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Comparative Effects of Metals on the Filtering Rate of the Brown Mussel (*Perna perna*)

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Metal concentrations in the brown mussel Perna perna collected from the southern African coast have been determined as part of the South African National Marine Pollution Monitoring Programme (WATLING and WATLING 1979). P. perna was included in this programme on the basis of the reported use of related species as biological indicators or monitors of metal pollution in the coastal marine environment (DARRACOTT and WATLING 1975). However, few data on the accumulator ability of this species or on its tolerance to metals are available.

The filtering rates of bivalves are known to be influenced by environmental parameters such as salinity, temperature, dissolved oxygen and concentration of suspended matter (COLE and HEPPER 1954; BADMAN 1975; FOSTER-SMITH 1975; MANE 1975; WIDDOWS 1973) and the effects of some pollutants on the filtering rate of Mytilus edulis have been measured (ABEL 1976). A comparative study of the filtering rates of four species of mollusc, including the effects of changing water salinity and temperature and of increased concentrations of four metals has been undertaken (WATLING 1981) using a modification of the neutral red suspension method as described by ABEL (1976).

In the present study, the comparative effects of eight metals on the filtering rate of P. perna have been measured. These experiments form part of a continuing investigation, the purpose of which is to define more clearly the conditions under which P. perna can be used as a biological indicator of metal pollutant levels in South African coastal marine environments.

MATERIALS AND METHODS

The method used for the estimation of P. perna filtering rates is described by WATLING (1981). Mussels in the size range 60–80 mm shell length were used for the experiments except where the effect of size on the measured toxicity of metal was being investigated. Experimental solutions were prepared from the metal chlorides with the exception of silver (nitrate), selenium (oxide), arsenic (sodium arsenate and arsenite, monosodium methanearsonate), mercury (mercuric, methylmercuric and ethylmercuric chlorides, phenylmercuric acetate) and chromium (trichloride and sodium dichromate). Solutions of low metal concentrations were found to be stable for the one-hour period required for each experiment.

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RESULTS AND DISCUSSION

Initially, the variation in filtering rate according to size (measured as shell length) was studied. Filtering rate increased rapidly from 30 to 90 ml/min in the size range 60-80 mm. As a result of this, individuals of similar size within this range were chosen for each experiment. Filtering rates for any given size were found to be constant for at least 40 min under these experimental conditions.

Some preliminary experimentation was required to determine the range over which each element affected filtering rate. The experiment was repeated from five to ten times for each element but the absolute filtering rates which were determined cannot be compared directly because of the variation in filtering rates already measured for different sized individuals. As suggested by ABEL (1976), in order to express the results in a simple numerical form, the concentration required to reduce the filtering rate to half its value at zero concentration was obtained from the relevant graph of concentration plotted against filtering rate for each experiment. These values are summarised in Table 1; mean concentrations refer to measurements made using mussels of 60-80 mm shell length.

The results show a considerable range of concentrations which cause a 50% reduction in P. perna filtering rate, from 0.025 µg/ml for mercury to 28 µg/ml for cadmium. The effective concentrations of mercury, copper and zinc for P. perna (Table 1) are in close agreement with those reported by ABEL (1976) for M. edulis (Hg 0.04 µg/ml; Cu 0.08-0.23 µg/ml; Zn 1.2-1.9 µg/ml). Chromium(VI) is slightly more toxic than chromiumIII. In the case of manganese, a steady increase in filtering rate occurred as the manganese concentration increased; a 20% increase was observed at 40 µg/ml.

The effect of selenium on filtering rate was more complex. Initially, at selenium concentrations between 0-0.3 µg/ml, the usual decrease in filtering rate was observed (Fig. 1). However, in repeated experiments, concentrations of from 0.3-0.7 µg/ml selenium caused dramatic increases in filtering rates with respect to the controls. The concentrations causing maximum filtering rates occurred in the range 0.4-0.8 µg/ml selenium and at greater concentrations the filtering rates were again reduced (Fig. 1).

The effects of mercury and selenium on the filtering rate of P. perna are seen to be antagonistic. Increasing mercury concentrations caused filtering rates to decrease to very low levels while moderate concentrations of selenium caused dramatic increases in filtering rates. The possible modification of the response of P. perna to mercury by the addition of selenium to the experimental solutions was tested (Fig. 2). A slight but consistent decrease in mercury toxicity was observed (Table 1), and

TABLE 1

Metal concentrations which caused a 50% reduction in P. perna filtering rate

Element		EC_{50} (µg/ml)			EC_{50} (µg/ml)
Ni	mean	0.7	Hg	mean	0.025
	range	0.6-1.0		range	0.015-0.035
Co	mean	1.7	Se(IV)	mean	0.2
	range	1.3-2.0		range	0.1-0.3
Cr(III)	mean	2.0	Hg+0.2 µg/ml Se	mean	0.04
	range	1.8-2.3		range	0.03-0.05
Cr(VI)	mean	1.6	Cu	mean	0.22
	range	1.0-2.0		range	0.10-0.50
Ag	mean	0.20	Cu*		0.16
	range	0.015-0.035	Cu+0.2 µg/ml Zn		0.22
Mn		>40	Cu+0.2 µg/ml Cd		>0.6
			Cu+0.2 µg/ml Pb		0.10
As		>150	Cu-EDTA complex		0.35
Cd*		28	Pb*		4.17
Zn*		0.75	Pb-EDTA complex		5.0
			EDTA		no measurable effect at 5.0µg/ml

*data from WATLING (1981)

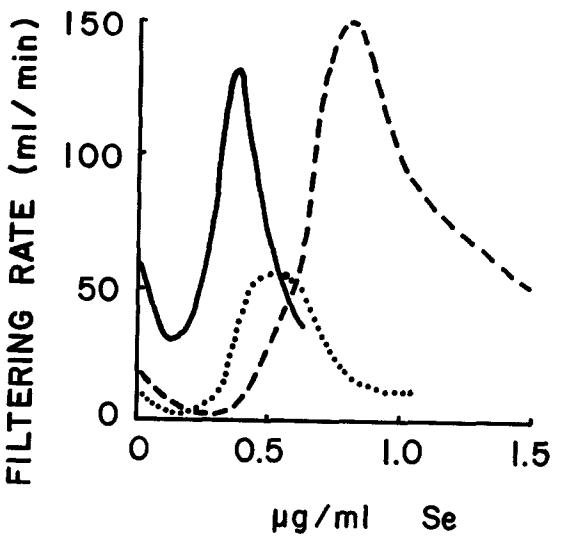

Fig. 1 The effect of selenium on filtering rate (3 experiments)

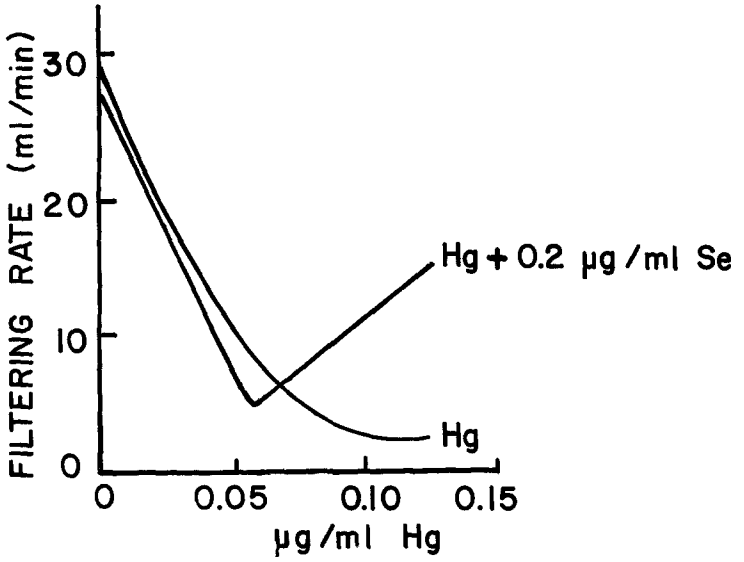

Fig. 2 The effect of selenium on mercury toxicity

the mercury-selenium mixture was less toxic than mercury alone at concentrations of approximately 0.1 µg/ml.

Although selenium modifications of mercury toxicity have been variously reported for vertebrates, few data are available for invertebrates. GLICKSTEIN (1978) studied the acute toxicity of mercury and selenium to oyster embryos and was able to show a slight (not statistically verifiable) decrease in mercury toxicity in the presence of moderate selenium concentrations. The existence of a mercury-selenium interaction is also suggested by the results of FOWLER and BENAYOUN (1976). These authors found a slight reduction in selenium uptake by adult Mytilus galloprovincialis in the presence of mercury in a sea water phytoplankton culture although statistical treatment of the results failed to show significant differences due to mercury.

The fairly wide range of copper concentrations which caused a 50% reduction in filtering rate were closely related to the size of mussel being tested. Smaller mussels (30-44 mm shell length) were most sensitive to copper (EC_{50} 0.10 µg/ml) and larger mussels (80-90 mm shell length) were less sensitive (EC_{50} 0.50 µg/ml). The effects of mussel size on element sensitivity were also tested for chromium and nickel for which no consistent size-toxicity relationships were found and for mercury, where the smaller mussels were also the least sensitive. It must be concluded that size alone is not the determining factor in element toxicity.

The effects of adding 0.2 µg/ml zinc, cadmium or lead to

solutions containing increasing copper concentrations were also investigated for mussels of 60-70 mm shell length. A mean EC_{50} of 0.18 µg/ml copper (range 0.15-0.25 µg/ml) was determined for these mussels. The presence of 0.2 µg/ml cadmium and to a lesser extent 0.2 µg/ml zinc have decreased the toxicity of copper, as also has complexation with EDTA; lead, in itself not particularly toxic, appears to act synergistically with copper (Table 1). Complexation of lead with EDTA has also caused a decrease in lead toxicity as measured by the effect of the comple on filtering rate (Table 1). EDTA in the range 0-30 µg/ml caused only a slight reduction in P. perna filtering rate.

The presence of EDTA in solution has also been shown to reduce the toxic effects of both zinc and copper for the black mussel Choromytilus meridionalis and of zinc for the oyster Crassostrea gigas (WATLING unpublished data). The presence of EDTA has also been shown to greatly reduce the effect of copper on both mortality and burrowing behaviour of the clam Venerupis decussata (STEPHENSON and TAYLOR 1975). As has been indicated by the results of many accumulation and acute toxicity experiments, the chemical form of the metal in solution is an important factor in the degree of element toxicity.

Substantial arsenic contamination in water can occur from the improper or careless use of arsenical pesticides (SANDHU 1977), yet little is known about the comparative toxicities of different arsenic compounds to aquatic animals or the accumulation of arsenic from such compounds in animal tissues (SPEHAR et al. 1980). Monosodium methanearsonate (MSMA), a selective herbicide for the eradication of jointed cactus, is being used extensively in the Eastern Cape of South Africa, a practice which is likely to continue for the next ten years. Studies on the partitioning of various forms of arsenic between water and sediment phases indicate that arsenic as the arsenate is more readily absorbed by sediments than in the methanearsonate form (WAUCHOPE and YAMAMOTO 1980) and is therefore more likely to be transported to estuarine and nearshore marine environments.

The effects of sodium arsenate, sodium arsenite, MSMA and MSMA with 'surfactant' on P. perna filtering rates have been investigated. The MSMA-surfactant mixture is supplied ready to use and the composition of the surfactant has not yet been determined. Arsenic as sodium arsenate does not affect filtering rate significantly at concentrations up to 150 µg/ml (Table 2). Sodium arsenite proved to be considerably more toxic, but in comparison with the values listed in Table 1, is shown to have a relatively moderate effect on filtering rates. Both MSMA and MSMA-surfactant are essentially non-toxic. The EC_{50} values of 25 and 20 µg/ml arsenic are too high to have relevance in the marine environment.

Both organic and inorganic mercury compounds have been shown to be present in the marine environment and biotransformations from

TABLE 2

Concentrations of arsenic and mercury compounds which caused a 50% reduction in P. perna filtering rate

Compound	EC_{50} (µg/ml)
sodium arsenate	>150
sodium arsenite	4
MSMA	25
MSMA with surfactant	20
mercuric chloride	0.025
methyl mercuric chloride	0.050
ethyl mercuric chloride	0.030
phenyl mercuric acetate	0.020
sodium acetate	No measurable effect at 1 µg/ml

one state to the other are well documented (NRIAGU 1979). Cases of mercury accumulation by marine molluscs and fish growing in mercury-polluted waters have been reported (e.g. YAMANAKA and UEDA 1975; LAARMAN et al. 1976). However, the relative toxicities of organic and inorganic mercury compounds are less well known. In this study the effects of mercuric, methylmercuric and ethylmercuric chlorides and of phenylmercuric acetate on P. perna filtering rates are compared. Phenylmercuric acetate was included because this compound is used in the manufacture of special glasses and it is possible that mercury-contaminated wastes may enter our local inshore environment from the glass manufacturing industries in Port Elizabeth, South Africa.

The results of this comparative study indicate that the organic mercury compounds tested have very similar effects on filtering rates to that of mercuric chloride (Table 2). Phenylmercuric acetate is slightly more toxic than the other compounds and methylmercuric chloride is the least toxic. The four mercury compounds are the most toxic of all the elements tested in this series of experiments.

Clearly many of the concentrations which have been determined are irrelevant in terms of environmental contamination because such high concentrations are most unlikely to occur in the marine environment. Nevertheless it is helpful to increase our knowledge of the relative toxicities of these elements in order to be able to study in greater detail the effects of those elements to which P. perna is most sensitive. The rank order of toxicity as determined in the present experiments is Hg>Cu,Ag,Se>Ni,Zn>CR(VI),CO,Cr(III)>As (as arsenite),Pb>Cd. Arsenic (arsenate and

MSMA) and manganese did not affect filtering rate significantly in the concentration range tested.

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