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Mercury and other metals in eggs and feathers of glaucous-winged gulls (*Larus glaucescens*) in the Aleutians

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Abstract

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Levels of mercury and other contaminants should be lower in birds nesting on isolated oceanic islands and at high latitudes without any local or regional sources of contamination, compared to more urban and industrialized temperate regions. We examined concentrations of arsenic, cadmium, chromium, lead, manganese, mercury and selenium in the eggs, and the feathers of fledgling and adult glaucous-winged gulls (*Larus glaucescens*) nesting in breeding colonies on Adak, Amchitka, and Kiska Islands in the Aleutian Chain of Alaska in the Bering Sea/North Pacific. We tested the following null hypotheses: 1) There were no differences in metal levels among eggs and feathers of adult and fledgling glaucous-winged gulls, 2) There were no differences in metal levels among gulls nesting near the three underground nuclear test sites (Long Shot 1965, Milrow 1969, Cannikin 1971) on Amchitka, 3) There were no differences in metal levels among the three islands, and 4) There were no gender-related differences in metal levels. All four null hypotheses were rejected at the 0.05 level, although there were few differences among the three test sites on Amchitka. Eggs had the lowest levels of cadmium, lead, and mercury, and the feathers of adults had the lowest levels of selenium. Comparing only adults and fledglings, adults had higher levels of cadmium, chromium, lead and mercury, and fledglings had higher levels of arsenic, manganese and selenium. There were few consistent interisland differences, although levels were generally lower for eggs and feathers from gulls on Amchitka compared to the other islands. Arsenic was higher in both adult feathers and eggs from Amchitka compared to Adak, and chromium and lead were higher in adult feathers and eggs from Adak compared to Amchitka. Mercury and arsenic, and chromium and manganese levels were significantly correlated in the feathers of both adult and fledgling gulls. The feathers of males had significantly higher levels of chromium and manganese than did females. The levels of most metals in feathers are below those known to be associated with adverse effects in the gulls or their predators. However, levels of mercury in some gull eggs are within a range suggesting that several eggs should not be eaten in one day by sensitive humans.

Keywords

Birds; Gulls; Pollutants; Heavy metals; Mercury; Age-related; Aleutian Islands

Introduction

Governmental agencies, Tribal Nations, policy-makers, managers, and the general public are concerned about the health of the environment, and require bioindicators that assess levels of contaminants in individual organisms, populations and communities. Chemical use is increasing in our environment, and may pose a threat to some species and populations. Levels of many chemicals are elevated in marine and coastal ecosystems because of the influx from rivers, as well as runoff and direct pollution (Furness and Rainbow 1990), and from atmospheric transport and deposition. Chemicals, such as mercury, are transported all over the Earth, including to relatively isolated lakes and marshes (Houghton et al. 1992; Fitzgerald 1989). Species that forage in aquatic environments are particularly vulnerable because of the potential for rapid movement of contaminants in water, compared to movement in terrestrial environments, and because chemicals can be stored in sediments in intertidal environments, providing a pool for years to come.

Many oceanic islands and polar regions are far from anthropogenic sources of contamination found near urban, industrial and agricultural centers in temperate regions where emissions, effluents and runoff abound (Mailman 1980). However, some polar regions have been found to contain pollutants (Nygard et al. 2001; Metcheva et al. 2006). Many of these regions are extremely important commercially, especially to the fishing industry. The Bering Sea ecosystem, for example, provides a large percentage of the fish and shellfish for commercial sale in the United States and elsewhere (AFSC 2003). Dutch Harbor in the Aleutians, the port for commercial fish in the Bering Sea, had the highest tonnage of fish landings in the world in 2003, and provides 17% of Alaska's $811 million fish landings (2.3 million metric tons of fish, NOAA 2004). Understanding contaminant levels in productive ecosystem, and having bioindicators for these systems, is very important for managers, scientists, and public policy makers.

Birds are often the most numerous representatives of vertebrates in polar and subpolar regions (Metcheva et al. 2006), making them ideal bioindicators of pollution (Gochfeld 1980; Walsh 1990; Peakall 1992; Furness 1993; Furness and Camphuysen 1997). Marine birds are exposed to a wide range of chemicals because they occupy a wide range of trophic levels, and those at the top of the food chain are susceptible to bioaccumulation of pollutants (Furness and Rainbow 1990; Lewis and Furness 1991; Burger and Gochfeld 2002; Nygard et al. 2001).

In this paper we examine the concentrations of arsenic, cadmium, chromium, lead, manganese, mercury and selenium in the eggs and in the feathers of fledgling and adult glaucous-winged gulls (*Larus glaucescens*) from breeding colonies on Adak, Amchitka, and Kiska Islands in the Aleutian Chain of Alaska. We test the null hypotheses that: 1) There were no differences among levels of metals in eggs and feathers of adults and fledglings; 2) there were no differences in metal levels among gulls nesting near the three underground nuclear test sites (Long Shot 1965, Milrow 1969, Cannikin 1971) on Amchitka, 3) There were no differences in metal levels among the three islands, and 4) There were no gender-related differences in metal levels. This study was part of a study of Amchitka Island conducted by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP), and a comprehensive report (Powers et al. 2005) is available at www.cresp.org.

Contaminant levels in eggs and feathers are useful bioindicators of exposure because they potentially represent different periods of exposure. 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 1996a). 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 for the breeding grounds, although the gulls are resident in the Aleutians (Kenyon 1961).

Feathers are useful indicators of metal contamination because: 1) Birds sequester metals in feathers which are composed of proteins rich in sulfur-containing amino acids, 2) The proportion of body burden that is in feathers is relatively constant for each metal, 3) A relatively high proportion of the body burden of certain metals is stored in the feathers

(Burger 1993), 4) There is a high correlation between levels of contaminants in the diet of seabirds and levels in their feathers (especially for mercury, Monteiro and Furness 1995). Breast feathers are the best indicator of whole-body burdens, particularly for mercury (Furness et al. 1986). As with other animals, susceptibility in birds often varies with age, reproductive stage, gender, life history strategy, diet, and habitat use (Burger 1993; Burger and Peakall 2003).

Materials and methods

Study sites and species

Under appropriate federal and state permits eggs and breast feathers (from fledglings and adults) were collected from glaucous-winged gulls nesting at Adak, Amchitka and Kiska Islands in the Aleutian Chain of Alaska. The Aleutian Islands were established as a National Wildlife Refuge in 1913 by executive order of President Taft (ATSDR 2004). Glaucous-winged gull reach full adult plumage at age 4–5 years (Verbeek 1993), thus we compare fledglings (about 35–45 days) with birds older than 4 years.

Adak Island is approximately 1,900 km west of Anchorage (Fig. 1 51°N; 176°W). A Naval Air Facility occupied the northern portion of the island from 1942 until 1997, when operations closed (ATSDR 2004). At its peak, over 100,000 military personnel were stationed on the island, creating the potential for historic contamination of the marine environment, particularly near the seaport and airport areas of Adak. In 1994 the Naval Air Station at Adak was placed on the National Priority List after an EPA RCRA inspection (ATSDR 2004). Most of the population (currently less than 200 people) resides in the town of Adak, which has an airport and seaport. The island is partly owned by the U.S. Fish and Wildlife Service, and partly by the Aleut Corporation, which is in the process of developing commercial fisheries.

Amchitka Island (Fig. 1, 51°N lat; 179°E long), about 2,200 km west of Anchorage, is part of the Alaska Maritime National Wildlife Refuge system. It contains important ecological resources (Merritt and Fuller 1977, Burger et al. 2005, 2006a, b). Amchitka Island is the only island where the U.S. detonated underground nuclear tests. It is unusual among DOE-contaminated sites because of its remoteness and the importance of its marine ecological resources and seafood productivity that could be at risk if there were significant seepage of radionuclides from the underground cavities to the marine environment.

Kiska (51°N lat; 177°E long) had military occupation during the Second World War, but has not been occupied since. It contains many of the same terrestrial and benthic environments as Amchitka (Burger et al. 2006b). The collection sites on Adak were at least 280 km from those on Amchitka; the collection sites on Kiska were at least 150 km west of Amchitka. Although Glaucous-winged gulls are certainly capable of flying those distances, and although our ship was regularly accompanied by gulls as we moved among islands, gulls tend to show colony tenacity, and generally spend most of their time, summer and winter, in the vicinity of their breeding colonies.

Protocol

Young fledglings were captured by hand when they were still flightless but had well-developed wing feathers. Adults were collected for a Department of Energy project to ascertain levels of radionuclides in biota (Powers et al. 2005). All gulls were weighed and adults were sexed by internal examination of gonads (gonads were not distinguishable in fledglings). Breast feathers were placed in individual envelopes and labeled for later identification. All specimens were then shipped to the Rutgers University for analysis. Breast feathers were selected because they are considered to be more evenly representative of exposure to metals than wing feathers which are produced sequentially over a period of weeks (Furness et al. 1986; Burger 1993). Further, Thompson et al. (1991) showed that essentially 100% of the mercury in feathers and muscle is methylmercury. Breast feathers were collected from young once they were fully formed, just prior to independence. Metals enter feathers during the 2–3 weeks it takes for a feather to grow out completely. Then the blood supply atrophies and there is no further deposition of metals (Burger 1993; Thompson et al. 1998). Thus, feathers are an archive of metal exposure during feather formation. All feathers were analyzed in the Elemental Analysis Laboratory of the Environmental and Occupational Health Sciences Institute in Piscataway, NJ.

Eggs were weighed, homogenized, and the contents were kept frozen in chemically clean jars until ready for digestion. The homogenate was air dried to constant weight prior to digestion. Feathers were washed three times with acetone, once with deionized water, air dried, and then digested individually. A 0.5 g (dry weight) sample of egg tissue (0.05 g for feathers) was digested in 3 ml ultrex ultrapure nitric acid and 2 ml deionized water in a microwave (MDX 2000 CEM), using a digestion protocol of three stages of ten min each under 50, 100 and 150 pounds per square inch (3.5, 7, and 10.6 kg/cm^2) at 70× power. Digested samples were subsequently diluted to 25 ml for eggs and 10 ml for feathers with deionized water. All laboratory equipment and containers were washed in 10% HNO solution and deionized water rinse, prior to each use (Burger et al. 2001).

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 ng/g (ppb) on a dry weight basis using weights obtained from air-dried specimens.

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, and spiked specimens. The correlation coefficient on the calibration curve exceeded 0.995. Recoveries on spiked specimens ranged from 88% to 102%. Batches with recoveries of less than 85% would have been reanalyzed. The coefficient of variation on replicate, spiked samples ranged up to 10%.

Non-parametric one way analysis of variance was performed using the Statistical Analysis System (SAS, PROC NPAR1WAY with the Wilcoxon option) which yields a chi square statistic. We also performed Duncan Multiple Range tests on log transformed data to distinguish significant differences between the islands. Multivariate analysis models were estimated using the General Linear Models routine (SAS 1995, PROC GLM), determine the relative contribution of age and location to variations in metals levels. Both arithmetic and geometric means are given in tables to facilitate comparisons with other studies. We accept a probability level of 0.05 as significance, but present all values below 0.10 to allow the reader to assess the significance themselves.

Results

Comparisons among eggs, fledglings and adults

There were significant differences among eggs and feathers of adults and fledglings for cadmium, lead, mercury and selenium, but not for arsenic and manganese (Table 1). The differences among stages (and ages) for chromium were nearly significant. Considering the geometric means, eggs had the lowest levels of cadmium, lead, and mercury, and the feathers of adults had the lowest levels of selenium. Comparing only adults and fledglings (regardless of significance), adults had higher levels of cadmium, chromium, lead and mercury, and fledglings had higher levels of arsenic, manganese and selenium (Table 1).

Comparison among sites on Amchitka

There were numerous gull colonies on Amchitka, and gulls nested close to each of the three test sites, allowing us to collect feathers from both adults and young fledgling in the breeding colonies. Since *Milrow* was located close to the Pacific Ocean side of the island, and *Long Shot* and *Cannikin* were close to the Bering Sea side of Amchitka, we hypothesized that there might be differences due to differences in the foods available on the foraging grounds. However, we found that there were few differences in levels in adult feathers, and where there were differences, they were small (Table 2). Chromium levels were higher in the feathers of adult gulls from *Milrow* compared to the feathers of those collected from the other two sites, and mercury levels were higher in the feathers of young gulls from *Long Shot* compared to the other sites. Because there were few differences, and the differences were small, we combined the data from the three sites for the interisland comparison. There were too few eggs from the test sites to make a comparison.

Comparison among islands

There were significant inter-island differences in metals levels in the feathers of adults for all metals except mercury and selenium (Table 3). Adult gulls from Adak had the highest levels of cadmium, chromium, lead and manganese; gulls on Amchitka had the highest arsenic levels. In the feathers of fledglings, only cadmium and manganese showed significant differences, but we did not have data for Adak (the chicks were too young for completely formed feathers). In both cases, levels were higher on Amchitka than on Kiska. For eggs, arsenic and cadmium were highest on Amchitka, chromium and lead were highest on Adak, and mercury was highest from Kiska (Table 3). There were few clear patterns in metal levels among islands, although feathers of adults from Amchitka had lower levels of cadmium, chromium, lead, manganese and selenium than those from the other islands. Egg levels from Amchitka were also lower for chromium, lead, and mercury than the other islands. Feathers from chicks on Kiska were lower than those from Amchitka only for cadmium and manganese. Arsenic was higher in both adult feathers and eggs from

Amchitka compared to Adak, and chromium and lead were higher in adult feathers and eggs from Adak compared to Amchitka.

Gender-related differences

Although male gulls are usually larger and heavier than females (Burger and Gochfeld 1996b), there were no significant body weight differences in our sample (Table 4). Levels of chromium and manganese were significantly higher in the feathers of adult males compared to adult females, but there were no differences for the other metals (Table 4).

Correlations among metals

Of the 21 possible inter-metal correlations, 10 were significant for the feathers of adults 3 were significant for the feathers of fledglings, and 5 were significant for eggs (Table 5). Only two relationships were significant for both adults and young: arsenic with mercury, and chromium with manganese in feathers (neither of which was significant for eggs, Table 5).

Discussion

Over time, in marine ecosystems, mercury and other metals can bioaccumulate to reach toxic concentrations that can lower survival and cause decreases in reproductive success in high trophic level species (Eisler 1987; Burger 1993; Bargagli et al. 1998; Scheifler et al. 2005). Because some pollutants undergo biomagnification up the food chain, their concentrations have often been studied in top-level predators such as raptors and fish-eating birds (Hunter and Johnson 1982; van Straalen and Ernst 1991; Burger 2002; Burger and Gochfeld 1997a, 2002a, 2004). In this study, we examined metals in the eggs and feathers of gulls which consume a variety of marine organisms both live caught and scavenged. We found some significant differences between eggs and feathers, between feathers of adults and young, among the sites on Amchitka, and among the islands. There are three key questions with the metals data from this study: 1) What are the causes of the age-related and interisland differences? 2) How do these levels compare to those in birds from other areas? and, 3) Are the levels sufficiently high to cause adverse effects in the birds themselves or in consumers of the birds (including humans who may eat their eggs)? Each of these questions will be discussed below.

Age and gender differences

Adult gulls are exposed to the metals through their food and water. Once ingested, contaminants can be excreted directly or absorbed into the circulation. Subsequently metals are delivered to organs or sequestered in feathers, (Braune 1987; Lewis and Furness 1991) bone, or other tissues. Some pelagic seabirds (albatrosses and petrels) are capable of demethylating methylmercury in the liver, and storing it as an immobilizable inorganic form (Kim et al. 1996), however the mercury in feathers is close to 100% methylmercury (Thompson et al. 1991). Heavy metals in the feathers represent circulating concentrations in the blood during the few weeks of feather formation, which in turn represents both local recent exposure and mobilization from internal tissues (Lewis and Furness 1991; Monteiro 1996). Once the feather matures, the vascular connection atrophies, leaving the feather as a

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record of blood levels at the time of its formation, and the concentration of metals in the feathers remains nearly constant (Braune and Gaskin 1987). Metals in eggs come mainly from recently ingested food, as well as some mobilization from body stores. Contaminant burdens in young birds can come from pollutants sequestered in the eggs, but as they grow, the contribution is soon exceeded by the contaminants in food provided by their parents. Although some seabirds feed hundreds of kilometers from their breeding site, nesting gulls we observed on Amchitka, foraged mainly in intertidal and nearshore waters within a few kilometers of their colony.

In general, levels of contaminants are higher in adults than in young, largely because adults have had longer to acquire and bioaccumulate contaminants. Burger (1993) summarized studies of metals in bird feathers, and reported that adults had significantly higher concentrations than young for mercury (20 of 21 studies), lead (4 of 7), cadmium (3 of 5), manganese (5 of 5), and selenium (3 of 3), with chromium showing less of a difference (only 1 of 4 studies). Since then, the same result has been shown for other species, mainly gulls and terns (Thompson et al. 1993; Gochfeld et al. 1996; Burger 1996; Stewart et al. 1997; Burger and Gochfeld 1997b), albatrosses (Burger and Gochfeld 2000a), and guillemots (Debacker et al. 2001).

In this study, adults generally had higher levels of cadmium, chromium, lead and mercury, and fledglings had higher levels of arsenic, manganese and selenium. Since adults have had longer to accumulate contaminants in their tissues, the higher levels of arsenic, manganese and selenium in the feathers is perhaps indicative of higher local levels than the adults obtained regionally. While the adults remain in the Aleutians during the non-breeding season (when their breast feathers were grown), they do not necessarily remain close to their breeding colonies.

Few studies of the levels of metals in feathers report gender-related differences because it is difficult to sex gulls by morphological appearances alone. However, we dissected and sexed the gulls (Burger 1993). Most studies found no gender-related differences in metal levels, and when differences were found, they were not found for all metals examined (Burger 1993). In a study of laughing gulls (*Larus atricilla*) culled near a major airport, Gochfeld et al. (1996) reported that males had barely significantly ($P < 0.06$) higher levels of lead than did females, but there were no gender-related differences for cadmium, chromium, manganese, mercury or selenium. In this study, males had significantly higher levels of chromium and manganese in their feathers than did females, but there were no other differences in metal levels. Both chromium and manganese are trace elements that are internally regulated, so perhaps males sequester more in their feathers to maintain internal levels. This would imply that they have higher exposure than females, and we cannot account for this difference.

Locational differences

Locational differences in metal levels in feathers would reflect different exposures related either to local difference in contaminant concentrations or differences in food web trophic structure. That is, adult gulls living on the different islands could eat different foods, of different sizes, and in different proportions, and they could feed their chicks different foods of different sizes. Glaucous-winged gulls eat a wide range of vertebrates and invertebrates (Verbeek 1993). The gulls we collected had mainly fish, molluscs, and a few sea urchins in their stomachs. In the eastern Aleutians glaucous-winged gulls 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. At Buldir Island (west of Kiska in the Aleutians), nearly 80% of the gulls' diet was birds and 20% was fish; in other places they do not eat birds (Verbeek 1993). Thus, their relative trophic level can vary even on geographically close islands, potentially accounting for differences in metal levels among islands. For example, Rocque and Winker (2004) reported differences in mercury levels among birds collected in the Northern Pacific, which they attributed to abandoned military installations.

All three islands were occupied by military operations in World War II. Amchitka was also occupied during the nuclear test period (1960's) and again during DOE cleanup (1990s). Adak was occupied by the military until 1997, and continues to be occupied by a small Aleut community. Kiska Island was occupied by the Japanese during World War II. In addition to the point sources (such as military activities on all the islands), metals 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).

In this study we found that there were few differences among the study sites on Amchitka (near the three nuclear test sites), although the adults collected near *Milrow* had higher levels of chromium than did those from other sites, and young gulls from near *Long Shot* had significantly higher levels of mercury than the young gulls from elsewhere on Amchitka. These differences might relate to the differences in nuclear test operations at the three sites, and to differences in runoff into the surrounding bays and intertidal flats.

For most studies of metals in feathers, it is also important to understand both the timing and pattern of molt and where birds were at the time of the molt. Glaucous-winged gulls in the Aleutians are generally resident, and do not migrate (Verbeek 1993), making them ideal because they represent local or regional (Aleutian Island) exposure. For most birds, feathers and eggs can serve as an indicator of internal contamination (Goede and deBruin 1984, 1986; Furness et al. 1986; Burger 1993). These levels can then be used to assess whether there are potential reproductive deficits in populations (Burger 1994).

We found few consistent interisland differences in metal levels, although chromium and lead levels were significantly lower in eggs and adult feathers from Amchitka compared to the other islands. Arsenic was higher in both adult feathers and eggs from Amchitka compared to Adak, and chromium and lead were higher in adult feathers and eggs from Adak compared to Amchitka. In a related study of adult common eiders and adult tufted puffins from only Amchitka and Kiska, lead levels were higher on Kiska than Amchitka, but the differences were not great (Burger and Gochfeld 2002). If we only compare the levels in the feathers of adult gulls from Amchitka and Kiska, the pattern would be similar (i.e. adult gulls from Kiska had higher levels of lead than those from Amchitka. Thus, it seems consistent that lead levels are higher in the foods the adult birds are acquiring near Kiska than Amchitka. Since Amchitka had military occupation, and defense operations (nuclear test shot) occupation for much longer than Kiska, this result is surprising, but may relate the very active bombing and strafing of Kiska harbor and the sunken ships that still lie there.

Comparison of regional levels

There are no data on levels of heavy metals in feathers of seabirds from the Aleutians. However, in a related study examining radionuclides and mercury in gull and eider (*Somateria mollissima*) eggs from these same islands, we found that gulls had significantly higher levels of mercury on Kiska than on Amchitka (Burger and Gochfeld 2007), but we did not analyze eggs from Adak (the island inhabited by Aleuts), nor did we analyze arsenic, chromium, manganese or selenium. Braune et al. (2002) examined mercury levels in eggs of glaucous-winged gulls from the High Arctic, and showed that mercury levels increased with latitude; mercury levels ranged from 600 ppm to 4,900 ppm. Levels from Prince Leopold Island were therefore much higher than those from the Aleutians. The levels of selenium we found for the Aleutians (mean of 2,170 ppm) was within the range Braune et al. reported for eggs (1,100 to 2,700 ppb) from the High Arctic.

Burger and Gochfeld (2000c) examined metals levels in the feathers of 12 species of seabirds from Midway Atoll (28° 15′N, 177° 20′W) in the northern Pacific Ocean, some 2,875 km south from Amchitka. Midway was the site of communications operations since the early 1900's, and served as a military base during and after World War II until 1997, when it was taken over by the U.S. Fish & Wildlife Service. It was thus used for military operations for longer, and more intensely, than the Aleutian Islands. Species examined included terns, noddies, shearwaters, tropicbirds, and albatrosses. For all metals (except manganese), the mean levels in feathers of gulls in the Aleutians were well below the species with the highest means from Midway: arsenic (mean of 144 ppb for adult glaucous-winged gull, 459 ppb for white tern, *Gygis alba*); cadmium (77 ppb for adult gull, 950 ppb for grey-backed tern *Sterna lunata*); chromium (mean of 829 ppb for adult gull, 6,570 ppb for Laysan albatross *Diomedea immutabillis*), lead (855 ppb for adult gull, 2,380 ppb for Christmas shearwater *Puffinus nativitatis*);; mercury (3680 ppb for adult gull; 19,700 ppb for Bonin petrel *Pterodroma hypoleuca*); selenium (1,290 ppb for fledgling gull, 10,100 ppb for Christmas shearwater; Burger and Gochfeld 2000a). Manganese levels in fledgling glaucous-winged gulls were higher than the species with the highest levels on Midway (2,200 ppb for fledgling gull; 2,050 ppb for Christmas shearwater).

Rocque and Winker (2004) examined levels of several metals in the livers of rock sandpipers (*Calidris ptilocnemis*) in Attu, Adak, Amlia and the Alaskan Peninsula, and found that arsenic was highest in Attu, mercury was highest in the Alaska Peninsula, and there were no differences in the other metals. Rocque and Winker (2004) found that levels were generally higher in the sandpipers (eating small invertebrates) than in the cormorants (eating medium-sized fish). These data indicate that there is a need for more studies that examine levels in feathers and other tissues to allow for conversions among tissues.

In contrast to feathers, levels of heavy metals in eggs have been examined in a wide range of seabirds from high latitudes and the Arctic. As part of an on-going temporal study of contaminants in seabirds, eggs of five seabird species were collected in 1998 from Lancaster Sound, Nunavut. The concentrations of total mercury in glaucous-winged gull eggs were significantly higher than in all other species examined (Braune et al. 2005). The levels they reported (mean of 3,400 ± 300 ppb, dry weight) were considerably higher than the levels found in gull eggs in the Aleutians (703 ppb, dry weight). In contrast, kittiwake eggs (*Rissa tridactyla*) from the Arctic had similar levels (600 ppb, dry weight) to those of the glaucous-winged gull eggs from the Aleutians. Mercury in kittiwake eggs in the Canadian Arctic remained relatively constant from 1975 to 2003 (Braune, 2007). Levels of mercury in glaucous-winged gulls eggs increased with latitude (Braune et al., 2002). The eggs of ivory gull (*Pagophila eburnean*), a Canadian high Arctic nester that has suffered severe population declines in the last 25 years, had exceedingly high levels of mercury (mean of 6,370 ppb, dry weight in 2004, compared to 2,570 ppb for glaucous-winged gulls from the Canadian Arctic (Braune et al. 2006), and 703 ppb for the glaucous-winged gulls from the Aleutians (collected in 2004, this study).

Significance of levels for wildlife

Laboratory studies have been used to identify the levels of metals that result in adverse impacts on the behavior, physiology or reproductive success of birds, and in determining adverse effects on higher trophic levels. Levels of metals in gulls are of interest because of potential effects on the birds themselves, on predators that might eat them or their eggs (either as prey or as carrion), and on subsistence people who might eat them. While gulls are not a preferred Aleut food, they are sometimes eaten, and their eggs are a delicacy during the early breeding season (Patrick 2002; Hamrick and Smith 2003; Fish & Wildlife Service 2004, see below).

Mercury is the metal contaminant of most concern in marine ecosystems (Mailman 1980; Thompson and Furness 1998). In general, mercury levels in feathers that are associated with adverse reproductive effects in birds are 5,000 ppb (Eisler 1987; Burger and Gochfeld 2000b). Concentrations of 15,000 ppb mercury are required for adverse effects in some predators (Spry and Wiener 1991; Wiener and Spry 1996) including seabirds. The average mercury levels in feathers of gulls from Adak, Amchitka and Kiska averaged 3,680 ppb (adults) and 1,980 ppb (fledglings), below the level known to cause adverse effects. Further, most seabirds are less sensitive to mercury and cadmium than other birds because they evolved with exposure to the natural background levels of these elements in seawater. They often have higher levels of mercury in their tissues than do fresh water species, without exhibiting apparent effects (Thompson and Furness 1989a, 1989b). The levels of mercury in the gull eggs are within the range known to affect avian predators (Eisler 1987), but seabirds themselves seem less vulnerable to mercury than other birds (Thompson and Furness 1989a, 1989b).

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 2000b). Adverse effects in birds occur at lead levels of 4,000 ppb in feathers (Custer and Hoffman 1994; Burger and Gochfeld 2000b). The levels of lead in the

Aleutian Islands examined in this study were far lower, suggesting that lead poses no threat to the gulls themselves.

Cadmium is a teratogen, carcinogen, and a possible mutagen that causes sublethal and behavioral effects at lower concentrations than lead and mercury (Eisler 1985). In general, marine organisms are less sensitive than freshwater organisms, and mammals and birds are comparatively resistant to Cadmium (Eisler 1985). Feather levels known to be associated with adverse effects in the birds themselves have not been determined from laboratory studies. Using a conversion factor from Burger (1993) suggests that feather levels that are associated with adverse effects range from 100 ppb (shearwaters) to 2,000 ppb (terns). Thus, the cadmium levels found in glaucous-winged gull feathers examined from the Aleutian Islands were below the estimated effects level even for shearwaters.

Selenium is an essential micronutrient, but it can be toxic at high levels (Coyle et al. 1993). Selenium concentrations of 1,000 ppb in food are toxic to other wildlife that consume them (Lemly 1993). The levels of selenium in the glaucous-winged gull eggs were above this level, suggesting the possibility of harm to some sensitive wildlife...

There are few controlled laboratory studies for the other metals, making it difficult to interpret the significance of these levels. This lack of data suggests a need for laboratory studies that not only examine the effects of particular doses, but also determine levels of contaminants in feathers and other internal tissues. Finally it is important to acknowledge that all field studies have methodological problems that often entail unbalanced designs. This is due to differences in nesting and breeding success caused by predators or inclement weather, and by collecting difficulties. Our expedition to the Aleutian Islands was timed to be optimal for collecting a wide range of invertebrates, fish, and birds (Powers et al. 2005; Burger et al. 2006a), making it less ideal for collecting fledgling gull chicks.

Significance of egg levels for humans

In contrast to the flesh of gulls, glaucous-winged gulls eggs are a delicacy among Aleuts, and are frequently consumed because they are easy to collect from these gulls that nest on the ground in accessible places (Patrick 2002; Hamrick and Smith 2003; Fish & Wildlife Service 2004). Since the eggs are fresh only for a relatively short period of time (in the few days following egg-laying), it is possible for Aleuts (including pregnant women) to eat gull eggs several times a week or even several times a day.

The main metal of concern in foods from marine environments is mercury, and methylmercury is one of the main contaminants of concern for subsistence foods. The US Food and Drug Administration action level for methylmercury in fish is 1.0 μg/g (ppm wet weight, FDA 1994), 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.

The glaucous-winged gull eggs from the Aleutians averaged 703 ppb (0.7 ppm) on a dry weight basis, which using the average moisture content converts to 0.24 ppm on a wet weight basis, which is very close to the 0.3 ppm value set by the European Commission. Further, those from Adak (where Aleuts live and hunt) also averaged 0.24 ppm, while those on Kiska averaged 0.30 ppm. While only 5% of the gull eggs had levels over 0.3 ppm (w/w), 30% had levels above 0.2 ppm, suggesting that caution should be applied by subsistence consumers if they are eating several meals of gull eggs a day or week.

Subsistence diets must cope with seasonal availability, and the effect of eating several gull egg meals on consecutive days (or of eating two or three meals a day) would need to be considered. Ginsberg and Toal (2000) even suggested that there may be a risk during pregnancy for exposure to a single-meal of high mercury if it occurred at a critical developmental period. Further, subsistence hunters might be expected to collect the first-laid egg in nests (assuring that the eggs were fresh), and first eggs usually have the highest mercury levels within a clutch (Becker 1992). We were not able to ensure that we collected the first-laid eggs in clutches.

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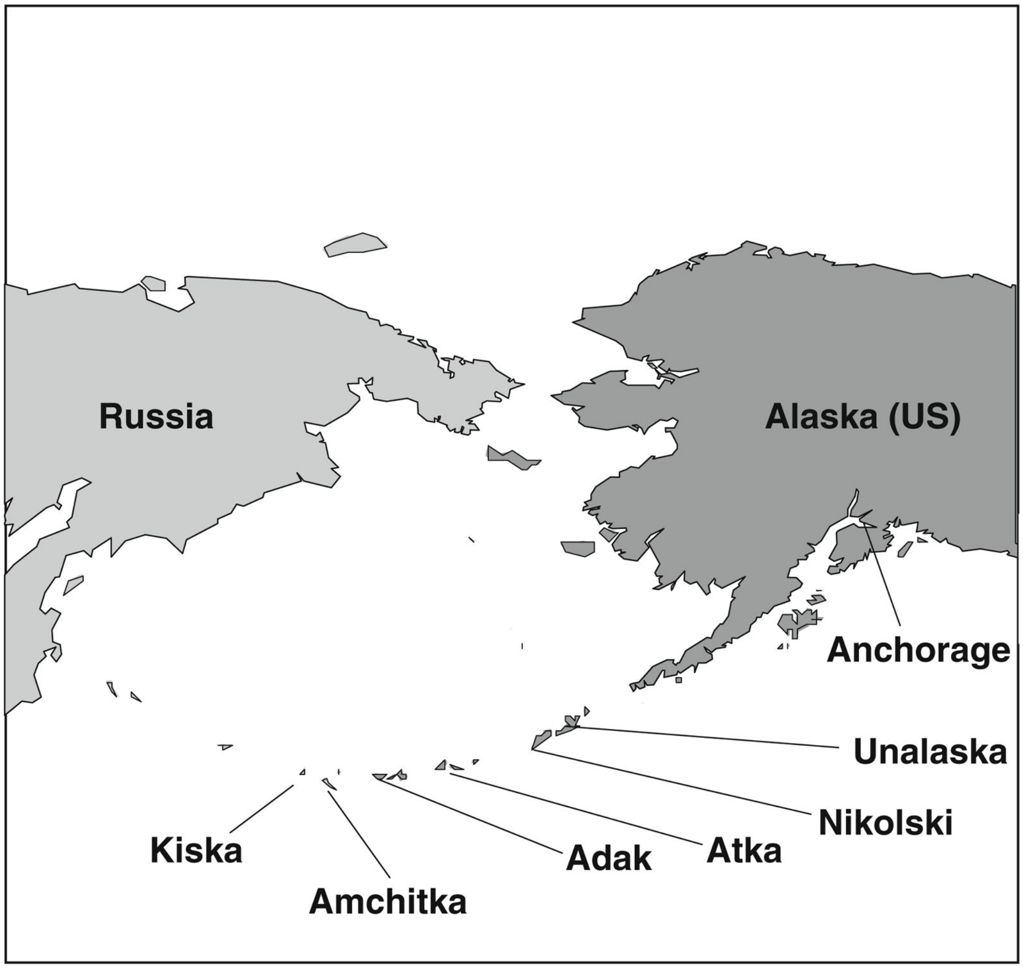

Fig. 1.
Map showing the locations of collections of eggs and feathers of adult and young glaucous-winged gulls on Adak, Amchitka and Kiska Islands in the Aleutians

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Table 1

Metal levels (ppb, dry weight) (ng/g) in feathers and eggs of glaucous-winged gulls collected from the Aleutian Islands

	Feathers		Eggs	
	Adults	**Chicks**		X^2(p)
	n=63	*n*=36	*n*=21	
Arsenic	144±26.7	140±23.9	126±25.6	0.8 (NS)
	15.7	31.9	47.8	
	(B)	(A,B)	(A)	
Cadmium	77.3±12.1	33.7±5.2	84.1±18.6	13.2 (0.001)
	50.5	24.4	10.6	
	(A)	(A,B)	(B)	
Chromium	829±190	602±98.8	248±25.4	5.3 (0.07)
	383	328	226	
	(A)	(A)	(A)	
Lead	855±133	270±85.3	107±29.4	43.1 (<0.0001)
	444	27.4	0.9	
	(A)	(B)	(C)	
Manganese	1430±255	2200±482	1080±104	4.4 (NS)
	766	1280	950	
	(A)	(A)	(A)	
Mercury	3680± 374	1980±180	703±70.8	30.1 (<0.0001)
	2370	1680	631	
	(A)	(A)	(B)	
Selenium	996±53.5	1290±69.7	1570±91.1	24.1 (<0.0001)
	848	1210	1520	
	(B)	(A)	(A)	

Given are arithmetic means±SE (geometric means below) with Kruskal–Wallis Chi Square values and p values. Duncan values are given in parenthesis

Table 2

Metal levels (ppb, dry weight)(ng/g) in breast feathers of glaucous-winged gulls collected from 3 test sites on Amchitka

	Milrow	Long Shot	Cannikin	X^2(p)
Adults	*n*=18	*n*=5	*n*=7	
Arsenic	165±38.0	129±25.5	81.5±22.8	1.0 (NS)
	39.3	120	31.9	
	(A)	(A)	(A)	
Cadmium	43.3±6.3	40.6±11.2	56.6±6.3	1.1 (NS)
	31.0	31.5	53.6	
	(A)	(A)	(A)	
Chromium	554±259	95.6±21.0	107±23.6	12.3 (0.002)
	287	80.6	90.7	
	(A)	(B)	(B)	
Lead	760±221	483±282	307±85.3	2.1 (NS)
	458	206	83.8	
	(A)	(A)	(A)	
Manganese	528±59.8	570±292	1040±328	1.5 (NS)
	475	81.2	732	
	(A,B)	(B)	(A)	
Mercury	3960±718	3740±1350	4350±1170	0.1 (NS)
	2490	2830	3190	
	(A)	(A)	(A)	
Selenium	1010±110	850±215	987±106	0.6 (NS)
	842	727	952	
	(A)	(A)	(A)	
Chicks	*n*=6	*n*=7	*n*=8	
Arsenic	59.7±32.1	250±79.5	94.0 ±41.7	4.2 (NS)
	6.6	124	13.8	
	(A)	(A)	(A)	
Cadmium	43.3±18.4	47.3±13.4	45.3±12.0	0.3 (NS)
	29.7	36.3	33.6	
	(A)	(A)	(A)	
Chromium	481±168	864±207	791±343	1.7 (NS)
	344	643	177	
	(A)	(A)	(A)	
Lead	644±447	285±94.8	258±153	1.3 (NS)
	87.6	74.8	12.2	
	(A)	(A)	(A)	
Manganese	1120±244	5390±2130	2510±840	4.6 (NS)
	991	3630	1450	
	(A)	(A)	(A)	

	Milrow	Long Shot	Cannikin	X^2(p)
Mercury	1180±179	3480±389	1840±169	13.9 (0.0009)
	1100	3330	1780	
	(C)	(A)	(B)	
Selenium	1410±114	1120±253	1490±136	1.0 (NS)
	1380	934	1440	
	(A)	(A)	(A)	

Given are arithmetic means±SE (geometric means below) with Kruskal–Wallis Chi Square values and *p* values. Duncan values are given in parenthesis

Table 3

Metal levels (ppb, dry weight) (ng/g) of glaucous-winged gulls collected from 3 islands (east to west) in Alaska

	Adak	Amchitka	Kiska	X^2(*p*)
Adults	*n*=16	*n*=30	*n*=17	
Arsenic	177±91.2	140±24.3	119± 26.1	6.7 (0.03)
	1.2	45.1	29.7	
	(B)	(A)	(A)	
Cadmium	130±41.2	46.0±4.5	83.0±16.3	7.4 (0.03)
	76.4	35.3	64.0	
	(A)	(B)	(A)	
Chromium	2080±578	382±165	414±61.3	35.6 (<0.0001)
	1600	182	355	
	(A)	(C)	(B)	
Lead	1050±96.1	618±148	1080±401	10.4 (0.005)
	906	281	494	
	(A)	(B)	(A)	
Manganese	2500±825	656±100	1800±397	19.9 (<0.0001)
	1560	391	1290	
	(A)	(B)	(A)	
Mercury	2970±571	4010±540	3760±864	1.1 (NS)
	2050	2690	2170	
	(A)	(A)	(A)	
Selenium	1050±96.1	978±77.5	981±116	0.7 (NS)
	906	845	801	
	(A)	(A)	(A)	
Chicks		n=21	n=15	
Arsenic		136±35.6	144±29.5	0.6 (NS)
		23.3	49.5	
		(A)	(A)	
Cadmium		45.4±7.8	17.4±1.9	7.7 (0.006)
		33.3	15.8	
		(A)	(B)	
Chromium		727±152	426±91.2	1.3 (NS)
		329	326	
		(A)	(A)	
Lead		377±140	121±38.3	1.5 (NS)
		39.2	16.5	
		(A)	(A)	
Manganese		2960±785	1190±265	4.0 (0.05)
		1700	867	
		(A)	(A)	

	Adak	Amchitka	Kiska	$X^2(p)$
Mercury		2190±257	1680±228	1.2 (NS)
		1910	1400	
		(A)	(A)	
Selenium		1350±105	1220±79.3	1.4 (NS)
		1230	1180	
		(A)	(A)	
Eggs	*n*=8	*n*=7	*n*=6	
Arsenic	56.5±18.6	210±52.6	120±41.2	5.9 (0.05)
	12.4	152	74.9	
	(B)	(A)	(A,B)	
Cadium	5.8±3.9	158±28.4	102±26.4	13.8 (0.001)
	0.2	131	65.7	
	(B)	(A)	(A)	
Chromium	311±49.7	173±23.7	250±35.9	6.2 (0.05)
	289	164	238	
	(A)	(B)	(A,B)	
Lead	256±30.5	0.0±0.0	34.3±26.0	16.4 (0.0003)
	236	0.0	0.2	
	(A)	(C)	(B)	
Manganese	964±108	1320±211	951±215	2.5 (NS)
	897	1160	814	
	(A)	(A)	(A)	
Mercury	734±106	490±89.9	910±136	6.2 (0.04)
	664	451	870	
	(A,B)	(B)	(A)	
Selenium	1600±166	1500±134	1600±196	0.1 (NS)
	1540	1470	1540	
	(A)	(A)	(A)	

Given are arithmetic means± SE (geometric means below) with Kruskal–Wallis Chi Square values and *p* values. Duncan values are given in parenthesis

Table 4

Metal and metalloid concentrations (ng/g= ppb on dry weight) in adult glaucous-winged gull feathers by gender

Feathers	Male	Female	$X^2(p)$
Adults	*n*=33	*n*=24	
Body weight (g)	1,530±63.6	1350±38.6	2.7 (NS)
Arsenic	139±38.4	127±23.2	1.8 (NS)
	7.5	43.0	
Cadmium	66.8±8.2	60.0±11.1	0.3 (NS)
	49.3	42.8	
Chromium	1,200±334	274±66.9	15.1 (0.0001)
	592	188	
Lead	793±104	733±183	1.5 (NS)
	571	277	
Manganese	1,440±190	840±274	13.5 (0.0002)
	1,140	365	
Mercury	3,670±573	3,800±469	0.4 (NS)
	2,350	2,760	
Selenium	939±76.8	1,010±75.2	0.2 (NS)
	744	935	

First row gives arithmetic mean±SE. Second row gives geometric mean. Right hand column compares differences using Kruskal–Wallis non-parametric one-way analysis of variance yielding chi square values and *p* values

Table 5

Correlation of contaminant levels in glaucous-winged gull feathers and eggs from the Aleutians (all islands combined)

	Arsenic	Cadmium	Chromium	Lead	Manganese	Mercury	Selenium
Feathers							
Arsenic	*********	NS	−0.2 (0.03)	NS	NS	0.2 (0.01)	NS
Cadmium	NS	*********	0.2 (0.05)	0.2 (0.05)	0.3 (0.003)	NS	NS
Chromium	NS	NS	*********	0.3 (0.003)	0.3 (0.0007)	NS	NS
Lead	NS	NS	NS	*********	0.2 (0.01)	NS	NS
Manganese	NS	NS	0.3 (0.02)	NS	*********	−0.2 (0.03)	NS
Mercury	0.2 (0.05)	NS	NS	0.3 (0.02)	NS	*********	0.3 (0.004)
Selenium	NS	NS	NS	NS	NS	NS	*********
Eggs							
Arsenic	*********	0.3 (0.03)	NS	−0.4 (0.02)	NS	NS	NS
Cadmium		*********	NS	−0.6 (0.001)	0.3 (0.08)	NS	NS
Chromium			*********	0.4 (0.03)	NS	NS	NS
Lead				*********	NS	0.3 (0.09)	NS
Manganese					*********	NS	NS
Mercury						*********	0.4 (0.01)
Selenium							*********

Given are Kendall tau correlations. Correlations for adults are above the diagonal and chicks below. NS=not significant