HEAVY METALS AND SELENIUM IN FEATHERS OF THREE SHOREBIRD SPECIES FROM DELAWARE BAY

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Abstract. Concentrations of lead, cadmium, mercury, selenium, chromium and manganese were examined in breast feathers of shorebirds migrating north through Cape May, New Jersey in 1991 and 1992. Although we predicted that metal levels would be positively correlated with weight, this was only true for mercury in red knots (*Calidris canutus*). Selenium was negatively correlated with weight in red knots. No other significant correlation of metal concentrations with weight were found. Lead and mercury were highest in sanderlings (*C. alba*). Selenium and manganese were highest in red knots, while chromium and cadmium levels were highest in semipalmated sandpipers (*C. pusilus*). For 1991, interspecific metals differences were significant for all metals except lead. For semipalmated sandpipers, cadmium and chromium concentrations were significantly higher in 1991 while manganese concentrations were significantly higher in 1992.

1. Introduction

Heavy metals can enter the food chain through a variety of anthropogenic sources as well as natural processes (Reid and Hacker, 1982; Stoewsand *et al.*, 1986; Grue *et al.*, 1986). Once a metal enters the body, it may be eliminated or accumulated. Birds can eliminate heavy metals and selenium in their feathers, making feathers useful for biomonitoring exposure because they reflect the body burden of metals at the time of formation (Goede and de Bruin, 1984). Numerous studies have evaluated levels of heavy metals in bird feathers (Goede and de Voogt, 1985; Gochfeld *et al.*, 1991; Burger and Gochfeld, 1991). Yet some highly migratory species, such as shorebirds, have been largely ignored. Migratory species that overwinter in South America may be expected to be exposed to high levels of contaminants on their wintering grounds.

This paper examines levels of mercury, cadmium, lead, selenium, manganese and chromium in the breast feathers of Red Knots (*Calidris canutus*), Sanderlings (*C. alba*) and Semipalmated Sandpipers (*C. pusilus*) from the Delaware Bay collected during their norther migration in May 1991. Semipalmated Sandpiper feathers were also collected from the same area in May 1992. The three species examined in this study are in the sandpiper family, allowing examination of interspecific differences in heavy metal levels in closely related species. Weights were taken for the Sanderlings and Red Knots from 1991 and from the Semipalmated Sandpipers from 1992, allowing comparison of feather metal levels with body size.

Migratory shorebirds travel great distances each year. Some species fly from their nesting grounds in the arctic to the Straits of Magellan, where they overwinter (Terres, 1980). Studies on the location of wintering shorebirds have shown that most (85%) Semipalmated Sandpipers were counted along the northern coast of South America, in the Guianas. Most (88%) Sanderlings were observed along the Pacific coast beaches of Peru and Chile. Red Knots winter primarily in southern Argentina and Tierra de Fuego (Morrison and Ross, 1989). Metal levels in migratory shorebirds can reflect pollution levels in many different areas (Becker, 1990). The Delaware Bay is an important stop-over place for these birds during their flight up the Atlantic Coast (Senner and Howe, 1984). Breast feathers were used in this study because they can be collected without harming the bird and they are quickly replaced (Furness and Hutton, 1979; Lindberg, 1984).

2. Materials and Methods

Under appropriate state and federal permits, breast feathers were collected from 16 Red Knots and 13 Sanderlings on Reed's Beach, and from 11 Semipalmated Sandpipers on Thompson's Beach during 1991. In 1992, feathers were collected from 15 Semipalmated Sandpipers at Dennis Creek marsh. All sites are on Delaware Bay, New Jersey (Figure 1).

Feather collection was in May when the birds were passing through New Jersey on their way to their summer breeding grounds in Northern Canada. The birds were captured in pull nets and mist nets for banding purposes by the Endangered and Non-game Species Program of the New Jersey Department of Fish, Game and Wildlife. A small pinch of breast feathers was removed, the birds were weighed, and all birds were then released immediately.

United States EPA procedures were modified for feather preparation and analysis (EPA, 1981). To remove surface contaminants, feathers were washed vigorously in acetone and distilled water. Feathers were dried and weighed before analysis. Feathers were digested in warm nitric acid and the residue was diluted to 10 ml with distilled water. Mercury was analyzed by cold vapor atomic absorption spectrophotometry, but was not done on the Semipalmated Sandpiper feather samples from 1991 because of a small amount of feathers. All other metals were analyzed by graphite furnace atomic absorption spectrophotometry. All samples were run with standards, blanks, a known reference solution, and spiked samples.

Kruskal-Wallis chi-square (χ^2) tests were used to distinguish species differences in metal levels, and Kendall tau correlation coefficients were used to determine relations among metals for individual birds. Non-parametric statistics were used because the underlying distributions were assumed to be non-normal (Siegel, 1956). All data are reported in arithmetic means $\pm$ one standard error in ppb (dry weight).

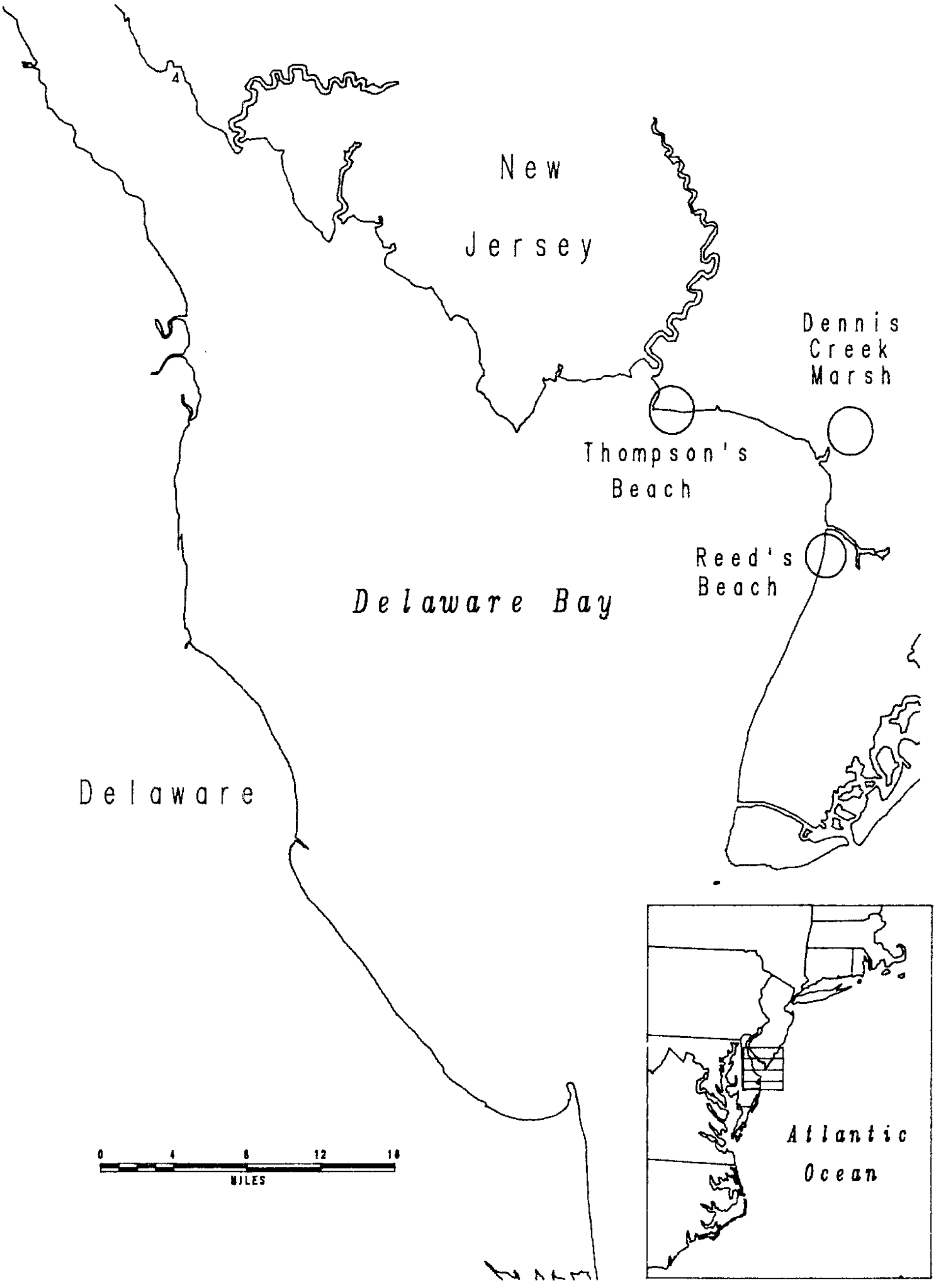

Fig. 1. Sampling sites.

TABLE I

Lead, cadmium, mercury, manganese, chromium and selenium levels in feathers of shorebirds from the Delaware Bay. Given are arithmetic mean ± SE in μg/kg dry weight (ppb); and Kruskal-Wallis chi-square values with associated P values in parentheses.

	Lead	Cadmium	Mercury	Selenium	Manganese	Chromium
Species						
1991						
Red Knot	1665±767	131±25	1163±201	6221±618	3781±260	24098±2578
Sanderling	2700±1010	139±55	2813±331	1301±133	1915±270	16525±2461
Semipalmated Sandpiper	2263±493	700±139	--	6032±880	2965±253	26294±4368
χ^2 (p)	4.2 (NS)	13.1 (0.002)	10.7 (0.001)	24.3 (0.0001)	16.0 (0.0003)	5.7 (0.05)
1992						
Semipalmated Sandpiper	2013±187	75±16	21±14	5428±759	7222±642	14530±1606
χ^2 (p)	9.9 (0.007)	0.8 (NS)	33.9 (0.0001)	27.96 (0.0001)	23.7 (0.0001)	5.4 (NS)

3. Results

In 1991, lead levels were highest in Sanderlings and lowest in Red Knots (Table I). Cadmium levels were highest in Semipalmated Sandpipers, while Sanderlings and Red Knots had similar values. Sanderlings had higher mercury levels than knots. Selenium levels were similar for knots and Semipalmated Sandpipers, while Sanderling values were lower. Manganese levels were highest in Red Knots and lowest in Sanderlings. Chromium levels were highest in Red Knots and Semipalmated Sandpipers. There were significant interspecific differences in 1991 for all metals except lead. For Semipalmated Sandpipers there were significant yearly differences for all metals except cadmium and chromium (Table I).

Concentrations for Semipalmated Sandpipers were significantly higher in 1991 than in 1992 for cadmium and chromium. Manganese concentrations were significantly higher in 1992. No yearly difference was found for lead or selenium (Table II).

Lead, cadmium and manganese were all correlated with mercury in Red Knots (Table III). In Sanderlings, selenium and manganese were significantly correlated. Selenium, chromium and manganese were correlated with cadmium in Semipalmated Sandpipers. In Red Knots, mercury positively correlated with weight ($p < 0.05$) and selenium correlated negatively with weight ($p < 0.05$). No other significant correlations between weight of birds and metal concentrations were found.

TABLE II

Differences in metal concentrations of Semipalmated Sandpipers from 1991 and 1992.

Metal	χ^2	p
Lead	0.1	NS
Cadmium	13.7	0.0002
Selenium	0.2	NS
Manganese	13.7	0.0002
Chromium	6.3	0.012

4. Discussion

The use of breast feathers in heavy metal monitoring offers many advantages. The removal of breast feathers does not affect flight or thermoregulation and the bird can be released unharmed. Feathers are easy to store under field conditions and removal does not require special expertise (Goede and de Bruin, 1984; Burger and Gochfeld, 1991).

Metal levels in the feathers partially reflect the extent of pollution at the location of the birds during feather formation (Goede and de Bruin, 1984). Selenium contamination of the feathers can come from secretions from the preen or salt glands, which indirectly shows selenium levels (Goede and de Bruin, 1985), but external factors can also cause contamination of the feathers after formation (Goede and de Bruin, 1984; Rose and Parker, 1981). The feathers were washed vigorously in distilled water and acetone, and thus external contamination was largely eliminated.

Feathers reflect the circulating metal concentrations at the time of formation (Furness and Hutton, 1979; Solonen and Lodenius, 1990), as well as body burdens. Much of the body burden of certain metals, such as manganese, copper, lead, cadmium and mercury, are deposited in the feathers and are eliminated via molting (Honda *et al.*, 1986; Lee *et al.*, 1989). For some metals, mercury in particular, the feathers may account for most of the body burden (Finley and Stendell, 1978). Braune and Gaskin (1987) found that the plumage contained 93% of the total body mercury in Bonaparte's Gulls (*Larus philadelphia*), while accounting for only 12% of the weight. Feathers have been shown to be good indicators of metal levels in birds (Furness and Hutton, 1979).

In this study we examined heavy metal and selenium levels in migrant shorebirds who accumulated them while on their wintering grounds in South America. Migratory shorebirds have extreme ranges, and inhabit different parts of their ranges at different times of the year (Terres, 1980). To some extent, breast feathers

TABLE III

Non-parametric correlation among metals for shorebirds at the Delaware Bay. Given are Kendall tau coefficient of correlation (probability).

	Red Knot	Sanderling	Semipalmated Sandpiper
Lead with:			
Cadmium	−0.19 (NS)	−0.10 (NS)	−0.04 (NS)
Mercury	−0.50 (0.01)	0.13 (NS)	−0.34 (NS)
Selenium	0.17 (NS)	0.00 (NS)	−0.17 (NS)
Chromium	−0.13 (NS)	0.00 (NS)	0.12 (NS)
Manganese	0.20 (NS)	−0.18 (NS)	0.07 (NS)
Cadmium with:			
Mercury	0.39 (0.03)	−0.15 (NS)	0.10 (NS)
Selenium	−0.18 (NS)	−0.28 (NS)	0.30 (0.05)
Chromium	−0.01 (NS)	−0.39 (NS)	0.35 (0.03)
Manganese	−0.11 (NS)	−0.27 (NS)	−0.33 (0.03)
Mercury with:			
Selenium	−0.13 (NS)	−0.15 (NS)	−0.29 (NS)
Chromium	−0.03 (NS)	0.24 (NS)	−0.15 (NS)
Manganese	−0.37 (0.05)	−0.12 (NS)	−0.23 (NS)
Selenium with:			
Chromium	0.00 (NS)	0.06 (NS)	0.12 (NS)
Manganese	0.10 (NS)	0.42 (0.05)	−0.08 (NS)
Chromium with:			
Manganese	0.20 (NS)	0.27 (NS)	−0.18 (NS)

represent metal levels at the time of their formation, and can be used to pinpoint metal levels at specific points in time (Becker, 1990).

Lead levels measured in feathers range from non-detectable for Laysan Duck, *Anas laysanensis* (Stoneburner and Harrison, 1981) to 67 000 ppb (ng/g) for Barn Swallows (*Hirundo rustica*) nesting near a highway (Grue *et al.*, 1984). Honda *et al.* (1986) found values of 1440 ppb in the Great Egret, which is similar to the values in this study. Goede and de Voogt (1985) reported lead values in the primary feathers on knots from the Dutch Wadden Sea to be 1000–32 000 ppb. When the knots arrived at the Wadden Sea, their levels were near the lower end of this range but rose dramatically after a few months, showing local lead contamination. The lead concentrations from the Delaware Bay Red Knots were closer to the low end of the range of the Wadden Sea Red Knots, which suggests low lead exposure in their wintering grounds where the feathers were formed.

Levels of cadmium reported in the literature for feathers range from non-detectable in the Puffin, *Fratercula arctica* (Osborn *et al.*, 1979) to 24 000 ppb in Great Egrets, *Egretta alba* in Korea (Honda *et al.*, 1986). The levels for Red Knots (339 ppb), Sanderlings (134 ppb) and Semipalmated Sandpipers (3435 ppb) from Delaware Bay were within this range. Related shorebirds in Korea had a mean cadmium value of 240 ppb in their breast feathers (Lee *et al.*, 1989), while knots from the Dutch Wadden Sea had a mean of 120 ppb in their primaries (Goede and de Voogt, 1985). These values are similar to the Red Knot and Sanderling levels but are lower than the Semipalmated Sandpipers from the Delaware Bay.

Mercury levels measured in feathers ranged up to 43 330 ppb, found in the Goshawk (*Accipiter gentilis*) in the Netherlands (Spronk and Hartog, 1970). Shorebirds in Korea had a mean mercury level of 1410 ppb in their breast feathers (Lee *et al.*, 1989). Knots in the Dutch Wadden Sea contained up to 5760 ppb in their primaries, a value that was much elevated because of local contamination (Goede, 1985). Red Knots from the Delaware Bay had low mercury levels (339 ppb) compared to these two studies. Sanderlings had an intermediate mean of 2734 ppb, showing a higher exposure.

Selenium levels in the Dunlin (*Calidris alpina alpina*) from the Wadden Sea ranged up to 7700 ppb (Goede and de Bruin, 1985). Goede (1985) reported selenium values for knots in the Wadden Sea ranging from 3680 ppb in juveniles to 53 960 ppb in adults. Red Knots from the Delaware Bay show values of 6404 ppb, which was within the lower part of this range. The relatively low levels in the Delaware Bay species suggests that they were exposed to lower environmental selenium levels.

Wild California Condors (*Gymnogyps californianus*) had chromium values in their feathers ranging from 640 ppb to 1600 ppb (Wiemeyer *et al.*, 1986). Chromium concentrations in the feathers of pre-fledging Tree Swallows (*Tachycineta bicolor*) averaged 25 500 ppb (Kraus, 1989). All three species of shorebirds from Delaware Bay had high chromium values (Table I), suggesting that they might be exposed to contamination on their wintering grounds. There are few studies on the effects of sublethal levels of chromium on birds. Heinz and Haseltine (1981) found that low levels of dietary chromium had no significant effect on avoidance responses of young Black Ducks (*Anas rubripes*).

Manganese in the feathers of adult Herring Gulls (*Larus argentatus*) averaged 1510 ppb (Struger *et al.*, 1987). All three species of shorebirds in this study had values in 1991 similar to those in the literature, but the Semipalmated Sandpipers from 1992 had higher concentrations (Table I). This suggests that the birds from 1992 had different wintering grounds than the birds from 1991. Studies on the effects of manganese toxicity have concentrated on mammalian species, so it is not known if the values in this study are within normal ranges (Suzuki *et al.*, 1983; Shukla and Chandra, 1987).

Taken altogether, these data suggest that the levels of cadmium, lead, mercury, selenium and manganese are similar to levels reported from other studies of shorebirds. The levels of chromium in this study are much higher than has been reported for other avian species.

Interspecific differences for lead in 1991 were not significant, showing similar exposures. However, there were interspecific differences for all of the other metals. This suggests differences in exposure, which could have resulted from a variety of factors.

The different species may migrate to different wintering grounds (Terres, 1980). Spray and Milne (1988) found that Mute Swans (*Cygnus olor*) feeding in different locations had different levels of lead exposure. Similarly, Herring Gulls (*Larus argentatus*) that feed in areas of high human activity had elevated metal levels compared to those that feed in more remote locations (Hutton, 1981). If the wintering grounds of the three species were in different locations, the extent of contamination might differ.

Interspecific differences in metal levels can arise even if the species share the same wintering grounds because shorebirds feed on different parts of the beach depending on tidal cycles (Connors *et al.*, 1981). When shorebirds congregate into large, mixed-species aggregations, they will partition themselves into different microhabitats (Recher, 1966; Burger *et al.*, 1977). If the species wintered in the same area, they may have segregated into different microhabitats which may have had differing levels of contamination.

Another factor which influences metal levels is trophic level: birds feeding higher on the food chain are subject to biological amplification of metals, so primarily vegetarian birds have lower metal levels than fish-eating species (Gochfeld, 1980; Gochfeld and Burger, 1982; Braune, 1987b). Several studies have shown that different species of birds on the same trophic level accumulate different metal levels depending on the specific prey species consumed (Maegden *et al.*, 1982; Goede, 1985). Red Knots eat mostly mollusks, but will also feed on insects, grasses and fish. Sanderlings prefer crustaceans, small mollusks and marine worms, while Semipalmated Sandpipers feed mostly on insects but will also eat small mollusks, worms and crustaceans (Terres, 1980). The differences among species with respect to metal levels suggests that during the time when breast feathers were forming, the three species were either in different areas, using different food resources, or both.

The Semipalmated Sandpipers from 1991 and 1992 probably came from different wintering grounds. Levels of cadmium, manganese and chromium were significantly different between the years, showing that the wintering grounds for the two groups had different levels of contamination.

This study tested the null hypothesis that weight of the birds would have no correlation with metal levels. This was true for all species and metals except mercury and selenium in Red Knots. Mercury positively correlated with Red Knot weights, possibly because larger birds can eat larger prey than smaller birds. The larger prey items can contain larger amounts of mercury than smaller prey of the same species (Braune, 1987a). This might result in larger birds accumulating higher mercury concentrations.

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