov, S.A., P. Donkin & F. Staff, 1997. Inhibition by the anionic surfactant, sodium dodecyl sulphate, of the ability of mussels *Mytilus edulis* to filter and purify the sea water (Anionnoje poverkhnostno-aktivnoje veshchestvo inghibirujet sposobnost' midij filtrovat' i ochishchat' morskuju vodu). Vestnik Moskovskogo Universiteta. Seria 16. Biologija. (Bulletin of Moscow University. Series 16. Biology) 3: 30-36.

Ostroumov, S. A., P. Donkin & F. Staff, 1998. Filtration inhibition induced by two classes of synthetic surfactants in the bivalve mollusc (Narushenije filtracii dvustvorchatymi molluskami pod vozdejstvijem poverkhnostno-aktivnykh veshchestv dvukh klassov). Doklady Akademii Nauk 362: 574-576.

Ostroumov, S.A., N. Walz & J. Widdows, 2001. Measuring activity of filter-feeders: linking organismal and superorganismal levels of hydrobiology and biological oceanography . Ecological Studies, Hazards, Solutions, 5: 26-27.

Ostroumov, S. A. , S. Dodson, D. Hamilton, S. Peterson & R. G. Wetzel, 2003a. Medium-term and long-term priorities in ecological studies. Rivista di Biologia/ Biology Forum. 96: 327-332.

Ostroumov, S.A., N.Walz & R. Rusche, 2003 b. Effects of a cationic amphiphilic chemical on rotifers. Doklady Akademii Nauk. 390 (3) : 423-426. [Transl. into English and published: Dokl Biol Sci. (Doklady Biological Sciences) 2003 390: 252-255].

Petersen, J. & H.U.Riisgård, 1992. Filtration capacity of the ascidian *Ciona intestinalis* and its grazing impact in a shallow fjord. Marine Ecology Progress Series, 88: 9-17.

Pilson, M., 1985. On the residence time of water in Narragansett Bay. Estuaries. 8: 2-14.

Rose, R., M. Warne & L. Lim, 2003. Exposure to chemicals exuded by fish reduces the filtration and ingestion rates of *Ceriodaphnia* cf. *dubia*. Hydrobiologia. 501: 215-217.

Smaal, A.C., J.Verhagen, J.Coosen & H. Haas, 1986. Interactions between seston quantity and quality and benthic feeders in the Oosterschelde, The Netherlands. Ophelia. 26: 385-399.

Sorokin, Yu.A., P.Yu.Sorokin, T.I. Mamaeva & O.V. Sorokina, 1997. The Sea of Okhotsk bacterioplankton and planktonic ciliates. In Sapozhnikov, V.V. (Ed.) Complex studies of ecosystem of the Sea of Okhotsk. VNIRO Press, Moscow: 210-216.

Shulman, G.E. & G.A. Finenko, 1990. Bioenergetics of Aquatic Organisms. Naukova Dumka Press, Kiev. 246 pp.

Shuntov, V.P., 2001. Biology of Far-Eastern seas of Russia. Vol.1. TINRO-Centre, Vladivostok. 580 pp.

Starkweather, P. & K.Bogdan,1980. Detrital feeding in natural zooplankton communities: discrimination between live and dead algal foods. Hydrobiologia. 73: 83-85.

Stuijfzand, S. C., M. H. S. Kraak, Y. A. Wink & C. Davids, 1995. Short-term effects of nickel on the filtration rate of the zebra mussel *Dreissena polymorpha*. Bulletin of Environmental Contamination and Toxicology. 54: 376-381.

Sushchenya, L. M., 1975. Quantitative Trends in the Feeding of Crustaceans. Nauka i Tekhnika press, Minsk. 208 pp.

Tsuchiya, M., 1980. Biodeposit production by the mussel *Mytilus edulis* L. on rocky shores. Journal Experimental Marine Biology and Ecology. 47: 203-222.

Vinogradov, M. E. & E.A. Shushkina, 1987. Functioning of plankton communities of the epipelagial of the ocean. Nauka Press, Moscow. 240 pp.

Widdows, J. & D. Page, 1993. Effects of tributyltin and dibutyltin on the physiological energetics of the mussel, *Mytilus edulis*. Marine Environmental Research. 35: 233-249.

Widdows, J., M.Brinsley, P.Salkeld & M.Elliott, 1998. Use of annular flumes to determine the influence of current vedlocity and bivalves on material flux at the sediment-water interface. Estuaries. 21 (4A): 552-559.

D:___papers in work\Antwerpen-presentation\Printout17Dec2003\29dec edited.doc

Witte, U., T.Brattegard, G.Graf & B.Springer, 1997. Particle capture and depostion by deep-sea sponges from the Norwegian-Greenland Sea. Marine Ecology Progress Series. 154: 241-252.

Yablokov, A. V. & S. A. Ostroumov, 1991. Conservation of Living Nature and Resources: Problems, Trends, Prospect. Springer Verlag, Berlin, Heidelberg, New York. 271 pp.

Zankai, N. , 1979. Jahreszeitliche Änderung der Filtrierrate der Copepoden *Eudiaptomus gracilis* (G.O.Sars) im Balaton-See. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie. 20: 2551-2555.

Zezina, O.N. , 1997. Brachiopods in a natural bottom biofilter at the shelves and slopes in the Far-Eastern Seas of Russia. In: Kuznetzov, A.P. & O.N.Zezina (eds) Composition and distribution of bottom invertebrate animals in the seas of Russia and adjacent waters. Institute of Oceanology, Moscow: 52-60.

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Table 1. Examples of the impact of fiter-feeders on the water column: clearance time.

System	Organisms	Per what period of time the total volume of water is filtered	References
A *Sphagnum* bog-pond, the areas of high biomass of sponges 31.8 g m^{-2}	*Spongilla lacustris* (sponge)	less than 24 h	Frost (1978)
Lake Tuakitoto (New Zealand)	*Hyridella menziesi* (bivalve)	32 h	Ogilvie & Mitchell, (1995)
Kцnigshafen $7.2 \cdot 10^6$ m^3	among dominants *Mytilus edulis, Crassostrea virginica*	0.9-2.8 d	Asmus & Asmus (1991)
North Inlet (South Carolina, USA) $22 \cdot 10^6$ m3	among dominants *C. virginica*	0.8-6.1 d	Dame et al. (1980);
South San Francisco Bay $2500 \cdot 10^6$ m^3	among dominants *Potamocorbula amurensis*	0.6 d	Cloern (1982)
Narragansett Bay $2724 \cdot 10^6$ m^3	among dominants *Mercenaria mercenaria*	32.1 d	Pilson (1985)
Oosterschelde $2740 \cdot 10^6$ m^3	among dominants *M.edulis, Cerastoderma edule*	3.7 d	Smaal et al. (1986)
Chesapeake Bay $27\,300 \cdot 10^6$ m^3	among dominants *Crassostrea virginica*	87.5 d	Newell (1988)
Marina da Gama $0.025 \cdot 10^6$ m^3	-	1.1 d	Davies et al. (1989)
Kertinge Nor, Denmark $11\,000 \cdot 10^6$ m^3	among dominants *Ciona intestinalis* (ascidian)	0.8-5 d	Petersen & Riisgård (1992)
Bay of Brest, France $1480 \cdot 10^6$ m^3	multiple species	2.8-6 d	Hily (1991)

Table 2 . Some examples of diversity of taxons of benthic organisms involved in removing seston from water.

Organisms	Biomass or another quantitative parameter used	Filtration (Removal) rate	Reference
Polichaeta, Sabellidae;	per 1 g of biomass (dry body weight);	0.5-1.8 l g^{-1} h^{-1} (sabellids remove particles 3-8 μm)	Dame et al., 2001)
Polichaeta, Sabellidae; *Sabella spallanzanii*	per 1 g of biomass (ash-free dry weight; AFDW)	1 l g^{-1} h^{-1}	Dame et al., 2001
Polichaeta , Serpulidae:	per 1 g of biomass (dry body weight)	4.7-10.2 l g^{-1} h^{-1} (they remove particles 2-12 μm)	Dame et al., 2001
Spongia (Porifera) *Thenea abyssorum*	per 1 g of biomass (ash-free dry weight; AFDW); in nature the biomass is up to 1524 mg AFDW m^{-2} (Norwegian-Greenland Sea, depth 2020-2630 m)	up to 12 l g^{-1} h^{-1}	(Witte et al., 1997:
(sponge,) *Spongilla lacustris*	per 1 g of dry weight	2 ml g $^{-1}$ sec^{-1}	(Frost , 1980)
Ascidia, *Ascidiella aspersa*	per 1 g of ash free dry weight, AFDW	2.7 l g^{-1} h^{-1}	Dame et al., 2001
Bryozoa, *Plumatella fungosa*	per 1 g of dry weight	2.2 l g^{-1} h^{-1}	Monakov, 1998)
Cirripedia, *Balanus crenatus*	per 1 g of AFDW	2 l g^{-1} h^{-1}	Dame et al., 2001
Mollusca, *Ostrea edulis*	per 1 g of AFDW)	up to 8.8 l g^{-1} h^{-1}	Dame et al., 2001
Decapoda, *Porcellana longicornis*	per 1 animal (crab)	0.1-0.27 l crab^{-1} h^{-1}	(Achituv & Pedrotti, 1999)
Echinodermata, Ophiuroidea, *Ophiothrix fragilis*;	per 1 g of AFDW	10.4 l g^{-1} h^{-1}	Dame et al., 2001
Corals, *Alcyonium digitatum*	per 1 g of biomass	0.16 mg C g^{-1} h^{-1} (the suspension filtered: the culture of diatoms *Skeletonema costatum*)	(Migne & Davoult, 2002)
Brachiopoda, *Laqueus californianus*	up to 3000 animals m^{-2}; depth: 2-1600 m	no data	Krylova, 1997;
Brachiopoda,	up to 900 animals m^{-2};	no data	Krylova, 1997;

Diestothyris frontalis	depth 0-435 m,		

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Table 3

Effect of the increase in concentration of algae (*Chlorella vulgaris*) on the filtration rate and the amount consumed (C, %) by rotifers *Brachionus calyciflorus*. [Calculated by the author on the basis of the data presented in Monakov (1998)].

Level of the concentration of algae, No.	Biomass of algae		Consumption of algae per day by one animal	
	mg l^{-1} A	A as % of that at level 1	% of the weight of the animal, B	B as % of that at level 1
1	38	100	31	100
2	75	197	37	119
3	150	397	72	232
4	300	789	59	190
5	450	1184	64	206

Table 4. The ratio F: P in some groups of organisms . The ecosystem of the Sea of Okhotsk. Units: cal m^{-2} d^{-1}

Calculated by the author on the basis of the data on P and F from the work by Sorokin et al. 1997.

Organisms	Productivity P	Excreted non-digested, non-assimilated organic material F	F : P (%)
Microzooplankton	1200	1000	83.33
Zooplankton (non-predatory)	1800	4000	222.22
Zooplankton (predatory)	500	600	120.00
Zoobenthos	600	1600	266.67
Fish	150	250	166.67
Mammals and birds	2	15	750.00

Table 5. The ratio F : (P+R) in some filter feeders (calculated by the author per 1 unit of energy spent on the sum of productivity and respiration)

Organisms	P+R (production+ respiration)	F	F : (P+R), %	References for the data on P, R, and F
Mytilus galloprovincialis 2 g (wet weight with shells); natural seston	4.8-51, average 25 % of calories of filtered matter	75%	300	Shulman & Finenko, 1990
M.galloprovincialis 10 g (wet weight with shells)	10-63, average 31	69%	222.58	
M.galloprovincialis 30 g (wet weight with shells)	15.4-90, average 41	59%	143.90	
Appendicularia	2.9 kcal $m^{-2} d^{-1}$	1.9 kcal $m^{-2} d^{-1}$	65.52	Vinogradov & Shushkina, 1987
Doliolidae	0.8 kcal $m^{-2} d^{-1}$	0.53 kcal $m^{-2} d^{-1}$	66.25	
Calanoida (small)	1.5 kcal $m^{-2} d^{-1}$	0.94 kcal $m^{-2} d^{-1}$	62.67	
Calanoida (large)	5.7 kcal $m^{-2} d^{-1}$	3.8 kcal $m^{-2} d^{-1}$	66.67	

Note: Vinogradov & Shushkina, 1987 – the region of the upwelling (Peru, 2 miles from the seashore)

Table 6. Results of the ecological tax.. Biosediments formation

System	Organisms	Amount	Comments	References
Rocky shores	*Mytilus edulis*	11.9 kg m^{-2} y^{-1} (dry weight), of which faeces 9.2 kg, pseudofaeces 2.7	-	Tsuchiya (1980)
Norwegian-Greenland Sea, depth 2020-2630 m	sponge *Thenea abyssorum*, biomass up to 1524 mg AFDW m^{-2}	0.6-2.2 mg C m^{-2} d^{-1}	The poriferan community possibly adds up to 10% to the vertical particle flux	Witte et al. 1997
	Thenea abyssorum	up to 0.7 g C m^{-2} y^{-1}	-	author's estimate based on the data (Witte et al. 1997)
Baltic coastal ecosystem	*M.edulis*	1092 g m^{-2} y^{-1} dry weight	Sedimentation was 3521 g m^{-2} y^{-1} dry weight	Kautsky & Evans, 1987
Marine/ estuarine	*M.edulis*	60 g m^{-2} h^{-1}	-	Widdows et al., 1998
Netherlands	bivalves	25 g m^{-2} h^{-1}	-	Smaal et al., 1986
Marine/ estuarine	*M. chilensis*	18 g m^{-2} h^{-1}	-	Jaramillo et al., 1992

Table 7. Contribution of various aquatic organisms to oxidation of organic matter in the ecosystem of central part of the Sea of Okhotsk (the period of time: the summer minimum of phytoplankton, the end of July - beginning of August) (Sorokin et al., 1997).

organisms	Respiration (% of the total respiration of the community)
macrophytes	0.3
phytoplankton	8.9
bacteria	55.6
microzooplankton	7.7
zooplankton (non-predatory)	12.2
zooplankton (predatory)	4.45
zoobenthos	8.3
fish	2.5
mammals and birds	0.05

Table 8. Some chemicals that have an adverse effect on the filtering activity of the filter-feeders. As a result, the amount of suspended matter removed from the water by the filter feeders decreased. Therefore the amount of suspended matter left in the water was more than that in control. (Ostroumov 2003 a, with additions)

Measurement No.	Chemical (described in the text)	Concentraton of the chemical, mg l^{-1}	Organism	Effect of the chemical (the ratio of the concentration of suspended matter in the system with the chemical to that in the control), %	Reference
1.	TDTMA	0.5	*Crassostrea gigas*	344.2	New data
2.	SD1 (L)	20	*C.gigas*	261.7	New data
3.	LD2 (F)	*2*	*M.galloprovincialis,*	218.8	Ostroumov, 2001b
4.	LD2 (F)	*2*	*C.gigas*	1790.0	New data
5.	SD2 (I)	*10*	*M.galloprovincialis*	157.8	Ostroumov, 2002c
6.	SD3 (D)	*30*	*C.gigas*	5800.0	Ostroumov, 2002c
7.	Triton X-100	*1*	*M.edulis*	236.2	Ostroumov et al., 1998
8.	Triton X-100	*4*	*M.edulis*	1505.6	
9.	SDS	*1*	*M.edulis*	271.1	Ostroumov et al., 1997
10.	SDS	*4*	*M.edulis*	1473.2	
11.	SD4 (OMO)	*50*	*Unio tumidus*	186.7	Ostroumov, 2001a

Abbreviations: LD1 (E) liquid detergent E; LD2 (F) liquid detergent Fairy; SD1 (L) synthetic detergent Lanza; SD2 (I) synthetic detergent IXI; SD3 (D)synthetic detergent Deni; SD4 (OMO) synthetic detergent OMO.

Table 9. Some features of water-filtering biomachinery

№	Features (facts)	Comment / Consequences	Fundamental Principles (in short)
1	Significant amount of water filtered per unit of biomass of animals or per unit of area or per unit of time	Significant contribution to the ecological repair of water quality	Large-scale repair of water quality
2	Parallel functioning of several taxons of filter-feeders	Increase in reliability of the biomachinery of water filtration	Contribution to the reliability of the mechanism and stability of ecosystem
3	The higher the concentration of particles, the lower the filtration rate and relative grazing pressure	Positive feedbacks that in turn may lead to the increase in heterogeneity of parts of the water column	Potential contribution to creating habitat heterogeneity
4	The amount of suspension that is being filtered out of water is usually more than needed for metabolism	A significant amount of the formerly suspended matter is finally packed, ejected and/or excreted as pellets	Ecological taxation: filter-feeders pay ecological tax to the ecosystem
5	Filter-feeders produce pellets	The pellets gravitate towards the bottom or the lower layers of the water column	Acceleration (biocatalysis) of migration of elements
6	Filter feeders remove bacteria (inter alia)	Regulatory effect (control) on bacteria (the latter may perform over 50% of the total metabolism of the ecosystem)	Contribution to the regulation of the metabolism of ecosystem

Table 10 . The level–block approach to the analysis of ecological hazards of anthropogenic effects on the biota . After Ostroumov , 2003 b , 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 O_2 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 filtration rates and elimination of suspended 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

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