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Bioconcentration Patterns of Zinc, Copper, Cadmium and Lead in Selected Fish Species from the Fox River, Illinois

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A majority of studies related to heavy metal concentrations in aquatic organisms emphasize bioaccumulation (the ability of an organism to concentrate an element above abiotic environmental levels) or biomagnification (the tendency for elements to be concentrated with trophic level transfer) (NAMMINGA *et al.* 1974, McNURNEY *et al.* 1975, ENK and MATHIS 1977, ATCHISON *et al.* 1977, ANDERSON *et al.* 1978). Relatively few heavy metal studies have investigated patterns of bioconcentration within a species. The studies that have been conducted often examined the influence of size on heavy metal concentrations within certain target organs or tissues, e.g., liver and muscle, rather than whole body burdens of the metals (MATHIS and KEVERN 1975, BROOKS and RUMSEY 1974, MEARS and EISLER 1977, BOHN and FALLIS 1978).

DAVIS and BOYD (1978) and GOODYEAR and BOYD (1972) have emphasized the importance of knowing whole body elemental compositions for the preparation of nutrient budgets and for studies of biochemical cycles. Determinations of whole body heavy metal contents are critical to the study of biomagnification, because predators consume entire prey, not selected organs. Consequently whole body metal concentrations from both contaminated and uncontaminated sites are of increasing importance to investigators. Patterns of heavy metal bioconcentration with age or size, can influence, to the extent of masking, observed trends in biomagnification. A need therefore exists to investigate heavy metal bioconcentration patterns for various fish species.

This study was conducted to determine if bioconcentration patterns were similar between four common essential and non-essential trace elements. The whole body concentrations of Zn, Cu, Cd and Pb were related to the whole body dry weights of bluegill (*Lepomis macrochirus*), black crappie (*Pomoxis nigromaculatus*), black bullhead (*Ictalurus melas*), and yellow perch (*Perca flavescens*). Zinc, Cu, Cd, and Pb were selected because most studies of heavy metal concentrations in fish have examined one or more of these elements. These metals are often closely associated with each other as natural impurities (THOMANN *et al.* 1974) or as alloys (McKEE and WOLF 1963). Zinc and Cu are essential components of metallo-enzymes (see FISHER 1975). Cadmium and Pb have not been shown to have essential functions in fishes, but rather inhibit biological systems and competitively interfere with Zn and Cu (KAGI and VALLEE 1961, HILL *et al.* 1963, RIBAS-OZONAS *et al.* 1970, NIKLOWITZ and YEAGER 1973). The fish species were chosen on

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the basis of their importance as recreational and food species and their frequent use in both field and laboratory studies.

STUDY SITES AND METHODS

The fish were collected during Summer, 1973 from riffle and pool areas of the Fox River downstream of a flood control weir at Algonquin, Illinois. At the time of collection, Algonquin had no major industrial effluents and only a few storm drains located in the area. The primary sources for metal inputs were from local sewage treatment plants and from recreational boating in the Algonquin area and Chain of Lakes region upstream from Algonquin. Most fish were captured by seining. Several black bullheads were donated by local fishermen. Fishes used for analysis varied in length and weight (TABLE 1) sufficiently so that at least two year classes were included (CARLANDER 1969, 1978). Upon capture fish were placed in ice and frozen until analyzed.

TABLE 1

Mean standard length (mm) and dry weights (g) of fishes collected from the Fox River

Series	No.	Mean Length (Range)	Mean Weight (Range)
Yellow perch	40	104 (38-151)	11.2 (0.3-30.4)
Bluegill	61	95 (52-142)	16.4 (1.7-54.9)
Black crappie	26	109 (69-157)	18.1 (2.1-56.6)
Black bullhead	10	172 (141-218)	41.6 (19.6-83.2)

Prior to sample preparation fish were thawed and rinsed in distilled water to remove foreign particles, excess mucus coating, or other such materials that could have adsorbed metals. Gastrointestinal contents were then removed from all fish to reduce metal contamination from food material in the digestive tract. Digestive tract contents have been demonstrated to influence observed metal levels in the crane fly larva, *Tipula* spp. (ELWOOD *et al.* 1976). Wet weight determinations of the fish were then obtained. Whole fish dry weight was determined by multiplying fish wet weight by the ratio of sample dry weight to sample wet weight.

Metal concentrations were determined with a single beam Varian Techtron atomic absorption spectrophotometer, Model AA, with direct aspiration of the sample into an air-acetylene flame. Methods for sample preparation and correction for background and matrix effects have been previously described (ANDERSON *et al.* 1978).

Patterns of metal bioconcentrations with fish size were determined by simple linear regression. Two-tailed tests for assessing the significance of the slope of the regression line were performed at the 5% significance level.

RESULTS AND DISCUSSION

With few exceptions, whole body metal concentrations showed no change as fish weight increased (Table 2). No significant relationships for any metals were found for black crappies or yellow perch. Zinc concentrations in black bullhead and bluegill were inversely related to weight. No significant relationship with fish weight was found for the other metals in bluegills and black bullheads, except Cd in bluegills (see below).

Results from our study are in general agreement with other investigations (Table 3). Overall, none of the four metals in question tend to concentrate with increasing fish size. In the case of bluegill Cd concentrations which increased with fish weight, the t value, comparing the slope of metal concentration regressed on weight to a zero slope, was low (2.04; $t_{0.05(2), 59}$ = 2.00). Increased sample size may have shown this relationship to be nonsignificant at the 0.05 level.

CEARLY and COLEMAN (1974) reported that the concentration of Cd in bluegill and largemouth bass tissues developed an equilibrium with water concentrations after two months of exposure. They stated that Cd accumulated to only a certain extent due to inhibition of an active transport mechanism. This process may, therefore, be of significance in limiting body burdens of non-essential heavy metals.

Accumulation patterns are related, in part, to the interdependancy of uptake and elimination rates of elements (CROSS *et al.* 1973). Once a sufficient level of the elements essential for metabolism is sequestered in the body, an equilibrium of sorts is established between the body burden of both essential and non-essential metals and environmental concentrations. The body burden then seems to remain relatively stable or decrease as the size and age of the fish increases.

Discrepancies in bioconcentration patterns observed by researchers may be due to inconsistencies in analyzing either whole body or various tissues. JUDE (1973), for instance, found whole-body burdens of Cd to be less variable and more stable than Cd concentrations in organs and tissues. Furthermore, the susceptibility of individual tissues to metal uptake varies considerably.

A primary reason for a decrease in metal concentration with size is related to new tissues being incorporated at a greater rate than metals can be actively transported into the tissues to establish a steady-state concentration (dilution by growth) (CROSS *et al.* 1973). O'REAR (1971) observed a negative correlation for Zn and Cu in small striped bass due to rapid growth. However, in larger bass he found no correlation, indicating less rapid growth which allowed a steady-state of metal uptake and elimination from tissues to be established. Furthermore, CROSS *et al.* (1973) indicated Zn and Cu exchange rates between muscle and blood are

TABLE 2

Regression equations for effect of fish weight on Zn, Cu, Cd, and Pb whole body concentrations. y = g metal/g dry weight fish, x = dry weight fish, r^2 = coefficient of determination, t = t value from t test comparing slope of regression equation with a line of zero slope, n = number of fish analyzed.

Element	Mean Concentration (µg/g)	Regression Equation	r^2	t	$t_{0.05(2),n-2}$	Increase (+), decrease (-), or no change (0) with body weight.
	Yellow perch (*Perca flavescens*), n = 40, mean dry weight = 11.22 g.					
Zn	106	y = 113.95 - 0.650x	0.049	-1.398	2.024	0
Cu	20	y = 18.61 + 0.129x	0.003	0.332	2.024	0
Cd	0.2	y = 0.18 + 0.001x	0.400	0.400	2.024	0
Pb	2.2	y = 1.94 + 0.023x	0.008	0.550	2.024	0
	Bluegill (*Lepomis macrochirus*), n = 61, mean dry weight = 16.40 g.					
Zn	108	y = 125.88 - 1.113x	0.158	-3.330	2.000	-
Cu	16.5	y = 19.11 - 0.158x	0.006	-0.579	2.000	0
Cd	0.2	y = 0.16 + 0.004x	0.066	2.043	2.000	+
Pb	2.6	y = 3.66 - 0.063x	0.026	-1.265	2.000	0
	Black crappie (*Pomoxis nigromaculatis*), n = 26, mean dry weight = 18.09 g.					
Zn	113	y = 136.66 - 1.327x	0.135	-1.939	2.064	0
Cu	27.5	y = 32.50 - 0.244x	0.030	-0.861	2.064	0
Cd	0.2	y = 0.19 - 0.000x	0.000	-0.002	2.064	0
Pb	1.3	y = 1.75 - 0.274x	0.055	-1.187	2.064	0
	Black bullhead (*Ictalurus melas*), n = 10, mean dry weight = 41.59 g.					
Zn	94.8	y = 131.56 - 0.883x	0.647	-3.8321	2.306	-
Cu	15.8	y = 18.62 - 0.069x	0.035	-0.540	2.306	0
Cd	0.3	y = 0.37 - 0.002x	0.059	-0.710	2.306	0
Pb	1.1	y = 2.08 - 0.023x	0.237	-1.577	2.306	0

TABLE 3

Literature survey of the relationship of metal concentration to fish length, weight, or age.*

Species (tissues analyzed)	Zn	Cu	Cd	Pb
Moki, Kahawai, trevally, gurnard, hupaka[1] (muscle)	0	0		
Kingfish[1] (muscle)	-	-		
Tara kihi[1] (muscle)	+	-		
Snapper[1] (muscle)	0	-		
Coho salmon, lake trout, fresh-water drum[2] (decapitated and eviscerated)			0	
Lake trout[3] (decapitated and eviscerated)				0
Cod, whiting, pike[4] (whole body)			0	
Atlantic manhaden, Atlantic croaker, Bag anchovy[5] (whole body)	-			
Morid[6] (muscle)	-	-		
Bluefish[6] (muscle)	0	0		
Chain pickerel[7] (whole body)	-	0	0	
Largemouth bass[8] (whole body)	0	0		
Largemouth bass, yellow perch, yellow bullhead, hybrid sun-fish, lake chubsucker[9] (muscle)			0	0
Bluegill[10] (whole body)	0		0	0
Bluefish[11] (liver)	0	0	0	
Tautog-male[11] (liver)	0	-	0	
Tautog-female[11] (liver)	0	0	0	
Tilefish-male[11] (liver)	0	+	+	
Tilefish-female[11] (liver)	-	+	+	
Shorthorn sculpin[12] (liver)	+	0	0	-
Shorthorn sculpin[12] (muscle)	0	-		
Arctic char[12] (liver)	0	0	0	0
Arctic char[12] (muscle)	0	0		

*0 = no relationship; + = positive relationship; - = negative relationship

1: BROOKS and RUMSEY 1974, 2: LOVETT *et al.* 1972, 3: PAKKALA *et al.* 1972, 4: HAVRE *et al.* 1973, 5: CROSS and BROOKS 1971, 6: CROSS *et al.* 1973, 7: GIESY and WIENER 1977, 8: GOODYEAR and BOYD 1972, 9: MATHIS and KEVERN 1975, 10: ATCHISON *et al.* 1977, 11: MEARS and EISLER 1977, 12: BOHN and FALLS 1978.

constant, or decrease, over the life-span of an adult fish. This would also account for the negative and/or non-detectable bioconcentration patterns we observed for Zn and Cu.

Decreased metal concentrations with size have also been concluded to be related to a decrease in the percent composition of viscera (containing organs known to accumulate heavy metals) in a fish as the fish grows (CHERNOFF and DOOLEY 1979). Other factors cited to decrease metal levels with size are changes in muscle composition or decreased intake of metals due to dietary changes (CROSS *et al.* 1973). Physiological requirements for survival that dictate maintenance of certain levels and ratios of elements (GOODYEAR and BOYD 1972) could also account for increases in concentrations of the metals of concern not being observed.

SCHROEDER and TIPTON (1968) provided evidence that Cd and Pb deposition is cumulative in man, while HUCKABEE and BLAYLOCK (1973) implied Cd bioconcentrates in fish. An explanation for these anomalies may be that the strategy of higher organisms in dealing with toxic elements is to sequester rather than eliminate the elements (GIESY and WIENER 1977). This would cause an overall metal accumulation over time. Whole body concentrations measure the total amount of the element relative to the organisms' biomass. The quantity of an element can still increase over time but a positive correlation need not occur if the amount accumulated is proportional to or less than the biomass increase over the same time period (GIESY and WIENER 1977).

CROSS *et al.* (1973) cautioned that interspecific comparisons of heavy metal concentrations for which values vary as a function of age (e.g., Hg) should only be made among fishes of the same age. The results of our study, coupled with supportive evidence in the literature, indicate this precaution may not be necessary with Cd and Pb. Individual variation of whole body concentrations of Cd and Pb are large, therefore, trends with weight are seldom observed. Research also indicates that fish will reach a maximum concentration after a given period of time (CEARLY and COLEMAN 1974 - Cd in two months, SULLIVAN *et al.* 1978 - Cd in 20 days). Caution in interspecific comparisons for Cd and Pb may need to be taken only to assure that the fish have inhabited respective sampling locations for an adequate period of time to reflect possible environmental contamination. However, evidence is not strong enough to warrant comparisons of Zn and Cu from various sites using fishes of differing weights, lengths or ages. If adequate numbers of fish cannot be obtained for given weight or size, a possibility exists for comparing slopes of metal concentrations and weight regressions. Variations in the slopes may then be used to assess potential contamination of aquatic systems by essential heavy metals. WIENER and GIESY (1977) have stated that the ability of fish to regulate essential metals makes monitoring of metals such as Zn and Cu of limited value. As the non-essential metals, Cd and Pb, are often associated with Zn and Cu, it may be of more benefit and practicality to monitor these metals, as WIENER and GIESY suggest.

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