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Assessment of metals in down feathers of female common eiders and their eggs from the Aleutians: arsenic, cadmium, chromium, lead, manganese, mercury, and selenium

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Abstract Concentrations of arsenic, cadmium, chromium, lead, manganese, mercury and selenium were examined in the down feathers and eggs of female common eiders (*Somateria mollissima*) from Amchitka and Kiska Islands in the Aleutian Chain of Alaska to determine whether there were (1) differences between levels in feathers and eggs, (2) differences between the two islands, (3) positive correlations between metal levels in females and their eggs, and (4) whether there was more variation within or among clutches. Mean levels in eggs (dry weight) were as follows: arsenic (769 ppb, ng/g), cadmium (1.49 ppb), chromium (414 ppb), lead (306 ppb), manganese (1,470 ppb), mercury (431 ppb) and selenium (1,730 ppb). Levels of arsenic were higher in eggs, while chromium, lead, manganese, and mercury were higher in feathers; there were no differences for selenium. There were no significant interisland differences in female feather levels, except for manganese (eider feathers from Amchitka were four times higher than feathers from Kiska). Levels of manganese in eggs were also higher from Amchitka than Kiska, and eider eggs from Kiska had significantly higher levels of arsenic, but lower levels of selenium. There were no significant correlations between the levels of any metals in down feathers of females and in their eggs. The levels of mercury in eggs were below ecological benchmark levels, and were below human health risk levels. However, Aleuts can seasonally consume several meals of bird eggs a week, suggesting cause for concern for sensitive (pregnant) women.

Keywords Birds · Eiders · Pollutants · Heavy metals · Mercury · Feathers · Aleutian Islands · Arsenic · Lead · Cadmium · Chromium · Selenium · Manganese

Introduction

Heavy metals enter the food chain through a variety of anthropogenic sources as well as from natural processes (Fitzgerald 1989). Once in the food chain, metals enter the body, and may be eliminated or accumulated. Birds can eliminate metals in their feathers (Braune 1987; Lewis and Furness 1991; Braune et al. 2002) and females can sequester metals in their eggs (Fimreite et al. 1974, 1982). The concentrations of metals in eggs are derived from females and represent recent exposure in waters close to the breeding grounds, as well as mobilization of stored metals from past intake (Fimreite et al. 1982; Burger 1994; Burger and Gochfeld 1996). Metals circulating in the blood at the time of egg-laying may be different from those that are available at the time of feather formation, especially for migratory species that moult away from the breeding grounds. Heavy metals in the breast feathers (and presumably the down feathers) represent circulating concentrations in the blood during the few weeks of feather formation, which in turn represents both local exposure and mobilization from internal tissues (Lewis and Furness 1991; Monteiro 1996).

Marine birds are useful as bioindicators of pollution (Gochfeld 1980; Walsh 1990; Peakall 1992; Furness 1993; Furness and Camphuysen 1997) because they are exposed to a wide range of chemicals and occupy high trophic levels, making them susceptible to bioaccumulation of pollutants (Lewis and Furness 1991; Burger and Gochfeld 2002; Nygard et al. 2001). Feathers are useful indicators of metal contamination because they are easy to collect non-invasively and to store indefinitely, birds sequester metals in their feathers, the proportion of body burden that is in feathers is relatively constant for each metal, a relatively high proportion of the body burden of certain metals is stored in the feathers (Goede and de Bruin 1986; Burger 1993) due to their affinity for the sulfhydryl rich keratin protein and melanin pigments, and there is usually a high correlation between levels of contaminants in the diet of seabirds and levels in their feathers (Burger 1993; Monteiro and Furness 1995).

In this paper we examine the levels of arsenic, cadmium, chromium, lead, manganese, mercury, and selenium in the down feathers and eggs of female common eiders (*Somateria mollissima*) from Amchitka and Kiska Islands in the Aleutian Chain of Alaska to determine whether there were differences between levels in feathers and eggs, or between the two islands, and whether levels in females and their eggs were correlated. We were also interested in whether there was more variation in metals levels within or among clutches. Eiders in the western Aleutians remain in the vicinity of the islands, moving offshore between October and April (Kenyon 1961); thus levels should reflect local exposure. Information on metal levels in breast feathers from both male and female eiders can be found in Burger and Gochfeld (2008, in press) and on radionuclide levels in eider muscle and eggs can be found in Burger and Gochfeld (2007).

Materials and methods

We collected samples from eiders nesting on Amchitka Island (Fig. 1, 51°N lat; 179°E long) and Kiska Island (51°N lat; 177°E long) in the Aleutian

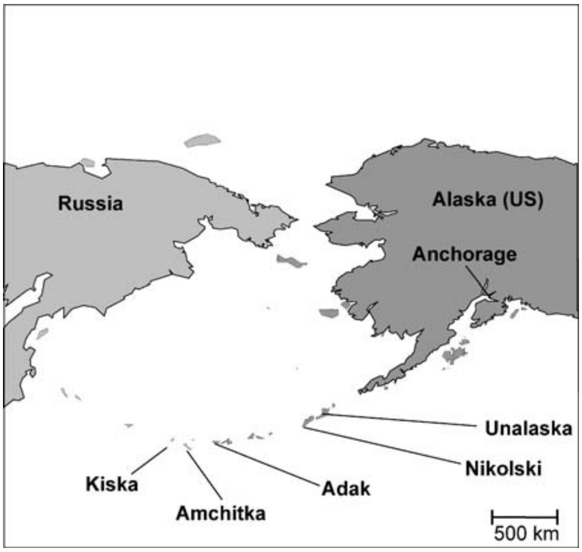

Fig. 1 Map showing location of Amchitka and Kiska Island where samples were collected

Chain of Alaska. Amchitka contains important ecological resources (Merritt and Fuller 1977; Burger et al. 2005, 2006a, b), and Kiska had the same benthic environments as Amchitka (Burger et al. 2006b). Amchitka is the only island where the USA detonated underground nuclear weapons tests (*Long Shot* in 1965, *Milrow* in 1969, and *Cannikin* in 1971). Amchitka is unusual among Department of Energy sites because of its remoteness, depth below ground surface of the radionuclide contamination, and the importance of its ecological resources and seafood productivity (Burger et al. 2006b). Kiska was occupied briefly by the Japanese military occupation during the Second World War, but has not been occupied since then. The collection sites on Kiska were about 140 km west of Amchitka. Both islands are part of the Alaska Maritime National Wildlife Refuge, originally established in 1913 by executive order of President Taft (ATSDR 2004).

Common eiders reach adult breeding plumage at 2 to 4 years (Goudie et al. 2000), and have a circumpolar breeding distribution (Goudie et al. 2000). They are highly marine and feed on invertebrates. On Kiska and Amchitka, common eiders breed in small colonies in tall grass along flat coastal zones.

Under appropriate state and federal permits, we collected down feathers from the nests of incubating females and eggs from the same nests in June and July 2007 (see Powers et al. 2005). Wayland et al. (2005) found that levels of cadmium, mercury and selenium can vary by time of the year, so time of year should always be noted. We collected feathers and eggs from 30 females. We collected one eggs from each nest, unless the nest was abandoned, and then we collected the whole clutch to examine for interclutch variations (N=8). All samples were collected in July. Feathers were placed in individual envelopes and labeled for later identification, and eggs were frozen whole. Both were then shipped to Rutgers University for analysis.

Breast feathers were selected because they are considered to be more representative of exposure to metals than are other feathers, and the mercury in feathers is methylmercury (Furness et al. 1986; Burger 1993). Metals enter feathers during the 2–3 weeks it takes for them to grow; then the blood supply atrophies, and there is no further deposition of metals (Burger 1993; Thompson and Furness 1998). Thus, feathers are an archive of metal exposure during feather formation (Braune and Gaskin 1987).

All feathers were analyzed in the Elemental Analysis Laboratory of the Environmental and Occupational Health Sciences Institute in Piscataway NJ. Feathers were washed three times with acetone, alternating with deionized water. Eggs were homogenized and dried to a constant weight (moisture content averaged 65.5%). Then samples were digested individually in nitric acid using a microwave (MD 2000 CEM), and subsequently diluted with deionized water. Mercury was analyzed by cold vapor technique, and the other elements were analyzed by graphite furnace atomic absorption (Burger and Gochfeld 1991). All concentrations are expressed in nanograms per gram (parts per billion) on a dry weight basis. Detection limit ranges were: 0.02 ppb for cadmium, 0.08 ppb for chromium, 0.15 ppb for lead, 0.09 ppb for manganese, 0.2 ppb for mercury, and 0.7 ppb for selenium. All specimens were analyzed in batches with known standards, calibration standards, and spiked specimens. Recoveries ranged from 88 to 102%. Batches with recoveries of less than 85% were reanalyzed. The coefficient of variation on replicate, spiked samples ranged up to 10%.

Kruskal–Wallis non-parametric analysis of variance was performed using the SAS PROC NPAR1-WAY with the Wilcoxon option yielding a chi square statistic (SAS 1995). Both arithmetic and geometric means are given to facilitate comparisons with other studies. We accept a probability level of 0.05 as significance, but in view of sample size limitations present all probability values below 0.10 to allow the reader to assess significance for themselves.

Results

There were significant differences between the metal levels in eider eggs and feathers (Table 1). Arsenic levels were higher in the eggs, while cadmium, chromium, lead, manganese, and mercury were higher in feathers. There were no differences for selenium.

For feathers, there were no significant interisland differences, except for manganese (Table 2). Eider feathers from Amchitka were four times higher than the feathers from eiders collected at Kiska. The levels of manganese in eggs were also higher from Amchitka than Kiska, but the differences were smaller. Eider eggs from Kiska had significantly higher levels of arsenic, but lower levels of selenium (Table 2).

Table 1 Metal levels (ppb, dry weight)(ng/g) in eggs and feathers of female common eiders from the Aleutian Islands

	Common eider feathers	Common eider eggs	χ^2 (p)
	n=30	n=52	
Arsenic	161±19.0	769±69.9	39.7 (<0.0001)
	107	585	
Cadmium	27.3±4.81	1.49±0.40	25.4 (<0.0001)
	4.71	0.11	
Chromium	1,780±111	414±62.2	43.9 (<0.0001)
	1,700	303	
Lead	530±66.5	306±99.5	31.9 (<0.0001)
	456	80.9	
Manganese	10,500±2,250	1,470±94.6	35.0 (<0.0001)
	5,800	1,280	
Mercury	980±144	431±21.8	9.3 (0.002)
	660	401	
Selenium	1,610±117	1,730±135	(NS)
	1,470.0	1,500.0	

Given are arithmetic means ±SE (geometric means below) with Kruskal–Wallis chi-square values and p values.

Table 2 Metal levels (ng/g=ppb dry weight) in feathers and eggs of common eider collected from Amchitka and Kiska

Common Eider	Amchitka	Kiska	χ^2 (p)
Feathers	n=22	n=8	
Arsenic	163±23.8	156±30.7	0.0 (NS)
	100	131	
Cadmium	28.3±5.7	24.8±9.46	0.1 (NS)
	4.27	6.14	
Chromium	1,790±114	1,740±281	1.1 (NS)
	1,730	1,630	
Lead	489±55.5	642±202	0.1 (NS)
	436	515	
Manganese	13,100±2,860	3,370±833	5.0 (0.03)
	7,550	2,820	
Mercury	886±157	1,240±323	0.3 (NS)
	625	766	
Selenium	1,600±154	1,640±127	0.0 (NS)
	1,430	1,600	
Eggs	n=35	n=17	
Arsenic	612±58.1	1,080±151	7.8 (0.005)
	517	750	
Cadmium	1.44±0.49	1.59±0.7	0.2 (NS)
	0.09	0.16	
Chromium	497±89.7	248±22.6	3.3 (0.07)
	346	233	
Lead	332±132	254±143	0.5 (NS)
	79.1	84.8	
Manganese	1,710±114	1,000±98.6	14.0 (0.0002)
	1,540	881	
Mercury	413±18.9	466±53.6	0.5 (NS)
	400	403	
Selenium	2,100±166	992±78.9	20.0 (<0.0001)
	1,900	935	

For each metal the first row gives arithmetic mean± standard error, and the second row gives the geometric means. Comparison are with Kruskal–Wallis non-parametric analysis of variance yielding chi-square statistics and (p values)

There were few significant correlations among metals levels for either feathers (2 of a possible 21) and for eggs (4 of 21). Selenium and mercury levels were not correlated in feathers or eggs, although with larger sample sizes the correlation may have been significant for eggs (Table 3). Selenium and mercury concentrations are often positively correlated, because of the mercury–selenoprotein complex which can decrease the bioavailability of mercury in the organism (DeCampo et al. 2002).

There were no significant correlations between the levels of any metal in eggs and feathers. Variation among the eight clutches is shown in Table 4; there was variation among clutches, even within clutches of two and three eggs. The pattern of variation, however, was complex. The largest clutch (# 34) had the lowest variation (less than the mean for all clutches) for chromium and lead. The smallest clutches (# 2 and 23) had the lowest variation for lead and mercury, as well as both lowest and the highest variation for cadmium. The clutch with the least variation (# 35) had three eggs. These smaller clutches were likely due to either early abandonment or to failure of some eggs to hatch.

Discussion

Differences between feathers and eggs of common eiders

We found that metal levels in eider eggs were significantly higher than levels in feathers only for arsenic and cadmium, and levels were higher in feathers than eggs for chromium, lead, manganese, and mercury. There are very few studies that compare levels of metals in feathers and eggs in the same year. However, Burger and Gochfeld (1996) examined levels of metals in Franklin's gull (*Larus pipixcan*) feathers and eggs and found that levels of cadmium, lead, mercury and manganese were higher in parents, while selenium and chromium were higher in eggs than in parental feathers. Thus, in both cases, selenium and chromium were higher in eggs, and lead and mercury were higher in feathers than eggs. These differences reflect accumulation differences as a function of tissues. For example, mercury is sequestered mainly in feathers compared to other tissues (Furness et al. 1986; Burger 1993).

In a related study examining radionuclides and metals in eiders (both males and females) from these same islands, we found that lead levels were higher and manganese levels were lower on Kiska compared to Amchitka (Burger and Gochfeld 2007, in press). In the present study of only females, only manganese differed significantly in feathers.

Relationship of metals in female eiders and their eggs

Since females can sequester heavy metals in their eggs (Fimreite et al. 1974, 1982; Burger and Gochfeld 1991, 1996, 2004), we expected to find a positive correlation between the levels of heavy metals in females and their eggs. However, we found no significant correlations between the level of any metal in the feathers of females and their eggs. In contrast, in a study of Franklin's gulls (*Larus pipixcan*), there was a positive correlation between females and their eggs for mercury, and a negative correlation for chromium and manganese (Burger and Gochfeld

Table 3 Inter-metal correlations for female common eiders from Amchitka and Kiska Islands combined

	Arsenic	Cadmium	Chromium	Lead	Manganese	Mercury	Selenium
Arsenic	–	*	*	*	*	*	*
Cadmium	*	–	*	*	*	*	*
Chromium	−0.2 (0.07)	*	–	0.3 (0.05)	*	0.4 (0.006)	*
Lead	*	*	*	–	*	0.2 (0.08)	*
Manganese	*	*	0.2 (0.05)	*	–	*	0.2 (0.08)
Mercury	*	*	*	*	*	–	*
Selenium	−0.2 (0.02)	*	0.2 (0.02)	*	0.3 (0.002)	0.2 (0.09)	–

Kendall tau correlations (*p* values) for feathers (n=30) are above the diagonal and for eggs (n=52) below.

*p values >0.10.

Table 4 Variation in metals in eggs of eiders from the same nest

Nest #	Number of eggs	Metal	Mean±SE	SE	Min	Max
All 8 clutches	25	As	941±94.4		15.2	2,060
		Cd	1.78±0.57		0.01	10.3
		Cr	345±62.2		79.0	1,690
		Pb	456±180		2.90	3,800
		Mn	1,500±132		109	2,830
		Hg	422±36.1		52.5	922
		Se	1,730±227		319	5,200
1	3	As	743±203		350	1,030
		Cd	0.77±0.76		0.01	2.30
		Cr	271±150		79.0	567
		Pb	37.0±4.00		33.0	45.0
		Mn	2,380±292		1,840	2,830
		Hg	518±91.6		366	683
		Se	2,120±594		1,430	3,310
2	2	As	1,400±124		1,280	1,530
		Cd	0.51±0.50		0.01	1.00
		Cr	308±114		194	422
		Pb	37.5±0.50		37.0	38.0
		Mn	1,170±564		610	1,740
		Hg	350±37.8		312	388
		Se	2,320±631		1,690	2,950
23	2	As	604±380		224	985
		Cd	3.36±3.35		0.01	6.70
		Cr	980±711		269	1,690
		Pb	98.5±0.50		98.0	99.0
		Mn	1,540±193		1,350	1,730
		Hg	261±6.75		254	268
		Se	1,460±357		1,100	1,810
24	3	As	856±95.5		667	976
		Cd	0.01±0.00		0.01	0.01
		Cr	319±96.9		216	513
		Pb	1,760±1,090		84.0	3,800
		Mn	2,171.08±147.51		1,994.23	2,460
		Hg	404±50.1		333	501
		Se	2,270±84.6		2,120	2,410
25	4	As	645±96.9		456	908
		Cd	2.87±1.59		0.01	5.50
		Cr	412±46.3		310	533
		Pb	1,120±496		33.0	2,300
		Mn	1,780±151		1,413	2,140
		Hg	451±18.4		398	480
		Se	3,190±825		1,770	5,200
33	3	As	905±469		15.2	1,610
		Cd	0.27±0.26		0.01	0.80
		Cr	284±94.2		176	472
		Pb	172±134		37.0	440
		Mn	808±360		109	1,310
		Hg	202±75.4		52.5	295
		Se	647±175		319	918
34	5	As	1,030±197		491	1,460
		Cd	3.42±1.97		0.01	10.3
		Cr	235±39.0		149	381

Table 4 (continued)

Nest #	Number of eggs	Metal	Mean±SE	SE	Min	Max
		Pb	134±32.7		73.0	240
		Mn	948±184		517	1,540
		Hg	612±109		390	922
		Se	1,050±125		702	1,40
35	3	As	1,420±322		1,000	2,060
		Cd	2.04±1.56		0.01	5.10
		Cr	197±27.8		147	243
		Pb	26.3±19.5		2.90	65.0
		Mn	1,370±130		1,140	1,580
		Hg	366±28.5		325	421
		Se	822±62.2		698	897

1996). Similarly, Burger and Gochfeld (1991) found a positive relationship for female common terns (*Sterna hirundo*) and their eggs for cadmium and lead. One possibility is that levels are lower in eiders than in gulls and terns, which are higher on the food chain (they normally eat fish or other organisms; Burger 2002). We cannot otherwise account for the lack of correlation between females and their eggs in this study, and suggest that these relationships need further study.

Intra clutch variation

One objective of the study was to examine variation in metals levels within and among clutches. For most metals, two or three clutches showed less variation (SE) than the overall mean, and most had greater variation than the mean for these clutches (refer to Table 4). However, for manganese, only one clutch of three eggs showed less variation than the mean SE. Further, the clutches with more eggs (four or five) did not show more variation than those with two or three eggs. We had expected that variation would be greater among clutches than within a clutch for all metals, but this was not the case.

In most cases, the clutches we collected were likely not full clutches since clutch size averages around five eggs. The eggs we did collect were likely either eggs that were abandoned before the full clutch was laid, or were those that had failed to hatch. Our data thus suggest that a future study of variation within clutches should collect full clutches early in incubation, and should limit collection to clutches close to the mean size for this species.

Geographical comparisons

In a previous study we examined the levels of metals in male and female eiders, and compared them to other geographical areas (Burger and Gochfeld 2008, submitted). However, that paper did not examine eggs, which provide perhaps the best comparison because they represent local exposure; female eiders are close to their nest areas or in the region in the weeks before egg-laying. The following discussion is thus limited to levels of metals in eggs, and we compare levels in ppm because the other studies used this metric).

There are comparative data for common eiders in the Canadian Arctic (Mallory et al. 2004). They reported the following ranges of means for eider eggs in different locations: cadmium (non-detect, through <0.3 to 1 ppm, dry weight), lead (non-detect to 0.27 ppm), and mercury 0.33 to 0.64 ppm). Thus, the levels from Amchitka 0.08, 0.21, and 0.43 ppm respectively) were similar or lower than those reported for the Canadian Arctic. Further, Fisk et al. (2005) reported that the levels found in eiders in Nunavut were not adversely influencing the health of the eiders. In eastern Canada, average mercury levels in eider eggs in the early 1970s ranged from 0.03 to 0.08 ppm (Pearce et al. 1979).

In coastal Maine, mercury levels in eider eggs (mean of 0.12 ppm, wet weight,=ca. 0.4 dry weight) were also below ecological screening benchmark levels (0.50 ppm, wet weight, Mierzykowski et al. 2005). In the Aleutians, mercury levels (0.14 ppm, wet weight) were lower than those found in coastal Maine. In Finland, Franson et al. (2000) reported that mercury levels in common eider eggs were 0.55 ppm wet weight, and selenium levels were 0.10 ppm (compared to 0.14 ppm and 0.570 respectively). In the Barents Sea, levels of mercury in common eider eggs averaged 0.06 ppm (Barrett et al. 1996), well below the level from the Aleutians, and the effects levels.

These, and other studies with metals and eggs, indicate that one problem is the use by different researchers of wet and dry weight. Often, the conversion is not given in the papers, making it difficult to extrapolate between studies. Especially when dealing with bird eggs it is critical to give wet weight, or the conversion for those particular eggs, because seabird eggs are often delicacies among native and subsistence peoples. In this study eider egg contents averaged 65.5% moisture content leading to a 3:1 conversion factor from dry to wet weight.

Potential adverse health effects

Mercury is the primary metal of concern in terms of health effects on organisms themselves and on the predators that might consume them (Furness and Rainbow 1990; Burger and Gochfeld 1997). Mercury levels in eggs are normally between 10 and 20% of those in liver (Ohlendorf et al. 1978), suggesting that liver levels in eiders from the Aleutians may be approximately 1,400 ppb wet weight, which is below the known effects level of over 3,000 ppb (Fisk et al. 2005). This suggests that the eiders themselves are not affected by mercury.

Metal levels in eggs of eiders (431 ppb dry weight; 140 ppb wet weight), eaten by a range of avian predators, were below the range known to affect avian predators (1,000 ppb, Eisler 1987). Further, seabirds seem less vulnerable to mercury than other birds (Thompson and Furness 1989). However, sensitive birds can exhibit effects at dietary mercury concentrations of 50 to 500 ppb, and sensitive mammals can exhibit harmful effects at dietary levels of 1,100 ppb Eisler 1987; WHO 1990, 1991). Thus, we did not find any cause for concern for trophic level exposure.

Additionally, there is no cause for concern for human exposure from mercury in eggs of eiders even though they are a delicacy for Aleuts. The levels in eider eggs (0.14 ppm, wet weight) are below human health standards. Methylmercury is one of the main contaminants of concern for subsistence foods. The USFDA action level for methylmercury in fish (which should be similar for other foods) is 1.0 μg/g (ppm wet weight, FDA 2005), a regulatory action level rather than a risk level. In 1982 the European Commission set an Environmental Quality Standard for mercury; the mean concentration in mercury of a representative sample of fish shall not exceed 0.3 ppm (wet weight). The US EPA (2001) promulgated 0.3 ppm as an ambient freshwater quality standard in 2001. Nonetheless, caution should be applied by subsistence consumers if they are eating several meals of eider eggs a day or week, particularly during pregnancy.

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