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Inhibition of mussel suspension feeding by surfactants of three classes

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Abstract

Effects of three surfactants on the filtration rates by marine mussels were studied. The xenobiotics tested represented anionic, cationic and non-ionic surfactants (tetradecyltrimethylammonium bromide, a representative of a class of cationic surfactants; sodium dodecyl sulphate, a representative of anionic alkyl sulfates; and Triton X-100, a representative of non-ionic hydroxyethylated alkyl phenols). All three surfactants inhibited the clearance rates. The significance of the results for the ecology of marine ecosystems is discussed.

Abbreviations: CR – clearance rate; EMIS – the electromagnetic induction system; SDS – sodium dodecyl sulphate; TDTMA – tetradecyltrimethylammonium bromide; TX100 – Triton X-100

Introduction

Suspension feeders (filter-feeders) play a significant functional role in aquatic ecosystems. The important role of filter-feeders (particularly molluscs) is due to their high rates and volumes of water filtration (Walz, 1978; Alimov, 1981; Jørgensen et al., 1986; Kryger & Riisgård, 1988; Shulman & Finenko, 1990; Zaika et al., 1990; Dame, 1996). As a result of biological filtration, suspended particles and cells of phytoplankton and microbial plankton are removed from the water. This process also accelerates mineralization of organic substances in the filtered matter. Therefore, biological filtration contributes significantly to water purification in aquatic ecosystems.

Filter-feeders can accelerate carbon fluxes in ecosystems, because the production of biodeposits (faecal and pseudofaecal pellets) leads to enhanced rates of sedimentation. As a result, bivalves were shown to influence material flux at the sediment–water interface (Smaal et al., 1986; Kautsky & Evans, 1987; Jaramillo et al., 1992; Dame, 1996; Widdows et al., 1998).

Biodeposition rates were estimated as high as 60 g m^{-2} h^{-1} at a density of 1400 mussels m^{-2} (i.e., 50% surface cover) in a mussel (*Mytilus edulis*) bed at Cleethorpes (Humber estuary, England) (Widdows et al., 1998), which is higher than maximum recorded biodeposition rates of 25 g m^{-2} h^{-1} for *M. edulis* in the Oosterschelde in the Netherlands (Smaal et al., 1986) and 18 g m^{-2} h^{-1} for *M. chilensis* in an estuary in Chile (Jaramillo et al., 1992). Biodeposition rates in some ecosystems were up to 40 times the natural sedimentation rates. Kautsky & Evans (1987) estimated annual biodeposition per g mussel (*M. edulis*, dry weight including shells) as high as 1.76 g dry weight, 0.33 g ash-free dry weight, 0.13 g carbon, 1.7×10^{-3} g nitrogen and 2.6×10^{-4} g phosphorus. The annual biodeposition is 11.7 g dry weight per g mussel shell-free dry weight. When average mussel biomass was 620 g m^{-2} (dry weight including shells) or 91 gm^{-2} (dry flesh weight), the annual biodeposition per m^2 was 1092 g (dry weight), including 80.7 g C, 10.4 g N, 1.6 g P (Kautsky & Evans, 1987). The average composition during the year, expressed as percent

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of dry weight of biodeposition, was 12.88% C, 1.54% N, and 0.19% P. With a total mussel biomass of about 10,000 tons in the total 160 km^2 research area (the northern Baltic proper), the annual contribution from mussels biodeposition would be 1300 tons of carbon, 170 tons of nitrogen, and 26 tons of phosphorus, which means that the total annual deposition (sedimentation) of C, N, and P is increased by about 10% by mussels as a result of their filtering activity (Kautsky & Evans, 1987).

Therefore the measurement of filtration rates is of ecological importance.

The marine mussels (*Mytilus edulis, M. galloprovincialis* and their hybrids) are important filter-feeders and dominant members of many benthic communities and marine ecosystems. Mussels (*M. edulis*) have been the focus of many studies concerning accumulation of pollutants and their biological effects (Donkin et al., 1989, 1991, 1997). However, few studies have investigated the toxic effects of synthetic surfactants.

Generally, surfactants (with very few exceptions) are not included in the list of priority pollutants (e.g., Scientific Committee for Toxicity and Ecotoxicity of Chemical Substances, European Commissions – see Bro-Rassmunsen et al., 1994) or are considered of uncertain hazard to the environment. According to Bailey (1996), many surfactants are considered virtually non-toxic for aquatic organisms, provided that the criteria of the Environmental Protection Agency (USA) are valid.

Alkyl sulphates, hydroxyethylated alkyl phenols, and quaternary ammonium compounds are important classes of surfactants. Previous research has reported inconsistent effects of surfactants on certain organisms (Ostroumov, 2000a, 2001a) (i.e. both negative and stimulating effects have been recorded). However, at present there is little information on how these surfactants may affect the feeding rate of bivalve molluscs, such as marine mussels.

The primary aim of this work was to quantify the effect of surfactants of three classes on the feeding rate of mussels on the algal cell (*Isochrysis galbana*). The surfactants studied were sodium dodecyl sulphate (SDS), a representative of alkyl sulfates; Triton X-100 (TX100), a representative of hydroxyethylated alkyl phenols; and tetradecyltrimethylammonium bromide (TDTMA), a representative of quaternary ammonium compounds.

Materials and methods

The methods used were similar to those described by Ostroumov (2002a, 2003b). Mussels (*M. edulis*) were collected from a coarse-sand substrate at Exmouth (Devon, England) and used in experiments with SDS and TX100. Mussels (natural hybrids *M. edulis*/*M. galloprovincialis*) were collected from the intertidal rocks at Whitsand Bay (Cornwall, England) for use with TDTMA. Mussels were placed in 2-l beakers equipped with magnetic stirrers and kept at 16 °C in a thermostatically controlled room. Seawater was collected from the Eddystone (~15 km offshore from Plymouth) and filtered through WCN nitrocellulose filters with a pore diameter of 0.45 μm (Whatman, Great Britain). A total of 16 animals were studied in each experiment. Eight of them were treated with the xenobiotic, the other eight were controls (no toxicant). The surfactants were added to the experimental beakers 1.5 h before the experiment. The surfactant concentrations shown in the tables and the text are the initial concentrations of the xenobiotics added to the beakers.

In the experiments with SDS and TX100, eight beakers contained eight pairs of mussels with a raw weight of 16–20 g per beaker. An additional beaker containing the 2 l of seawater was used as a reference to confirm that there was no significant change in algal cell concentration in the absence of a mussel and biological filtration of the water. Equal volumes of algal suspension were added simultaneously to the nine beakers.

In the experiments with TDTMA, there were 16 beakers that each contained one mussel (average wet weight with shell 4.5–5 g). The clearance rate by mussels was determined from the exponential decline in algal cell concentration (*I. galbana* Parke, strain CCAP 927/1). The algal strain was obtained from the NERC Culture Collection of Algae and Protozoa, Dunstaffnage Marine Laboratory, PO Box 3, Oban, Argyll, PA34 4AD, Scotland, UK). Algal cell concentrations were counted with a Coulter Electronics counter (Industrial D model).

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Results

The clearance rate, or the volume of water cleared of algal cells per hour, was calculated for each experimental surfactant concentration and control condition. The clearance rate at each toxicant concentration was expressed as a percentage of the control value (the clearance rate in control mussels was 100%). The effects of the anionic surfactant SDS on clearance rate are presented in Table 1. There was increasing inhibition of clearance rate with increasing toxicant concentration. The inhibitory effects of SDS on clearance rate appeared to decline with exposure time during the course of the 90-min experiment from the moment labeled as T0 (the beginning of the experiment) to the moment labeled as T3 (the end of the third 30-min period). These findings are consistent with the results obtained in another bivalve species (Bressan et al., 1989).

Triton X-I00, a non-ionogenic detergent of the group of hydroxyethylated alkyl phenols, also inhibited the clearance rate by mussels (Table 2).

TDTMA also inhibited the clearance rates of mussels in the experiments with *M. edulis*/*M. galloprovincialis* (Table 3). Clearance rate ceased at 1 mg l^{-1} and was substantially inhibited at 0.3 mg l^{-1}. The concentrations in the range 0.05–0.3 mg l^{-1} are similar to those found in the most polluted ecosystems (Review on the Ecological State of Seas, 1992).

Table 1. Inhibition by the anionic surfactant SDS of the mean clearance rates (CR) of mussels (*Mytilus edulis*)

SDS (mg l^{-1})	Time period (30 min each)	CR (% of control)
0.5	T0–T1	95.4
	T1–T2	No inhibition measured
	T2–T3	No inhibition measured
1	T0–T1	77.2
	T1–T2	80.8
	T2–T3	88.2
2	T0–T1	55.3
	T1–T2	72.3
	T2–T3	No inhibition measured
4	T0–T1	23.2
	T1–T2	17.9
	T2–T3	30.5
5	T0–T1	4.3
	T1–T2	11.9
	T2–T3	10.3

CR is expressed relative to the control (suspended matter: algae *Isochrysis galbana*) (calculated on the basis of the data of Ostroumov et al., 1997, 1998; Ostroumov, 2001a).
Note. At each of the concentration there were 8 molluscs tested, with 4 experimental and 4 control beakers. There were two molluscs in each of the experimental and control beakers.

Discussion

The levels of surfactants in marine ecosystems often go above maximum permissible concentrations (MAC) reaching levels of >10 MAC and more (Review on the Ecological State of Seas, 1992). In addition, samples of seawater for testing pollutants are usually collected at a distance of >300–500 m from the source of pollution. Therefore, the concentration of pollutants within the area of several hundred meters between the site of sampling and the source of pollution is even higher. This area may include very important coastal ecosystems. Therefore, the results obtained in this study suggest significant deleterious effects caused by environmental levels of surfactants.

Previous studies have shown that the suspension feeding activity of *M. edulis* is also inhibited by other pollutants, including some pesticides (Donkin et al., 1997). Low concentrations of organic pollutants were found to cause a decrease in the feeding rate by *M. galloprovincialis* (Bressan et al., 1989). Furthermore, some commercial detergents (mixtures of several chemicals including surfactants) inhibited water filtering by *M. galloprovincialis* (Ostroumov, 2001a, c).

Similar effects of inhibiting the filtration rate were found when studying effects of TDTMA (0.5 mg l^{-1}) and SDS (0.5 mg l^{-1}) on *Crassostrea gigas* (Ostroumov, 2003b).

Using the electromagnetic induction system (EMIS), it has been shown that several pollutants (copper, cadmium, zinc, lead, tributyltinoxide, chlorine, dispersed crude oil) induced the valve closure response of *M. edulis* (Kramer et al., 1989).

Table 2. Effect of the non-ionic surfactant Triton X-100 (TX100) on the mean clearance rates (CR) of mussels (*Mytilus edulis*) expressed relative to the control (suspended matter: algae *Isochrysis galbana*)

TX100 (mg l^{-1})	Time period (30 min each)	CR (+TX100) l h^{-1}	CR in control (−TX100) l h^{-1}	CR (% of control)	Coefficient of inhibition (%)
1	T0–T1	4.04	5.23	77.25	22.75
	T1–T2	4.95	6.13	80.75	19.25
	T2–T3	3.74	4.24	88.21	11.79
2	T0–T1	1.765	4.48	39.42	60.58
	T1–T2	2.77	4.65	59.62	40.38
	T2–T3	2.86	4.72	60.85	39.15
4	T2–T3	0.43	3.02	14.24	85.76
	T3–T4	0.59	1.84	32.06	67.94

Note. At each of the concentration there were 8 molluscs tested, with 4 experimental and 4 control beakers. There were two molluscs in each of the experimental and control beakers.

Table 3. Effect of the cationic surfactant TDTMA on the mean clearance rates (CR) of mussels (*Mytilus edulis*/*M. galloprovincialis*) expressed relative to the control (Suspended matter: algae *Isochrysis galbana*)

TDTMA (mg l^{-1})	Time period (50 min each)	CR (+TDTMA) l h^{-1}	CR in control (−TDTMA) l h^{-1}	CR (% of control)
0.05	T0–T1	1.005	1.559	64.47
	T1–T2	1.096	1.290	84.98
	T2–T3	0.936	1.013	92.47
0.1	T0–T1	0.708	1.479	47.84
	T1–T2	0.668	1.383	48.28
	T2–T3	0.455	1.099	41.41
0.3	T0–T1	0.645	1.620	39.82
	T1–T2	0.819	1.640	49.92
	T2–T3	0.350	1.053	33.25
1	T0–T1	0.114	1.168	9.74
	T1–T2	0.100	1.218	8.21
	T2–T3	0.048	0.971	4.89
5	T0–T1	0.051	1.334	3.84
	T1–T2	0.028	1.248	2.20
	T2–T3	0.028	0.871	3.16

Note. At each of the concentration there were 8 molluscs tested, with 8 experimental and 8 control beakers. There was one mollusc in each of the experimental and control beakers.

The same toxicants (except crude oil) were detected by the valve closure response of *Dreissena polymorpha* measured by the EMIS (Kramer et al., 1989).

Therefore, the effects observed in this study are consistent with the results of other authors. These findings place a particular emphasis on the disturbances to suspension feeders and biofiltration in aquatic systems, a new aspect of the ecological hazard resulting from chemical contamination of the environment with surfactants. Water pollution with sublethal concentrations of synthetic surfactants of various classes can inhibit biofiltration in ecosystems, thereby giving rise to additional aspects of ecological hazards (Ostroumov, 2002a, b, 2004). The ecological consequences of biofiltration inhibition may include impairment of water clearance (Ostroumov, 1998), disturbance of biogeochemical fluxes of carbon, increased turbidity and reduced light penetration in the

water column (Ostroumov et al., 1997, 1998) with adverse effects on phytoplankton and phytobenthos, as well as other important ecological processes in aquatic ecosystems (Ostroumov, 2000b, 2001b, d, e), which provides further evidence in support of the new approach to prioritization of anthropogenic effects on biota (Ostroumov, 2003a).

The ecological significance of the data on pollutant-induced inhibition of the filtration rate was discussed in depth in (Ostroumov, 2002c, d).

Our studies of organisms that are part of benthic communities ('societies') make us think of a new interpretation of the poetic words:

There is society, where none intrudes,
By the deep sea, and music in its roar:
I love not man less, but nature more.

Lord Byron 1788–1824:
Childe Harold's Pilgrimage (1812–1818).

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