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Cadmium Uptake from Seawater and Food by the Western Rock Lobster *Panulirus cygnus*

K. A. Francesconi, E. J. Moore, J. S. Edmonds

Western Australia Marine Research Laboratories, P.O. Box 20, North Beach 6020, Australia

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Cadmium is a natural trace constituent of sea water occurring at levels generally less than 0.05 µg/L (Ray and McLeese 1987). Natural weathering or industrial/domestic inputs may result in considerably higher concentrations in near-shore and estuarine regions. Marine invertebrates are capable of accumulating cadmium in their tissues to levels well above those in sea water. They tolerate this potentially harmful cadmium by effectively removing it from their normal biochemical functionings using detoxification mechanisms involving the synthesis of cadmium-binding proteins (Rainbow and Scott 1979), or inert intracellular granules (George 1983).

Although elevated levels of cadmium in seawater do not necessarily present a marine ecological problem, the ability of edible marine organisms to bioaccumulate cadmium can be of human toxicological concern. As a safeguard to human health, regulatory authorities set maximum permitted concentrations (MPCs) for cadmium in various foods. The MPCs take into account the natural levels of the metal in a particular food, and the contribution that the food makes to the overall diet. In Australia the MPC for cadmium in crustaceans applies only to the edible part (i.e. muscle tissue), and is set currently at 0.2 mg/kg wet weight.

The western rock lobster, *Panulirus cygnus*, is abundant in the near-shore waters off Western Australia, and forms the basis of an important commercial fishery. The Five Fathom Bank, a lobster fishing ground in the southern part of the fishery, is near the industrialised area of Cockburn Sound. Cadmium-containing wastes discharged into the waters of Cockburn Sound from a fertilizer factory have previously been responsible for localized high levels of cadmium in the sedentary biota (Talbot and Chegwidden 1982). Discussions regarding an alternative disposal site for the fertilizer effluent included the evaluation of a proposed submarine pipeline terminating in the vicinity of the Five Fathom Bank. The work reported here was undertaken to determine possible consequences of the proposed pipeline to the levels of cadmium in rock lobsters from the Five Fathom Bank in regard to the MPC for cadmium in crustaceans.

MATERIALS AND METHODS

Lobsters (carapace length 71-76 mm, approximately 3 year old animals) were collected from the Five Fathom Bank near Fremantle, Western Australia, and

Correspondence to: K. A. Francesconi

transported in aerated seawater to the laboratory aquarium. They were randomly distributed into six groups of ten animals. The lobsters from one group were sacrificed immediately and the individual tail muscles and digestive glands analysed for cadmium.

Lobsters from a second group (control group) were maintained in flowing seawater on a diet of mussels under ambient aquarium conditions for the duration of the experiment (57 days). In this period the ambient aquarium water temperature and salinity ranged from 17.8-20.7°C and 34.3-35.3 ‰ respectively. The background level of cadmium in the aquarium seawater was 0.02 µg/L (Francesconi 1989), and the mussels contained a mean background level of 0.16 mg Cd/kg (range 0.11-0.21 mg/kg, $n=10$).

Two groups of lobsters were maintained for 57 days in aerated seawater spiked with cadmium at concentrations of 0.2 µg/L or 1.0 µg/L. These concentrations cover the range of values found for the waters of Cockburn Sound adjacent to the point of fertilizer effluent discharge (Rosman *et al* 1980). The lobsters were fed mussels (≈3g mussel/lobster/day) with only background levels of cadmium. Water was changed and recharged with cadmium daily, shortly after the lobsters had been fed.

Two groups of lobsters were maintained for 57 days in flowing seawater with no added cadmium. They were fed mussels (≈3 g mussel/lobster/day) artificially raised in cadmium concentration to approximately 10 or 50 mg/kg. Cadmium-rich mussels at the required concentration were obtained by holding them in seawater spiked with cadmium for a predetermined time calculated empirically as follows. Eighty mussels were maintained in seawater containing 200 µg Cd/L or 1,000 µg Cd/L (changed and recharged with cadmium daily) for 11 days. Five mussels were removed and analysed for cadmium daily, and calibration curves of cadmium concentration in the mussels versus exposure time were constructed. From these data mussels subsequently exposed to 200 µg Cd/L for two days were calculated to contain ≈9 mg Cd/kg (nominal value of 10 mg Cd/kg), and mussels exposed to 1,000 µg Cd/L for six days were calculated to contain ≈55 mg Cd/kg (nominally 50 mg Cd/kg).

At the end of the 57 day experimental period the lobsters were treated as follows. Individual lobsters were sacrificed by twisting the tail from the carapace, and the digestive gland was removed from the head. The tail muscle was separated from the exoskeleton and homogenised in a Waring blendor. Portions of digestive gland and tail muscle were digested in a mixture of $HNO_3/HClO_4$ (5:1) prior to analysis by electrothermal atomic absorption spectrophotometry.

Analysis of variance (ANOVA) was used to test for significant differences in cadmium concentrations between the various lobster groups.

RESULTS AND DISCUSSION

The western rock lobster, *Panulirus cygnus*, collected from the Five Fathom Bank contained appreciable levels of cadmium in the digestive gland with a mean of 10 mg/kg (Table 1). Crustaceans have an ability to accumulate cadmium in their digestive gland, and there have been several reports of high levels associated with this tissue (McLeese *et al.* 1981; Ray *et al.* 1981). The tail muscle from *P. cygnus*, however, contained very low levels of cadmium with a mean of 0.02 mg/kg, well below the MPC (0.2 mg/kg).

In the current study, when *P. cygnus* were exposed for 57 days to elevated levels of cadmium in seawater, there was no significant difference in the cadmium levels in the tail muscle or the digestive gland of the exposed animals compared with the controls (Table 1). These results agree with those reported by Thurburg *et al.* (1977) showing no cadmium accumulation in the tail muscle or digestive gland of the American lobster *Homarus americanus* following exposure to seawater at 6 μg Cd/L for 60 days. Ray and McLeese (1982), on the other hand, reported that *H. americanus* accumulated cadmium, mainly in the hepatopancreas (digestive gland), from seawater containing 7 μg Cd/L. Similarly, when the shrimp *Penaeus duorarum* was exposed to 2 μg Cd/L for 50 days the cadmium levels in tail muscle tissue increased from <0.10 to 0.25 mg/kg (Nimmo *et al.* 1977).

In contrast to the results from the seawater exposure experiments, *P. cygnus* accumulated high levels of cadmium when exposed to cadmium-enriched food (Table 1). This cadmium load, however, was effectively retained in the digestive gland; the cadmium levels in the tail muscle of lobsters fed Cd-rich mussels were not significantly different ($P>0.1$) from those for the control lobsters. Thus, the lobster digestive gland served as a trap preventing cadmium from reaching the tail muscle. The digestive gland is so efficient in this role that there is no significant relationship ($P>0.1$) between the cadmium concentration in the digestive gland and that in the tail muscle. The experiments reported here were carried out over a relatively short period (57 days), and some translocation of cadmium into the tail muscle with time is possible. This is considered unlikely, however, as cadmium levels were very low in the tail muscle of freshly caught *P. cygnus* (three year old animals), and these animals contained appreciable quantities of cadmium in the digestive gland.

The total amount of cadmium ingested by the lobsters over the course of the experiment was estimated from the total weight and cadmium concentration of the mussels given to the lobsters. Total cadmium retained or accumulated by the lobsters was calculated from the cadmium concentration and weight of the digestive gland (the tail muscle contributed an insignificant amount). Hence, the percentage retention of cadmium (total Cd accumulated/total Cd ingested) by the lobsters was estimated to be 50% and 41% for the 10 mg/kg and 50 mg/kg groups respectively. These estimates are biased slightly toward a low value as the amount of cadmium actually ingested would have been less than that provided - the lobsters ate most but not all of the available food. On the basis of these data, *P. cygnus* retains a greater percentage of ingested cadmium than either the crab *Carcinus maenas* (10%) (Jennings and Rainbow 1979) or the shrimp *Penaeus pugio* (low) (Nimmo *et al.* 1977).

The results from this study indicate that, if cadmium-containing fertilizer effluent were discharged in the Five Fathom Bank area, the cadmium levels in *P. cygnus* would not be significantly increased by direct uptake from seawater. However, other organisms (e.g. mussels) in the same waters could accumulate cadmium, and increased cadmium levels in the lobster might result from food chain bioaccumulation. This accumulated cadmium would be confined to the digestive gland, and the edible part of the lobster, the tail muscle, would remain essentially free of cadmium. The samples of western rock lobster in this study, including animals fed cadmium-rich mussels at 50 mg/kg for 57

Table 1. Cadmium concentration (mg/kg wet weight) in tail muscle and digestive gland of *P. cygnus*.

Treatment	Tail muscle			Digestive gland		
	n	Range	Mean (Std. Dev.)[a]	*n*	Range	Mean(Std.Dev.) [a]
Controls	8	<0.01 - 0.02	0.01 (0.01)	8	4.6 - 11	8.1 (2.4)
Freshly caught	10	<0.01 - 0.025	0.02 (0.01) N.S.	10	4.9 - 21	10 (6) N.S.
0.2 μg Cd/L water	2[b]	both <0.01	<0.01	10	6.0 - 13	9.2 (2.4) N.S.
1 μg Cd/L water	10	all <0.01	<0.01 N.S.	10	6.5 - 16	8.7 (2.8) N.S.
10 mg Cd/kg food	2[b]	both <0.01	<0.01	10	33 - 81	52 (15) ***
50 mg Cd/kg food	10	0.01 - 0.08	0.02 (0.02) N.S.	10	150 - 400	265 (85) ***

a: Denotes if mean is significantly different from control mean. N.S. $P > 0.1$ *** $P < 0.001$

b: Only 2 of 10 samples were analysed because at higher exposure (1 μg Cd/L water or 50 mg Cd/kg food), mean [Cd] was not significantly different from control mean.

days, all complied with the current Australian MPC for cadmium in crustaceans. In addition, the results suggest that rock lobsters from regions containing cadmium (of either anthropogenic or natural origin), although likely to have high cadmium levels in the digestive glands, will probably have very much lower, and acceptable levels in the tail muscle.

REFERENCES

Francesconi KA (1989) Distribution of cadmium in the pearl oyster, *Pinctada albina albina* (Lamarck), following exposure to cadmium in seawater. Bull Environ Contam Toxicol 43:321-328

George SG (1983) Heavy metal detoxification in the mussel *Mytilus edulis*. Composition of Cd-containing kidney granules (tertiary lysosomes). Comp Biochem Physiol 76C:53-57

Jennings JR and Rainbow PS (1979) Studies on the uptake of cadmium by the crab *Carcinus maenas* in the laboratory. I. Accumulation from seawater and a food source. Mar Biol 50:131-139

McLeese DW, Ray S, Burridge LE (1981) Lack of excretion of cadmium from lobsters. Chemosphere 10:775-779

Nimmo DWR, Lightner DV, Bahner LH (1977) Effects of cadmium on shrimps, *Penaeus duorarum*, *Palaemonetes pugio* and *Palaemonetes vulgaris*. In: Vernberg FJ, Calabrese A, Thurberg FP, Vernberg WB (eds) Physiological responses of marine biota to pollutants, Academic Press, New York, pp 131-183

Rainbow PS, Scott AG (1979) Two heavy metal-binding proteins in the midgut gland of the crab *Carcinus maenas*. Mar Biol 55:143-150

Ray S, McLeese DW (1982) Notes on bioavailability of cadmium and lead to a marine crustacean through food and water. Environment Canada Surveillance Report EPS-5-AR-82-1, pp 19-24

Ray S, McLeese DW (1987) Biological cycling of cadmium in marine environment. In: Nriagu JO, Sprague JB (eds) Cadmium in the aquatic environment, Wiley-Interscience, New York, pp 199-229

Ray S, McLeese DW, Burridge LE (1981) Cadmium in tissues of lobsters captured near a lead smelter. Mar Pollut Bull 12:383-386

Rosman KJR, De Laeter JR, Chegwidden A (1980) Distribution of cadmium in Cockburn Sound, Western Australia. Sci Total Environ 16:117-130

Talbot V, Chegwidden A (1982) Cadmium and other heavy metal concentrations in selected biota from Cockburn Sound, Western Australia. Aust J Mar Freshwater Res 33:779-788

Thurberg FP, Calabrese A, Gould E, Greig RA, Dawson MA, Tucker RK (1977) Response of the lobster, *Homarus americanus*, to sublethal levels of cadmium and mercury. In: Vernberg FJ, Calabrese A, Thurberg FP, Vernberg WB (eds) Physiological responses of marine biota to pollutants, Academic Press, New York, pp 185-197