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Copper, Cadmium, and Nickel Accumulation in Crayfish Populations Near Copper-Nickel Smelters at Sudbury, Ontario, Canada

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The Sudbury basin, an elliptical 646 square mile depression containing a number of freshwater reservoirs, has been subjected to extreme ecological disturbances from logging, mining and smelting activities (Winterhalder 1984). The impact of acid precipitation and heavy metal contamination on the water, soil, atmosphere and vegetation of the region has been discussed by Freedman and Hutchinson (1980a, 1980b, 1980c) and Chan et al. (1980).

The literature on the occurrence and effects of heavy metals in aquatic systems has been reviewed by Gorham and Gordon (1960). However, much of the information available on freshwater invertebrates pertains to the determination of tolerance limits. Gale et al. (1973) correlated the mean concentrations of lead, zinc, copper, manganese and cadmium in whole crayfish to the variations of these metals in the environment. Anderson and Brower (1978) evaluated the effects of different sublethal environment concentrations on accumulation and concentration of cadmium, copper, lead and zinc in crayfish. The purpose of the present study was to compare tissue concentration of copper, cadmium and nickel in freshwater crayfish at selected distances of the habitat from the emission source. Various tissue concentrations in crayfish from the sites were also examined to determine if particular body tissues were specific sites for metal accumulation.

MATERIALS AND METHODS

Intermoult adult *Orconectes virilis* were collected from Ramsey Lake (46° 28'N 80° 57'E) in Sudbury (Ontario), and *Cambarus bartoni* were obtained from Joe Lake (46° 44'N 81° 01'E) in Chelmsford (Ontario), and Wizard Lake (47° 44'N 81° 46'E) in Gogama (Ontario). Wizard Lake, situated at a distance of 150 km from the smelter, is an uncontaminated site whereas Ramsey Lake and Joe Lake' are 12 km and 30 km downwind, respectively, and are heavily contaminated with copper, cadmium and nickel (for details, see Freedman and Hutchinson 1980a).

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Ten animals (5 females and 5 males, average wet weight = 5.4 g; average carapace length = 45 mm) collected from each site were separated by sex, quick frozen, and stored at -15°C. The hepatopancreas, exoskeleton, abdominal muscle, digestive gut (alimentary canal) and remaining viscera (including gills, viscera, reproductive organs, etc.), were oven dried for 48 hours at 80°C, and dry weights were determined. Samples for analysis by Perkin-Elmer atomic absorption spectrophotometer were digested in boiling concentrated aqua regia (3 ml concentrated nitric acid: 1 ml concentrated hydrochloric acid, British Drug House standards), diluted to 20 ml with 1 M nitric acid and analysed for copper, cadmium and nickel by the flame method (Perkin-Elmer manual, 1971).

Statistical analysis of the data was computed with the aid of a DEC-VAX/VMS computer, using SPSS^x software (SPSS, Chicago, Ill., U.S.A.). An initial three-way ANOVA evaluated the effects on metal levels by site, sex and tissue of the crayfish. Within site and tissue comparisons were made using one-way ANOVA with Duncan's Multiple Range test. All data were checked for normality (Kolgomorov-Smirnoff test) and homogeneity of variance (Bartlett-Box F test), and they were log transformed where necessary.

RESULTS AND DISCUSSION

Tables 1 to 3 summarize data on concentrations of studied trace metals in the crayfish from the three sampling sites. Since differences in metal concentrations between males and females were not significant ($P > 0.05$), the data for the two sexes were pooled. The general relationship between the crayfish tissue metal concentrations at the three sites was cadmium (Cd) < nickel (Ni) < copper (Cu). This relationship did not reflect that observed by Freedman and Hutchinson (1980a)(Cd < Cu < Ni) in the environment. A similar relationship between the tissue accumulation of cadmium, copper, lead and zinc and the environment concentration of these metals was suggested by Anderson and Brower (1978).

Differences between metal concentrations at the three sites were significant at the 0.05 level. In general, highest tissue metal concentrations were observed in crayfish obtained from Ramsey Lake, and lowest from those collected from Wizard Lake. This implied that there was an inverse relationship between tissue metal contents and the distance of the habitat from the smelter. Freedman and Hutchinson (1980a) have mentioned that 40% of the copper and 42% of the nickel emitted from the Sudbury smelter was deposited within a 60 km radius. Yan and Dillon (1982)observed a similar relationship between the metal output to the environment and the distance from the smelter. Thus, the occurrence of higher concentrations of at least these two metals in crayfish collected from Ramsey and Joe Lakes as compared to those from Wizard Lake was related to the input of these metals into the habitat. Similar findings have been reported by Anderson and Brower (1978)

Table 1. Mean concentration of copper (μg/g dry wt) in various tissues of crayfish collected from Ramsey, Joe and Wizard Lakes.

Tissues	Ramsey	Joe	Wizard
Hepatopancreas	$1986^{a,1}$	$996^{a,2}$	$111^{a,3}$
	(1448, 2725)*	(641, 1546)	(51, 243)
Exoskeleton	$57^{b,1}$	$96^{b,1}$	$28^{b,2}$
	(49, 66)	(74, 124)	(11.6, 69.9)
Abdominal muscles	$100^{c,1}$	$114^{b,1}$	$50^{b,2}$
	(78, 129)	(81, 161)	(41, 62)
Digestive gut	$601^{d,1}$	$182^{c,2}$	$79^{a,3}$
	(397, 909)	(127, 260)	(55, 114)
Viscera	$109^{c,1}$	$118^{b,2}$	$63^{a,3}$
	(87, 136)	(99, 141)	(47, 83)

* 95 per cent confidence limits.
Means within each column followed by the same letter, and within each row followed by the same number are not significantly different at the 5% level.

Table 2. Mean concentration of cadmium (μg/g dry wt) in various tissues of crayfish collected from Ramsey, Joe and Wizard Lakes.

Tissues	Ramsey	Joe	Wizard
Hepatopancreas	$37^{a,1}$	$32.5^{a,1}$	$2.4^{a,b,c,2}$
	(27.8, 51.3)*	(21.4, 49.2)	(1.5, 4.0)
Exoskeleton	$6.3^{b,1}$	$4.9^{b,1}$	$4.7^{b,1}$
	(5.4, 7.3)	(4.1, 5.9)	(2.9, 7.3)
Abdominal muscles	$3.0^{c,1}$	$4.4^{b,1}$	$1.8^{c,1}$
	(1.7, 5.4)	(2.5, 7.6)	(1.0, 3.5)
Digestive gut	$18.2^{d,1}$	$15.5^{c,1}$	$3.4^{a,b,c,2}$
	(9.5, 34.9)	(8.5, 28.2)	(1.2, 10.0)
Viscera	$5.0^{b,c,1}$	$4.9^{b,1}$	$2.7^{a,b,c,2}$
	(4.4, 5.9)	(4.5, 5.5)	(2.1, 3.6)

* 95 per cent confidence limits.
Means within each column followed by the same letter, and within each row followed by the same number are not significantly different at the 5% level.

Table 3. Mean concentration of nickel (µg/g dry wt) in various tissues of crayfish collected from Ramsey, Joe and Wizard Lakes.

Tissues	Ramsey	Joe	Wizard
Hepatopancreas	$240^{a,1}$	$0.8^{a,2}$	$0.3^{a,2}$
	(144.0, 402.2)*	(0.0, 55.6)	(0.0, 13.1)
Exoskeleton	$213.5^{a,1}$	$54.0^{b,1}$	$6.9^{a,2}$
	(127.2, 358.2)	(2.3, 1243)	(0.4, 103.5)
Abdominal muscles	$26.6^{b,1}$	$0.0^{a,2}$	$1.0^{a,2}$
	(3.0, 232.0)	(0.0, 1.26)	(0.0, 37.2)
Digestive gut	$921^{a,1}$	$0.33^{a,2}$	$24.4^{a,3}$
	(518.9, 1636.0)	(0.0, 21.2)	(0.0, 697)
Viscera	$140.9^{c,1}$	$82^{b,1,2}$	$15.9^{a,2}$
	(85.3, 232.8)	(13.7, 493.4)	(1.9, 127.3)

* 95 per cent confidence limits.

Means within each column followed by the same letter, and within each row followed by the same number are not significantly different at the 5% level.

for aquatic crustacean species, and Price et al.(1974), and Hopkin and Martin (1983) for terrestrial arthropods.

Highest concentration of each metal, in the present study, was observed inside the hepatopancreatic tissue, and the lowest in the abdominal muscles (Tables 1 - 3). This is not surprising, since hepatopancreas, according to Brown (1982), is the main regulatory organ in crustacean species, and as such it would be the prime site for metal storage and detoxification in these animals. The relatively high concentrations of copper observed in the hepatopancreas of the crayfish obtained from contaminated lakes reflected the storage capacity of this organ for copper. Given the substantially lower concentration of this metal in the hepatopancreas of crayfish from uncontaminated waters, the storage capacity probably surpasses physiological requirements for this metal. Hopkin et al. (1985) suggested that storage instead of excretion of this metal may be a method employed by crustacean species to conserve energy.

Copper has also been shown to be a regulated metal in several species of marine and freshwater decapods (Bryan, 1968). This may be related to the essential biochemical role of this metal in the production of the respiratory protein, haemocyanin (Bonaventura and Bonaventura, 1980). According to Dallinger (1977), the limits within which copper is regulated, are closely adjusted to the average concentration of all copper sources available in a particular habitat. This would also explain the relatively high copper concentrations found in the hepatopancreas of crayfish from Ramsey and Joe Lakes even though copper is regulated.

Cadmium and nickel are generally thought to be biologically non-essential metals. According to Hopkin and Martin (1985), non-essential elements enter the animal by following the same biochemical pathways as essential elements with which they are chemically similar. Cadmium has been shown to be assimilated by the same route as copper, and it has been found to be stored in the protein metallothionein (Overnell and Trewella, 1979; Overnell, 1982). The presence of substantial concentration of cadmium and nickel in the exoskeleton might indicate that this tissue was involved in the excretion of these metals. However, further study will be required to support this contention.

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