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Lead, mercury, cadmium, chromium, and arsenic levels in eggs, feathers, and tissues of Canada geese of the New Jersey Meadowlands

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ABSTRACT

The New Jersey Meadowlands are located within the heavily urbanized New York/New Jersey Harbor Estuary and have been subject to contamination due to effluent and runoff from industry, traffic, and homes along the Hackensack River and nearby waterways. These extensive wetlands, though heavily impacted by development and pollution, support a wide array of bird and other wildlife species. Persistent contaminants may pose threats to birds in these habitats, affecting reproduction, egg hatchability, nestling survival, and neurobehavioral development. Metals of concern in the Meadowlands include arsenic, cadmium, chromium, lead, and mercury. These metals were analyzed in eggs, feathers, muscle, and liver of Canada geese (*Branta canadensis*) breeding in four wetland sites. We sampled geese collected during control culling ($n=26$) and collected eggs from goose nests ($n=34$). Levels of arsenic were below the minimum quantification level (MQL) in most samples, and cadmium and mercury were low in all tissues sampled. Chromium levels were high in feather samples. Mercury levels in eggs of Canada geese, an almost exclusively herbivorous species, were lower (mean ±SE 4.29 ± 0.30 μg/g wet weight) than in eggs of omnivorous mallards (*Anas platyrhynchos*), and insectivorous red-winged blackbirds (*Agelaius phoeniceus*) and marsh wrens (*Cistothorus palustris*) from the Meadowlands, consistent with trophic level differences. However, lead levels were higher in the goose eggs (161 ± 36.7 ng/g) than in the other species. Geese also had higher levels of lead in feathers (1910 ± 386 ng/g) than those seen in Meadowlands passerines. By contrast, muscle and liver lead levels were within the range reported in waterfowl elsewhere, possibly a reflection of metal sequestration in eggs and feathers. Elevated lead levels may be the result of sediment ingestion or ingestion of lead shot and sinkers. Finally, lead levels in goose liver (249 ± 44.7 ng/g) and eggs (161 ± 36.7 ng/g) may pose a risk if consumed frequently by humans. Mill Creek, the site with the most documented prior contamination, had significantly elevated cadmium, chromium, mercury, and lead in goose tissues.

1. Introduction

The expansive wetlands of the New Jersey Meadowlands have long been recognized as a critical resource for wildlife, especially birds. Given its location amidst the highly urbanized landscape of New York City, its importance as an oasis for wildlife cannot be overlooked. This diverse mosaic of habitats includes tidal, brackish, freshwater and forested wetlands that are home to many breeding bird species, several of which are listed as "endangered" or "threatened" by the State of New Jersey. The U.S. Fish and Wildlife Service identified the Meadowlands as a significant habitat complex in the New York/New Jersey Harbor Area (USFWS, 1996). Non-profit conservation organizations recognizing the importance of this region for birds and wildlife have worked diligently over the last three decades to raise public and government agency awareness of the natural resource value of the Meadowlands (Kane and Githens, 1997; Kiviat and MacDonald, 2004). The New Jersey Meadowlands Commission (NJMC) made preservation and restoration of open space a high priority in its Master Plan (NJMC, 2002).

Large industrial facilities including paint and pigment manufacturing plants, and petroleum and chemical refineries, have been located along the banks of the Hackensack River since the industrial revolution. Effluent from these facilities has caused severe contamination of sediments in Meadowlands wetlands (Steinberg et al., 2004; USFWS, 2005, 2007). Most of the industrial facilities in the study area have been shut down, and the water

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quality in the Hackensack River and the overall NY/NJ Harbor Estuary has improved since the 1970s, however, high contaminant levels may persist in sediments at some wetlands in the Meadowlands District (Steinberg et al., 2004). Some sites such as Kearny Marsh and Riverbend Preserve are still considered to be of "substantial concern" because of existing high contaminant levels (USFWS, 2005).

Contaminants of concern in the Meadowlands include the elements arsenic, cadmium, chromium, mercury, and lead, as well as polychlorinated biphenyls (PCBs), tetrachlorodibenzodioxin ('dioxin'), and persistent pesticide compounds (ENSR International, 2004; USFWS, 2005). Some of these chemicals, for example organics and methylmercury, are known to bioaccumulate (Burger, 2002a; Weis, 2005). A contaminant present at low concentrations in the water or the sediments can be biomagnified, reaching harmful concentrations in tissues of higher level consumers with increasing risk to organisms at the top of food webs. Contaminant exposure can have negative effects on reproduction, egg hatchability, hatchling survival and neurobehavioral development (Heinz, 1974; Ohlendorf et al., 1989; Bouton et al., 1999; Custer et al., 1999; Burger and Gochfeld, 2000a). Aquatic bird species are particularly vulnerable because of the potential for rapid movement of contaminants in aquatic, compared to movement in terrestrial environments, and because chemicals can accumulate in sediments, providing a long term source for years to come (Burger and Eichhorst, 2005). 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. People appreciate these areas not only because they provide opportunities for fishing and other recreation, but because they provide opportunities to relax outdoors (Burger, 2002b). 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 (USFWS, 2007). Birds are especially susceptible, as they are mobile and can colonize new habitats fairly rapidly. However, birds attracted to the new habitats may be unable to successfully reproduce because of exposure to high contaminant levels (Fry, 1995; Rattner and McGowan, 2007; Smith et al., 2009). Thus, these new habitats can have adverse effects on the bird populations using them.

The Meadowlands wetlands complex is used extensively by waterfowl, shorebirds and long-legged wading birds (Kiviat and MacDonald, 2004; Mizrahi et al., 2007; Tsipoura et al., 2008). The most commonly observed waterfowl species in the Meadowlands are Canada goose (*Branta canadensis*) and mallard (*Anas platyrhynchos*), which breed locally and are year-round residents (Mizrahi et al., 2007). Canada geese are almost exclusively herbivorous (Owen, 1980); their diets are determined by seasonal variation in nutritional requirements and availability of specific foods (Mowbray et al., 2002). In urban/suburban environments they graze on domesticated grasses throughout the year (e.g., Conover and Kania, 1991). In this paper we examine the levels of metals in tissues of Canada geese which are resident throughout the year. We compare results with other Meadowland species including mallard (Tsipoura, unpublished data), red-winged blackbird (*Agelaius phoeniceus*) and marsh wren (*Cistothorus palustris*) (Tsipoura et al., 2008). Our primary objectives were to (1) determine contaminant levels in feathers, liver and muscle tissue and in eggs of Canada geese breeding in the Meadowlands; (2) examine differences in contaminant levels of avian tissues at different Meadowland sites; (3) compare these levels with those in other species; and (4) determine whether these levels pose a health risk for human consumption.

2. Methods

Under appropriate collecting permits from the United States Department of Agriculture (USDA), the Fish and Wildlife Service (USFWS), and the State of New Jersey we obtained eggs, feathers, muscle, and liver tissue from Canada geese at several sites in the NJ Meadowlands (Fig. 1) during the 2007 breeding season. The goose tissues were provided by the USDA during goose culling projects (see below). Specific collection sites included Kearny freshwater marsh, Harrier Meadow, Mill Creek, and Skeetkill Marsh (Fig. 1). Canada geese nest at all of these sites and typically forage nearby during the breeding season. Studies of urban resident geese have shown that they generally stay close to their primary foraging and loafing areas even outside the breeding season (Seamans et al., 2009), and when hazed in efforts to reduce nuisance populations, only move an average of less than 2 miles (Holevinski et al., 2007).

Kearny Marsh is a freshwater impoundment, dominated by phragmites. Harrier Meadow is a restored tidal marsh surrounded by tidal mudflats on two sides and urban development and landfill on the remaining two sides. During restoration, three large, tidally influenced open-water areas surrounded by high-marsh and fringe-upland vegetation were created. This site is different from the other restored marsh sites in the Meadowlands because it was constructed on top of rubble and other hard materials. Mill Creek is a restored site, formerly highly contaminated, that includes open water, scrub-shrub habitat, and low marsh habitats that are flushed daily with the tides. Mill Creek is a known contaminated site (Adams et al., 1998; Windham et al., 2004). During restoration dredge material was excavated, tidal flow re-established, and the surface was graded to provide low marsh and upland habitat. Finally, Skeetkill Marsh includes about 16 acres of tidal channels, open water, low marsh habitat and upland islands that have been created by the NJMC. Before the NJMC acquired the site, it was largely a dense monoculture of phragmites, with very little open water or tidal flow. Skeetkill marsh lies in the middle of an urban area dominated by industry.

Contaminants information is available for sediment and water at these sites. At Kearny Marsh, lead (Pb) exceeded the Surface Water Quality Standards with an average concentration of 10.5 μg/l. Elevated concentrations of arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and mercury (Hg) that exceeded the Ontario Aquatic Sediment Quality Lower Effect Levels were found in the sediment at this site (Langan Engineering and Environmental Services, 1999). Cadmium exceeded the NJDEP residential direct contact soil cleanup criteria in 20 of 24 soil samples at Harrier Meadow, ranging from not detected to 2.96 mg/kg. Similarly, it exceeded these standards in 5 of 8 samples at Skeetkill Marsh, ranging from not detected to 7.91 mg/kg. No Pb was detected in surface waters at these sites (Schulze, 1998). Many of the detected concentrations of metals in sediment at Mill Creek are within ranges where effects in organisms (lowered reproduction and/or survival) would occur. For example, Cr and Pb concentrations, ranging from 27.7 to 520 ppm and from 8.7 ppm to 415 ppm, respectively, were above levels where effects may be expected in 40% of the sediment samples. Mercury ranged from 0.07 to 13.4 ppm with 70% of the samples at levels where adverse effects may be expected. However, most concentrations were predominantly within the range of or below background values reported in the NY/NJ Estuary (HMDC, 1997).

A single egg was collected from 29 Canada goose nests at Mill Creek. A few eggs were obtained at Kearny Marsh ($n=2$) and Skeetkill Marsh ($n=3$). Eggs were wrapped in aluminum foil, labeled, and placed in a protected container in a cooler. Eggs were refrigerated up to one week until transfer to the Elemental Analysis Laboratory at the Environmental and Occupational Health Sciences Institute (EOHSI) in Piscataway, New Jersey. Breast feathers, muscle and liver tissue were collected from adult and juvenile birds during their flightless stage while molting. All Canada goose tissue samples were collected by the USDA as part of a wildlife control program under a U.S. Fish and Wildlife Service depredation permit. The USDA provided the authors with samples of liver, muscle, and feathers. The birds were not sexed. These birds are all resident and the samples were collected during or shortly after molting, therefore are a good reflection of the contaminant load to which these birds are being subjected.

Feathers were placed in labeled envelopes and stored in a light-inhibiting box until transport to the EOHSI laboratory. A sample of breast muscle and liver were frozen immediately and transferred within a week to EOHSI. We recorded information on age (adult or young of the year) for all feather, liver and muscle samples for comparisons between age groups.

Two passerine bird species, red-winged blackbirds and marsh wrens, were previously sampled in the New Jersey Meadowlands during this study. Results of these analyses are reported elsewhere (Tsipoura et al., 2008), but we also make some comparisons with tissue metal levels reported in this paper. Finally, eggs ($n=6$) from mallard nests located during the course of the field work, were also collected and analyzed. While this is a small sample size, it provides an additional waterfowl sample from the New Jersey Meadowlands.

2.1. Metal analysis

All samples were analyzed for levels of cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), and arsenic (As). Cadmium, lead, and mercury were examined because they are the major contaminants of concern in marine environments including the New York–New Jersey Bight (Fowler, 1990; Spahn and Sherry, 1999; Burger and

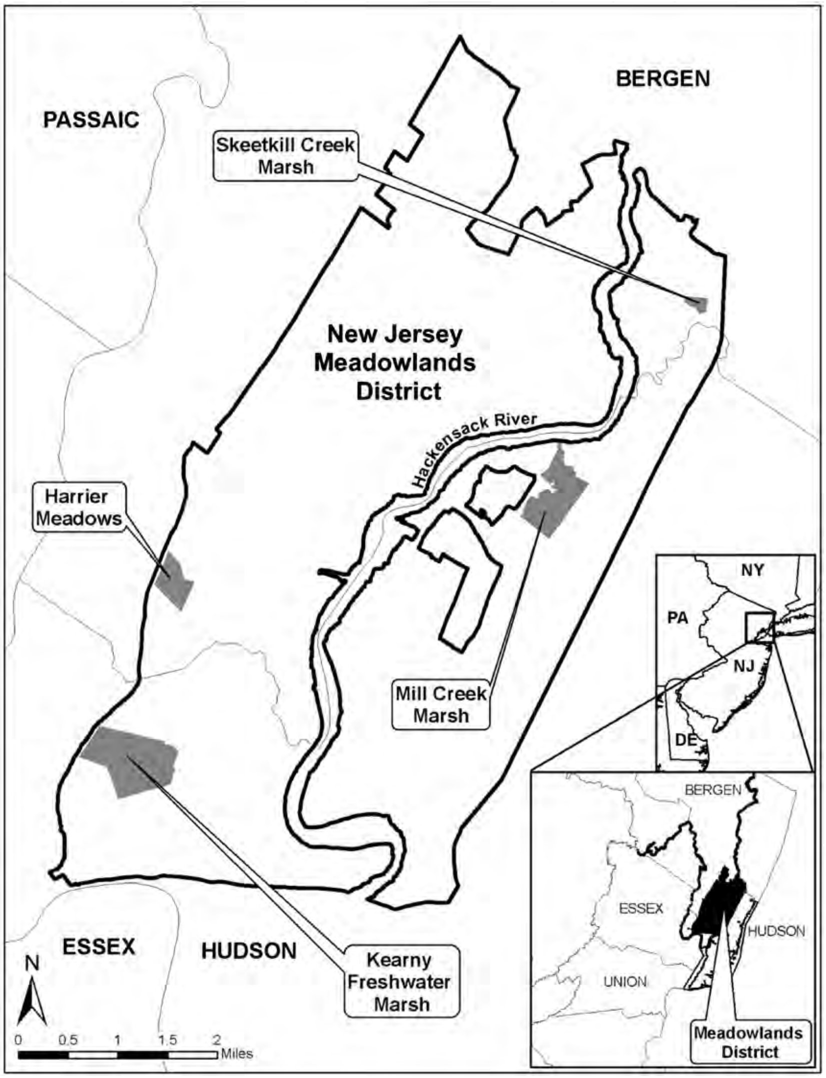

Fig. 1. Map of the study sites in the Meadowlands District.

Gochfeld, 2004). Arsenic has been a concern for wildlife in marine and estuarine ecosystems (Neff, 1997). 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). Our study measured only total chromium and total mercury.

Mercury was analyzed by cold vapor atomic absorption spectrophotometry as total mercury, of which about 85–90% is assumed to be methylmercury (Wolfe et al., 1998; Burger and Gochfeld, 2004). Other metals were analyzed by graphite furnace (flameless) atomic absorption. Whole egg contents were homogenized, dried and digested individually. To minimize external contamination, feathers were washed vigorously three times with acetone, once with deionized water, air dried, and then digested individually. All tissues were digested with trace metal grade nitric acid within microwave vessels using a digestion protocol of three stages of 10 min each under 3.5, 7.0, and 10.5 kg/cm^2 (settings of 50, 100, and 150 pounds per square inch) at 70% power and subsequently diluted with deionized water. Instrument minimum quantification limits (MQL) were 0.02 ppb for arsenic and cadmium, 0.08 ppb for chromium, 0.15 ppb for lead, and 0.2 ppb for mercury. Values below the MQL were set at half the MQL. For As, most samples were below the MQL. All specimens were run in batches that included blanks along with replicate and spiked specimens for QA/QC, and a calibration curve. We also analyzed reference materials (trace elements in natural water, certified from the National Institute of Standards and Technology [NIST]). DORM-2 certified dogfish muscle, provided by NIST, was used as a reference material for mercury. Acceptable results for the reference materials were between 90% and 110%. Eggs contents were weighed and then dried, so that both dry weight (dw) and wet weight (ww) are reported for easier comparisons with other published values. Feather results are reported as dry weight. Metal concentrations in liver and muscle are reported as wet weight. Tissues were dried to provide conversion factors for comparisons with other values reported in the literature. The average moisture content was 68.1% for eggs, 71.7% for muscle and 69.0% for liver which resulted in conversion factors of 3.14 for eggs, 3.59 for muscle, and 3.26 for liver.

2.2. *Data analysis*

Metal levels in tissues were in most cases not normally distributed (SAS PROC UNIVARIATE Shapiro-Wilks statistic $p < 0.001$), so non-parametric statistics were used for comparisons among species and log-transformations were used in any parametric statistics. We used multivariate analysis of variance (MANOVA) on log-transformed data to explore the effects of age, tissue (liver, muscle and feathers) and site. When significant effects were found, we followed up with 2-way ANOVA to explore differences. Eggs were not included in the MANOVA because they were almost all collected from one site and they correspond to no ‘age’ variable. A multivariate analysis of variance model that would also include species was also not feasible, since sample collection sites differed among species and only eggs were compared in this paper. Therefore, we used non-parametric procedures (PROC NPAR1WAY, Kruskal Wallis χ^2 test, SAS, 2005) to explore tissue and species differences in heavy metal levels. We also used these non-parametric procedures to explore differences among tissues including eggs. These tests are more conservative and are suited for small datasets with non-normal distributions. When significant differences were found, we used the parametric post-hoc Duncan’s multiple range tests to explore which tissues and sites were different (Burger and Gochfeld, 2003, 2004). These are indicated by letters (A,B,C,D) in the tables. For tissues we achieved 69–80% power to detect a 50% difference between sites ($\alpha = 0.05$). The sample of eggs was almost entirely from Mill Creek, and no between site testing was conducted. Metal correlations among tissues were tested using non-parametric Kendal τ.

3. Results

Levels varied among elements and tissues (Tables 1 and 2). Lead, chromium, and mercury were detected in all eggs samples.

Table 1
Element levels (mean ± SE) in tissues collected in 2007 from Canada geese in the Meadowlands by location. All values are in parts per billion (ng/g) wet weight. Multivariate analysis of variance revealed a weak effect of site on contaminant levels. Means marked with different letters (A, B) were significantly different by Duncan post-hoc test. Significantly high values are in bold and significantly low values in italics.

Tissue/metal	Mean ± SE			
	Harrier Meadow	Mill Creek	Skeetkill Marsh	ANOVA F (p)
	$n=13$	$n=5$	$n=8$	
Arsenic (As)[a]				
Feather	6.39 ± 4.26	198 ± 122	85.1 ± 63.3	1.08 (0.36)
Liver	6.24 ± 4.45	3.04 ± 2.12	0.10 ± 0.00	1.29 (0.30)
Muscle	1.11 ± 0.78	0.10 ± 0.00	0.10 ± 0.00	1.02 (0.37)
Cadmium (Cd)				
Feather	69.3 ± 9.52 (B)	**153** ± 29.4 (A)	69.8 ± 12.1 (B)	**4.75 (0.02)**
Liver	*122* ± 38.5 (B)	221 ± 58.6 (AB)	**311** ± 41.7 (A)	**4.75 (0.02)**
Muscle	4.17 ± 0.78	6.40 ± 1.31	7.73 ± 2.52	1.00 (0.38)
Chromium (Cr)				
Feather	801 ± 184 (B)	**2740** ± 545 (A)	1400 ± 480 (B)	**10.09 (0.0007)**
Liver	201 ± 72.7	150 ± 38.5	110 ± 50.3	0.5 (0.61)
Muscle	48.5 ± 14.0 (B)	**203** ± 64.1 (A)	28.1 ± 7.88 (B)	**7.12 (0.004)**
Lead (Pb)				
Feather	1650 ± 556	3140 ± 904	1570 ± 637	0.92 (0.41)
Liver	208 ± 58.1	376 ± 146	238 ± 66.0	1.35 (0.28)
Muscle	3.31 ± 2.09 (B)	**60.4** ± 35.1 (A)	3.31 ± 2.12 (B)	**5.19 (0.014)**
Mercury (Hg)				
Feather	200 ± 63.5	276 ± 72.7	340 ± 73.7	1.19 (0.32)
Liver	36.8 ± 10.4	52.0 ± 14.7	40.7 ± 11.4	0.91 (0.42)
Muscle	8.16 ± 2.91 (B)	**23.2** ± 9.77 (A)	12.7 ± 2.84 (AB)	**5.05 (0.015)**
	Kearny Marsh	Mill Creek	Skeetkill Marsh	
Eggs (wet weight)[b]	$n=2$	$n=29$	$n=3$	
Arsenic (As)[a]	*0.03* ± 0.00	4.54 ± 2.43	18.1 ± 18.0	
Cadmium (Cd)	*0.02* ± 0.02	0.24 ± 0.09	0.18 ± 0.09	
Chromium (Cr)	27.7 ± 7.33	39.0 ± 7.32	27.3 ± 5.51	
Lead (Pb)	61.2 ± 40.8	178 ± 42.3	64.8 ± 23.7	
Mercury (Hg)	*1.90* ± 0.25	4.56 ± 0.32	3.27 ± 0.65	

[a] Most arsenic values were below the MQL.

[b] Egg contaminant values are presented, but no statistical comparisons were made due to small sample size at two of the three sites.

Table 2
Tissue differences (mean ± SE) for Canada goose samples collected in 2007. Element levels are in parts per billion (ng/g) and are presented as wet weight for eggs, dry weight for feathers and wet weight for liver and muscle. Means marked with different letters (A, B, C) were significantly different by Duncan post-hoc test. NS= non-significant. Significantly high values are in bold and significantly low values in italics. Values below the minimum quantification level (MQL) are set as one half of the MQL.

	Mean ± SE, n, ppb				Comparison by tissues
	Liver (wet weight)	Muscle (wet weight)	Feathers (dry weight)	Eggs (wet weight)	Kruskal Wallis χ^2 (P)
Canada goose	$n=26$	$n=26$	$n=26$	$n=34$	
Arsenic (As)	3.74 ± 2.28 (B)	0.60 ± 0.39 (B)	**67.5 ± 32.0 (A)**	5.47 ± 2.55 (B)	42.7 (< 0.0001)
Cadmium (Cd)	**199 ± 29.8 (A)**	5.70 ± 0.92 (C)	85.6 ± 10.2 (B)	*0.22 ± 0.08* (C)	88.9 (< 0.0001)
Chromium (Cr)	163 ± 40.0 (B)	72.0 ± 18.6 (B)	**1360 ± 241 (A)**	37.3 ± 6.29 (B)	70.3 (< 0.0001)
Lead (Pb)	249 ± 44.7 (B)	14.4 ± 7.72 (B)	**1910 ± 386 (A)**	161 ± 36.7 (B)	66.9 (< 0.0001)
Mercury (Hg)	40.9 ± 6.72 (B)	12.5 ± 2.63 (B)	**258 ± 41.8 (A)**	4.29 ± 0.30 (B)	71.0 (< 0.0001)

Cadmium was above the MQL in 14 of 34 eggs, and As was above MQL in 6 of 34 eggs. The two eggs from Kearney were among four lowest values for mercury (joint probability that the two eggs would be in the four lowest values=0.013). Lead was detected in all liver samples, all but two feather samples, but in only 9 of 26 muscle samples, with no difference between age groups. Cadmium was detected in all feather and muscle and all but one liver samples.

Sampled birds included 16 adults, 9 juveniles, and 3 of indeterminate age. Multivariate analysis of variance reveals no effect of age on contaminant levels (Wilks' $\lambda=0.93$, F $(5, 59)=0.91$, $p>0.48$); so we combined the data for the two age groups in all further analyses. This analysis revealed a strong effect of tissue (Wilks' $\lambda=0.09$, F $(10,118)=26.24$, $p<0.0001$), and a weak effect of site (Wilks' $\lambda=0.73$, F $(10,118)=1.96$, $p<0.043$) on contaminant levels that are further explored below.

Feathers from Canada geese at Mill Creek had higher Cd and Cr levels than those from other sites (Table 1). Muscle Cr and Pb levels were highest at Mill Creek and not different among the other three sites, while muscle Hg levels were also highest at Mill Creek and lowest at Harrier Meadow, with Skeetkill not being different from either one (Table 1). Finally, Cd liver levels were highest at Skeetkill and lowest at Harrier Meadow, with Mill Creek not being different from either one (Table 1). The distribution of non-detect values (values below the minimal quantification limit or MQL) were evenly distributed among sites and age groups. Most problematic of the elements was arsenic which was above the MQL in only 6 of 34 eggs,

Table 3
Species differences in metal levels in eggs (Mean ± SE, ppb, wet weight) of Canada Goose (present study; collected in 2007), Mallard (Tsipoura unpublished data; collected in 2006), compared with insectivorous Red-winged Blackbird and Marsh Wren eggs (collected in 2006 see Tsipoura et al., 2008). Means marked with different letters (A, B, C) were significantly different by Duncan post-hoc test. Significantly high values are in bold and significantly low values in italics.

	Mean ± SE				
	Canada goose	Mallard	Red-winged blackbird	Marsh Wren	Kruskal Wallis χ^2 (P)
	n=34	n=6	n=35	n=31	
Arsenic (As)	5.47 ± 2.55	16.2 ± 6.01	5.98 ± 1.61	10.1 ± 3.61	NS
Cadmium (Cd)	0.22 ± 0.08	0.29 ± 0.14	0.26 ± 0.08	0.37 ± 0.17	NS
Chromium (Cr)	37.3 ± 6.29 (B)	42.6 ± 20.5 (B)	**120** ± 27.6 (A)	59.1 ± 16.9 (AB)	21.6 (< 0.0001)
Lead (Pb)	**161** ± 36.7 (A)	62.1 ± 12.7 (B)	38.5 ± 5.33 (B)	34.7 ± 5.28 (B)	34.5 (< 0.0001)
Mercury (Hg)	*4.29* ± 0.30 (C)	75.1 ± 12.8 (B)	48.2 ± 6.42 (B)	**197** ± 19.2 (A)	84.6 (< 0.0001)

and six feather, four liver, and two muscle samples out of 26 birds. There was no difference in proportion of detectable values by age.

3.1. Species differences

Since we had collected eggs from mallards (Tsipoura, unpublished) and had previously reported egg metal levels in eggs of two insectivorous passerines (Tsipoura et al., 2008), we were able to make comparisons among species (Table 3). Canada goose had the highest lead and lowest mercury levels. Levels of Hg were lower in goose than mallard eggs (Table 3). There were no differences among species in egg As, and Cd, while Cr levels were lower in the two waterfowl species than in red-winged blackbirds (Table 2). Comparisons between blackbirds and wrens have been published previously (Tsipoura et al., 2008).

3.2. Differences among tissues

Comparisons among tissues revealed that all elements were highest in feathers, except for Cd, which was highest in liver (Table 2). All elements had higher concentration in liver than in muscle. Except for chromium, the results for muscle and liver levels were congruent across sites (Table 1). However, feather levels varied independently from tissue levels.

Feather, muscle and liver tissue was collected from each goose so we were able to analyze inter-tissue correlations in metal levels (Table 4). Levels of Hg and Cd in liver were correlated with those of muscle ($p < 0.001$ and 0.02, respectively), while Cr and Pb levels in muscle were correlated with feather levels (p=0.03 and 0.003, respectively). We did not find a correlation between feather and liver levels of any metals.

4. Discussion

Little is known about contaminant levels in NJ Meadowlands biota (Kraus, 1989; Weis, 2005; Tsipoura et al., 2008). 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. A screening level risk assessment for the Meadowlands (ENSR International, 2004) modeled exposure to avian receptors, without the benefit of actual site-specific avian data. More recently, research in the Meadowlands has shown that in passerine bird eggs, feathers, and blood, As and Cd levels are generally low and most likely inconsequential, while Hg, Pb, and Cr are generally high compared to the levels reported elsewhere (Tsipoura et al., 2008).

There were some differences for feather and tissue levels of contaminants among sites (eggs were not compared across sites). Of the 15 levels we report here (Table 1), Mill Creek had the highest values for nine. Six of the comparisons showed statistically significant differences among sites with Mill Creek the highest in five cases. Among non-significant results, four showed very similar means. Five comparisons had quite different means, but high intra-group variation that precluded a conclusion about differences.

Table 4
Correlation between tissues for contaminant levels in Canada geese (all locations combined, n=26). Given are Kendall τ correlations (p). Significant ($p < 0.05$) values are in bold.

	Muscle and liver	Muscle and feather	Liver and feather
Arsenic (As)	−0.1 (NS)	−0.1 (NS)	0.0 (NS)
Cadmium (Cd)	**0.3 (0.02)**	0.0 (NS)	−0.1 (NS)
Chromium (Cr)	0.0 (NS)	**0.3 (0.03)**	0.2 (NS)
Lead (Pb)	0.3 (NS)	**0.5 (0.002)**	0.2 (NS)
Mercury (Hg)	**0.5** (0.0008)	**0.3 (0.07)**	0.0 (NS)

We found no difference in the metal levels (Cd, Cr, Pb, Hg) between adult and juvenile geese. Rather both adults and young are growing feathers and sequestering metals in similar places and amounts. Metal levels were generally highest in feathers, and higher in liver than in muscle. One finding of the present study is that expected trophic level differences exist for mercury between herbivorous geese (lowest Hg) and the other three species, while the opposite trend occurs for Pb. Among metals, Pb was the only one that was consistently high in Canada geese across all tissues sampled.

4.1. Interspecific differences

Analyses of eggs showed significant interspecies differences for chromium, lead, and mercury, with suggestive differences for arsenic (Table 3). Mean cadmium levels were remarkably similar across species.

Mercury levels in eggs of the herbivorous Canada goose were lower than levels in the omnivorous mallards, as would be expected because of trophic level differences of the two species. Similar trophic level effects of contaminants that bioaccumulate have been reported in other waterfowl studies. For example, organochlorines in breast tissue of birds harvested in Eastern Canada were generally lower in grazers such as snow goose (*Chen caerulescens*) and Canada goose and higher in omnivores such as mallards and pintails (*Anas acuta*, Braune et al., 1999). Organic contaminants were also detected more often and at higher concentrations in dabbling ducks than geese (Braune and Malone, 2006). Similarly, Evers et al. (2005) report increasing levels of methylmercury in muscle tissue of waterfowl going from herbivorous to piscivorous species. Conversely, Pb levels were highest in goose eggs. While it is not clear why this is the case, concentrations of Pb in tissues of waterfowl from the Chesapeake Bay have shown a similar pattern with higher levels in mostly herbivorous species compared to omnivorous and carnivorous species, possibly relating to the ingestion of a lead laden diet (DiGiulio and Scanlon, 1984), a residue from the era of leaded gasoline. Alternatively some grasses are hyperaccumulators of metals, including lead (McCutcheon and Schnoor, 2003), and efficiently extract lead from soil. Herbivorous species that consume these grasses would be expected to have elevated Pb levels.

Similar differences existed between Pb and Hg in goose eggs and those reported for eggs of NJ Meadowlands passerines (Tsipoura et al., 2008). There was no difference in the egg levels of the other metals analyzed for the two waterfowl species and both had lower Cr levels than those of passerines (Tsipoura et al., 2008). Canada Geese are quite sedentary while nesting. However, the general lack of differences in egg metal contaminant levels among sites does not provide any evidence that site differences would change the result of comparisons across the entire study area.

4.2. Differences among tissues

Most metal contaminants were highest in feathers as would be expected because birds sequester metals in this tissue (Burger, 1993). Among the other tissues, highest concentrations were recorded in liver. While we found some correlations between liver and muscle levels and between feather and muscle levels, we found no correlation between liver and feather levels of any of the metals analyzed. We suggest that because samples were collected from birds that were at various stages of molt and thus at various stages of eliminating metals in their feathers (Condon and Cristol, 2008), few patterns and correlations between metal levels in tissues were revealed in our data. This is an important aspect to remember when deciding when to use feathers as a bioindicator of internal levels.

4.3. Geographical comparisons and biological significance by metal

4.3.1. Arsenic and cadmium

Arsenic is associated with pesticides and with industry, especially smelting (Eisler, 1988). Most As levels were non-detectable, but when present, the As levels we found (Table 3) were on the lower range of those reported by others (e.g. 960 ppb average reported in Burger, 1993), and also below the level where biological impacts would be anticipated (2000–10,000 ppb; Eisler, 1988).

Similarly, the Cd levels we report for Meadowlands waterfowl were well below the level viewed as evidence of probable Cd contamination in vertebrates (2.0 ppm; Eisler, 1985) and the levels considered elevated above background (3 ppm; Scheuhammer, 1987). Cadmium was above the MQL in 14 of 34 eggs, including some from all three sites. Egg Cd at 0.22 ppb (ww) for goose eggs and at 0.29 ppb for mallard eggs were generally low compared to other levels reported in the literature (2–200 ppb, Burger et al., 2004; Burger and Gochfeld, 2004). Feather Cd levels in our study at an average of 85.6 ppb for feathers were also in the lower range of those reported previously (50–41,000 ppb, Burger, 1993; Burger and Gochfeld, 2000b). Muscle Cd levels at an average 5.7 ppb were lower than those reported in Arctic seabirds (160–5220 ppb, dw, about 44–1450 ppb ww, Savinov et al., 2003) and similar to those reported in breast muscles of mallards in Europe (25–215 ppb ww, average 82 ppb ww; Szymczyk and Zalewski, 2003). Cadmium levels in liver of Canada geese although higher than in the other tissues at over 200 ppb at Mill Creek and over 300 ppb at Skeetkill Marsh (Table 2) were not anywhere close to the avian threshold for Cd poisoning (160,000 ppb dw; Furness, 1996).

These Cd levels were at the lower range of those reported for waterfowl elsewhere, for example Black Ducks (*Anas rubripes*) and Greater Scaup (*Aythya marilla*) from Raritan Bay, NJ, averaged about 250 and 600 ppb ww (Burger et al., 1984). Lesser Scaup from the Great Lakes ranged up to about 3000 ppb dw (approximately 0.55–835 ppb ww; Custer and Custer, 2000; Custer et al., 2000, 2003) and eiders in the Canadian Arctic average 10,500–33,500 ppb dw (2920–9325 ppb ww; Wayland et al., 2001).

4.3.2. Chromium

Chromium was omnipresent in the samples, probably reflecting its role as an essential element. At high environmental concentrations, hexavalent Cr is a mutagen, teratogen, and carcinogen. Trivalent Cr has low toxicity and is an essential trace element. These oxidation states co-occur in soil and sediment, depending on redox conditions. We did not speciate Cr, which undergoes complex redox cycling in nature and in the body (Eisler, 1988). Chromium contamination is high within the NY/NJ Harbor region because of chromite processing facilities, which operated in Hudson County prior to 1970, disposing of chromite ore processing residue (COPR) or slag at nearly 200 waste sites, some of them close to Newark Bay (Burke et al., 1991). Eisler (1986) suggests that Cr tissue levels in excess of 4000 ppb dw should be considered evidence of Cr contamination.

In this study, Cr levels in Canada goose were relatively low. Levels in goose feathers were higher, especially at Mill Creek at an average of 2740 ppb. These are still within the lower range of Cr concentrations reported in birds, (average 8,800 ppb, with high values up to 17,900 ppb as reviewed by Burger, 1993). They are also lower than those reported for cattle egrets (*Bubulcus ibis*) in the Northeast (average 8200 ppb; Burger et al., 1992) and black-crowned night-herons (*Nycticorax nycticorax*) in the Chesapeake and Delaware Bays (averages 2500–6120 ppb; Custer et al., 2008; Golden et al., 2003), but higher than those reported for black-crowned night-herons in the NY/NJ Harbor (450–1260 ppb; Padula et al., 2010). In addition, two feather samples were over the 4000 ppb level, therefore, potentially a cause for concern. The levels of Cr in goose liver averaged at 160 ppb ww were lower than the range of Cr reported elsewhere (700–3000 ppb dw or 195–835 ppb ww in livers of waterfowl in Spain; Mateo and Guitart, 2003). Similarly, Cr in muscle, averaged 70 ppb ww, below the levels in muscle of laughing gulls in New York and New Jersey (250 ppb ww, Gochfeld et al., 1996), but similar to those of Franklin's gulls in Minnesota (88–107 ppb ww; Burger and Gochfeld, 1999).

4.3.3. Mercury

Sediment concentrations of Hg in Upper Newark Bay and in the Hackensack River are above the median level at which adverse biological effects are expected (Steinberg et al., 2004). Elevated Hg levels can impact bird behavior, physiology and reproductive success (Thompson, 1996; Gochfeld, 1997; Wolfe et al., 1998; Burger and Gochfeld, 2003). This metal accumulates especially well in bird feathers because it has high affinity for the sulfhydryl groups in keratin. Feather Hg above 5000 ppb is linked to reduced reproduction (Eisler, 1987a; Burger, 1993; Wolfe et al., 1998; Evers et al., 2008). Mercury can also be sequestered in eggs (Gochfeld, 1997), adversely affecting hatchability at levels between 500 and 1500 ppb ww, and nestling behavioral development at levels of 500–1000 (Wolfe et al., 1998). Mercury in eggs and feathers of Canada geese averaging 4 ppb ww and 260 ppb, respectively, was lower than those harmful effect levels, and Hg levels in goose eggs were lower than in the two passerine species (48–197 ppb ww; Tsipoura et al., 2008) or in mallard eggs (mean 75 ppb ww). These levels are lower than levels that can affect hatching success (Eisler, 1987a). All reported Hg levels were below or in the lower range of values reported by Burger and Gochfeld (1997b) for eggs and feathers of birds from the NY/NJ Bight. Goose feather levels of Hg were lower than those reported for black-crowned night-herons in Chesapeake and Delaware Bays (810–1250 ppb; Golden et al., 2003) and seabirds in the Pacific Ocean (Burger and Gochfeld, 2000b), species that occupy higher trophic levels in the food chain.

Levels of Hg in goose liver (mean 41 ppb, maximum 130 ppb ww) were low compared to levels reported for greater scaup in Long Island (800–3800 ppb dw or approximately 245–1160 ppb ww; Cohen et al., 2000), Raritan Bay greater scaup (mean 400 ppb ww; Burger et al., 1984), or Raritan Bay black ducks (approximately 200 ppb ww; Burger et al., 1984). The goose levels of liver Hg were lower than those of wintering waterfowl in the Great Salt Lake (average 1700–14,000 ppb ww; Vest et al., 2009) and in the lower range of seaducks, (400–12,000 ppb dw or approximately 122–3670 ppb ww; Henny et al., 1995). Levels of Hg in muscle averaged 10 ppb with a maximum of 60 ppb ww. This is on the lower range of values reported for waterfowl harvested in Canada (30 average, 156 max ppb ww; Braune and Malone, 2006) and below the levels in muscle (620–830 ppb ww) found to be associated with behavioral changes in nesting mallards (Heinz, 1979). These are also much lower than the 3000 ppb effect levels reported elsewhere (Barr, 1986; Fisk et al., 2005).

All Hg levels were lower than those reported for ducks in the Hackensack Meadowlands in the early 1980s (Galluzzi, 1981), which were on average 2800 ppb for feathers, 340 ppb for muscle, and 1100 ppb for liver.

4.3.4. Lead

Lead levels as low as 0.4 ppm in blood can result in adverse physiological effects, while 4 ppm in feathers is associated with negative effects on behavior, thermoregulation, locomotion, and depth perception resulting in lowered nestling survival (Eisler, 1987b; Scheuhammer, 1987; Burger, 1995; Burger and Gochfeld, 2000a; Takekawa et al., 2002). 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). This may result in high tissue Pb levels in biota.

The levels of Pb we report here for goose feathers at an average of 1900 ppb were higher than the levels that we reported in passerine species in the New Jersey Meadowlands (Tsipoura et al., 2008) and similar to those reported for black-crowned night-herons breeding in the NY/NJ Harbor (Padula et al., 2010). Approximately 42% of the values observed were above the median value of 1600 ppb reported in an extensive review of metal levels in birds (Burger, 1993; Burger et al., 1997). In addition 4 out of 26 goose feather samples had Pb levels above 4000 ppb, the level associated with negative effects. Feather Pb levels were especially high in Canada geese from Mill Creek, averaging 3140 ppb. These are much higher than levels reported in feathers of black-crowned night-herons in Chesapeake and Delaware Bay (Golden et al., 2003) and eiders (Burger et al., 2008) and possibly a cause for concern.

Goose eggs at an average of 505 ppb dw (Table 2) had higher levels of Pb than those reported from passerine species at that site (Tsipoura et al., 2008) and also higher than those reported in Alaskan eiders (Burger et al., 2008), and than those of grebes from Agassiz National Wildlife Refuge (Burger and Eichhorst, 2005). These levels were more within the range of those reported in common terns in New Jersey (Burger and Gochfeld, 2003, 2004) and seabirds in California (average 314–1040 ppb; Sydeman and Jarman, 1998), all species feeding at higher trophic levels; The mean of lead concentrations in eggs of piscivorous species from 29 studies indicated a range of 20–6700 ppb, with a median of 190 ppb wet weight (reviewed by Burger, 2002a); five goose eggs in our study exceeded that median value. Mallards had lower egg Pb levels relative to the geese (Table 2), but higher than those reported by Tsipoura et al. (2008) in Meadowlands passerines.

Muscle levels of Pb of Canada geese (mean 23 ppb, maximum 190 ppb ww) were relatively low and similar to those reported in laughing gulls (average 65.5 ppb; Gochfeld et al., 1996) and Franklin's gull (71–101 ppb; Burger and Gochfeld, 1999). Scheuhammer et al. (1998) report that Pb levels of pectoral muscle in game birds killed by lead shot averaged much higher than what we report here, at 1400 ppb ww. The liver levels of Pb, at an average of 250 ppb ww are within the range reported for waterfowl in a nationwide survey (420–1690 ppb; Beyer et al., 1998) and lower than those reported in Coeur d'Alene, Idaho (all samples of geese greater than 8000 ppb ww, while mallard livers ranged from 340 ppb to 2800 ppb; Blus et al., 1995). In Spain 24% of waterfowl sampled had liver Pb concentrations greater than 5000 ppb, suggestive of lead poisoning (Mateo and Guitart, 2003). In our study, all liver levels of Pb were below the subclinical (2000–5900 ppb) and clinical poisoning levels (6000–15,000 ppb) (Friend, 1989; Pain, 1996).

While the muscle and liver Pb levels we found in Canada geese in the Meadowlands are within the same range or lower than those reported in many other studies (Burger et al., 1984; Henny et al., 1995; Beyer et al., 1998; Mateo and Guitart, 2003; Fedynich et al., 2007) the birds were collected at the end of the breeding season and were involved in active molt. Therefore they may have been actively mobilizing and sequestering their contaminant loads in feathers. Average levels of egg Pb, typically much lower than those in liver (Ohlendorf et al., 1989), were approximately 64% of the liver values in our study. This suggests that the birds likely sequester large amount of this contaminant in the egg as has been seen in Pb dosing studies (e.g. Jeng et al., 1997). Similarly, the high levels of Pb in feathers compared to other tissue imply that birds are successful at sequestering Pb in feathers.

The higher levels of Pb in tissues of Canada geese compared to insectivorous passerines in the Meadowlands (Tsipoura et al., 2008) and piscivorous birds (Burger, 2002a) was somewhat surprising considering that the geese forage at a lower trophic level. Studies in marine environments have shown some trophic level effects in concentrations of this metal in bird eggs although the relationships are not always clear (Burger and Gochfeld, 2000b; Burger, 2002a). Most marine organisms primarily accumulate Pb from the water as lead is not transferred efficiently through the marine food chain (Szefer, 1991; Dietz et al., 2000), although lead may be transferred more efficiently from marine animals to mammalian consumers (Regoli and Orlando, 1994). In Greenland, mussels had higher lead levels than fish, gulls, and ringed seals from the same ecosystem (Dietz et al., 2000). These studies indicate that Pb may not get biomagnified through the marine food chain and high concentrations of Pb may be found at the lowest trophic levels.

We found no significant differences in Pb levels between the three sites where these birds were sampled, although the Pb levels in muscle were somewhat higher at Mill Creek than at other sites (Table 1). Although there was a lot of variability in our samples and sample size was small, this implies that the elevated Pb levels in our samples may reflect elevated levels of this contaminant in geese throughout the NJ Meadowlands. Heavy metal concentrations in sediment in the New Jersey Meadowlands can exceed concentration levels that result in possible or probable effects on biota (Long et al., 1995; HMDC, 1997; Schulze, 1998; Barrett and McBrien, 2006). Barrett and McBrien (2006) found detectable levels of Pb in 98% of the sediment samples collected at Oritani Marsh in the Meadowlands, and of these more than half were above 47 ppm, which is the "effects range-low" value, the concentration at which biological effects were found in

10% of studies (Long et al., 1995). Similarly, 42% of sediment samples from Mill Creek, one of our surveys sites, exceeded the "effects range-low" value (HMDC, 1997). Heavy metals in sediments are taken up by *Spartina* and other marsh plants and are redistributed in the leaves or root systems (Weis and Weis, 2004). Herbivorous species like Canada geese that forage on spartina and other marsh plants may play an important role in the mobilization and transfer of heavy metals through the estuarine food web. In addition, Pb in sediments may be directly bioavailable to waterfowl. It has been shown that consumption of lead-contaminated sediments originating from mining operations along the Coeur d'Alene River (Idaho) is an important exposure route that can result in the accumulation of lead in tissues and adverse effects in waterfowl (Hoffman et al., 2000).

Another potential source for increased Pb levels in the Canada geese may be through ingestion of Pb shot or Pb fishing weights. Waterfowl are known to be subject and susceptible to poisoning from ingested Pb shot (Belrose, 1959; Mowbray et al., 2002; Pokras and Kneeland, 2008). Large waterfowl die-offs can potentially occur at a site when birds ingest Pb shot (Szymczak and Adrian, 1978; Kendall and Driver, 1982; Windingstad and Hinds, 1987). Ingestion of Pb shot was estimated to poison and kill up to 4% of the duck population nationwide, an estimated 1.6–2.4 million birds, the largest single source of mortality to wildlife (Friend, 1989; Fairbrother, 2009). Canada geese dying from ingestion of lead shot had liver levels above 6 ppm (Friend, 1989; Pain, 1996). In 1991, the USFWS instituted a ban on the use of this type of shot for hunting ducks and coots after being petitioned by conservation groups (Fairbrother, 2009). Waterfowl mortality levels have been declining with the conversion from Pb shot to non-toxic shot for waterfowl hunting, however, Pb shot deposited prior to the ban is still accessible in wetland sediments, and is being ingested by waterfowl in appreciable amounts (Anderson et al., 2000). In addition, lead sinkers used in fishing, result in increased Pb levels in waterfowl (Pokras and Chafel, 1992; Pokras and Kneeland, 2008; Pokras et al., 2009). Large amounts of Pb continue to be deposited in aquatic and terrestrial ecosystems where it can accumulate to appreciable mass over time (Rattner et al., 2009).

4.4. *Effects on predators and human food consumption*

Increased contaminant levels in birds of the Meadowlands District can impact predators that consume them, including humans. Generally, levels of most metals were not high, but we found levels of Pb in feathers, eggs and liver of Canada geese in the New Jersey Meadowlands that may be a cause for concern. Increased Pb levels in soft tissues of prey birds result in increased levels of this metal in the predators that consume them. A variety of raptor species have been exposed to or poisoned by Pb from predating or scavenging lead-shot game (Clark and Scheuhammer, 2003; Hunt et al., 2006,) and waterfowl (Pattee and Hennes, 1983; Pain et al., 1993; Kendall et al., 1996; Mateo et al., 1999; Miller et al., 2002; Pain et al., 2009). In wetlands where hunters have used Pb shot, raptors that feed on unretrieved game are more likely to ingest shot in their prey than those in wetlands with no hunting (Fisher et al., 2006). Studies have shown that Pb isotope ratios in eagles and waterfowl closely matched that for lead-shot pellets, corroborating the view that the ingestion of Pb shot is the main source of elevated tissue Pb in these species (Scheuhammer and Templeton, 1998). While we did not identify the source of elevated Pb in goose tissues, further study is needed to address concerns about the impacts of this metal on potential predators on waterfowl and their eggs in the NJ Meadowlands.

Since bans on Pb in gasoline, instituted primarily in the 1980s lead levels in northern hemisphere humans have declined dramatically (Pirkle et al., 1994, 1998; Verbrugge et al., 2009). However, indigenous people who rely on subsistence foods, especially in the Arctic, continue to have elevated blood lead levels, associated with ingestion of lead from spent ammunition (Tsuji et al., 2008; Verbrugge et al., 2009). In addition, large numbers of people may be at risk of lead exposure from recreational and subsistence hunting and fishing (Watson and Avery, 2009).

Levels of Pb in Canada goose eggs may be of concern for human consumption: three of the eggs had Pb levels over 0.5 ppm, the FDA action level for Pb in food products, and almost all had Pb levels over 0.1 ppm, the FDA action level for candy intended for use by infants and children (ATDSR, 2005, FDA, 2006). Similarly, goose liver had high Pb with 4 samples (15%) being greater than 0.5 ppm, and 20 samples (over 75% of the samples) greater than 0.1 ppm, the levels at which ingested food products may be harmful (ATDSR, 2005; FDA, 2006). While most human populations do not consume goose eggs, wild bird eggs are considered a delicacy among some of the Asian people who are recent immigrants to the NY area, and Canada geese are popular game birds (Burger, 2002b).

Usually the metal of most concern for consumption is Hg, but this was not the case in the tissues we analyzed in this project. The environmental quality standard for human consumption set for Hg by the US Food and Drug Administration (FDA) is 1.0 ppm (FDA, 2006, from Burger et al., 2008), while the more stringent European environmental standard is 0.3 ppm. Therefore, consumption of goose tissue with the Hg levels we report here would not pose a problem for humans in terms of the Hg levels.

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