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ORIGINAL ARTICLE

Metals and radionuclides in birds and eggs from Amchitka and Kiska Islands in the Bering Sea/Pacific Ocean ecosystem

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Abstract Metals and radionuclide levels in marine birds of the Aleutians are of interest because they are part of subsistence diets of the Aleut people, and can also serve as indicators of marine pollution. We examined geographic and species-specific variations in concentrations of radionuclides in birds and their eggs from Amchitka, the site of underground nuclear tests from 1965 to 1971, and Kiska Islands (a reference site) in the Aleutians, and the levels of lead, mercury and cadmium in eggs. In 2004 we collected common eiders (*Somateria mollissima*), tufted puffins (*Fratercula cirrhata*), pigeon guillemot (*Cepphus columba*) and glaucous-winged gulls (*Larus glaucescens*) from Amchitka and Kiska, and eggs from eiders and gulls from the two island. We also collected one runt bald eagle (*Haliaeetus leucocephalus*) chick from both Amchitka and Kiska Islands. For most species, the levels of radionuclide isotopes were below the minimum detectable activity levels (MDA). Out of 74 cesium-137 analyses, only one composite (gulls) was above the MDA, and out of 14 composites tested for plutonium (Pu-239, 240), only one exceeded the MDA (a guillemots). Three composites out of 14 tested had detectable uranium-238. In all cases, the levels were low and close to the MDAs, and were below those reported for other seabirds. There were significant interspecific differences in metal levels in eggs: gulls had significantly higher levels of cadmium and mercury than the eiders, and eiders had higher levels of lead than gulls. There were few significant differences as a function of island, but eiders had significantly higher levels of cadmium in eggs from Kiska, and gulls had significantly higher levels of mercury on Kiska. The levels of cadmium and mercury in eggs of eiders and gulls from this study were above the median for cadmium and mercury from studies in the literature. The levels of mercury in eggs are within the range known to affect avian predators, but seabirds seem less vulnerable to mercury than other birds. However, the levels of mercury are within the action levels for humans, suggesting some cause for concern if subsistence Aleuts eat a large quantity of eggs.

Keywords Birds · Eggs · Radionuclides · Mercury · Lead · Human consumption · Risk

1 Introduction

Increasingly the public, governmental agencies, conservationists, researchers and public policy makers are

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interested in assessing the health and well-being of the environment. Contaminants are one important environmental stressor of concern that derive from geological and oceanic processes, as well as from anthropogenic sources, including industrial emissions, agricultural runoff and effluents (Mailman, 1980). Atmospheric transport and deposition contribute to local sources (Fitzgerald, 1989). Once in aquatic environments, contaminants enter the food chain by different routes, and with each step in the food chain, there is the potential for bioamplification, particularly for mercury (Lewis and Furness, 1991). Contaminants, such as metals and radionuclides, can have adverse effects on the health and well-being of organisms, including humans, creating the need for information on contaminant trends.

Top-level carnivores are often used as bioindicators because they are exposed to higher levels of contaminants than species that are lower on the food chain (Monteiro and Furness, 1995). Seabirds are ideal indicators of environmental contaminants because they are often at the top of food chains, are common and widespread, numerous, long-lived, and are of interest to the public (Monteiro and Furness, 1995; Thompson and Furness, 1998; George, 1999; Burger and Gochfeld, 2000, 2001). While there is a voluminous literature on metal and organochlorines in marine birds (Burger and Gochfeld, 2001), there is much less on radionuclides (Brisbin, 1991); still fewer studies examine two of these classes at once, especially in areas where radionuclide exposure may have occurred.

In the 1960's Amchitka Island was chosen by the Atomic Energy Commission (a predecessor of the Department of Energy) for nuclear testing. *Cannikin*, the last and largest shot (ca 5 megatons), had an elevator shaft that was over 1800 m below the surface, and the blast and resulting chimney collapse formed a new lake (Cannikin Lake) on the island surface. The three Amchitka test shots accounted for about 16% of the total energy released from the US underground testing program, and *Cannikin* was the largest U.S. underground blast (Robbins *et al.*, 1991; Norris and Arkin, 1995; DOE, 2000). Although there was some release of radioactivity to the surface, the leaks were not considered to pose serious health risks at the time (Seymour and Nelson, 1977; Faller and Farmer, 1998). Since Amchitka Island is in one of the most volcanically and seismically active regions of the world (Jacob, 1984; Page *et al.*, 1991), stakeholders are concerned that earthquakes could open pathways into the sea and marine food webs (Kohlhoff, 2002). BEST (2003) noted that over 40% of all the United States fish and shellfish landings (by weight) derive from the Eastern Bering Sea (including Dutch Harbor). This fish/shellfish community also serves as the food base for many marine birds, as well as for subsistence fishing by Aleuts (NRC, 1996; Jewett, 2002; Patrick, 2002; Hamrick and Smith, 2003). Some of the most abundant and diverse seabird communities breed in the Northern Pacific/Bering Sea ecosystem (Kenyon, 1961; Rocque and Winker, 2004). Thus there is interest not only in ascertaining the levels of radionuclides in marine biota around Amchitka, but in assessing particular organisms as potential bioindicators of future exposure.

In this paper we report on the levels of radionuclides and metals in seabirds and their eggs from near Amchitka and Kiska Islands in the Aleutian Chain in the Bering Sea/Northern Pacific. We studied the birds living on Amchitka Island as part of an assessment of possible radioactive contamination from the underground nuclear tests, and Kiska was selected as a reference site because of the similarity of its marine communities to those at Amchitka. A major concern of stakeholders is that the radioactive residues in the underground cavities could migrate through porous rock or through faults and fractures to reach the sea and contaminate the marine food chain. A Department of Energy (DOE) groundwater model predicted that such breakthrough of radionuclides to the sea might occur between 10 and 1000 years after the tests (DOE, 2002), making it important to examine biota for evidence of possible radionuclide seepage into the marine environment. This was one of the overall objectives of the CRESP expedition which collected marine algae, invertebrates and fish as well as birds; no clear evidence of such breakthrough was identified in 2004 (Powers *et al.*, 2005).

We examined several radioisotopes in tissues of common eiders (*Somateria mollissima*), tufted puffins (*Fratercula cirrhata*), pigeon guillemots (*Cepphus columba*) and glaucous-winged gulls (*Larus glaucescens*), and in eggs from eiders and gulls from the two islands in 2004. We also collected one runt bald eagle (*Haliaeetus leucocephalus*) chick from nests on each island. Eagles were collected as a screen for radionuclides, and to compare with previous work (Anthony *et al.*, 1999). We also examined the levels of lead, mercury and cadmium in the eggs of gulls and eiders; these three metals are contaminants of

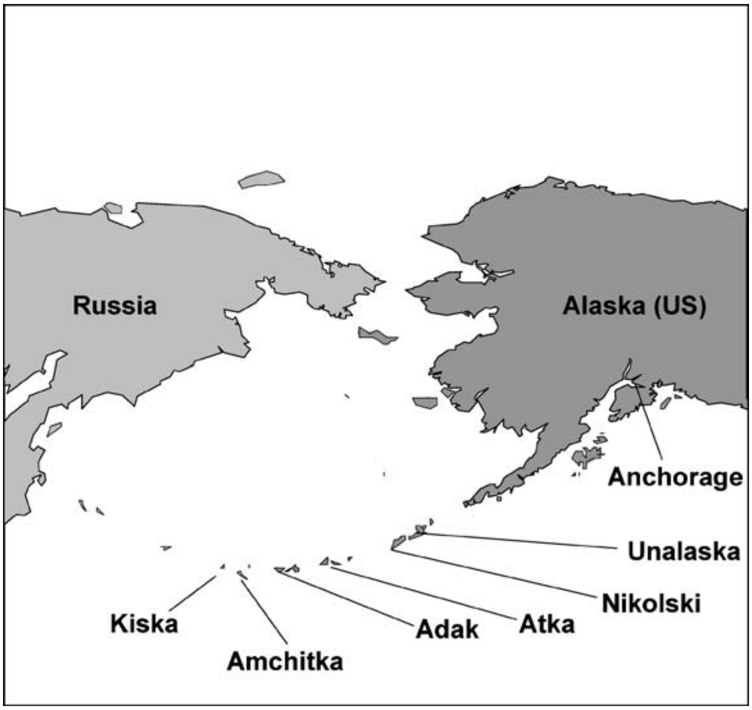

Fig. 1 Map showing the location of Amchitka and Kiska Islands in the Aleutians, Alaska.

widespread concern in marine ecosystems (Mailman, 1980). We test the null hypotheses that there were no differences as a function of species and location (Kiska vs Amchitka), but hypothesized that radionuclide levels would be higher at Amchitka because of previous nuclear testing. Amchitka Island was the site of three underground nuclear tests from 1965–1971, and both islands were occupied by the military during World War II (Kiska was occupied by the Japanese). We were also interested in comparing the levels of metals and radionuclides to those for other seabirds, and in determining whether concentrations posed a health risk to themselves or consumers. This report is part of a larger project of the Consortium for Risk Evaluation with Stakeholder Participation (CRESP), an independent, multi-university consortium of researchers, to evaluate radionuclides in the marine environment around Amchitka Island (Powers *et al.*, 2005).

2 Study area and methods

2.1 Study site

Amchitka Island is in the DOE complex (Crowley and Ahearne, 2002), and is part of the Alaskan Maritime National Wildlife Refuge, administered by the U.S. Fish and Wildlife Service. The marine biological resources in the region are of high value in cultural, commercial, and ecological terms (Merritt and Fuller, 1977; NRC, 1996). Amchitka was a military base during World War II, used as a staging area to drive the Japanese off of nearby Kiska Island, and was subsequently used for underground nuclear testing. Glaucous-winged gulls had nesting colonies over and around each nuclear test site on Amchitka, and the other species nested along the shore on sea cliffs or on offshore islets.

Kiska Island contains many of the same terrestrial and benthic environments as Amchitka. Although it did not experience any underground nuclear tests, both the Japanese and later the U.S. occupied the island during World War II. The marine benthic resources around Kiska Island have not been described extensively (Burger *et al.*, 2006a). Both islands are bordered on the south by the North Pacific and on the north by the Bering Sea (Fig. 1).

2.2 Protocol

Birds were collected under appropriate state and federal permits from both Amchitka and Kiska Islands in a balanced design (20–30 adults from each island) from late June–July 2004 (Fig. 2). We also collected 20 gulls chicks from each island, and eggs where possible. Gulls (adults, eggs, chicks) were attributed to one of the three test shots because they were collected at colony sites located at each test shot. Adult gulls on Amchitka and Kiska normally obtain their food from the marine environment in the vicinity of the colony.

All specimens were tracked from field to their ultimate destination with chain of custody forms. In the shipboard laboratory, birds were dissected, weighed, measured, and muscle was removed and labelled. Avian tissue and eggs were then immediately frozen for later analysis. Radionuclide analyses were conducted on composites of 5 individuals each (eggs and birds), and metal analyses were conducted on individual eggs. Composites were selected on the basis of collection location and age (adult vs young of the year). That is, organisms were composited from the same location (where location = the three test shot regions and Kiska). Samples were prepared for analysis and homogenized in a radio-clean and metal-clean laboratory at Rutgers University, and subsequently analyzed for metals at Rutgers University and for radionuclides at Vanderbilt University and Idaho National Laboratory (INL).

Radionuclide analysis. Our radionuclide analysis design was based on trophic level considerations, and sample availability and quantity. Detailed analytic and quality assurance methods are published on the CRESP website (CRESP, 2005). We analyzed radioac-

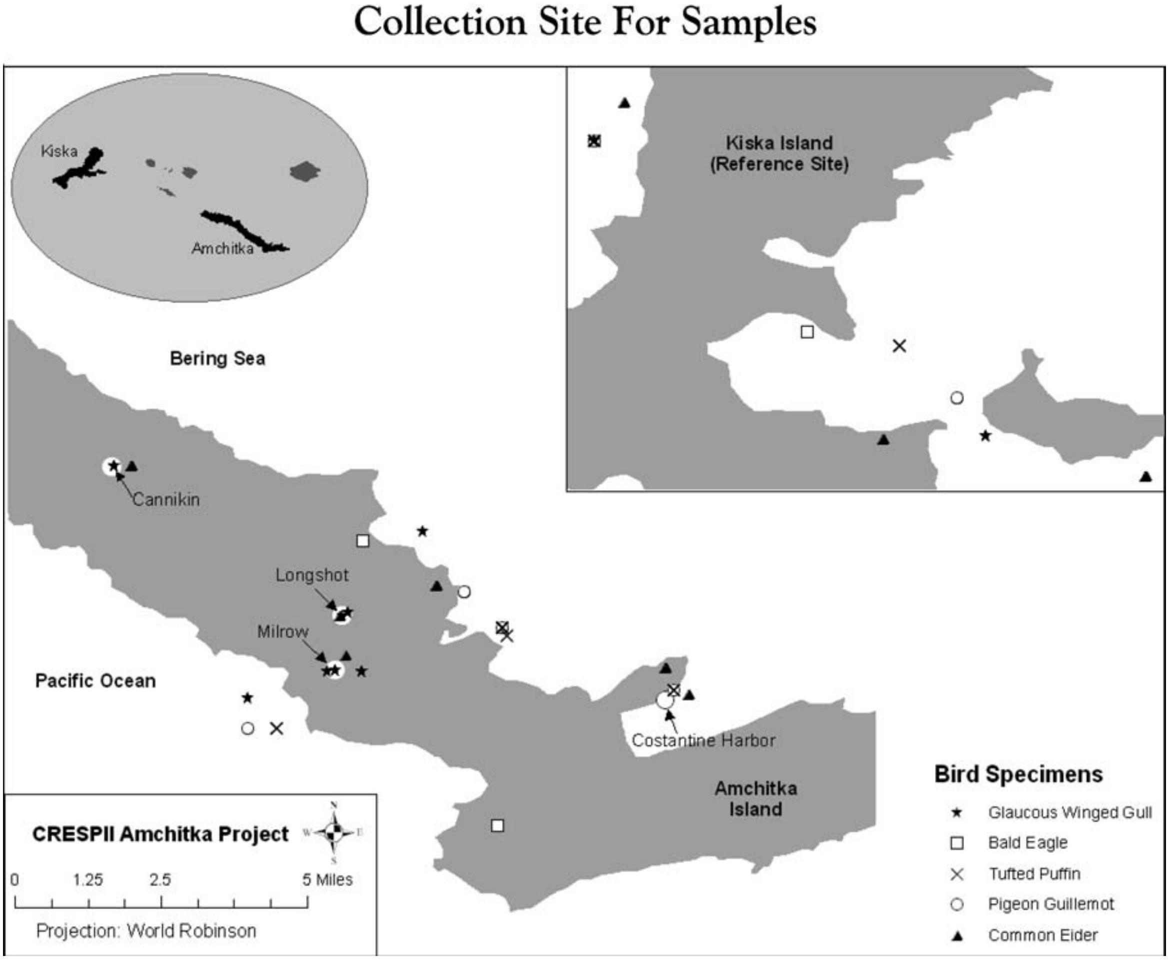

Fig. 2 Map showing the locations of collection of specimens for the study of radionuclides and metals on Amchitka and Kiska Islands, Aleutians, Alaska.

Table 1 Number of analyses for birds from Amchitka and Kiska Islands, shown are 100 g samples; we also analyzed some 1000 g samples to achieve lower Minimum Detectable Activity levels (shown in parenthesis). All 100 g samples contained 5 individuals[a]. No Pigeon Guillemots were analyzed with 1000 g samples due to their small size

Species	Tissue	Cs-137	I-129	Co-60	Eu-152	Sr-90	Alpha[d]	Tc-99
Source		anthro-pogenic	anthro-pogenic					
Common Eider	Muscle	4 (2)	(2)	4 (2)	4 (2)			
	Egg[c]	6 (2)	3 (2)	6 (2)	6 (2)	3		3
Pigeon Guillemot	Muscle	7	3	7	7	3		3
	Bone	3		3	3	3	3	
Tufted Puffin	Muscle	6 (2)	3 (2)	6 (2)	6 (2)	3		3
	Bone	3		3	3	3	3	
Glaucous-winged Gull[b]	Muscle	18(2)	8 (2)	18(2)	18(2)	8		8
	Bone	8		8	8	8	8	
	Egg	(2)	(2)	(2)	(2)			
Bald Eagle[c]	Muscle	(2)	(2)	(2)	(2)			

[a] From 7–15 eggs were necessary for the 1000 g samples.
[b] Half of 100 g samples were adults, and half were chicks
[c] Only 2 individual Bald Eagle chicks were analyzed.
[d] Consists of americium, plutonium and uranium.

tive cesium (Cs-137), iodine (I-129), cobalt (Co-60), europium (Eu-152), strontium (Sr-90), technetium (Tc-99), americium (Am-241), plutonium (Pu-238, Pu-239, 240), and uranium (U-234, U-235, U-236, U-238). The rationale for our radionuclide analyses are provided in Powers *et al.* (2005). Analyses at Vanderbilt and INL provided inter-laboratory validation. Gamma emitters (Cs-137, Eu-152, Co-60) were analyzed using gamma spectroscopy with high purity germanium detectors calibrated to the standard container geometry. I-129 was analyzed by low energy photon measurement. The beta emitter Sr-90 was analyzed by its daughter decay product, yttrium-90. Counts were adjusted for background counts, and the Minimum Detectable Activity (MDA) was ±2 SD background. The actinides (uranium, plutonium, americium) were quantified using radiochemical techniques and alpha spectroscopy. Due to high analysis costs, not all tissues and eggs were analyzed for all radionuclides (see Powers *et al.*, 2005). For example, we analyzed only bone for actinides because they concentrate in bone, assuring that we would find actinides if they were present (we might have missed some low actinide levels if we analyzed only muscle). Initially for gamma emitters we counted 100 g samples for 24 hrs, but all results were below the MDA. To enhance sensitivity, we also analyzed 1000 g samples for 72 hrs. MDAs for cesium-137 ranged from 2.74-4.39 Bq/kg for 100 g samples, and 0.10–0.29 Bq/kg for 1000 g samples. Our analysis stream for radionuclides is shown in Table 1. All values are presented in Bq/kg, wet weight in text and tables.

Metal analysis. Due to the timing of our expedition (July) and the cliff-nesting habits of the guillemots and puffins, we were only able to collect eggs from gulls and eiders. In the laboratory, egg contents were emptied into acid-washed weigh boats, weighed, and digested and analyzed in the Elemental Laboratory at the Environmental and Occupational Health Sciences Institute in Piscataway, New Jersey. Whole egg contents were homogenized and digested individually in 70% nitric acid within microwave vessels for ten min at 150 pounds per square inch (10.6 kg/sq cm), and subsequently diluted with deionized water. Mercury was analyzed by cold vapor atomic absorption spectrophotometry and other metals were analyzed by graphite furnace (flameless) atomic absorption.

Mercury was analyzed as total mercury, of which about 90% is assumed to be methylmercury. All concentrations are expressed in ng/g (parts per billion) on wet weight basis (multiply concentration by 3 to obtain an approximate dry-weight equivalent, Burger, 1993). Instrument detection limits were 0.02 ppb for cadmium, 0.15 ppb for lead, 0.2 ppb for mercury, but matrix detection limits were about an order of magnitude higher. All specimens were run in batches that included a standard calibration curve and spiked specimens. The accepted recoveries on spiked specimens ranged from 85% to 115%. The C.V. (coefficient of variation) on replicate samples was usually less than 10% and discrepancies were re-analyzed.

Methodological considerations. With metal analysis, the detection limits are set by the capabilities of the instrumentation as well as interferences in the matrix, and are effectively the same for all analyses of a particular tissue (see above). However, for radionuclides, the Minimum Detectable Activity levels (MDAs) are a function of counting times and sample mass. That is, to achieve lower MDAs, it is necessary to increase sample mass, increase counting times, or both. Our initial analysis strategy for radionuclides was to use 100 g samples (24 hour counts), determined on the basis of achieving MDAs that were well below acceptable human health guidelines and known health effects levels (Powers *et al.*, 2005). However, having all non-detectable levels does not provide any information on which species might be most useful as a bioindicator for future biomonitoring. That is, if all bird species we examined had non-detectable levels of radionuclides, it would not be possible to know which species might be most useful for future collection and analysis. Therefore, we also analyzed some 1000 g samples of all five species for 72 hours, thus decreasing our MDAs by an order of magnitude. Nonetheless very few counts exceeded the MDA.

Even with large samples, and long counting times, it is sometimes difficult to achieve low MDAs. For example in a recent study of eiders, Trust *et al.* (2000) achieved a mean MDA of 79 Bq/kg. Our mean MDAs for the 100 g samples ranged from 2.74 to 3.12 (24 hr counts), but for the 1000 g samples they ranged from 0.10 to 0.66 (72 hr counts). This illustrates the problem of optimizing counting times, sample quantities, and costs. However, it is more difficult to collect enough sample to prepare and homogenize 1000 g of avian muscle, and it takes more preparation time and money to do so. Going from 24 to 72 hr counts, obviously, increases analysis time per specimen three-fold. Even with these difficulties, however, Thomas and Gates (1999) proposed that birds and mammals were the most cost-effective and robust method of environmental monitoring for radionuclides.

Finally, compositing partly dilutes the effect, since if one value is much higher than the others, they are essentially averaged over the entire sample. A very high level, however, would bring all the radionuclide levels above the MDA. Only the radionuclide samples were composited, largely because of the very high costs associated with these analyses.

Data analysis. Metals data were right skewed, and were analyzed by Kruskal-Wallis non-parametric one way ANOVA using PROC NPAR1WAY in SAS with the Wilcoxon option (SAS, 1995). We accepted a $P < 0.05$ as our significance level. For computing mean concentrations of metals, we used the values above detection levels and half the minimum detectable levels for those below the detection level.

3 Results

3.1 Radionuclides

On the 100 g samples, there were no values above the MDA for Cs-137, I-129, Co-60, Eu-152, Sr-90, Tc-99, Am-241, Pu-238, U-234, U-235, and U-236, regardless of species or location. There was one value for guillemot above the MDA for Pu-239,240, and one value for puffin and two values for gulls above the MDA for U-238: the values were 0.31 Bq/kg (*Milrow*), 0.42 Bq/kg (*Long Shot*), 0.45 Bq/kg (*Cannikin*) and 0.19 (Kiska) Bq/kg respectively. The alpha analyses were done on bone, which accumulates higher levels than muscle.

Although we analyzed 1000 g samples for Cs-137, I-129, Co-60, and Eu-152, all levels were below the MDA except for one Cs-137 analysis for muscle of glaucous-winged gull (value of 0.90 Bq/kg, Table 2). 1000 g samples were analyzed to increase sensitivity. Since only one composite had a value above the MDA, we could not test the null hypotheses with radionuclides.

3.2 Metals

There were significant interspecific differences in metals levels in avian eggs (Fig. 3), rejecting the null hypothesis of no species differences. Gulls had significantly higher levels of cadmium and mercury than the eiders ($X^2 = 9.3$, $P < 002$; $X^2 = 6.3$, $P < 0.01$, respectively), and eiders showed a non significant trend toward higher levels of lead than gulls ($X^2 = 2.8$, $P < 0.09$).

When metal levels were examined in eggs by island for each species, there were only two significant dif-

Table 2 Cesium-137 in muscle and eggs of birds from Amchitka and Kiska Islands (only 1000 g samples, counted for 72 hours)

Species	Stage	Number of analyses	Number of individuals	Number above MDA	Highest MDA Bq/kg
Bald Eagle	Runt chick	2	2	0	0.66
Glaucous-winged Gull	Adults	2	18	1	0.26
	Chicks	2	20	0	0.19
	Eggs	2	14	0	0.24
Tufted Puffin	Adults	2	15	0	0.12
Common Eider	Adults	2	10	0	0.23
	Eggs	2	29	0	0.10

MDA = minimum detectable activity
Note. Guillemots were too small to provide 1000 g samples

ferences. Cadmium levels in eiders were significantly higher on Kiska (mean = 124 ± 26 ppb) than on Amchitka (mean = 52 ± 14 ppb, $X^2 = 8.9$, $P < 0.003$); mercury levels in gulls were significantly higher at Kiska (mean = 909 ± 136) than at Amchitka (mean = 489 ± 89, $X^2 = 5.9$, $P < 0.01$). Thus the null hypothesis of no locational differences was rejected for metals.

4 Discussion

4.1 Sources of radionuclides and metals

Metals and radionuclides in bird eggs can come from geological and oceanic processes, and/or from anthropogenic sources (Mailman, 1980). Both Amchitka and Kiska were occupied by military operations in World War II, and Amchitka was also occupied during the underground nuclear test shots and again during DOE cleanup. Kiska Island was occupied by the Japanese during World War II. In addition to point sources (such as military activities on the islands), metals and radionuclides derive from global transport and fallout, and oceanic transport. Global transport generally confers a uniform distribution within a local area, although there are regional variations attributable to precipitation regime (Simon *et al.*, 2004). Another source is global fallout from accidents, such as Chernobyl (Baeza *et al.*, 1991). A uniform spatial distribution on the local level is often attributed to global transport from atmospheric testing or accidental releases such as Chernobyl (Holgye *et al.*, 2004), rather than local source contributions.

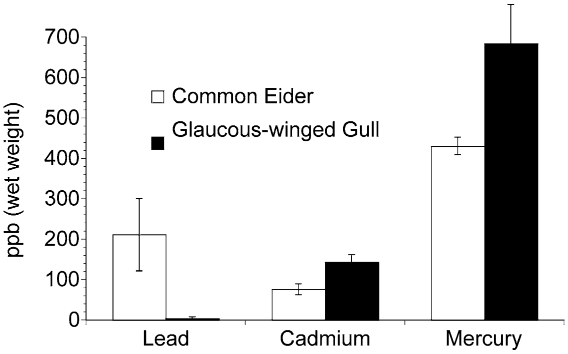

Fig. 3 Levels (ppb, ug/kg, wet weight) of lead, cadmium and mercury in eggs of common eider ($N = 54$) and glaucous-winged gull ($N = 13$) nesting on Amchitka and Kiska Islands in the Aleutians.

There is also the possible migration of radionuclides and metals through oceanic and/or sediment transport; the currents generally move from west to east in the Northern Pacific/Bering Sea ecosystem. Radionuclide sources in the Former Soviet Union (FSU) include deliberate dumping of nuclear waste and submarine cores and accidents (Mount *et al.*, 1998; Layton *et al.*, 1999). These sources could potentially pose a risk to coastal Alaska and the Western Aleutian Islands by a complex set of marine transport mechanisms. Cross-Aleutian transport involves knowledge of FSU waste sites and source terms (Suokko and Reicher, 1993), the amount of nuclear waste that was directly released into the marine ecosystem (GAO/RCED, 1995), weather patterns, ocean current circulation, sediment flow and transport, fishing fleet activity patterns, the globalization of the seafood markets, and fish and marine mammal range and migration patterns (see Burger *et al*., 2006b for a further discussion of Soviet sources). Waste streams associated with current Russian naval operations, the decommissioning of Russian nuclear powered vessels and reactors, and spent fuel reprocessing facilities in the Russian Far East require further understanding. Thus, metals and radionuclides found in birds nesting on Kiska and Amchitka Islands could reflect any of these sources, with Kiska being closer to the source(s).

4.2 Radionuclides

Birds nesting on Amchitka and Kiska Islands could be exposed to radionuclides through global fallout and oceanic transport, and in the case of Amchitka, from either terrestrial or oceanic seepage from the underground nuclear test shots. Dasher *et al*. (2002) recently examined possible leakage of anthropogenic radionuclides from the nuclear test sites on Amchitka to the surface environment, and did not find any evidence of leakage; that study did not include birds.

Overall, we found little evidence of either natural or anthropogenic levels of radionuclides in the marine birds of Amchitka and Kiska. The detectable levels were for both anthropogenic (one value each for Cs-137 and Pu-238,240) and natural (three values for U-238) sources.

There is little comparative radionuclide data on seabirds in the literature, except for cesium; the one cesium level above the MDA was well below those reported for other seabirds from elsewhere (Table 3). Levels of Cs-137 in black-headed gulls (*Larus ridibundus*) from Ravenglass, England, where population declines were attributed to radionuclides, were 2–14 Bq/kg (Woodhead, 1986; Lowe, 1991); Eisler (1994) notes that these levels could not have caused population declines. It should be noted that in most cases, our MDAs were below the mean concentrations found for birds from elsewhere (Table 3), suggesting that we could have detected cesium typical of other regions.

Table 3 Geographical comparison for Cs-137 for birds

		Concentration Bq/kg (w/w)	Range	Number of Analyses
East Irish Sea Region[a]	1980–1984			
Grey Lag Goose	*Anser anser*	57.7	57.7	1
Black-headed gull	*Lotus ridibundus*	13.8	<mda-27.9	8
Great Black-backed Gull	*Larus marinus*	158	158	1
Lesser Black-backed Gull	*Larus fuscus*	9	9	1
Herring Gull	*Larus argentatus*	155.8	9.7-301.9	2
Oystercatcher	*Haematopus ostralegus*	612.8	578.8–647	2
Barents Sea Region	1995–1996			
Great Black-backed Gull	*Larus marinus*	4	2.4–5.6	2
Common Gull	*Larus canus*	1	1	1
Great Skua	*Stercorarius skua*	3.5	3.0–4.0	2
Spotted Redshank	*Tringa erythropus*	4.3	4.3	1
Little Stint	*Calidris minuta*	1.5	1.5	1
Common Eider	*Somateria mollissima*	0.17	nd–0.30	4
Black Guillemot	*Cepphus grylle*	0.43	0.43	1
European [Great] Cormorant	*Phalacrocorax carbo*	0.45	<0.2–0.64	3
Amchitka-Kiska[d]	2004			
Common Eider	*Somateria mollissima*	Non-detect	<mda of 0.23	14
Tufted Puffin	*Fratercula cirrhata*	Non-detect	<mda of 0.26	13
Glaucous -winged gull	*Larus glaucesceus*	0.09[c]	<mda − 0.09	32
Pigeon Guillemot	*Cepphus columba*	Non-detect	<mda of 2.0	13
Bald Eagle	*Haliaeetus leucocephalus*	Non-detect	<mda of 0.66	2

[a] Samples of 1980–1984 reported by Lowe 1991.

[b] Samples of 1995–1996 reported by Matishov and Matishov 2004

[c] Only one gull had a value <mda (= 0.09 Bq/kg).

[d] Both 100 g and 1000 g samples

The Pu-239 and Pu-240 isotopes are not distinguished radiochemically, hence are usually analyzed together. The only level above the MDA for Pu-239,240 from the present study, 0.31 Bq/kg for a guillemot composite near *Milrow*, was less than that reported for other species by Lowe (1991): mallard (*Anas platyrhynchos*; 3.4 Bq/kg) and black-headed gull (0.5 Bq/kg), but was greater than for black-backed gull (*Larus marinus*; 0.1 Bq/kg)(Lowe, 1991). Other shorebirds had Pu-239, 240 levels of 0.03 to 0.5 Bq/kg (Eisler, 1994).

The difficulty with examining effects of radiation on wildlife is a lack of data on the relationship between tissue levels and effects in the wild. There are a number of laboratory studies that correlate dose with effects, but the necessary tissue analysis studies have not been completed (see Eisler, 1994 for a fuller discussion). We cannot now measure radionuclide levels in the field and postulate whether these levels are having any sublethal effects. Standards for protection of biota are only now being developed, which leaves us with the use of human standards and limits to protect ecosystems (see Higley and Alexakhin, 2004). While protecting man may suffice for most biota, we have no way of knowing whether all biota are protected by human health standards. Nonetheless, the levels found for radionuclides in the birds from Amchitka are very low compared to those from elsewhere, suggesting no cause for concern.

4.3 Metals

Metals can bioaccumulate over time to reach toxic levels that can cause decreases in reproductive success and lowered survival. Because some pollutants undergo biomagnification up the food chain, their concentrations have mainly been studied in top level predators such as raptors and fish-eating birds (Hunter and Johnson, 1982; van Straalen and Ernst, 1991; Burger, 1993, 2002; Burger and Gochfeld, 1993, 1997, 2001, 2004). Contaminants, such as metals, are generally not examined in birds that are relatively low on the food chain, and short-lived, such as most passerines, because it is assumed their levels are low (Burger, 1993; Burger *et al.*, 2004).

In this study, we examined mercury, lead and cadmium in the eggs of eiders and gulls (relatively high on the food chain). There are three key questions with the metal data for eggs: 1) What is the cause of the interspecific and interisland differences? 2) How do these levels compare to other areas? and 3) Are the levels sufficiently high to cause adverse effects in the birds themselves or in consumers of the eggs? Each of these questions will be discussed below.

Interspecific and interisland differences in metals. Gulls had significantly higher levels of cadmium and mercury than the eiders; eider eggs had marginally significantly higher levels of lead than gulls. The interspecific differences may be due to diet differences. We found small molluscs and crustaceans in the stomachs of the eiders, along with some kelp which may have been incidental. Eiders are known to take mainly benthic invertebrates, mainly in the rocky intertidal and kelp beds (Goudie *et al.*, 2000). The gulls had mainly fish, molluscs, and a few sea urchins in their stomachs. In the eastern Aleutians they feed mainly on invertebrates (Irons *et al.*, 1986). However, in the western Aleutians, Trapp (1979) reported great variation in foods taken. For example, the percent of sea urchins in the diet ranged from 1 to 80 on different islands, the percent of fish ranged from 0.2 to 77, and the percent of birds eaten ranged from 0.2 to 87. Thus, their relative trophic level can vary, even on geographically close islands.

There were few interisland differences in metal levels, and in both cases, levels were higher in eggs from Kiska Island compared to Amchitka, although the differences were not great. The higher levels may have come from natural oceanic movement of currents, since the level of anthropogenic activity on Kiska was lower, for a shorter period of time compared to Amchitka.

Finally, it should be noted that seabirds also transport contaminants both to on-land breeding sites, and to foraging sites (Blais *et al.*, 2005). Comparison of nearby islands can also clarify patterns of exposure. For example, Rocque and Winker (2004) found differences in mercury levels, which they attributed to abandoned military installations.

Comparisons of metals levels with other areas. One method of evaluating the levels of metals found in eggs of the birds from Amchitka and Kiska is to compare them with levels found elsewhere (Table 4, after Burger, 2002). The mean levels of cadmium and mercury in the eggs of both species were higher than the median for a number of other studies, while the lead levels were lower for gulls and similar for eiders. The means from the eggs of gulls and eiders from Amchitka and Kiska, however, were well below the maximum

Table 4 Metals in eggs of raptors, seabirds and other fish-eating birds (mean ± standard error in ppb wet weight). After Burger 2002

Metal	Number of studies	Range of concentration	Median	Common Eider	Glaucous-Winged Gull
Cadmium	32	2–600	15	76 ± 13	143 ± 19
Lead	29	20–6700	190	211 ± 89	16 ± 12
Mercury	68	70–7290	340	431 ± 22	684 ± 97

from elsewhere, but not as low as reported by Fox *et al*. (2005) for scaup (*Aythya affinis*) eggs. Cadmium and mercury levels, however, are often quite high in marine birds (Furness, 1996). Some seabirds are able to demethylate mercury and store inorganic mercury in the liver (Thompson and Furness, 1989a, 1989b), which may suggest that the levels we found are not toxic for marine birds.

Effects of metals in biota. The third question is whether the levels of metals in the eggs of eiders and gulls might cause adverse effects in the birds themselves or in animals that consume them. The relationship between levels in eggs and adverse developmental effects in biota is known for mercury (Eisler, 1987). Adverse effects, including mortality, lowered hatching rates, higher chick defects, and other neurobehavioral deficits can occur when egg levels are as low as 500 ppb (wet weight), and more severe effects usually occur at 1000 to 2000 ppb (Eisler, 1987). Further, Thompson (1996) suggested that mercury levels of greater than 200 ppb are more likely to have deleterious effects. Thus, the levels in this study suggest that there may be some adverse effects in the birds themselves.

The eggs of gulls and eiders are eaten by other birds and humans. Bird predators may be less sensitive to cadmium in their diet than mammals, but are adversely affected at levels of 1000 ppb (Eisler, 1985), suggesting that avian predators would not be affected by the levels in the eggs from Amchitka and Kiska. In nearby arctic regions, there is some evidence that cadmium levels in some seabirds are high enough to cause kidney damage (AMAP, 2002).

Lead is a neurotoxin that causes behavioral deficits in vertebrates (Weber and Dingel, 1997), and can cause decreases in survival, growth rates, learning, and metabolism (Eisler, 1988; Burger and Gochfeld, 2000). Dietary levels as low as 100 to 500 ppb are associated with learning deficits in some vertebrates (Eisler, 1988), suggesting that the levels in some eider eggs may pose a problem for some predatory birds.

Mercury is the contaminant of most concern in marine ecosystems (Mailman, 1980). Concentrations of 15,000 ppb mercury are required for adverse effects in some predators (Spry and Wiener, 1991; Wiener and Spry, 1996). However, sensitive birds can exhibit effects at dietary mercury concentrations of 50 to 500 ppb; for sensitive mammals, harmful effects occur at dietary levels of 1100 ppb Eisler, 1987; WHO, 1990, 1991). Therefore, the average levels for eider and gulls eggs from Amchitka and Kiska are within the range for sensitive birds. However, most seabirds are less sensitive because they evolved with exposure to natural mercury derived from seawater (rather than anthropogenic sources). They often have higher levels of mercury in their tissues than do other species, without exhibiting apparent effects (Thompson and Furness, 1989a, 1989b).

4.4 Metals in eggs and risk to people

Increasingly there is interest in tracking mercury levels in food chains that lead to subsistence foods (Thomas and Gates, 1999). Mercury in the eggs of eiders and gulls is of special concern because they are preferred subsistence foods of the Aleuts (NRC, 1996; Jewett, 2002; Patrick, 2002; Hamrick and Smith, 2003; Fish & Wildlife Service, 2004), and are relatively easy to collect from these nesting islands.

Safe levels of mercury in human foods is controversial. The U.S. Food and Drug Administration (FDA, 2001) has an action level for methylmercury in fish. However, the level of 1.0 ppm is a regulatory action level, rather than a risk level. That is, if a fish exceeded this level, it would not be allowed in interstate commerce. Originally the FDA had set 0.5 ppm as the action level, comparable to many other nations (reviewed in Burger and Gochfeld, 2004). The United Kingdom and the European Union have established 0.5 ppm as the allowable mercury level in edible fish. China has set standards for methylmercury in most

Table 5 Percentage of common eider and glaucous-winged gull eggs greater than 0.3 ppm, 0.5 ppm, and 1 ppm mercury. This information relates to the possible risk to humans from consuming bird eggs.

	Eider	Glacous winged gull
No of eggs	54	13
Mean and SE (ppm)	0.4 ± 0.2	0.68 ± 0.09
% above 0.3 ppm	81	100
% above 0.5 ppm	26	62
% above 1.0 ppm	0	8

canned fish of 0.5 ppm. In 1982 the European Commission set an Environmental Quality Standard for mercury of 0.3 ppm. The U.S. EPA (2001) promulgated 0.3 ppm as an ambient freshwater quality standard in 2001. Table 5 indicates the percent of eggs that were above these action levels. Even with this array of standards, it is clear that the mean mercury levels in the eggs of both eiders (0.4 ppm) and gulls (0.7 ppm) are within the range to cause concern. While subsistence hunters would normally eat bird eggs only during the avian breeding season, it is possible that pregnant women might be eating eggs for several consecutive meals during a critical developmental period. Ginsing and Toal (2000) have suggested that there may be risk during pregnancy for even a single-meal exposure, particularly for food with levels of over 2.0 ppm. We caution that egg sample sizes were low, but suggest further work on subsistence eggs from the Aleutians is necessary to resolve this issue.

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