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Biomagnification of Heavy Metals by Organisms in a Marine Microcosm

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Protection of the public health requires that marine organisms used for food be protected from contamination by heavy metals which are potentially toxic to the consumer. Bioaccumulation of heavy metals by oysters, clams, crabs, shrimp, and fish in near-shore environments has been shown in a number of investigations including those of Colwell et al. (1976), Mason et al. (1974), Kopfler (1974), Sims and Pressley (1976), Brooks and Rumsby (1965), and Zook et al. (1976). Many previous studies have been concerned primarily with the passage of mercury and other metals through food chains; however, Mason et al. (1974), reported that inorganic mercury can also be ingested with organic detritus, by complexing of metals by coordinate linkages, and by up-take in physiological ion exchange mechanisms.

Municipal and industrial wastes discharged into the marine environment contain sufficient quantities of heavy metals to contaminate bays and estuaries. Those metals adsorb onto, or react with organics in sediments, providing a continual source from which the metals can be imparted to the water as organic material is degraded. Decay of organic compounds results in Eh and pH changes of the water, making the metal compounds more soluble, and more readily available to marine organisms.

To assure that the consuming public is not harmed by seafoods which have bioaccumulated toxic quantities of injurious metals, marine organisms used for food must be tested for content of several metals. For this purpose the National Shellfish Sanitation Program of the Food and Drug Administration, U.S. Department of Health, Education, and Welfare has published analytical methods (1976) for measurement of certain heavy metals.

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Perhaps a more important factor than testing for bioaccumulation of metals by marine organisms in contaminated near-shore areas, is the prevention of metal contamination of the environment in which seafood organisms live and reproduce. To reduce contamination of the environment by waste discharges containing metals, the Texas Water Quality Board issued an Order (1975) regulating the maximum allowable concentration of 12 hazardous metals in discharges to inland and tidal waters. Such regulations reduce the potential contamination of the marine environment by heavy metals, but do not completely remove the danger in all areas since some sediments contain a reservoir of metals from previous discharges. It is necessary, therefore, that the mechanisms and pathways of metal bioaccumulation by marine organisms be more completely understood. With more complete knowledge of these mechanisms and pathways, better control of bioaccumulation of hazardous metals by human food organisms may be accomplished.

The objective of this investigation was to study possible pathways of bioaccumulation by determining the relative bioaccumulation of ten selected, potentially toxic metals by the marine organisms comprising limited microcosms in two Texas bays.

MATERIALS AND METHODS

Study Areas

Organisms for test were collected from two bays on the Gulf Coast of Texas. Chocolate Bay lies approximately 26 km Southwest of Galveston. It is fed by Chocolate Bayou, which drains agricultural and residential areas. Dredge spoil islands and natural reef islands within the Bay are the location of cabins which are intermittently occupied. The Bay has been closed to commercial harvesting of shellfish for about the past 20 years because of bacterial contamination.

Jones Bay is a small segment of Galveston Bay located at the West end of the Galveston Causeway. The Bay receives drainage only from residential, commercial, highway and railroad areas, and is used heavily for launching boats for recreation. The area is closed to commercial harvesting of shellfish because of its utilization, location and high bacterial counts.

Additional oyster samples, harvested in Galveston Bay areas which are open for commercial shellfish harvesting, were obtained from commercial sources.

The Microcosm

One of the food organisms known to be a bioaccumulator of heavy metals is the eastern oyster (Crassostrea virginica) found in many bays of the U.S. Gulf Coast. This oyster grows in clumps, or colonies with a rough shell arrangement. This provides a suitable environment for the development of other organisms, thus forming a microcosm of marine life living in and around the colony of oysters. Such microcosms consist of fixed populations of several oysters and clams of various sizes, and of barnacles. Motile organisms, polychaetes and small blue crabs, live in the crevasses and pockets formed by the oyster shells.

Test Organisms

Clumps of oysters (Crassostrea virginica) and shell were collected manually in Chocolate and Jones Bays, iced immediately, and returned to the laboratory within six hours of collection. There, the clumps were broken and barnacles (Balanus aburneus) and clams (Rangia cuneata) were removed from oyster shells. Blue Crabs (Callinectes sapidus) and polychaetes (Nereis sp.) were removed from spaces between shells. Oyster, clam and barnacle shells were opened and meats removed without contamination from the shell. At least six individuals of each species were placed in blenders and emulsified. Crab shells were cracked and tissues removed from leg and abdominal areas. Tissue from at least six crabs were blended. Six polychaetes were washed and pooled for each sample. Each organism sample, and water and sediment samples from the collection sites were placed aseptically in snap-top vials, weighed and frozen for shipment to the Radiation Research Laboratory at Virginia Polytechnic Institute and State University for analysis by neutron activation to determine concentrations of iron (Fe), barium (Ba), zinc (Zn), manganese (Mn), cadmium (Cd), copper (Cu), selenium (Se), chromium (Cr), arsenic (As), and mercury (Hg).

One way analysis of variance and the Tukey's range test were performed using the Statistical Package For The Social Sciences (SPSS). An Alpha=0.05 was set for the level of significance (Nie et al., 1975).

RESULTS

Sediment from collection sites contained the highest concentrations of nine of the ten metals tested (Table 1). The single exception was Zn which was highest in the barnacles, oysters, and polychaetes, respectively. Crabs had the lowest concentrations of all ten metals among the test organisms in the microcosm. Barnacles had the highest concentrations of eight metals among the organisms in the microcosm. The exceptions were that Cu concentrations in the oysters, clams and polychaetes were higher than those in the barnacle, and Cd was higher in polychaetes.

The water in which the microcosm developed provided the source of metal for the filter feeding barnacles, oysters, and clams. Barnacles bioaccumulated significantly greater concentrations of Fe, Ba, Zn, Cr, and As than were present in the water. Barnacles had lower, but not significantly so, concentrations of only Cd, than were found in water. Oysters had significantly higher concentrations of Zn, Cu, and As, and clams had significantly higher concentrations of As than the water in which they lived. Oysters were lower in Ba, and Mn; clams had lower concentrations of Ba, and Cd than did water, but none of these differences was significant.

The motile crabs could have received metals from either sediment or water, yet only the concentrations of As and Cu were greater in crabs than in the water. The concentration of Cd was significantly lower in crabs than in the water, and the concentrations of Fe, Ba, Cd, Cu, Cr, and As in crabs were significantly lower than in sediment. Polychaetes which may also have received metals from both sediments and water had significantly greater concentrations of Zn, Cu, and As than did water, and significantly greater concentration of Zn than was found in sediment. The polychaetes, however, had significantly lower concentrations of Fe, Ba, Mn, and Cr, than did sediment.

Commercial oysters from Galveston Bay were lower in Ba, Zn, Mn, Cd, Cu, Hg, and As than those collected in Chocolate Bay and Jones Bay (Table 2). Of these differences, only the concentrations of Cd, Zn, and Cu were significant. Oysters from all sources had significantly greater ($p = 0.05$) amounts of Fe, Zn, and Cu than other metals (Table 2). Barnacles had significantly higher concentrations of Fe, Zn, Mn, Ba, and Cu; the polychaetes, Fe, Zn, Cu, and Mn; and crabs and clams had significantly greater amounts of Fe in comparison to other metals (Table 1).

TABLE 2

Comparisons of metal concentrations in oysters from different sources (mg/kg, wet weight)

	Source	
Metal	Chocolate-Jones Bays	Commercial
Fe	31.44	31.00
Ba	3.57	1.94
Zn	103.39	31.2*
Mn	1.39	0.38
Cd	0.48	0.19*
Cu	40.66	9.39*
Se	0.14	0.60
Cr	0.43	0.69
Hg	0.07	0.05
As	0.57	0.32

*Difference significant at 0.05 levels

The data in Table 3 depict the quality of water in Chocolate Bay, and in most Texas estuaries during periods of optimal freshwater inflow. These conditions are characteristic of the quality of water in many bayous on the Texas Coast which drain into highly productive estuarine ecosystems. The opportunity for ingestion of detritus by the filter feeders is easily understood if the levels of total suspended solids present in the Bay water are considered. Results typify the nutrient rich inflow to estuarine waters which contribute to the comparatively high biological productivity characteristic of all Texas estuaries receiving freshwater inflows of any magnitude.

TABLE 1

Concentrations of metals in environment and organisms forming microcosms in Chocolate and Jones Bays (mg/kg, wet weight)

Sample	Metal									
	Fe	Ba	Zn	Mn	Cd	Cu	Se	Cr	Hg	As
Bay Water	22.14	7.67	4.11	2.37	1.17	1.31	0.11	0.11	0.009	0.005
Sediment	5,196.00	131.00	26.80	113.83	1.88	148.03	1.44	19.88	0.49	2.40
Barnacle	752.33	40.45	648.00	56.63	1.19	15.28	0.77	3.73	0.28	2.00
Crab	12.80	1.50	3.45	0.34	0.14	2.99	0.08	0.05	0.005	0.07
Oyster	31.44	3.51	103.39	1.39	0.48	40.66	0.14	0.43	0.07	0.57
Clam	71.16	1.45	12.83	7.60	1.19	22.75	0.54	0.99	0.11	2.39
Polychaete	21.03	4.70	41.04	7.47	1.75	42.27	0.49	2.02	0.14	1.12

TABLE 3

Values for some physical and chemical water quality parameters in Chocolate Bay and Bayou during sampling period

Test	Value Bayou	Value Bay
Dissolved Oxygen, mg/l	7.8	7.6
Temperature, °C	23.9	23.5
Ambient Temp., °C	23.4	23.3
pH	8.1	7.8
Secchi Disc, in.	8	9
Salinity, °/oo	1.5	9.7
Conductivity, µmhos/cm	13,600	25,600
Turbidity, J.T.U.	100	44
Color Units	25	10
Total Dissolved Solids, mg/l	9,900	16,500
Total Suspended Solids, mg/l	32	25
Volatile Suspended Solids, mg/l	6	5
Biochemical Oxygen Demand, mg/l	16	7
Chemical Oxygen Demand, mg/l	147	116
Total Organic Carbon, mg/l	16	10
Total Inorganic Carbon, mg/l	31	20
Ammonia-N, mg/l	0.28	0.05
Nitrate-N, mg/l	5.62	2.54
Total Kjeldahl Nitrogen, mg/l	5.56	1.61
Ortho-Phosphate, mg/l as P	1.18	0.19
Total Phosphate, mg/l as P	3.91	0.47

DISCUSSION

Water in Chocolate and Jones Bays is subject to contamination by surface runoff from residential and agricultural areas which are not controlled as to content of heavy metals. Water in these Bays had higher concentrations of Ba, Cd, Se, Mn, and Fe than surface supplies used for drinking water (Guthrie et al., 1977) but had lower concentrations of As, Cr, Cu, and Zn than surface water. All water sources tested had low, and essentially the same concentrations of Hg. Sediments in the Bays accumulated significantly larger concentrations of As, Ba, Cr, Cu, Mn, and Fe than was present in the water. Of organisms forming the microcosms studied from Chocolate and Jones Bays, barnacles appeared to most readily accumulate the metals studied. With the exception of Cu and Cd, barnacles had the highest concentration of each metal, and only the concentration of Cd in barnacles was less (but not significantly so) than that in water. Polychaetes most readily biomagnified Cd and Cu; they were next highest to the barnacles in concentrations of As, Ba, Cr, and Hg; and were third highest in Se, Zn, and Mn among the populations of the microcosms which are not a danger to man in the biomagnification of these metals.

The biomagnification of Zn, Cu, and As by oysters in these enviroments may be hazardous to man. These three metals are among those controlled by the Texas Water Quality Board Order of 1975. Zn and Cu were bioaccumulated by oysters in Chocolate and Jones Bays at a significantly greater level than by commercial oysters grown in less contaminated water. Arsenic accumulation in oysters from all sources was not significantly different. These results are comparable to those reported by Sims and Presley (1976) for the Texas Gulf Coast.

Clams appear to be very similar to oysters in biomagnification of metals in these microcosms. Clams accumulate Fe, Zn, and Cu to the greatest extent, and only the concentration of As in clams was significantly higher than in water.

Crabs, although possibly receiving metals from both water and detrital sediment in these microcosms, appear to be least likely to biomagnify the metals studied, having As and Cu concentrations greater than water with neither difference being significant. Contrary to data reported by Zook et al. (1976), concentrations of As, Cd, Cu, and Zn in crabs were significantly less than those in other edible organisms in the microcosms, and were either equivalent to or less than those concentrations in commercial oysters grown in less contaminated water.

In summary, these data indicate that the food organisms (crab, oyster, and clam) residing in these microcosms are the least likely of the entire population to biomagnify the ten heavy metals studied. Crabs biomagnified less than the attached, filter feeding oysters and clams. Polychaetes and barnacles were the major biomagnifiers of the metals studied in these microcosms.

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