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Distribution of Cadmium in the Pearl Oyster, *Pinctada albina albina* (Lamarck), Following Exposure to Cadmium in Seawater

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It has been known since the 1950s that some marine organisms have the ability to concentrate cadmium to levels several orders of magnitude above those to which they are exposed in their natural environment (Mullin and Riley, 1956), and this behaviour is most widely recognised in bivalve molluscs (Brooks and Rumsby, 1965; Bryan, 1973). The concentration of cadmium varies between the different tissues of an individual mollusc and, until recently, has always been reported as higher in the viscera than in the muscle tissue (e.g., Brooks and Rumsby, 1965; Topping, 1973; Ishii *et al.*, 1985).

Laboratory studies on the uptake of cadmium from seawater have shown that bivalve molluscs readily accumulated cadmium from this medium and that the relative concentrations of cadmium between viscera and muscle were always the same (viscera [Cd] > muscle [Cd]) as those found in natural populations (Brooks and Rumsby, 1967; George and Coombs, 1977; Zaroogian, 1980; Ward, 1982; Robinson and Ryan, 1986). These results suggested that in the natural environment seawater was a major source of cadmium for bivalve molluscs. Further support for this view has come from field studies such as that showing a significant relationship between cadmium levels in samples of mussels (*Mytilus edulis*) and seawater collected from a number of sites off southern Australia (Talbot, 1985).

Results of a recent study by McConchie *et al.* (1988) have indicated that seawater is not always the major contributor of cadmium to bivalve molluscs. These authors reported high levels of cadmium in the pearl oyster *Pinctada albina albina*, (previously referred to as *Pinctada carchariarum* (Jameson)) collected from Shark Bay in Western Australia, and noted that there was no correlation between cadmium concentrations in

the oysters and cadmium concentrations in the surrounding seawater. Moreover, the distribution of cadmium within the pearl oyster was unusual in that the adductor muscle had considerably higher concentrations of cadmium than the viscera. It is possible, as suggested by Lawrance (1985), that *P. albina albina*, in its Shark Bay environment, obtains most of its cadmium burden from sources (e.g. suspended sediments) other than seawater and this may explain the observed distribution of cadmium in this oyster. Alternatively, *P. albina albina* may accumulate cadmium in the observed manner regardless of the source of cadmium.

Australia is one of several countries which have a maximum permissible level of cadmium in molluscs (Nauen, 1983). The possibility that the pearl oyster, and perhaps other molluscs as well, may accumulate cadmium preferentially in different tissues depending upon the source of cadmium has important implications in the area of contaminants in marine foodstuffs. The present study reports the uptake and distribution of cadmium within *P. albina albina* when subjected to cadmium in seawater alone.

MATERIALS AND METHODS

Pearl oysters (*P. albina albina*) were collected near Monkey Mia (25°45'S, 113°42'E) in Shark Bay, Western Australia and transported live by air to the laboratory.

A constant-flow dosing system was used for the cadmium accumulation studies. Seawater (pumped directly from the adjacent inshore waters and stored in a primary header tank) was passed through a nylon sieve (125μm, 30cm diameter) to a secondary header tank equipped with an overflow going to waste and four outlets each feeding an experimental tank (70 L) via plastic tubing and a mixing chamber. Cadmium, dispensed by a multichannel peristaltic pump from a stock solution (at 6 mL/h) was mixed with seawater from the secondary header tank (at 1 L/min) in the mixing chamber, and gravity fed to the experimental tank. The concentrations of cadmium in the stock solutions were set to give 1, 5 and 20 μg Cd/L in three tanks; a control tank received only seawater at the background level in the natural seawater supply of *ca* 0.02 μg Cd/L. Actual seawater concentrations of cadmium were monitored by graphite furnace atomic absorption spectrometry following solvent extraction with APDC/MIBK.

Following an acclimation period of six weeks, 68 oysters of comparable size (most were 80-90mm dorso-

ventral length) were removed; 4 were dissected and analysed (see below) and the remainder were evenly distributed among the four experimental tanks. After 5, 10, 20, 40, 60 and 88 days two oysters were removed from each tank and placed in a holding tank for 24 hours before analysis. Each oyster was measured (dorso ventral length) and, following removal of the foot and byssus, dissected into four parts; gill (G), adductor muscle (A), viscera (V) and mantle (M). Wet and dry weights (24 h at 85°) were recorded for each tissue prior to digestion ($HNO_3/HClO_4$) and analysis for cadmium by flame atomic absorption spectrometry. All values are reported as μg Cd/g dry weight. Analysis of cadmium in reference material National Bureau of Standards (NBS) SRM 1566 (oyster tissue) certified at 3.5 μg/g returned a mean value of 3.4 μg/g (five analyses, coefficient of variation, 5%).

Over the course of the experiment (from late December to April) seawater temperature varied between 21 and 24° and salinity and pH remained fairly constant at 35 to 36^0/oo and 8.1 - 8.2 pH units respectively. No supplementary food was given to the experimental animals and loss of condition and some deaths (6% mortality) were recorded.

McConchie *et al.* (1988) have shown a relationship between size and cadmium concentration for the pearl oyster. The effects of this relationship on the cadmium accumulation were minimised in this study by using animals of comparable size. Size effects were not further considered in the analysis of data.

RESULTS AND DISCUSSION

Following an acclimation period of six weeks a sample of oysters was analysed for cadmium just prior to beginning the accumulation experiments. The results agreed with those of McConchie *et al.* (1988) in that the adductor muscle contained the highest concentration of cadmium (Table 1).

All groups of experimental animals showed significant inverse linear relationships between weight and time. Although all tissues suffered weight losses, these were greatest for the adductor muscle (*ca* 50%) and least for the gills (*ca* 30%). There was, however, no suggestion that exposure to cadmium was contributing to these weight losses; analysis of variance showed no significant difference in loss of weight with time between the two extreme groups, control and 20μg/L animals.

Table 1. Initial cadmium concentrations (μg/g dry wt.) in tissues of pearl oysters.

TISSUE	NO	RANGE	MEAN
Gill	4	13 - 25	20
Adductor muscle	4	77 - 144	108
Viscera	4	32 - 62	46
Mantle	4	36 - 60	47

In the present study where oysters were kept for 88 days in seawater with up to 20 μg Cd/L there was a 6% mortality overall. These deaths were not apparently related to cadmium exposure (one death recorded for each tank) but appeared to result from a general loss in condition of the oysters, perhaps due to insufficient or inappropriate food in their ambient seawater.

The concentration of cadmium in the adductor muscle, gill and mantle of the control animals remained virtually unchanged during the experimental period (see Table 2). Since these tissues lost weight over this period there was a corresponding net reduction in total cadmium. The viscera of the control group retained its cadmium while losing weight over the experimental period resulting in increased cadmium concentrations proportionate to weight losses. These effects have been taken into account when determining the relative rates of accumulation of cadmium shown by the various tissues of the experimental animals subjected to elevated levels of cadmium.

With the exception of adductor muscles of animals exposed to 1 μg Cd/L there was a significant linear relationship between cadmium concentration and time at 1, 5 and 20 μg Cd/L for each of the four tissues (see Table 2). The rates of accumulation of cadmium at 1 and 5 μg Cd/L in the gill and mantle were comparable to that in the adductor muscle. The viscera appeared to accumulate cadmium at a greater rate than the adductor muscle at 1 and 5 μg Cd/L but the differences were not significant ($P>0.05$) possibly because of the high initial levels of cadmium. At 20 μg Cd/L however, the rates of cadmium accumulation were clearly higher in the viscera and gill than in the mantle or adductor muscle. Actual rates of accumulation of cadmium in μg/g/day at 20 μg Cd/L were gill (7.2), viscera (6.1), mantle (2.5), adductor muscle (1.7) and, by combination of individual parts, whole wet tissue (*ca* 4).

Table 2: Linear regressions of cadmium concentrations (Y) in μg/g dry weight on time (X) in days for various tissues of pearl oysters. (N.S., not significant, $P>0.05$; for all other regressions $P<0.01$).

TISSUE	CONTROL	1 μg Cd/L	5 μg Cd/L	20 μg Cd/L
Gill	$Y = 18 + 0.10X$	$Y = 19 + 0.54X$	$Y = 26 + 1.4X$	$Y = 39 + 7.2X$
	$r^2 = 0.17$ (N.S.)	$r^2 = 0.64$	$r^2 = 0.69$	$r^2 = 0.83$
Adductor muscle	$Y = 126 - 0.01X$	$Y = 131 + 0.60X$	$Y = 114 + 1.4X$	$Y = 126 + 1.7X$
	$r^2 = 0$ (N.S.)	$r^2 = 0.15$ (N.S.)	$r^2 = 0.60$	$r^2 = 0.71$
Viscera	$Y = 48 + 0.54X$	$Y = 45 + 1.9X$	$Y = 64 + 2.6X$	$Y = 52 + 6.1X$
	$r^2 = 0.65$	$r^2 = 0.69$	$r^2 = 0.75$	$r^2 = 0.83$
Mantle	$Y = 40 - 0.11X$	$Y = 46 + 0.81X$	$Y = 49 + 1.5X$	$Y = 50 + 2.5X$
	$r^2 = 0.10$ (N.S.)	$r^2 = 0.57$	$r^2 = 0.73$	$r^2 = 0.86$

The different rates of accumulation of cadmium shown by the various tissues of the pearl oyster resulted in the adductor muscle being displaced by the gill and the viscera as the tissue with the highest cadmium concentration within 20 days of exposure at 20 μg Cd/L. At the end of the 20 μg Cd/L experiment (88 days) both the viscera and the gill had cadmium concentrations over twice those in the adductor muscle, and the mantle had attained cadmium concentrations comparable to those in the adductor muscle. The combined effect of relative weight losses (adductor muscle was highest) and relative rate of accumulation of cadmium (adductor muscle was lowest) over the experimental period at 20 μg Cd/L greatly altered the distribution of total cadmium in the pearl oyster (Table 3). The adductor muscle initially represented 58% of the total cadmium, but, after 88 days exposure to 20 μg Cd/L it accounted for only 20% of the total. During this period the percentage of total cadmium contained in the gill increased from 3 to 22% and the viscera became the tissue containing the greatest load with 46% of the total cadmium. Thus, the pearl oyster *P. albina albina*, when subjected to elevated levels of cadmium in seawater accumulates cadmium preferentially in the viscera rather than in the adductor muscle - a result consistent with the findings of similar studies using bivalve molluscs (e.g. George and Coombs, 1977; Ward, 1982).

Table 3. Initial and final cadmium concentrations (μg/g dry wt) and percentage load in tissues of pearl oyster exposed to 20μg Cd/L for 88 days.

	INITIAL [a]		FINAL [b]	
TISSUE	[Cd]	% Load	[Cd]	% Load
Gill	20	3	612	22
Adductor muscle	108	58	277	20
Viscera	46	24	617	46
Mantle	47	14	271	12

a Mean of four individuals b Mean of two individuals

There are several possible explanations for the observed differences in cadmium concentrations in the viscera and the adductor muscle of the pearl oyster before and after the accumulation experiments. Factors such as seawater chemistry, concentration of cadmium, length of exposure and nutritional status of the animal

may play a role. However, although these factors can affect the rate of accumulation of cadmium in the whole wet tissues of molluscs, changes in the distribution of cadmium between the tissues such as those reported here have not occurred (George and Coombs, 1977; Janssen and Scholz, 1979; Kohler and Riisgard, 1982; Ward, 1982; Zaroogian, 1980). An alternative explanation is that in Shark Bay the major source of cadmium for the pearl oyster is not seawater but either food, or, as suggested by Lawrance (1985), suspended sediments, and the distribution of cadmium within the oyster is dependent upon the source.

This hypothesis requires that the viscera treat the cadmium it obtains directly from the gut differently from the cadmium it receives from the gill via the haemolymph. A biochemical explanation for this is not readily apparent and would require further investigation.

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REFERENCES

Brooks RR, Rumsby MG (1965) The biogeochemistry of trace element uptake by some New Zealand bivalves. Limnol Oceanog 10: 521-527

Brooks RR, Rumsby, MG (1967) Studies on the uptake of cadmium by the oyster, *Ostrea sinuata* (Lamarck). Aust J Mar Freshwater Res 15: 53-61

Bryan GW (1973) The occurrence and seasonal variation of trace metals in the scallops *Pecten maximus* (L) and *Chlamys opercularis* (L). J mar biol Ass UK 53: 145-166

George SG, Coombs TL (1977) The effects of chelating agents on the uptake and accumulation of cadmium by *Mytilus edulis*. Mar Biol 39: 261-268

Ishii T, Nakamura R, Ishikawa M, Koyanagi T (1985) Determination and distribution of trace elements in marine invertebrates. Bull Jap Soc Sci Fish 51: 609-617

Janssen HH, Scholz N (1979) Uptake and cellular distribution of cadmium in *Mytilus edulis*. Mar Biol 55: 133-141

Kohler K, Riisgard HU (1982) Formation of metallothioneins in relation to accumulation of cadmium in the common mussel *Mytilis edulis*. Mar Biol 66: 53-58

Lawrance LM (1985) The role of fine iron-oxides in the concentration of heavy metals in the marine sediment and biota of the Shark Bay area, Western Australia. B. Sc. Hons. Thesis presented in the Department of Geology at the University of Western Australia

McConchie DM, Mann AW, Lintern MJ, Longman D, Talbot V, Gabelish AJ, Gabelish MJ (1988) Heavy metals in marine biota, sediments, and waters from the Shark Bay area, Western Australia. J Coastal Res 4: 51-72

Mullin JB, Riley JP (1956) The occurrence of cadmium in sea water and in marine organisms and sediments. J Mar Res 15: 103-122

Nauen CE (1983) Compilation of legal limits for hazardous substances in fish and fishery products. FAO Fisheries Circular No. 764

Robinson WE, Ryan DK (1986) Metal interactions within the kidney, gill, and digestive gland of the hard clam, *Mercenaria mercenaria*, following laboratory exposure to cadmium. Arch Environ Contam Toxicol 15: 23-30

Talbot V (1985) Relationship between cadmium concentrations in seawater and those in the mussel *Mytilus edulis*. Mar Biol 85: 51-54

Topping G (1973) Heavy metals in shellfish from Scottish waters. Aquaculture 1: 379-384

Ward TJ (1982) Laboratory study of the accumulation and distribution of cadmium in the Sydney rock oyster *Saccostrea commercialis* (I and R). Aust J Mar Freshwater Res 33: 33-44

Zaroogian GE (1980) *Crassostrea virginica* as an indicator of cadmium pollution. Mar Biol 58: 275-284

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