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Bioaccumulation of Heavy Metals in Pre-fledgling Tree Swallows, *Tachycineta bicolor*

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Wetlands in urbanized areas are frequently degraded by human activity. The Hackensack River Estuary in Northeastern New Jersey is no exception. This estuary contains over 1,600 acres of landfill, and receives various levels of treated effluent from seven different sewage treatment plants. In addition, until regulations were enacted in the early 1970's, the uncontrolled discharge of industrial wastes was common, leaving several hazardous waste sites in the basin.

Heavy metals are a common pollutant in the Hackensack River Basin. A variety of metals has been reported in the sediments (Torlucci 1982); vegetation (Kraus 1988); invertebrates and fish (Santoro and Koepp 1986); reptiles (Albers et al. 1986); and mammals (Galluzzi 1976) of this estuary. Very little information exists on heavy metal concentrations in birds using the Hackensack River Basin.

Bioaccumulation of heavy metals in birds is a well documented phenomenon. Studies have shown that near shore predatory birds such as cormorants (Phalacrocorax auritus) and terns (Sterna hirundo and S. paradisaea) have higher mercury levels in their feathers than do pelagic predatory birds such as kittiwakes (Rissa Tridactyla) and phalaropes (Phalaropus lobatus) (Braune 1987). Other studies have shown that insectivorous pied flycatcher (Ficedula hypoleuca) nestlings (Nyholm 1987) and black-crowned night heron (Nycticorax nycticorax) pre-fledglings (Custer and Mulhern 1983) show heavy metal body burdens that correlate well with the distance of their nests from a heavy metal source.

The tree swallow (Tachycineta bicolor) is a common summer resident in the Hackensack Meadowlands. This species readily nests in man-made nest boxes (Bent 1942), and has used boxes erected for this purpose in the Hackensack Meadowlands District (HMD). The swallows feed primarily on adult midges (Chironomus decorus) which are prevalent in the region. This relationship makes the tree swallows and midges an ideal model for food chain bioaccumulation studies.

MATERIALS AND METHODS

The study area, known as the Kingsland Impoundment, is located in Lyndhurst, Bergen County, N.J., USA. The site is approximately 31.2 ha in size, and has been severely impacted by human activity. This impoundment is bound to the west by a 50.6 ha county landfill, to the north by a commuter rail line, and to the south and east by a liquid natural gas pipeline. This system has restricted tidal flow through two 92.3 cm pipes, and receives landfill leachate, parking lot runoff, and seepage from a residential type septic system.

Ten sediment samples were collected from the Kingsland Impoundment. These samples were air dried and then dried to a constant weight at 60°C. Dried sediments were pulverized and passed through a 2mm sieve prior to digestion for metals analysis.

Adult midges were collected using a hand-held, portable vacuum and were frozen at - 12°C prior to digestion for metals analysis. A total of nine, 1g midge samples were analysed.

A total of 12 swallow eggs were collected from three nests. Embryos were removed from the shell and were frozen at - 12°C prior to digestion. All samples from any given nest were pooled to provide a sample large enough for analysis. This yielded three egg shell, and three embryo samples. Six pre-fledgling swallows were collected from 3 nests different from those where eggs had been collected. Two pre-fledglings were removed from each nest, and were sacrificed using chloroform. After sacrifice, the swallows were weighed, feathers removed, and liver, breast muscle, brain, and gizzard were excised. All tissues, except the gizzard, were immediately frozen at - 12°C. Gizzards were dissected and analyzed as to content. After this examination, gizzards were rinsed in distilled water and then were handled by the same procedure described above for other tissues.

All biological samples were prepared for heavy metal analyses using USEPA methods recommended for fish tissue (USEPA 1980). Sediments were prepared for analysis using methods described by the USEPA as well (USEPA 1980). Samples were analyzed for Cd, Cr, Cu, Pb, and Ni using atomic absorption spectrophotometry (Perkin-Elmer 272). Quality control was maintained through the analysis of known metal standards and NBS sediment standards (NBS 1645, 1646). All data were analyzed using the Students t-test.

RESULTS AND DISCUSSION

Metal recovery in the NBS sediment standards agreed very closely with the certified values. Of the metals analyzed, chromium was found in the highest concentrations in Kingsland Impoundment sediments, while Cd was found in the lowest concentrations (Table 1).

Midges had detectable amounts of Cr, Cu, Pb and Ni, but Cd was below the detection limit. Embryonic bird tissue contained small amounts of Cr, Pb and Ni, but Cd and Cu were not detected. Conversely, swallow egg shells contained all of the analyzed metals, in amounts greater than those found in the embryo (Table 1).

Pre-fledgling tree swallows analyzed in this study were of equivalent weights (21.1 g $\pm$ 1.3). The gizzards of all birds were full. The predominant item found in the gizzard was adult midges, although one to two wasps (hymenoptera) were found in each gizzard, and one gizzard contained fragments of a beetle (coleoptera). In addition, all of the gizzards analyzed contained molluscan shell fragments, and/or small pebbles.

Cadmium was detected in only one tissue sample. Breast muscle tissue from one pre-fledgling contained 1.6 mg/kg of this element. Copper was not detected in the brain tissue of any of the bird samples, and was only present in two liver samples (3.1 and 7.1 mg/kg). Lead was only detected in one brain sample (67.4 mg/kg) and one muscle sample (21.2 mg/kg). Both Cr and Ni were found in all pre-fledgling tissue samples analyzed, while Cu was present in every feather sample, and Pb was found in every liver sample analyzed (Table 2).

Chromium levels in brain tissue were significantly greater ($P<0.5$) than the levels of chromium in any of the other tissues analyzed. Nickel levels in brain tissue were also significantly greater ($P<0.05$) than levels found in muscle, gizzard, or feathers. Concentrations of chromium and nickel found in liver tissue were also significantly greater ($P<0.05$) than concentrations found in feathers, and chromium levels in liver tissue were significantly greater ($P<0.05$) than levels in breast muscle. In addition, Cr and Cu levels were significantly ($P<0.05$) higher than levels found in feathers, Cr in gizzards was significantly higher ($P<0.05$) than levels found in feathers, and Pb was significantly higher ($P<0.05$) in feathers than it was in gizzard tissue.

The swallow data reported in this study are preliminary. The small sample size allowed the hypothesis to be tested, yet did not greatly affect the swallow population. This study suggests that the predator/prey relationship between tree swallows and midges and the life cycles of these species make them an ideal model for bioaccumulation studies. The midges spend their larval stages in the sediments and emerge as breeding adults (Utberg and

Table 1. Amounts of Cr, Ni, Cu, Pb and Cd found in NBS standards, sediments from the Kingsland Impoundment, tree swallow eggs, and midges. Data are expressed as mg/kg. Mean and standard deviations are given where appropriate.

Sample		Chromium	Nickel	Copper	Lead	Cadmium
NBS River	Sediment					
	certified	29.6×10^3	45.8	109.0	714	10.2
	retrieved	21.6×10^3	50.4	109.5	768	9.2
NBS Estuarine	Sediment					
	certified	76.0	32.0	18.0	28.2	0.4
	recovered	40.8	25.2	12.4	25.1	ND[b]
Sediments	(N=10)	1098.6 ± 495.2	79.7 ± 18.8	180.4 ± 50.3	202.3 ± 54.4	4.9 ± 3.1
Egg Shell	(N=3)	173.6 ± 108.0	31.4 ± 19.8	2.4 ± 2.5	90.9 ± 59.5	1.8 ± 0.0
Embryo	(N=3)	6.5 ± 2.0	1.6 ± 1.2	ND[a]	2.3 ± 50.5	ND
Midges	(N=9)	42.2 ± 28.5	22.1 ± 15.6	54.0 ± 16.5	5.9 ± 4.0	ND

a The lower detection limit for copper is 0.02 mg/l
b The lower detection limit for cadmium is 0.005 mg/l
ND non-detectable

Table 2. Amounts of Cr, Ni, Cu, and Pb in representative tissues of pre-fledgeling tree swallows. Data are presented so that values across a given row are from the same individual. Mean and standard deviation are also presented. Data are expressed as mg/kg.

	Brain	Liver	Muscle	Gizzard	Feather
Chromium	223.1	115.7	24.6	49.5	10.2
	84.2	105.1	58.3	59.3	27.7
	151.8	123.5	30.1	71.2	40.3
	189.6	113.2	70.6	171.2	20.2
	258.4	83.6	73.6	72.1	31.4
	363.1	69.4	79.6	82.9	23.4
	211.7±95.5	101.8±20.9	56.1±23.4	84.4±44.1	25.5±10.2
Nickel					
	6.0	19.9	7.0	7.0	7.0
	40.8	12.7	9.4	2.4	0.8
	21.5	15.0	4.3	17.2	7.0
	26.8	13.7	5.0	16.6	2.9
	36.5	19.1	6.9	11.7	5.1
	34.2	62.6	12.9	1.7	3.3
	27.6±12.7	23.8±19.2	7.6±3.2	9.4±6.8	4.3±2.5
Copper	a	b	2.5	5.0	4.1
			ND[d]	12.0	4.7
			ND	14.4	4.1
			1.8	ND	6.1
			2.5	2.4	4.2
			2.7	2.1	4.7
			1.6±1.3	6.0±5.8	4.7±0.8
Lead	c	46.3	c	ND[e]	16.3
		21.0		ND	16.1
		24.7		28.5	16.1
		22.6		27.4	ND
		44.6		19.2	8.4
		222.1		ND	ND
		63.6±78.5		12.5±14.1	4.3±2.5

a Copper was not detected in any of the brain tissue analyzed.
b Only two samples had detectable amounts of copper.
c Only one sample had detectable amounts of lead.
d The lower detection limit for copper is 0.02 mg/l
e The lower detection limit for lead is 0.10 mg/l
ND non-detectable

Sutherland 1982). Midges do not feed as adults; therefore, it can be assumed that heavy metal body burdens found in adult midges were accumulated from the contaminated sediments during the larval stages. Since adult midges are one of the primary food sources of tree swallows in the HMD, it can also be assumed that heavy metals found in the tissues of pre-fledgling tree swallows were accumulated by the ingestion of local insects (predominantly midges) fed to the nestlings by parent birds. This assumption is further supported by the fact that swallow embryos contained relatively small amounts of Cr, Pb, and Ni when compared to pre-fledglings, and embryos contained no Cd or Cu. This suggests that the accumulated metals found in pre-fledglings were derived after hatching (presumably through ingestion) instead of through the egg.

Relatively high amounts of heavy metal in the egg shells of tree swallows support the hypothesis that female birds may excrete heavy metals in eggs (Gochfeld and Burger 1987). Interestingly, the present study suggests that certain metals are bound in the shell structure and that very little metal is passed onto the embryo itself.

The current study suggests that the accumulation of metals in bird tissue depends on the tissue type, as well as the type of metal being analyzed. Brain tissue accumulated chromium in significantly higher amounts than any of the other tissues analyzed. Nickel showed the same pattern of accumulation except that there was no significant difference between levels in brain and liver tissue. Interestingly, even though copper and lead were significant contaminants in the tree swallow environment, copper was not detected in brain tissue, and lead, which was detected in low levels in midges, was only detected in one sample.

The liver traditionally has been the target organ for detection of heavy metals. Liver analysis in a variety of ducks (Gochfeld and Burger 1987), sea birds (Braune 1987), and an insectiverous bird (Nyholm 1987) seems to indicate that the liver is a good target organ for detecting heavy metal stress in a bird's environment. Despite this, the present study, as well as others (Custer and Mulhern 1983), suggest that the liver may not always accumulate all of the metals affecting a species. Nickel is not always reliably detected in night heron livers (Custer and Mulhern 1983), and the present study found that copper was not detected in tree swallow livers, although this element was found to be a significant contaminant in the food supply of this species.

Both muscle tissues (pectoralis and gizzard) showed comparable metal uptake patterns. Chromium and nickel showed up consistently in the samples, while copper and lead were not always detected. There was a general trend towards the gizzard containing higher levels of metal when compared to pectoralis however. This is probably due to the direct contact the gizzard has with all ingested materials, although differences in uptake between smooth and striated muscle may partially explain this as well.

It has been suggested that the analysis of bird feathers may be a non-invasive and reliable way of identifying contaminants in a birds environment (Appelquist et al. 1984; Goede and DeBruin 1986). The present study agrees with this hypothesis, but suggests that in most cases these data would be qualitative, not quantitative. Bird feathers did not contain the high levels of metal found in other tissues, particularly brain and liver tissue. Despite this, the feathers were the only tissue type analyzed that consistently contained detectable amounts of chromium, nickel, copper and lead. Cadmium, which was not detectable in the primary food source (midges), was not detectable in the feathers either.

This study has demonstrated that heavy metals can move from contaminated estuarine sediments through midges and bioaccumulate in pre-fledgling tree swallows. It has also shown that the accumulation of metals in bird tissue is dependent on tissue and metal type. These data should be of particular interest in designing biomonitoring projects, and strongly suggest that sewage sludge and other heavy metal-laden wastes should not be disposed of in estuarine systems.

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REFERENCES

Albers PH, Mulhern BM (1986) Effects of environmental contaminants on snapping turtles of a tidal wetland. Arch Environ Contam Toxicol 15:39-49

Applequist HS, Asbirk S, Drabaek I (1984) Mercury monitoring: Mercury stability in bird feathers. Mar Pollut Bull 15:22-24

Bent AC (1942) Life histories of North American flycatchers, larks, swallows, and their allies. Dover Publ Inc New York

Custer TW, Mulhern BL (1983) Heavy metal residues in pre-fledgling black-crowned nigh-herons from three Atlantic Coast colonies. Bull Environ Contam Toxicol 30:178-185

Galluzzi PF (1976) Mercury concentrations in muskrats, Ondatra Zibethicus from the Hackensack Meadowlands, New Jersey. MS thesis, Fairleigh Dickinson Univ, Rutherford, New Jersey

Gochfeld M, Burger J (1987) Heavy metal concentrations in the liver of three duck species: Influence of species and sex. Environ Pollut 45:1-15

Goede AA, DeBruin M (1986) The use of bird feathers for indicating heavy metal pollution. Environ Monit Assess 7:149-256

Kraus ML (1988) Accumulation and excretion of five heavy metals by the saltmarsh cordgrass Spartina alterniflora. Bull New Jersey Acad Sci 33:39-43

Nyholm NEI (1987) Bio-indication of industrial emissions of heavy metals by means of insectiverous birds In: Lindberg SE, Hutchinson TC (eds) Proceedings of the International Conference on Heavy Metals in the Environment, Vol II, pp 45-47

Santoro ED, Koepp SJ (1986) Mercury levels in organisms in proximity to an old chemical site (Berrys Creek, Hackensack Meadowlands, New Jersey, USA). Mar Pollut Bull 17:219-222

Torlucci J (1982) The distribution of heavy metals concentration in sediment surrounding a sanitary landfill in the Hackensack Meadowlands. MSc thesis, Rutgers Univ, Newark, New Jersey

USEPA (1980) Interim methods for sampling and analysis of priority pollutants in sediments and fish tissue. EPA 600/4-81-055

Utberg GL, Sutherland DJ (1982) The temporal distribution of Chironomus decorus (Chironomidae) in Northern New Jersey. New York Entomological Soc 50:16-25

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