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Metal concentrations in three species of passerine birds breeding in the Hackensack Meadowlands of New Jersey

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Abstract

The New Jersey Meadowlands is an important natural area, a diverse mosaic of wetland habitats positioned within the heavily urbanized NY City Metropolitan area and the NY/NJ Harbor. Persistent contaminants may pose threats to wildlife inhabiting these habitats, affecting reproduction, egg hatchability, nestling survivorship, and neurobehavioral development. Metals of concern in the Meadowlands include arsenic, cadmium, chromium, lead, and mercury. These metals were analyzed in feathers and blood of three passerine birds breeding in wetland habitats, including red-winged blackbirds (*Agelaius phoeniceus*), marsh wrens (*Cistothorus palustris*), and tree swallow (*Tachycineta bicolor*), as well as eggs of the first two species. These widespread species are abundant in wetland habitats across the Meadowlands District, and eat insects and other invertebrates. Lead levels were low in eggs, higher in feathers and very elevated in blood in all species compared to those that have been reported for other bird species. Lead levels were especially high in blood of marsh wren (mean of 0.8 ppm) and swallow (mean of 0.94 ppm, wet weight). Levels of lead in the blood for all three species sampled were higher than the negative impact threshold of 0.4 ppm. Mercury levels, while below the levels considered biologically harmful, were higher in eggs (mean of 0.2, wet weight) and feathers (3.2 ppm, dry weight) of marsh wren from Meadowlands than those seen in other passerines, and even some fish-eating birds. Furthermore, unhatched wren eggs had higher mercury levels (0.3 ppm, wet weight) than eggs randomly selected before hatch (0.18 ppm, wet weight). Blood tissue levels of mercury were low in all three species (mean of less than 0.035 ppm, wet weight). Chromium levels were relatively high in eggs and in blood, but lower in feathers when compared to those reported in the literature. Cadmium and arsenic levels were generally low for all tissues and in all species studied compared to those measured in other studies. Finally, all metal levels for tree swallow tissues in our study were much lower than those reported previously for this species in the Meadowlands District.

Keywords: Passerines; Lead; Mercury; Chromium; Meadowlands; Contaminants; New Jersey

1. Introduction

The Meadowlands District and its extensive wetlands have long been recognized as a critical resource for wildlife, especially birds. Located amidst a highly urbanized landscape, the Meadowlands consist of a diverse mosaic of tidal, brackish, freshwater, and forested wetlands. The US Fish and Wildlife Service designated the Meadowlands/Hudson River Complex as part of New Jersey's North Atlantic Coast Waterfowl Focus Area, and non-profit conservation organizations have worked diligently over the last three decades to raise public and government agency awareness of the incredible natural resource value of the Meadowlands. The New Jersey Meadowlands Commission, recognizing the District's value to wildlife, made

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preservation and restoration of open space a high priority in its Master Plan.

Large industrial facilities, including chemical, pesticide, pharmaceutical and paint manufacturing plants, metals processing, and petroleum refineries, have been located along the banks of the Hackensack River. Effluent from these facilities has caused severe contamination of sediments in Meadowlands wetlands (USEPA, 1995). Although the majority of the industrial facilities in the study area have been shut down, and the water quality in the Hackensack River and the overall NY/NJ Harbor Estuary has improved since the 1970s, elevated contaminant levels may persist in sediments at some wetlands in the Meadowlands District (Steinberg et al., 2004).

Restored wetlands and landfills in the Meadowlands urban estuary can enhance the quality of the urban landscape and improve habitat for fish and wildlife, thereby increasing the public's opportunities for wildlife viewing and their appreciation for nature. However, because of persistent sources of contaminants in the Meadowlands, these restored habitats also may create an "attractive nuisance" by drawing fish and other wildlife to areas that still have high levels of toxic chemicals. Birds are especially vulnerable as they are mobile and can colonize new habitats rapidly.

In this study, the concentrations of arsenic, cadmium, chromium, lead and mercury were examined in three species of insectivorous passerine birds breeding in the Meadowlands: red-winged blackbirds (*Agelaius phoeniceus*), marsh wrens (*Cistothorus palustris*) and tree swallows (*Tachycineta bicolor*). These species occur all across North America and are abundant in wetland habitats in the Meadowlands District. Our primary objective was to explore differences in contaminant loads among species, tissues, and sites of varying levels of concern for restoration (USFWS, 2005). Therefore, samples from both restored and un-restored areas were collected and metals (Cd, Pb, and Hg) that are considered as major contaminants in the marine environment (Fowler, 1990; Spahn and Sherry, 1999; Burger and Gochfeld, 2004) were analyzed. Besides, Cr was analyzed as it has posed a major environmental contamination problem from former industrial processes in northern New Jersey (Burke et al., 1991). In addition, As was analyzed because it is a concern for wildlife in marine and estuarine ecosystems (Neff, 1997).

Some contaminants, such as methyl mercury, the organic form in which mercury most often occurs in wildlife, are of special interest because they biomagnify as predators ingest them in increasingly large amounts (Burger, 2002; Weis, 2005). A contaminant that is not found in high concentrations in the water or the sediments can potentially be found in harmful concentrations in tissues of higher trophic level consumers due to biomagnification, with increasing risk to organisms at the top of the food chain. Others have studied organochlorine contaminants in birds of this region (e.g., Stansley and Roscoe, 1999; Rattner et al., 2000).

Contaminant exposure can have negative effects on reproduction, egg hatchability, hatchling survivorship and neurobehavioral development (Heinz, 1974; Ohlendorf et al., 1989; Bouton et al., 1999; Custer et al., 1999; Burger and Gochfeld, 2000a). Contaminant loads and biology of tree swallows have been studied in the Meadowlands (Kraus, 1989), and in the northeast and elsewhere (e.g., McCarty, 2002; Custer et al., 2003; Echols et al., 2004).

Surprisingly little is known about contaminant levels in wildlife in the Meadowlands biota. A screening level risk assessment for the Meadowlands (ENSR International, 2004) modeled exposure to avian receptors, without the benefit of actual avian data. Although Weis (2005) published contaminant data in fish of the Meadowlands, the only published report on contaminants in Meadowlands birds is from nearly 20 yeas ago (Kraus, 1989). Yet this area, currently being actively restored, preserved, and managed, is of great interest to government agencies and non-profit organizations alike for its value as an urban natural area. Our research provides information needed in the decision-making process and provides a baseline to evaluate future clean up and restoration activities. There are clear management decisions that must be made concerning which lands to clean up, to what levels. Furthermore, since there is limited information on contaminants in passerine bird species (Burger et al., 1993, 1997, 2004) this project can contribute to our state of understanding of metal bioaccumulation in passerines that are at intermediate trophic level.

2. Methods

2.1. Study sites

The Meadowlands District is located in northern New Jersey in Bergen and Hudson Counties, and is an integral part of the Hudson/Raritan Estuary (Fig. 1). Samples from the three species of passerine birds were collected at five sites within the Meadowlands District. Red-winged blackbird samples were collected at Harrier Meadow, Kearny Freshwater Marsh, and Marsh Resources Meadowlands Mitigation Bank (Marsh Resources). Marsh wren samples were collected at Riverbend Wetlands Preserve, Kearny Freshwater Marsh, and Marsh Resources. Finally, a small number of tree swallow samples were collected at DeKorte Park. Some sites were only accessible by canoe, and others were accessible on foot.

Harrier Meadow and Marsh Resources are restored tidal marshes surrounded by tidal mudflats with urban development and landfill on the remaining two sides. The low marsh areas are dominated by smooth cordgrass (*Spartina alterniflora*), dwarf spike rush (*Eleocharis parvula*), and marsh fleabane (*Pluchea purpurascens*). The more upland areas are dominated by groundsel tree (*Baccharis halmifolia*). Harrier Meadow site is different from the other restored marsh sites in the Meadowlands because it was constructed on top of rubble and other hard materials and one would anticipate lower levels of contamination since not much sediment was moved during site construction.

Kearny Marsh is a freshwater impoundment, dominated by *Phragmites* and located adjacent to the Keegan Landfill. This marsh is heavily affected by runoff from the landfill, which contains elevated levels of polyaromatic hydrocarbons (PAHs), polychlorindate biphenyls (PCBs), lead, chromium, and mercury. An estimated 65 million gallons per year of leachate from the Keegan Landfill is estimated to go into Kearny Marsh

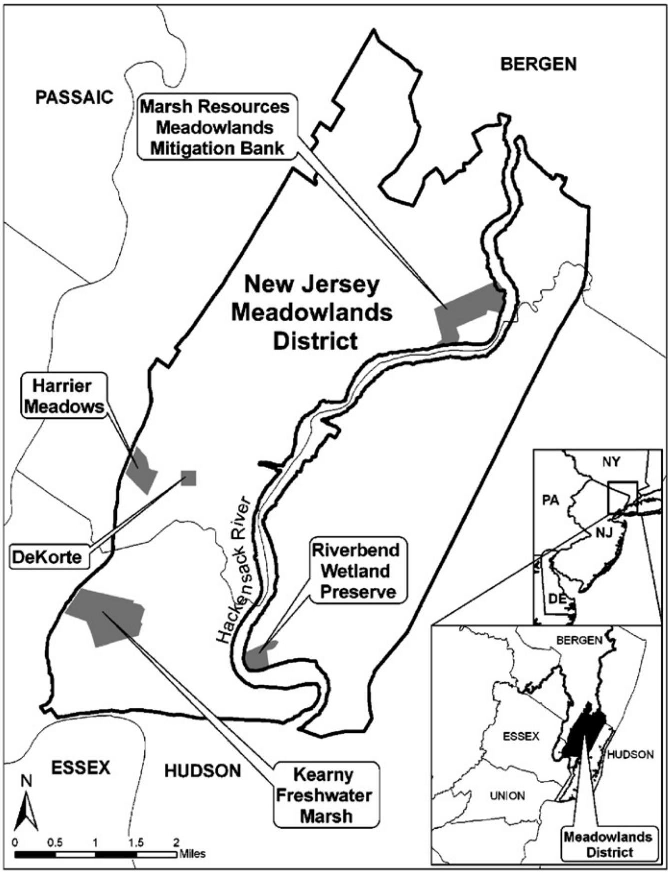

Fig. 1. Map of the study sites in the Meadowlands District.

(Camp et al., 1998). Similarly, Riverbend Wetland Preserve lies along possibly the most contaminated area of the Hackensack River. The site is located close to Newark Bay and the Passaic River and their influences, adjacent to a landfill, and lies close to three State Remediation Sites. Sediment samples from this site exceed guidelines for arsenic, cadmium, chromium, lead, and mercury, as well as organic contaminants (Steinberg et al., 2004; USFWS, 2005). The vegetation at Riverbend Wetlands Preserve consists of high saltmarsh vegetation, primarily *Spartina patens*, and areas dominated by *Phragmites* and open water.

DeKorte Park lies adjacent to the Kingsland Impoundment, which is tidally influenced. This site is impacted by former landfill operations but has been restored and is currently utilized as a park.

2.2. Field collection methods

Nest-searching for marsh wren and blackbird took place from mid-May until the beginning of July of 2006, and all samples were collected under appropriate state and federal permits and with a Rutgers University protocol. One random fresh egg was collected for contaminants analysis from each nest found during the egg stage. Freshness was determined by floating the egg in water when the age of the nest was unknown (recently laid eggs sink to the bottom, while developed eggs float). Collected eggs were wrapped in aluminum foil, labeled and placed in a protected container in a cooler. Eggs were refrigerated up to 1 week until transfer to the Elemental Analysis Laboratory at the Environmental and Occupational Health Sciences Institute (EOHSI) at Rutgers University in Piscataway, NJ. After nestlings fledged, unhatched eggs were collected to be compared with randomly eggs assumed viable.

Nests were visited again just prior to fledging and during this visit we banded the chicks with US Geological Survey bands and collected blood samples and feathers. Marsh wren chicks were banded at 10–11 days old and red-winged blackbirds were banded around 8–9 days old. When nests were found with chicks already present, the chicks' age was determined based on wing chord measurements and degree of eye opening (Welter, 1936; Holcolmb and Twiest, 1971) and we adjusted our visitation schedule accordingly.

Blood samples from each chick were collected in 70 µl Micro-Hematocrit tubes (Fisher Scientific, Pittsburgh, PA) after puncturing the brachial vein using a 26 gauge needle (Becton Dickinson and Company, Franklin Lakes, NJ). In keeping with humane practice guidelines (Gaunt and Oring, 1997), no more than 1% of the body weight of blood was obtained per nestling. Tubes were placed in individually labeled non-additive glass Vacutainer® (Fisher Scientific, Pittsburgh, PA) tubes. The Vacutainer® tubes were placed upright on ice and frozen the same day, until transport to the EOHSI laboratory. Feather samples from the breast of each nestling were pulled and pooled by nest. Feathers were placed in labeled envelopes and stored in a light-inhibiting box until transport to the EOHSI laboratory. Although use of only breast feathers may yield misleading information about total amounts of metals (at least for Hg) in total body plumage because of differential uptake by different kinds of feathers related to amount of keratin (Furness et al., 1986), there is extensive literature on metal levels of breast feathers (Burger, 1993; Burger et al., 1993; Burger and Gochfeld, 2000b) and we decided on this least invasive approach. Blood and feather samples from marsh wrens were collected at the same time as banding, at age 10–11 days. Blood samples for red-winged blackbirds could be collected at an earlier age (i.e., 6–7 days), but these nestlings were often not developed enough for banding or feather collection until 8–9 days old. Sample sizes by species, tissues and location are shown in Tables 1 and 2.

Feathers and blood samples from tree swallows nesting in artificial nest boxes were also collected. While many nest boxes are erected each spring throughout the Meadowlands District, in 2006 most of them were not designed to be opened; therefore, we were only able to collect samples from five nests at DeKorte Park.

2.3. Metal analysis

Blood samples were frozen, and eggs were refrigerated until they could be analyzed in the Elemental Analysis Laboratory of the EOHSI in Piscataway, NJ. Feathers were kept in envelopes at room temperature. All samples were analyzed for As, Cd, Cr, Pb, and Hg. Total mercury was analyzed using a Perkin-Elmer FIMS-100 mercury analyzer by cold vapor atomic absorption spectrophotometry. Eighty-five to ninety percent of total mercury is assumed to be methyl mercury (Wolfe and Norman, 1998). Other metals were analyzed using a Perkin-Elmer 5100 flameless atomic absorption spectrometer with Zeeman correction. Metal concentrations in feathers are expressed as ng/g (ppb) on a dry weight basis and blood is expressed in ng/g (ppb) on a wet weight basis. Metals levels for eggs were obtained as dry and transformed to wet weight based on moisture content (average 80% for marsh wrens and 82% for red-winged blackbird) for easier comparisons with other values from published literature.

All laboratory equipment and containers were washed in 10% HNO solution and rinsed with deionized water, prior to each use (Burger and Gochfeld, 2000a). Individual whole eggs were homogenized and dried to a constant weight. Feathers were washed three times with acetone, alternating with deionized water, and air-dried. A 0.05 g (dry weight) sample of feather, 1.0 g (dry weight) sample of egg, or 0.2 g (wet weight) sample of blood was digested in 4 ml 70% Ultrex ultrapure nitric acid and 2 ml deionized water in a microwave (MD 2000 CEM), using a digestion protocol of three stages of 10 min each under 50, 100, and 150 pounds/in.^{2} (3.5, 7, and 10.6 kg/cm^2) at 70X power. Digested samples were subsequently diluted to 10 ml with deionized water.

Instrument detection limits were 0.2 ppb for arsenic, 0.02 ppb for cadmium, 0.08 ppb for chromium, 0.15 ppb for lead, and 0.2 ppb for mercury. Matrix detection limits may be an order of magnitude higher, so our study may not attain the more sensitive levels. All specimens were analyzed in batches with known standards, calibration standards, and

Table 1
Metal levels (mean ± S.E., ppb) in different tissues for three species of birds in the Meadowlands District (all sites combined)

Tissue/metal	Mean ± S.E., *n* (ppb)			
	Red-winged blackbird	Marsh wren	Tree swallow	Kruskal-Wallis χ^2 (*P*)
Blood	$n=63$	$n=38$	$n=14$	
Arsenic (As)	4.64 ± 1.98	3.73 ± 2.61	0.95 ± 0.85	NS
Cadmium (Cd)	13.5 ± 3.35 (A, B)	26.9 ± 6.74 (A)	3.58 ± 1.09 (B)	12.0 (0.0024)
Chromium (Cr)	518 ± 104 (B)	505 ± 78.6 (B)	1030 ± 212 (A)	10.2 (0.0061)
Lead (Pb)	419 ± 52.4 (B)	796 ± 142 (A)	944 ± 226 (A)	9.43 (0.009)
Mercury (Hg)	23.2 ± 3.43	35.3 ± 9.7	19.4 ± 5.44	NS
Feathers	$n=29$	$n=15$	$n=5$	
Arsenic (As)	142 ± 30.1 (A)	7.01 ± 4.27 (B)	70.2 ± 39.3 (A, B)	5.34 (0.0158)
Cadmium (Cd)	18.6 ± 6.61 (B)	30.9 ± 7.06 (A)	11.4 ± 4.28 (B)	8.62 (0.0134)
Chromium (Cr)	607 ± 53.2 (B)	1040 ± 109 (A)	659 ± 219 (B)	14.1 (0.0009)
Lead (Pb)	1080 ± 142 (A, B)	432 ± 73.6 (B)	1360 ± 776 (A)	7.8 (0.0202)
Mercury (Hg)	826 ± 115 (C)	3230 ± 237 (A)	2040 ± 355 (B)	31.0 (0.001)
Eggs (wet weight)	$n=35$	$n=31$	N/A	
Arsenic (As)	5.98 ± 1.61	10.1 ± 3.61		5.4 (0.02)
Cadmium (Cd)	0.26 ± 0.08	0.37 ± .17		NS
Chromium (Cr)	120 ± 27.6	59.1 ± 16.9		6.8 (0.009)
Lead (Pb)	38.5 ± 5.33	34.7 ± 5.28		NS
Mercury (Hg)	48.2 ± 6.42	197 ± 19.2		32.5 (<0.0001)
χ^2 comparing among tissues				
Arsenic (As)	26.5 (<0.0001)	12.3 (0.006)	6.7 (0.009)	
Cadmium (Cd)	49.5 (0.0001)	49.2 (0.0001)	NS	
Chromium (Cr)	39.2 (0.0001)	47.3 (0.0001)	NS	
Lead (Pb)	62.9 (0.0001)	34.0 (0.0001)	NS	
Mercury (Hg)	78.1 (0.0001)	62.6 (0.0001)	10.5 (0.001)	

Metal levels are in parts per billion and are presented as wet weight for eggs and blood and dry weight for feathers. Letters in parentheses are from Duncan post-hoc test, indicating significant differences among species. In comparisons of metal levels in eggs since only two species were sampled, no Duncan post-hoc test was necessary.

spiked specimens. DORM-2 certified dogfish muscle was used as a reference material and recoveries ranged from 86% to 100%. The accepted recoveries for spikes ranged from 85% to 115%; no batches were outside of these limits. The coefficient of variation on replicate, spiked samples ranged up to 10%.

2.4. Data analysis

Non-parametric procedures (Kruskal-Wallis test, PROC NPAR1-WAY; SAS, 2005) were applied to determine species and site differences in heavy metal levels. When significant differences were found (0.05 level of significance), and in cases where we were comparing three species, Duncan's multiple-range tests was used to explore which species and sites were different (Burger and Gochfeld, 2003). These tests were also used to examine differences in heavy metals loads among the three tissue types (egg, blood, and feather) for each species, and differences between unhatched eggs and randomly collected eggs presumed to be viable. Non-parametric tests were used because they are more conservative and are best fitted for small datasets. For this analysis, data were not normalized when the Duncan multiple-range test was run.

3. Results

During this study, 98 red-winged blackbird and 351 marsh wren nests were located. Of these, 69 (70%) and 41 (12%) were active nests of red-winged blackbird and marsh wren, respectively. Of the 69 active red-winged blackbird nests, 15 were located at Harrier Meadow, 31 at Kearny Marsh, and 23 at Marsh Resources. Red-winged blackbird nests were located in either *Phragmites* or groundsel tree with the exception of three nests found in cattails (*Typha latifolia*) at Kearny Marsh. Five active marsh wren nests were found at Kearny Marsh, 13 nests at Riverbend and 23 nests at Marsh Resources. Even though some wren nests may have already fledged or been depredated, a large number of inactive nests that were probably 'dummy' nests were found. Male marsh wrens are known to build numerous dummy nests that are not used by females for egg-laying, but may serve as decoys for predators and as an indicator of male vigor or quality of his territory (Kroodsma and Verner, 1997). Only samples from five tree swallow nests were collected, all at DeKorte Park.

3.1. Species differences

Marsh wren had significantly higher levels of egg (wet weight) mercury and arsenic than red-winged blackbirds, and higher levels of feather mercury, cadmium and chromium than the other species (Table 1). Red-winged blackbirds had higher egg chromium and higher levels of and arsenic in feathers than did marsh wrens. Finally, tree swallows had higher levels of blood chromium than the

Table 2
Metal levels (mean ± S.E., ppb) in birds in the Meadowlands District as a function of location of tissue collection

Species/tissue	Mean ± S.E., *n* (ppb)			
	Kearny Marsh	Marsh Resources	Harrier Meadow	Kruskal-Wallis χ^2 (*P*)
Blackbird				
Eggs (wet weight)	$n=14$	$n=10$	$n=11$	
Arsenic (As)	3.87 ± 2.09 (B)	13.5 ± 4.10 (A)	2.3 ± 11.3 (B)	5.07 (0.012)
Cadmium (Cd)	0.16 ± 0.11	0.24 ± 0.14	0.41 ± 0.94	NS
Chromium (Cr)	128 ± 47.7	58.9 ± 5.37	178 ± 15.2	NS
Lead (Pb)	45.6 ± 10.5	38.6 ± 5.53	32.7 ± 22.7	NS
Mercury (Hg)	56.0 ± 12.7	54.4 ± 11.8	37.1 ± 19.8	NS
Blood	$n=35$	$n=11$	$n=17$	
Arsenic (As)	2.44 ± 2.34	5.63 ± 3.71	8.55 ± 5.03	NS
Cadmium (Cd)	15.7 ± 5.76	10.5 ± 4.71	11.0 ± 2.31	NS
Chromium (Cr)	452 ± 124	471 ± 121	684 ± 280	NS
Lead (Pb)	390 ± 54.5	309 ± 104	548 ± 143	NS
Mercury (Hg)	24.8 ± 4.79	18.1 ± 7.76	22.9 ± 6.53	NS
Feathers	$n=15$	$n=5$	$n=9$	
Arsenic (As)	110 ± 38.2	199 ± 74.5	165 ± 62.7	NS
Cadmium (Cd)	7.67 ± 2.28 (B)	12.6 ± 5.12 (B)	40.1 ± 19.6 (A, B)	NS
Chromium (Cr)	551 ± 74.1	841 ± 173	570 ± 54.5	NS
Lead (Pb)	1010 ± 198	1140 ± 371	1150 ± 269	NS
Mercury (Hg)	915 ± 180	1130 ± 297	510 ± 97.0	NS
Marsh wrens	Kearny Marsh	Marsh Resources	Riverbend	
Eggs (wet weight)	$n=4$	$n=16$	$n=10$	
Arsenic (As)	25.9 ± 11.3 (A)	2.15 ± 1.17 (B)	12.9 ± 8.84 (A)	3.36 (0.03)
Cadmium (Cd)	0.15 ± 0.09	0.1 ± 0.04	0.85 ± 0.49	NS
Chromium (Cr)	49.9 ± 15.2	35.3 ± 12.0	92.1 ± 47.0	NS
Lead (Pb)	49.5 ± 22.7	24.5 ± 4.31	47.5 ± 10.8	NS
Mercury (Hg)	87.5 ± 19.8	235 ± 24.7	188 ± 35.4	NS
Blood	$n=4$	$n=28$	$n=7$	
Arsenic (As)	0.1 ± 0	1.95 ± 1.85	14.4 ± 14.3	NS
Cadmium (Cd)	18.3 ± 12.4	19.2 ± 4.32	67.0 ± 33.6	NS
Chromium (Cr)	280 ± 133	489 ± 91.7	728 ± 231	NS
Lead (Pb)	257 ± 171	780 ± 160	1230 ± 467	NS
Mercury (Hg)	139 ± 69.8 (A)	21.4 ± 5.27 (B)	31.0 ± 11.5 (B)	12.4 (0.002)
Feathers	$n=1$	$n=11$	$n=3$	
Arsenic (As)	0.1	7.54 ± 5.61	7.4 ± 7.3	NS
Cadmium (Cd)	16	25.1 ± 4.66	57.3 ± 30.0	NS
Chromium (Cr)	1080	1000 ± 123	1180 ± 357	NS
Lead (Pb)	290	440 ± 95.0	450 ± 143	NS
Mercury (Hg)	3370	3010 ± 283	3980 ± 344	NS

Metal levels are in parts per billion and are presented as wet weight for eggs and blood and dry weight for feathers. Data for tree swallows not shown because they were collected only at DeKorte. Letters in parentheses are from Duncan post-hoc test, indicating significant differences among locations.

other species, higher levels of blood lead than red-winged blackbirds, and higher levels of lead, but lower levels of chromium in feathers than did marsh wrens (Table 1).

3.2. Tissue differences within species

Levels of all metals contaminant were significantly different between tissues in marsh wrens and red-winged blackbirds (Table 1). In tree swallows, there were significant differences for mercury and arsenic levels between different tissues, but no differences for cadmium, chromium, or lead (Table 1). For all species together, there were significant differences in arsenic, lead, and mercury levels among the different tissues, with concentrations being higher in feathers, followed by eggs and then by blood levels. Chromium levels were significantly higher in feathers than in eggs, but blood levels were not significantly different from the other two tissues. Feathers and blood had significantly higher levels of cadmium than eggs, but were not different from each other.

Levels of mercury differed between unhatched eggs of marsh wren (mean of 0.29 ppm, wet weight, $n=4$) and eggs collected randomly and assumed to be viable (mean of 0.18 ppm, wet weight, $n=27$) ($\chi^2=4.25$, $P=0.04$).

However, there were no differences for other metals in wren eggs or for all metals in blackbirds.

3.3. Site differences

There were few significant differences in metals levels among sites (Table 2). However, arsenic was higher in red-winged blackbird eggs from Marsh Resources than from the other sites. Kearny and Riverbend marsh wren eggs had significantly higher levels of arsenic (wet weight) than Marsh Resources. Finally, marsh wren blood samples had higher mercury levels at Kearny Marsh than at other sites.

4. Discussion

4.1. Trophic level and diet considerations

Concentrations of metals in different tissues reflect differences in the timing of exposure. Blood levels generally reflect the most recent exposure, while feather levels reflect the conditions and diet during the period of feather growth, when the feather is connected with blood vessels and metals are incorporated in the keratin structure (Dauwe et al., 2000). Concentrations in eggs typically reflect contaminants sequestered in the egg by females at the time of egg formation, which reflects both circulating levels in the blood and stored reserves (Burger and Gochfeld, 1996). Because the species in our study are territorial, arrive on the breeding ground well before egg-laying, and have narrow home ranges during the breeding season, contaminant levels in blood and eggs are indicative of diet acquired locally and delivered to the chicks by the adults. Feather contaminant levels are indicative of circulating levels at the time of feather formation.

Blood mercury levels were higher in marsh wrens at Kearny Marsh than at Marsh Resources or at Riverbend. This may be the result of higher mercury contamination at the nearby Keegan Landfill, leaching into Kearny Marsh (USFWS, 2005). Arsenic was higher in red-winged blackbird eggs from Marsh Resources than from the other sites, while wren eggs from Marsh Resources had significantly lower arsenic levels, probably reflecting different prey resources. Since arsenic levels were low overall, we do not think that differences are biologically significant to the birds, but they may reflect differences in contaminant loads between the sites. However, there was variability in contaminant levels within species and within sites, perhaps the result of a patchy distribution of the contaminants in water and in sediments. In addition, prey preferences of the three species may expose nestlings to different loads of each metal.

Our results indicate significant differences in contaminant levels between species (Table 1). Metal levels did not have a consistent pattern of being higher in any one species. In fact, each species appeared to have higher contaminant levels for at least one metal and in at least one tissue. All three species in our study are intermediate level consumers whose diet consists of insects and other invertebrates, although they forage differently. Red-winged blackbirds have a more varied diet than the other species (Robertson et al., 1992; Yasukawa and Searcy, 1995; Kroodsma and Verner, 1997). As some metal contaminants are known to biomagnify (Burger, 2002; Weis, 2005), higher levels in consumer tissues may result from foraging at different trophic levels. In the present study, the differences found were not large in magnitude, nor were they consistent and in the same direction for all metals. Thus, we believe that these three species likely feed at similar trophic levels but have different diets reflecting different foraging behavior, thereby obtaining different contaminant loads through their food.

4.2. Implications for effects

Metals levels in tissues can serve as an indication of potential effects, alerting managers and the public to future ecological problems. Arsenic is associated with pesticides and with industry, especially smelting (Eisler, 1988b). It is a relatively common element that is present in air, water, soil, and living tissues. In our study, all tissue concentrations were on the lower range of those reported by others (Burger, 1993; Golden et al., 2003), and were below the biological effects level for birds (Eisler, 1988b). Similarly, cadmium levels in our study at an average across all species of 20.31 ppb for feathers, 14.63 ppb for blood, and 0.31 ppb (wet weight) for eggs (Table 1) were generally low compared to other levels reported in the literature for feathers (50 to >1000 ppb, Burger, 1993; Burger and Gochfeld, 2000b), eggs (2–200 ppb, Burger et al., 2004; Burger and Gochfeld, 2004), and blood (9–90 ppb, Burger and Gochfeld, 1997). Additionally, cadmium levels in Meadowlands birds were lower than the level viewed as evidence of probable cadmium contamination in vertebrates, which is 2.0 ppm in whole body fresh weight (Eisler, 1985).

The present study measured only total chromium. Even though at high environmental concentrations, hexavalent chromium is a mutagen, teratogen, and carcinogen, the interconversion of trivalent and hexavalent chromium, both in the field and in laboratory specimens, have proven a challenge for analytic chemistry (Gochfeld, 1991). Improved analytic methods for quantifying hexavalent chromium will be helpful in future studies. Chromium contamination is high within the NY/NJ Harbor region because of chromite processing facilities in Hudson County and chromium waste sites close to Newark Bay (Burke et al., 1991). Indeed, relatively high chromium levels were found in eggs, similar to those reported in herring gull eggs (*Larus argentatus*) in the NY/NJ Harbor Bight (Gochfeld, 1997) and were higher than those reported for scrub jays (*Aphelocoma coerulescens*; Burger et al., 2004), and terns in New Jersey (Burger and Gochfeld, 2003, 2004). Chromium levels were especially high in red-winged blackbird eggs, with maxima >3.5 ppm (dry weight), which is nearing the

4.0 ppm level where they would be considered dangerously contaminated (Eisler, 1986). These values are higher than those reported in eggs of other avian species (reviewed by Burger et al., 2004). Chromium levels in blood were also relatively high in our study. Although chromium concentrations in avian blood are not well documented in the literature, the values we found, especially for tree swallows, are higher than those reported in gulls by Burger and Gochfeld (1997). Blood of tree swallows from the Meadowlands had a mean value almost twice as high as those in the Burger and Gochfeld (1997) study. Feather levels of chromium in all three species were in the lower range of chromium levels reported in birds (Burger, 1993), were lower than those for seabirds in the Pacific (Burger and Gochfeld, 2000b), and were lower than those reported for black-crowned night herons (*Nycticorax nycticorax*) in Chesapeake and Delaware Bays (Golden et al., 2003).

Lead is of particular concern because it can affect the developing brain and nervous system and can have serious health consequences for birds, including reduced weight gain for nestlings, reduced organ growth, and a reduced ability to sustain necessary metabolic function (Eisler, 1985; Burger, 1995; Burger and Gochfeld, 2000a). Lead contamination in the NY/NJ Harbor is relatively high and originates from various sources such as leaded gasoline, lead paint chips and residues, pesticides, and incinerator and other industrial emissions (Steinberg et al., 2004), which may lead to high tissue levels in birds.

Eggs of the three species studied had comparatively low levels of lead, with means between 0.03 and 0.06 ppm (wet weight). While these levels are higher than those reported in some other passerines (e.g., Florida scrub jays; Burger et al., 2004), they are relatively low compared with levels in seabirds in the region (Burger and Gochfeld, 1997, 2004).

Lead levels of 4 ppm in feathers are associated with negative effects including delayed parental and sibling recognition, impaired thermoregulation, locomotion, depth perception, and feeding behavior, and lowered nestling survival (Burger, 1995; Burger and Gochfeld, 2000a). Average feather lead levels for red-winged blackbirds and marsh wrens are lower than those reported elsewhere for passerines (Burger, 1993; Eens et al., 1999; Nam et al., 2003), and are below the 4 ppm adverse effect threshold. However, 30% of the lead concentrations observed in our study are above the median value of 1.6 ppm reported by Burger (1993) and Burger et al. (1997) in a review of metal levels in birds. Furthermore, tree swallows feathers had relatively high values compared to those reported in these other studies, with one sample above the 4 ppm adverse effects threshold (Fig. 2).

Blood lead levels were elevated in all species, but especially in marsh wrens and tree swallows (Fig. 2). Adverse physiological effects in birds may occur at blood lead levels as low as 0.4 ppm (Eisler, 1988a). All the blood lead values obtained from marsh wrens were higher than the 0.4 ppm effects threshold, with levels at Marsh Resources averaging 0.7 ppm with a high of 3.3 ppm and levels at Riverbend averaging 1.2 ppm with a high of 2.4 ppm. Similarly, tree swallows had average blood lead levels of 0.9 ppm, with a high value of 3.5 ppm. Finally, red-winged blackbirds had slightly lower values than the other two species, but they were still high, with average blood lead levels of 0.4 ppm, and a maximum value of 2.5 ppm. These levels are consistent with the higher range typically reported in avian blood from the NY/NJ Harbor area (Burger and Gochfeld, 1997), and they are at levels that are associated with adverse effects. Some nestlings were still actively molting when the blood samples were collected, so they may still have been mobilizing some of the metal to deposit in feather tissues. These high lead levels in Meadowlands birds are a concern and warrant further research.

Mercury concentrations in sediments in Newark Bay and in the Hackensack River are above the median level at which adverse biological effects are expected (Steinberg et al., 2004). Mercury can affect bird behavior, physiology and reproductive success (Gochfeld, 1997; Wolfe et al., 1998; Burger and Gochfeld, 2003). Mercury accumulates especially well in bird feathers because it has high affinity for the sulfhydryl groups in keratin. Female birds also can sequester mercury in eggs (Gochfeld, 1997).

None of the eggs in our study had mercury loads higher than 0.5 ppm, the value above which one may anticipate reduced hatchability and adverse behavioral effects on nestlings (Wolfe et al., 1998). However, egg mercury levels from the Meadowlands were higher than those reported in eggs of tree swallows, sparrows, and other passerines from Florida and New England (Burger et al., 2004; Evers et al., 2005; Lane and Evers, 2006) but lower than those reported in tree swallow eggs in Maine and Massachusetts (Longcore et al., 2007). Furthermore, unhatched marsh wren eggs had higher levels of mercury than eggs collected randomly early in the incubation period (Fig. 3). Because of this, we believe that the egg mercury level at which harm occurs in marsh wrens may in fact be significantly lower than the 0.5 ppm suggested by Wolfe et al. (1998).

Feather mercury levels in nestlings represent local environmental loads obtained mainly through their diet, in addition to loads obtained from egg constituents and typically reflect concentrations in the body of the nestling while the feathers are growing. Much of the ingested mercury may be sequestered in the feather shafts of the larger primaries, secondaries, and rectrices in addition to that in the breast feathers. Even so, the mercury levels we found in breast feathers were comparatively high (Fig. 3). Marsh wren feathers, especially, with values from 3 to 4.5 ppm, had significantly higher mercury values than those of the other two species, and approximate the 5 ppm level where negative effects may be anticipated (Eisler, 1987). Values of the present study are higher than those reported for passerines and terrestrial bird species elsewhere. For example, Solonen and Lodenius (1984) report levels from 1 to 2.5 ppm in Finland passerines (reviewed by Burger,

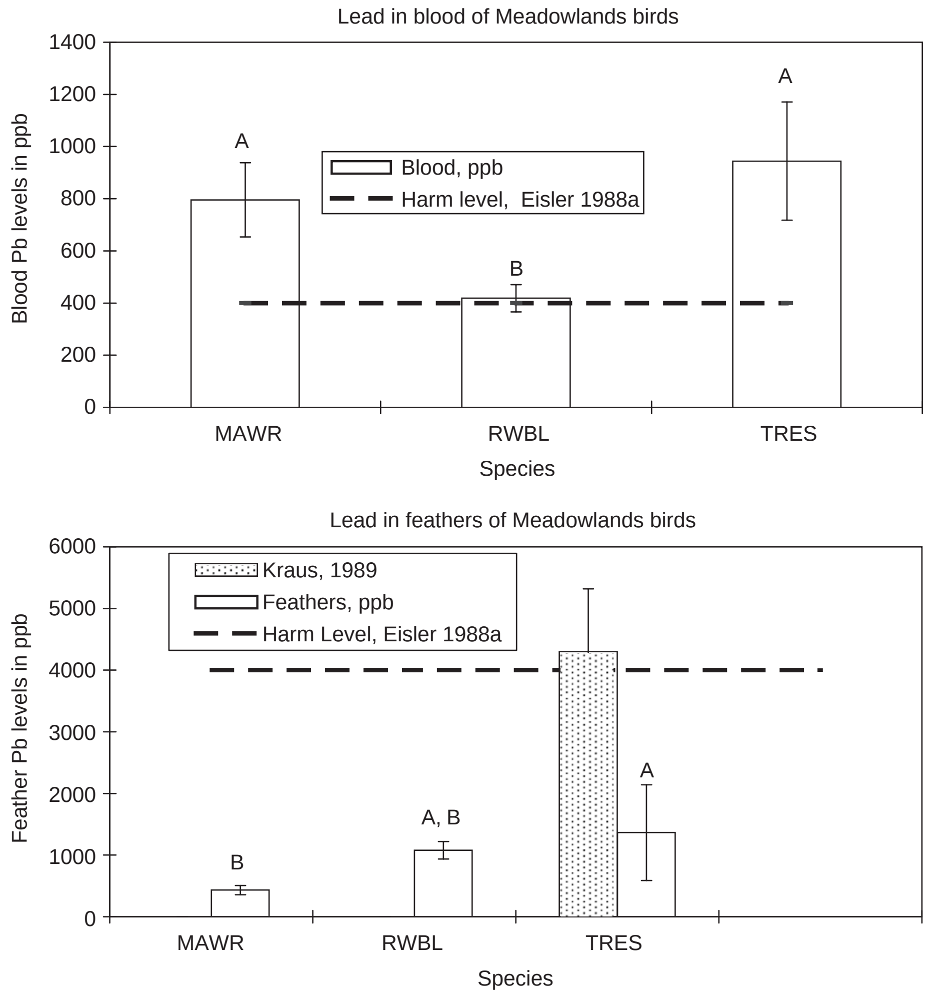

Fig. 2. Mean lead levels in blood (top; ppb wet weight) and breast feathers (bottom; ppb, dry weight), with S.E. The adverse effects level for feathers and blood from Eisler (1988a) are shown as dashed lines. MAWR, marsh wren, $n = 15$ (feathers) and 38 (blood); RWBL, red-winged blackbird, $n = 29$ (feathers) and 63 (blood); TRES, tree swallow, $n = 5$ (feathers) and 14 (blood). Letters (A and B) are from Duncan post-hoc test, indicating significant differences between species.

1993). Burger et al. (1993) found lower levels of mercury in passerine feathers in Papua New Guinea and for mourning doves (*Zenaida macroura*) in South Carolina (Burger et al., 1997). Rimmer et al. (2005), studying passerines in montane forests, report mean mercury levels from 0.4 ppm (blackpoll warbler, *Dendroica striata*) to 1.1 ppm (yellow-rumped warbler, *Dendroica coronata*).

In fact, feather mercury levels in all three of our study species are higher than those reported for young cattle egret (*Bubulcus ibis*) from the northeast United States (Burger et al., 1992) and were more similar to those reported for black-crowned night herons in Chesapeake and Delaware Bays (Golden et al., 2003) and seabirds in the Pacific Ocean. We believe that the high mercury levels in feathers that we observed, rivaling those in birds occupying higher trophic levels (i.e., night herons and seabirds), reflect high levels of contamination in insects, the primary diet item at our survey sites. Red-winged blackbirds had the lowest values, possibly reflecting a more varied diet than the other two species.

Mean levels of mercury in the blood of all three species were the same order of magnitude as those reported for breeding montane passerine birds (Rimmer et al., 2005) and similar (but again generally lower) than those reported for sparrows and other marsh birds in New England (Evers et al., 2005; Lane and Evers, 2006). Mercury levels in adults usually exceed those of juvenile birds (Burger, 1993; Burger and Gochfeld, 1997; Evers et al., 2005). Even when comparing our results with others passerine juveniles, the blood mercury values we obtained were generally more closely aligned to the lowest values reported (Evers et al., 2005).

The low levels of blood mercury are in contrast with the high levels of feather mercury found in the present study. Both blood and feather samples were collected from the same nestlings when feather were actively growing or had recently completed growing. Therefore, we think that the birds are effectively removing mercury from blood and other body tissues by sequestering it in the rapidly growing feathers during the nestling development period. Mercury

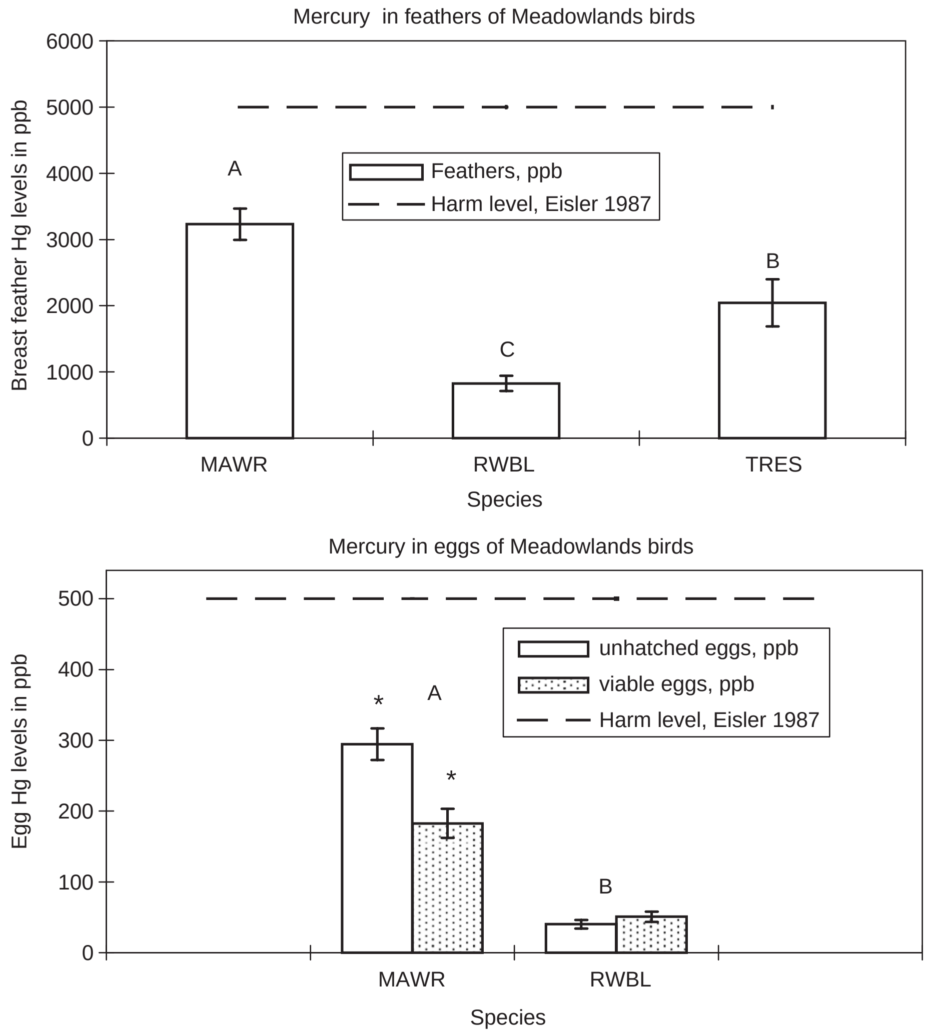

Fig. 3. Mean mercury levels in breast feathers (top; ppb dry weight) and eggs (bottom; ppb wet weight) of Meadowlands birds, with S.E. The adverse effects level for feathers and eggs from Eisler, 1987 are shown as dashed lines. MAWR, marsh wren, $n = 15$ (feathers), 27 (randomly collected eggs), and 4 (unhatched eggs); RWBL, red-winged blackbird, $n = 29$ (feathers), 31 (randomly collected eggs), and 4 (unhatched eggs); TRES, tree swallow, $n = 5$ (feathers). Letters (A and B) are from Duncan post-hoc test, indicating significant differences between species. Asterisks (*) indicate significant differences between unhatched and randomly collected eggs.

levels have been documented to be elevated in feathers of tree swallows while concentration of mercury in carcasses remains low, although the amounts in each are still correlated (Longcore et al., 2007). Metal levels in tree swallows are of particular interest because they have been previously examined from this region. Tree swallows feather chromium levels ranging between 0.3 and 1.5 ppm from the present study were much lower than the average 25.5 ppm reported for tree swallows by Kraus (1989). Similarly, lead feather concentrations ranging at 0.06–4.3 ppm from the present study are much lower than those reported by Kraus (1989) that had a mean of 4.3 ppm and some concentrations as high as 16.2 ppm (Fig. 2). We expected decreasing lead levels in feathers since 1988 (i.e., the year of Kraus's study) because of the steady decrease of environmental lead after the ban on leaded gasoline and the generally improved environmental conditions in the Meadowlands District. Moreover, many of the chromium contaminated sites in the vicinity had either removal of contaminated soil or were capped, thereby reducing the amount of airborne chromium dust (Freeman et al., 1995). Since we analyzed only five feather samples from tree swallows at one site, we cannot determine whether the decline we recorded represents an actual decrease in lead contamination in swallows throughout the District. However, these values are still relatively high, as were some levels of chromium and mercury in our samples.

Overall, the levels of chromium, lead and mercury that we found in three species of Meadowlands birds suggest that these metals may be a concern for wildlife. Even though we saw no deformities indicative of heavy metal poisoning in fledglings, contaminant levels need to continue to be evaluated carefully. Any construction or restoration of the Meadowlands that involves disturbance of soil or sediment with high levels of contamination, where these contaminants have been shown to be bioavailable, should be monitored closely to ensure that there is not an additional increase in exposure to birds consuming insects from the Meadowlands District.

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