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Food Chain Differences Affect Heavy Metals in Bird Eggs in Barnegat Bay, New Jersey

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There is an abundance of field data on levels of mercury in a wide variety of birds and on a suite of heavy metals in single species of birds, but few studies examine a suite of metals in a suite of birds that represent different trophic levels. Thus it is often difficult to determine whether food chain differences exist and have ecological relevance for the birds. In this paper I examine the levels of seven metals in the eggs of five species of marine birds that nest in Barnegat Bay, New Jersey to determine whether there are differences among species and whether such differences reflect food chain differences. There were significant differences among species for all metals, except cadmium, with black skimmers (*Rynchops niger*) having the highest levels of all metals except manganese and selenium. Metal concentrations in eggs mainly represented food chain differences. Mercury exhibited the greatest interspecific difference, with skimmer eggs having five times higher mercury levels than the eggs of great black-backed gulls (*Larus marinus*). Although there were significant interspecific differences in the other metals, they were generally less than an order of magnitude. There were few high, significant correlations among metals, although mercury was positively correlated with arsenic overall. Mean mercury levels exceeded the level known to adversely affect development in bird eggs for common (*Sterna hirundo*) and Forster's (*Sterna forsterii*) terns and for skimmers and exceeded the mean for eggs of fish-eating birds reported from 68 studies. © 2002 Elsevier Science (USA)

Key Words: **metals; birds; fate; effects; eggs; food chain; biomonitoring; bioindicator; ecological risk.**

INTRODUCTION

Increasingly it is necessary to understand the fate and effect of chemicals to assess the health of ecosystems and to provide early warning of changes in the environment that might indicate adverse effects. While anthropogenic contaminants from urban, industrial, and agricultural runoff are a major issue, levels are augmented by natural geological processes (Mailman, 1980). Global transport and deposition is an important source of mercury for many ecosystems, including the ocean (Fitzgerald, 1989). Recently in the United States, the deregulation of energy in the northeast and increases in industrialization in the midwest have led to the possibility of increased global transport of contaminants from the midwest to the eastern states. Assessment of changing environmental conditions that might lead to increased uptake of contaminants are particularly important, and seabirds can serve as bioindicators of such changes (Burger, 1993; Becker and Sommer, 1998; Becker *et al*., 1998).

In this paper I examine the levels of arsenic, cadmium, chromium, lead, manganese, mercury, and selenium in the eggs of five species of marine birds nesting in Barnegat Bay, New Jersey, including great black-backed gull (*Larus marinus*), herring gull (*Larus argentatus*), black skimmer (*Rynchops niger*), common tern (*Sterna hirundo*), and Forster's tern (*Sterna forsterii*). These species represent different trophic levels and consume fish of different sizes. Since contaminants often increase with the size of the fish that are eaten (Phillips *et al*., 1980; Lacerda *et al*., 1994; Lange *et al*., 1994; Park and Curtis, 1997), I predicted that there would be contaminant differences even within the strictly piscivorous species (terns and skimmers). I also wanted to determine whether the levels of contaminants in

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the eggs of these species were within the range known to cause adverse effects based on laboratory studies.

Seabirds are particularly vulnerable to contaminants because they are long lived and are often at the top of their food chains (Hunter and Johnson, 1982; Burger *et al.*, 1992a, 1994; VanStraalen and Ernst, 1991). Seabirds have been used as bioindicators of environmental contamination because they are often top-level predators (Monteiro and Furness, 1995; Burger and Gochfeld, 2000a).

In this paper I examine the levels in eggs because eggs and young are the most vulnerable to the effects of heavy metals, and eggs often represent local exposure of the adults that have laid them (Burger, 1993). These species all arrive in Barnegat Bay 45 to 65 days before egg-laying, allowing sufficient time for uptake of local contaminants, which are then deposited in the eggs. The species examined normally lay three eggs, but usually raise only two chicks (Burger and Gochfeld, 1993); by collecting only one egg from each clutch, the effects of collecting on these populations is reduced, making them ideal as bioindicators of environmental conditions. I hypothesized that there would be interspecific differences based on trophic-level differences. The gulls are omnivores, eating fish, invertebrates, and garbage (Burger, 1988), while the other species eat only fish. Because skimmers are about three times larger than the terns, they eat larger fish (Burger and Gochfeld, 1990, 1991) and might be expected to accumulate higher levels of contaminants.

Barnegat Bay is not highly industrialized, compared to many areas of northern New Jersey, and there is currently little new development in the region. The bay is considered relatively pristine, and part of the watershed that drains into the bay (Little Egg Harbor) has been designated a National Program Estuary because it is a pristine ecosystem along the east coast that deserves study and preservation and that can serve as a reference site for other, more highly polluted east coast estuaries.

SPECIES SELECTION AND METHODS

The five species of colonial birds that nest in Barnegat Bay, New Jersey include (in order of size: large to small): great black-backed gull, herring gull, black skimmer, common tern, and Forster's tern (Burger *et al.*, 2001). The two species of gulls nest in mixed-species colonies, the skimmers nest with common terns, and the Forster's terns normally nest in monospecific colonies. Between 12 and 15 eggs were collected from each species, except for common terns ($N = 35$), under appropriate state and federal permits.

Metals were analyzed in the Elemental Laboratory at the Environmental and Occupational Health Sciences Institute in Piscataway, New Jersey. Eggs (whole) were homogenized and were digested individually in 70% nitric acid within microwave vessels for 10 min at 150 pounds per square inch and subsequently diluted with deionized water.

Mercury was analyzed by a cold-vapor technique, and other metals were analyzed by graphite furnace atomic absorption. The mercury analysis is for total mercury, of which about 90% is assumed to be methylmercury. All concentrations are expressed in parts per billion on dry weights obtained from air-dried specimens. Instrument detection limits were 0.02 parts per billion (ppb) for arsenic and cadmium, 0.08 ppb for chromium, 0.15 ppb for lead, 0.09 ppb for manganese, 0.2 ppb for mercury, and 0.7 ppb for selenium, but matrix detection limits were about an order of magnitude higher.

All specimens were run in batches that included a standard calibration curve and spiked specimens. The accepted recoveries ranged from 87 to 105%, and batches with recoveries less than 85% were rerun (none needed to be return). The Coefficient of Variation (CV) on replicate, spiked samples ranged from 3 to 6%. Further quality control included periodic blind analysis of an aliquot from a large sample of known concentrations and blind runs of duplicate samples.

Data were analyzed by ANOVA to determine differences among species (SAS, 1995). I used the Duncan multiple range option with the ANOVA (SAS, 1995) as a post hoc test of the significance of the differences among means for the different species in Barnegat Bay. Both arithmetic and geometric means are given in the tables to facilitate comparisons with other studies in the literature. All results are reported as ng/g dry weight. For eggs, there was between 47% (common terns) and 60% (skimmers) moisture.

RESULTS

There were significant interspecific differences in metal levels in the eggs for all metals, except cadmium (Table 1). Although the differences were significant for most metals, they were not great. For mercury, skimmer eggs had five times higher levels than great black-backed gulls. However, most species exhibited a wide range of contaminants among individuals (Table 1). While mercury reflected trophic-level differences, other metals did not.

TABLE 1
Eggs Collected from Birds in Barnegat, New Jersey (2000)

	Herring gull ($N = 12$)	Great black-backed ($N = 4$)	Common tern ($N = 35$)	Forster's tern ($N = 15$)	Skimmer ($N = 12$)	Wilcoxon(p)
Arsenic	126 ± 26	100 ± 62	195 ± 21	190 ± 18	529 ± 55	24.64 (<0.0001)
	55 (B)	20 (B)	112 (B)	176 (B)	468 (A)	
	0.20–295	0.20–276	0.20–427	74–329	76–732	
Cadmium	5 ± 2	5 ± 2	4 ± 1	2 ± 0	2 ± 1	NS
	2 (A)	5 (A)	3 (A)	2(A)	1 (A)	
	0.53–27	2.90–10	0.04–20	0.48–4	0.02–8	
Chromium	110 ± 17	21 ± 2	45 ± 10	28 ± 6	105 ± 20	23.58 (<0.0001)
	94 (A)	20 (B)	8 (B)	10 (B)	84 (A)	
	29–237	14–27	0.08–185	0.08–85	21–245	
Lead	273 ± 69	227 ± 75	164 ± 25	56 ± 7	334 ± 83	29.71 (<0.0001)
	194 (A)	192 (A, B)	119 (A,B)	50 (B)	263 (A)	
	44–778	89–436	11–737	14–118	104–1154	
Manganese	1622 ± 108	1651 ± 100	2290 ± 139	1702 ± 143	1282 ± 112	19.55 (0.0006)
	1587 (B)	1642 (B)	2149 (A)	1632 (B)	1225 (B)	
	1154–2600	1470–1909	1146–4143	1095–3174	653–1828	
Mercury	419 ± 79	430 ± 103	1241 ± 165	1939 ± 284	2126 ± 292	31.94 (<0.0001)
	329 (B)	389 (B)	1027 (A, B)	1669 (A)	2064 (A)	
	113–853	208–625	304–3633	643–3497	1483–2776	
Selenium	1836 ± 91	1543 ± 154	2046 ± 89	1688 ± 86	1834 ± 146	9.99 (0.04)
	1806 (A,B)	1520 (B)	1984 (A)	1653 (A, B)	1757 (A, B)	
	1048–2151	1183–1933	649–3316	958–2164	871–2498	

Note. Given are the means and SE in ppb (dry weight): geometric means and Duncan values are under arithmetic means; range below geometric means. Means with same letter are not significantly different. NS, not significant.

For all eggs combined, there were significant correlations among metals for only 7 of the 21 possible correlations (Table 2). The highest correlations were for manganese with cadmium and chromium and for chromium with arsenic. Similarly, there were few significant correlations among metals for each species, including those for mercury, and there was no clear pattern. This is surprising given the relatively high levels of mercury.

TABLE 2
Significant Correlations among Metals for All Eggs Combined for Birds Nesting in Barnegat Bay, New Jersey (2000)

	Kendall tau	Probability
Mercury with lead	–0.17	0.04
Mercury with arsenic	0.21	0.02
Cadmium with manganese	0.33	0.0001
Chromium with selenium	0.17	0.03
Manganese with chromium	–0.24	0.002
Chromium with arsenic	0.22	0.004
Manganese with arsenic	–0.17	0.03

Note. Given are Kendall tau (probability).

DISCUSSION

Interspecific Considerations

As predicted, there were interspecific differences for all metals, except cadmium. However, the differences generally were not great, except for mercury. Several conditions can be drawn: (1) for arsenic, only skimmers had significantly higher levels than the other species, (2) for chromium and lead, both herring gulls and skimmers had higher levels than the other species, (3) for manganese and selenium, common terns had the highest levels, and (4) for mercury, the levels generally reflected trophic-level differences.

Trophic-level relationships have been reported for a range of species and for a number of contaminants (Burger, 1993; Lemly, 1993; Sundlof *et al.*, 1994; Barron, 1995), although there are more data for mercury than for other metals (Lacerda *et al.*, 1994; Wiener and Spry, 1996; Watras *et al.*, 1998; Snodgrass *et al.*, 2000). In general, species that are higher on the food chain accumulate higher levels of contaminants. Birds that are higher on the food chain and eat more or larger fish should accumulate higher levels than those that eat a range of different foods or eat smaller fish. Further, levels in birds should reflect the levels in the fish that they eat. In general, carnivorous fish have higher levels than herbivores, omnivores, or planktivores (Phillips *et al.*, 1980), and larger carnivores have higher levels than smaller carnivores (Lacerda *et al.,* 1994).

Mercury reflected trophic-level relationships, with skimmers having the highest levels. Skimmers eat only fish (Gochfeld and Burger, 1994), and they eat larger fish than the terns (Burger and Gochfeld, 1990, 1991). Gulls are omnivores, eating a variety of invertebrates, fish, and garbage (Burger, 1988). Thus the mercury levels reflect predictions based on trophic levels.

The levels of chromium and lead, which might be expected to be higher in species that eat invertebrates (because they accumulate in invertebrates), were highest in herring gulls and skimmers. Herring gulls eat more invertebrates than the other species (Burger, 1988), catch some fish, eat offal discarded by fishing boats, and eat dead fish that they find along the shore, while skimmers eat only fish. That skimmers eat only fish makes their higher levels of chromium and lead unusual.

The other conclusion, that common terns had the higher levels of manganese and selenium, were not predicted by trophic-level considerations. Although the differences were not great, they were consistent. The only ecological differences in foraging and foods in common terns and the other species is that the terns feed farther offshore than the other species (J. Burger, unpublished data). The other species feed mainly in the estuaries, while common terns feed in the inlets and in the nearshore ocean. It may be that selenium and manganese levels are higher in fish that live in the oceans as opposed to the estuaries, but this requires further study.

Other possible explanations for the differences include interspecific differences in kinetics and foraging in different regions. Differences as a function of kinetics are difficult to evaluate because there have been few studies on wild birds and none on these species. The differences are unlikely to be due to differences in foraging, since the eggs were collected from the same general region of the Bay (the south), and all the species were present for 6 weeks or more before they laid eggs, allowing them sufficient time for accumulation within the local area. All species, except common terns, feed within the bay in the same general area.

One advantage of studies such as this is that they provide baseline data which can be used in future years to evaluate differences within a specific geographical area. If increases in contaminant loads of eggs occur, it is likely that they are the result of increased local exposure due to either local sources or global deposition. Such data are critical to evaluating whether local or global pollution has increased in the biological component of ecosystems.

Correlations among metal levels for the whole data set (Table 2) indicated significant correlations for only 7 of 28 possible correlations. Thus, for the birds in Barnegat Bay, heavy metals were not generally correlated. However, it is important to examine such correlations because in some cases, the presence of one metal reduces the effect of another. For example, selenium has a protective effect on mercury toxicosis (Ganther *et al.*, 1972; Satoh *et al.*, 1985), and the two are often correlated, although at high levels; however, selenium can cause behavioral abnormalities, reproductive deficits, and ultimately mortality (Eisler, 1985, Heinz, 1996). In this study, however, they were not correlated.

Evaluating Effects

Females sequester heavy metals in their eggs during egg formation (Fimreite, 1974; Maedgen *et al.*, 1982; Burger and Gochfeld, 1991, 1993, 1995a; Burger, 1993, 1994; Burger *et al.*, 1999). Heavy metals are not sequestered equally in eggs; cadmium, for example, seems not to be transmitted to the egg in large quantities (Burger, 1993). Eggs are a good indicator of local exposure, since most birds in tropical and temperate regions spend many weeks on the breeding grounds before they lay eggs, acquiring sufficient resources (and thus heavy metals) locally to produce the eggs. While it is possible that some of the contaminants in eggs reflect contaminants acquired on the wintering ground, in common terns, levels acquired on the wintering grounds are much lower than those acquired in the northeast (Burger *et al.*, 1992b).

Interpreting the importance of the levels of contaminants in eggs requires knowing the tissue levels that are associated with adverse effects. Normally, such information comes from laboratory studies, which is the case with mercury (Eisler, 1987; Burger and Gochfeld, 1997). However, this is not the case with other heavy metals, and I make a plea for such studies. Many laboratory studies with the other metals give dose and effects, but do not examine tissue levels (Burger and Gochfeld, 1997). Another method of evaluating effects, although it is less ideal, is to compare the levels found with those normally occurring in similar species of birds, in this case, fish-eating birds.

Since most piscivorous species of birds are not adversely affected by levels of heavy metals in their

TABLE 3
Concentration of Metals (ppb Wet Weight) in Eggs of Raptors, Seabirds, and Other Fish-Eating Birds

Metal	Number of studies	Range of concentration[b]	Median	Species from this study above median[d]
Arsenic	Too few studies			
Cadmium	32	2–600[c]	15	None
Chromium	21	10–1000	210	None
Lead	29	20–6700	190	None
Manganese	13	350–4000	510	All but skimmer
Mercury	68	70–7290	340	Froster's tern, black skimmer
Selenium	13	300–7100	1100	None

Note. After Burger, 1994; Hothan *et al*., 1995; Mora, 1996; Barett *et al*., 1996; Burger and Gochfeld, 1996; Morera *et al.,* 1997; Becker and Sommer, 1998; Gochfeld and Burger, 1998; Becker *et al*., 1998; Fosola *et al*., 1998; Burger *et al*., 1999; Gordus, 1999; Sanpera *et al*., 2000.[a]

[a]Some studies report more than one year or location.

[b]Used range of arithemetic mean.

[c]Eared grebe (*Podiceps caspicus*) concentration of 3470 ppb (Burger and Gochfeld, 1996), is excluded.

[d]Wet weight = dry weight/3.

eggs, and have not suffered population declines (Burger and Gochfeld, 2001), it is likely that if the levels found in eggs from a particular region are not above the median for most piscivorous species, the birds are not adversely affected. While this method is not conclusive, it gives an indication of the species that might be affected. Table 3 provides data on a range of metals for many species; species from regions where levels are known to negatively affect reproductive success were not included. Using this method, the eggs of all species examined from Barnegat Bay were not affected by cadmium, chromium, lead, and selenium (Table 3). However, all species except skimmer exceeded the median values for fish-eating birds for manganese, and Forster's terns and black skimmer exceeded it for mercury (Table 3).

Manganese, an essential micronutrient, serves as an important cofactor in general body mechanisms (Drown *et al*., 1986). Exposure to high concentrations of manganese in the atmosphere can lead to adverse neurological and respiratory health effects in humans (Donaldson *et al*., 1984; Roels *et al*., 1992). In laboratory studies of mammals, manganese exposure causes mortality and decreased fertility (Gray and Laskey, 1980; Laskey *et al*., 1982), decreases in motor activity (Ingersoll *et al*., 1995), learning disabilities (Senturk and Oner, 1996), and nervous system dysfunction and convulsions (Mergler, 1986). In birds, manganese causes neurobehavioral defects, similar in nature to those caused by lead (Burger and Gochfeld, 1995b, 2000b). Unfortunately, the levels of manganese in tissues associated with these adverse effects are often not determined. Thus, the potential effects of manganese on Forster's terns and black skimmers are unknown, but deserve further study, particularly in light of its potential use in gasoline.

The relationship between metal level in eggs and adverse developmental effects is known for mercury (Eisler, 1987). A range of effects, including mortality, lowered hatching rates, higher chick defects, and other neurobehavioral effects can occur when eggs levels are as low as 0.5 ppm (wet weight), and more severe effects usually occur at 1.0–2.0 ppm (Eisler, 1987). This suggests that the levels of mercury in the eggs of Forster/s terns (1.9 ppm, dry weight = 0.83 wet weight) and black skimmers (2.1 ppm, dry weight = 0.84 wet weight) from Barnegat Bay may be sufficient to be causing some adverse effects that could affect population levels. Over the past 20 years the number of colonies of black skimmers have declined in Barnegat Bay; there is only one colony of Forster's terns, which has remained relatively stable (Burger *et al*., 2001). The decline of black skimmers in Barnegat Bay is disturbing because the species is already endangered in New Jersey, and populations in other areas of the state are also doing poorly. The causes of these declines are many, including human disturbance and the possibility of decreased food supply because of overfishing or global warming changing migration patterns of predatory fish that force prey fish into the estuaries where skimmers forage. Nonetheless, the added stress of contaminants may interact with other adverse effects to lower overall reproductive success and survival (Burger and Gochfeld, 2001). These data on mercury levels, in conjunction with the decreasing skimmer populations, suggest cause for concern. Moreover, energy deregulation may result in higher atmospheric mercury levels, and subsequently higher deposition levels in New Jersey, which would more quickly affect species that are higher on the trophic scale.

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