Cadmium Uptake by the Crayfish, *Orconectes propinquus propinquus* (Girard)

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*Orconectes propinquus* was exposed to 10, 100, and 1000 ppb Cd(Cl\(_2\)) containing 0.09 \(\mu\)Ci/liter \(^{199}\) Cd(Cl\(_2\)) for 1.5, 4.5, 10.5, 22.5, 46.5, 94.5, and 190.5 hours. At 10 ppb, total Cd uptakes between 1.5 and 94.5 hours were not significantly different. By 190.5 hours, the organisms had accumulated a mean concentration of 18.4 ppm Cd, which was significantly higher than the concentrations accumulated at earlier times. At 100 ppb, Cd uptake at 1.5 hours was significantly less (\(P < 0.05\)) than that at 22.5-190.5 hours and uptake at 4.5 hours was significantly less than that at 94.5 and 190.5 hours. Also, uptake at 10.5 hours was significantly less than that at 190.5 hours. Uptakes were not significantly different between 22.5 and 94.5 hours; but were significantly higher than at 1.5 hours and lower than at 190.5 hours. At 1000 ppb, uptake increased with time and was significantly greater (\(P < 0.05\)) at every time interval monitored. By 190.5 hours, the organisms had accumulated a mean Cd concentration of 534.4 ppm. At all time intervals at 1000 ppb, Cd uptake was significantly higher (\(P < 0.01\)) than that at 100 and 10 ppb. Uptakes at 100 and 10 ppb were not significantly different.

INTRODUCTION

The toxicity of cadmium (Cd) to man is well documented (Friberg et al., 1974; Nilsson, 1970). Because of increased use, Cd has found its way into fresh waters and, in some areas, drinking water has been reported to contain more than the 10-ppb guideline set by the U.S. Public Health Service (Public Health Service Publication No. 1049-A, 162-1963). The crayfish is an important link in aquatic food webs. It is preyed upon by at least 28 species of fishes, 5 species of amphibians, 11 species of reptiles, 36 species of birds, and numerous species of mammals, including man (Neill, 1952). The importance of crayfish in food webs, its ubiquitous distribution and commercial value (crayfish are grown commercially for human consumption) prompted our selection of this organism as an experimental subject. It was the purpose of this study to investigate the ability of the crayfish to take up and concentrate Cd from its environment.

MATERIALS AND METHODS

*Orconectes propinquus propinquus* (Crocker and Barr, 1971) were obtained from the section of Casenovia Creek located in Casenovia Park, Erie County, New York. One hundred specimens were collected (hand netting) ranging in weight from 0.2 to 1.5 g. They were transported to the laboratory within 1 hour of collection in plastic pails containing a small amount of creek water.

The crayfish were kept in a 200-liter polyethylene-lined holding tank in 50 liters of dechlorinated City of Buffalo tap water maintained at 11 ± 2°C in an environmental chamber. The water was constantly circulated (through a layer of cotton and activated charcoal over a limestone trickle filter) at a rate of 4 liters per minute. To
afford cover for the crayfish and minimize aggression, the tank contained large, flat stones.

The animals were maintained in a fixed photoperiod: 16 hours of light and 8 hours of darkness. They were fed every other day, initially with trout pellets (Strike Fish Food, Agway Corp., Syracuse, N.Y.) for 3 days and, then with beef liver, at 2% of their total average weight for the remainder of the experiment. Beef liver was substituted for trout pellets because the pellets tended to disintegrate, color, and foul the water.

The crayfish were kept in the holding tank for 7 days before being transferred to 2-liter beakers for exposure to Cd. Only new beakers were used. Before use, they were washed with detergent (Alconox, Alconox Inc., New York, N.Y.) and rinsed thoroughly with tap water. Each beaker was divided into five chambers with a Lucite divider to isolate individuals to eliminate the problems of aggression and identification.

Cadmium-109 Chloride (carrier free; in 0.5 M HCl; 4.8 mCi/ml) was purchased from New England Nuclear (Boston, Mass.). Measurements of radioactivity were made in a Packard Model 3213 γ scintillation spectrometer (counting efficiency: 20%).

Water temperature in the beakers was maintained at 11 ± 2°C (see above). The pH was measured daily with a Beckman Expandomatic pH meter (Model 76A) and a combination electrode and ranged between 7.0 and 7.2 throughout the experiment.

The O₂ concentration of each beaker was maintained near saturation with compressed air filtered through cotton and water and delivered through an air stone.

Each beaker was observed, at the same time, daily for dead crayfish. During Cd exposure, the crayfish were fed every other day (see above).

Sixty crayfish were selected from the holding tank for study. (The only criterion for selection was that the organisms had all their appendages.) They were dried on paper towels, weighed to the nearest milligram (Mettler P1200N top-loading balance), and placed in the beakers.

Three beakers (15 crayfish) were used as controls and contained only dechlorinated tap water. The remaining nine beakers were divided into groups of three and adjusted to concentrations of 10, 100, and 1000 ppb Cd (as CdCl₂), containing 0.09 μCi/liter ¹⁰⁹Cd (as CdCl₂) from the stock solutions. The crayfish were exposed to Cd for 190.5 hours. The control and Cd solutions were changed once during the experiment at 96 hours. The radioactivity levels of the solutions did not change appreciably during the experiment.

After 1.5 hours of exposure to Cd, each crayfish was removed from the beaker, dried, weighed, and placed in a numbered scintillation vial filled with dechlorinated tap water. Each vial was counted for 2 minutes. Because of the counting procedure, the crayfish were exposed to 4°C for 2½ hours. This had no observable effect on their survival or behavior. This procedure was repeated at 4.5, 10.5, 22.5, 46.5, 94.5, and 190.5 hours postexposure.

RESULTS

The experimental findings are summarized in Figs. 1 and 2. Figure 1 is a graph of the mean rate of Cd uptake by O. propinquus under the conditions of the experi-
FIG. 1. Mean rates of cadmium uptake by *O. propinquus*. Each point represents the mean of five animals.

Raw data in counts per minute (cpm) were converted to parts per million per crayfish employing the equation

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\frac{(\text{cpm per crayfish/cpm in solution})}{(\text{total Cd in solution})} \times \frac{1}{\text{weight per crayfish}} = \text{ppm}.
\]

Figure 2 is a least-squares fit of the mean concentration data that was plotted in Fig. 1. The lines all have positive slopes (0.08 for 10 ppb; 0.57 for 100 ppb; 1.93 for 1000 ppb).

To determine whether the data points within any one curve in Fig. 1 were significantly different and also whether the three curves differed significantly from one another, the data were subjected to an analysis of variance employing the Duncan Procedure of Multiple Range Tests (Nie et al., 1975).

FIG. 2. Least-squares fit of the data plotted in Fig. 1.
The seven data points of the 10-ppb curve of Fig. 1 were compared at the 0.05 significance level. It was found that the points at 1.5, 4.5, 10.5, 22.5, 46.5, and 94.5 hours were not significantly different from one another, whereas the point at 190.5 hours was significantly different from the other six points.

The seven data points of the 100-ppb curve of Fig. 1 also were compared at the 0.05 significance level. The point at 1.5 hours was found to be significantly different from the points at 22.5, 46.5, 94.5, and 190.5 hours. The point at 4.5 hours was significantly different from those at 94.5 and 190.5 hours and the point at 10.5 hours was significantly different from that at 190.5 hours. The data points at 22.5, 46.5, and 94.5 hours, although not significantly different from one another, were significantly different from the points at 1.5 and 190.5 hours. Finally, the data point at 190.5 hours was significantly different from the six other points of the curve.

When the seven data points within the 1000-ppb curve were compared at the 0.05 significance level, they all were found to be significantly different from one another.

Upon comparing the three curves, it was found that all the data points in the 1000-ppb curve were significantly different \((P < 0.01)\) from the corresponding points in the curves for 10 and 100 ppb (e.g., the data point at 1.5 hours in the 1000-ppb curve was significantly different from that at 1.5 hours in the 10- and 100-ppb curves). The 10- and 100-ppb curves were not significantly different \((P > 0.05)\).

**DISCUSSION**

Cadmium in drinking water at concentrations above 10 \(\mu g/\)liter (10 ppb) and in food levels exceeding 13 mg/kg wet wt (13 ppm) is considered hazardous to human health (Anonymous, 1962). In our study, it was observed that *O. propinquus* accumulated a mean of 18.4 ppm Cd over a period of 190.5 hours from water containing 10 ppb Cd. Obviously, this organism can concentrate Cd from water that is considered safe for human consumption and, over a relatively short time span (190.5 hours = approximately eight days), can accumulate more than the 13-ppm “safe” limit for food.

The mean concentration of Cd in the crayfish after 190.5 hours in water containing 1 ppm Cd was 534.4 ppm. Only 1 of the 15 experimental subjects died during the course of this study. Apparently, these organisms are highly resistant to Cd toxicity. Unfortunately, a hazard exists in the potential transfer of accumulated Cd from the crayfish to their predators. Biological magnification in the food web of the crayfish could lead to the consumption of toxic levels of Cd by higher-order predators.

In some areas of the United States drinking water contains more than the recommended limit of 10 ppb Cd (Public Health Service Publication No. 1049-A, 1962–1963). After 190.5 hours in 10 ppb Cd, *O. propinquus* accumulated an unsafe (for human consumption) level of Cd. The last data point on the 10-ppb uptake curve of Fig. 1 was significantly different from all the other points. This data point was obtained 96 hours after the next closest point and from the shape of the curve it does not seem unreasonable to speculate that if the experiment had been carried out for a longer time, the Cd level in the crayfish might have been considerably greater. Thus, it follows that even in water containing USPHS acceptable levels of Cd, crayfishes could accumulate significant levels of Cd in a time-dependent manner.
As indicated by the slopes of the least-squares lines (Fig. 2), *O. propinquus* accumulated Cd at an increasing rate with increasing levels of Cd in its environment. Cadmium is toxic to man and if rigid control measures are not instituted and implemented, its concentration in the world's waters may increase greatly with time. If this is true, then Cd in the food web of the crayfish is bound to increase. This could have deleterious effect, directly and/or indirectly, on important human food sources. Unfortunately, little is known concerning the mechanism of Cd transfer from one level of a food chain to another. Other invertebrates such as fiddler crabs, oysters, lobsters, and scallops (O'Hara, 1973; Eisler *et al.*, 1972) have been observed to accumulate Cd from water containing 10 ppb of cadmium. Since these animals along with crayfish are ingested directly by man, a potential human health hazard exists. The ultimate effect of Cd on the ecosystem could be disastrous (Friberg *et al.*, 1974) and further research in this area is desperately needed.

REFERENCES