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Baseline

Mercury concentrations in breast feathers of three upper trophic level marine predators from the western Aleutian Islands, Alaska

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ABSTRACT

Mercury (Hg) is a toxic element distributed globally through atmospheric transport. Agattu Island, located in the western Aleutian Islands, Alaska, has no history of point-sources of Hg contamination. We provide baseline levels of total mercury (THg) concentrations in breast feathers of three birds that breed on the island. Geometric mean THg concentrations in feathers of fork-tailed storm-petrels (*Oceanodroma furcata*; 6703 ± 1635, ng/g fresh weight [fw]) were higher than all other species, including snowy owl (*Bubo scandiacus*; 2105 ± 1631, ng/g fw), a raptor with a diet composed largely of storm-petrels at Agattu Island. There were no significant differences in mean THg concentrations of breast feathers among adult Kittlitz's murrelet (*Brachyramphus brevirostris*; 1658 ± 1276, ng/g fw) and chicks (1475 ± 671, ng/g fw) and snowy owls. The observed THg concentrations in fork-tailed storm-petrel feathers emphasizes the need for further study of Hg pollution in the western Aleutian Islands.

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Mercury (Hg) is a toxic metal with a global distribution that can negatively influence wildlife health (Scheuhammer et al., 2007). Microbial activity can convert inorganic Hg into its most toxic form, methylmercury (MeHg; Benoit et al., 2003), where it is rapidly incorporated into the food web and biomagnifies from one trophic level to the next (Ochoa-acuna et al., 2002). Atmospheric mercury concentrations are increasing globally, due in large part to anthropogenic releases, such as industrial emissions, waste incinerators, and coal-fired power plants (Pirrone et al., 2010). As a result of global transport paired with localized MeHg production, even isolated ecosystems can contain elevated Hg concentrations in resident biota (Landers et al., 2008). In Alaska, atmospheric deposition of Hg is attributed to long-range transport, associated in part with large-scale increases in coal combustion and expanding industry in several developing countries (AMAP, 2002). Additionally, the proportionally faster warming temperatures in Arctic regions may further exacerbate Hg exposure in northern latitudes by both releasing snowpack- and permafrost-entrained Hg, and by enhancing conditions that facilitate MeHg production (AMAP, 2002).

Several studies in the Aleutian archipelago (hereafter, Aleutians), a remote 1900 km island chain that extends westward from the tip of the Alaska Peninsula (Fig. 1), have shown that avian species are exposed to high concentrations of Hg and other contaminants (Anthony et al., 1999, 2007; Stout and Trust, 2002; Burger et al., 2007, 2009; Ricca et al., 2008). Specifically, an increasing east–west gradient along the archipelago was detected for Hg concentrations in tissues of glaucous-winged gulls (*Larus glaucescens*) and bald eagles (*Haliaeetus leucocephalus*; Anthony et al., 2007; Ricca et al., 2008). Recent studies focused on freshwater fishes and marine mammals documented similar patterns, with highest Hg concentrations at Agattu Island (hereafter, Agattu; Fig. 1) compared to eastern Aleutian Islands and mainland Alaska (Kenney, unpublished data; Rea et al., 2013).

Avian feathers provide an effective, non-invasive tool to examine Hg exposure in birds, particularly when monitoring Hg exposure in species of conservation concern, or birds that are sensitive to disturbance during the breeding season. Mercury from internal tissues (e.g., blood, liver, kidney, muscle) is depurated and sequestered in growing feathers during molt, where it is tightly bound to the keratin protein matrix. Because feathers are regularly molted, feather replacement can serve as a major pathway for the elimination of Hg body burden (Braune, 1987; Bearhop et al., 2000). Research has increasingly demonstrated that MeHg can impair growth and development, behavior, motor skills, and

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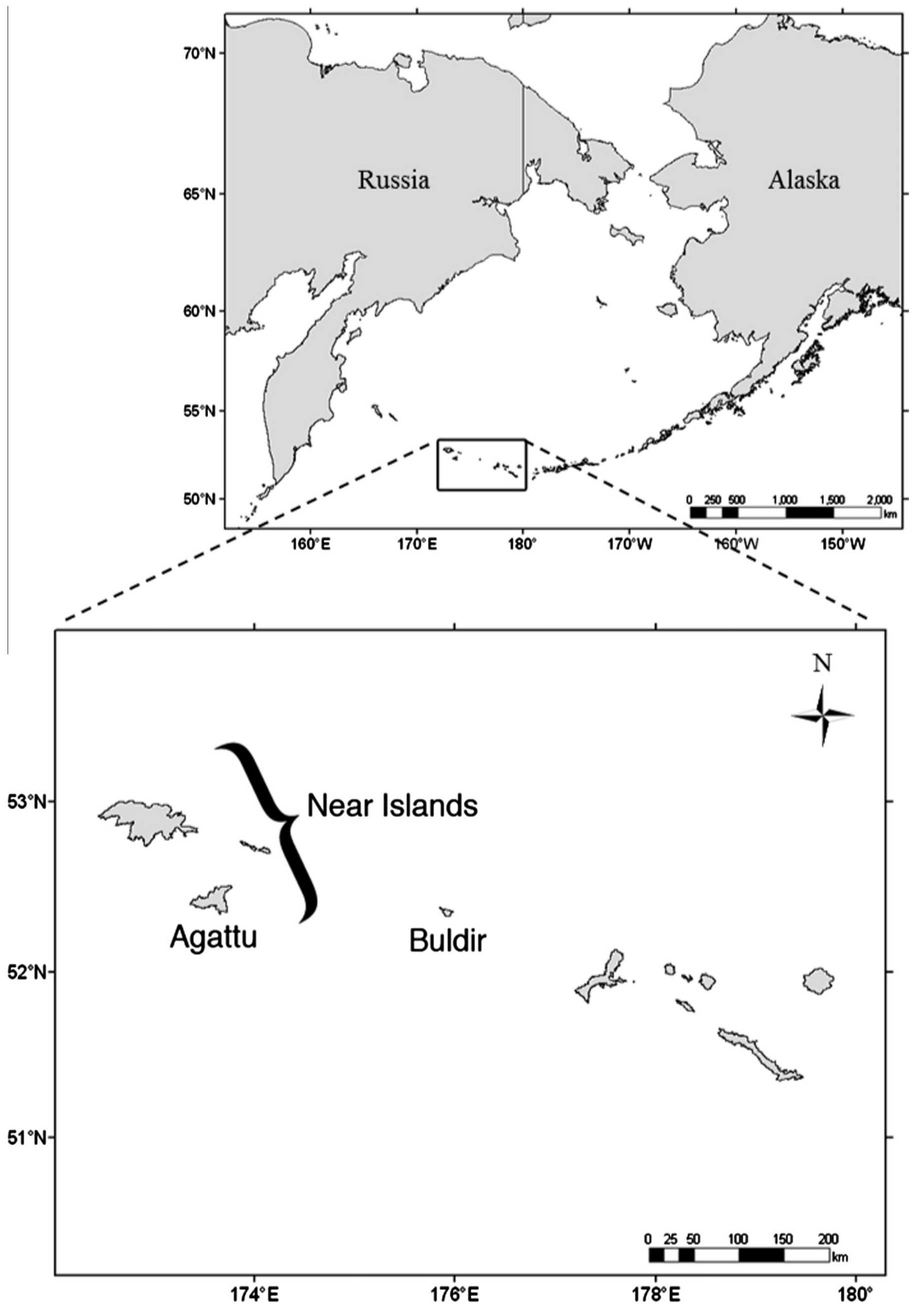

Fig. 1. Location of study at Agattu Island, in the Near Islands in the western Aleutians, Alaska.

survivorship in birds (Scheuhammer et al., 2007; Bennet et al., 2009). Interpreting the toxicity of Hg in feathers can be difficult due to the time lag of exposure that feathers may represent, as well as species-specific variation in tissue-feather Hg partition coefficients (Eagles-Smith et al., 2008). However, in some bird species feather Hg concentrations of 5000–40,000 ng/g have been related to reduced reproductive performance and lifetime productivity (Burger and Gochfeld, 1997; Evers et al., 2008), especially in piscivorous birds and upper trophic level species (Eisler, 1987).

We evaluated Hg levels among three species of birds, representing a range of trophic positions as indicators of regional Hg exposure in the western Aleutians. Kittlitz's murrelet (*Brachyramphus brevirostris*) is a pursuit-diving piscivore-planktivore endemic to Alaska and the Russian Far East that feeds on both marine forage fish and macrozooplankton (Day et al., 1999; Hatch, 2011). Little is known about the diet and migration habits of Kittlitz's murrelets during the non-breeding season. The fork-tailed storm-petrel (*Oceanodroma furcata*) is an abundant and widespread surface-feeding piscivore-planktivore that nests on islands from California to Alaska and northeastern Asia and winters at-sea near their breeding grounds (Boersma and Silva, 2001; Gibson and Byrd, 2007). In the western Aleutians, the fork-tailed storm-petrel diet is composed of macrozooplankton and mesopelagic marine fishes (Dragoo et al., 2012). The snowy owl (*Bubo scandiacus*) is a non-migratory apex predator in the western Aleutians and subsists entirely on a diet of birds at Agattu Island (Fig. 1), an island lacking terrestrial mammals (Kenney unpublished data; Williams and Frank, 1979).

Breast feathers from our focal species were collected during the course of four field seasons at Agattu (2008–2011). Breast feather samples were opportunistically collected either at nest sites or roosting sites. Specifically, while studying the breeding biology of Kittlitz's murrelets in 2008–2011, we collected adult breast feathers from nest scrapes during the incubation and chick-rearing periods and samples represent a composite of a breeding pair (2008: $n = 6$; 2009: $n = 6$; 2010: $n = 9$; 2011: $n = 8$). Breast and primary feathers were sampled from murrelet chicks found dead in their nests. Due to small sample size (2008: $n = 2$; 2009: $n = 2$; 2010: $n = 1$; 2011: $n = 3$), chick feathers for all years were pooled for analyses. Fork-tailed storm-petrel breast feathers were salvaged following depredation events at colonies. All storm-petrel samples were collected > 500 m apart and represent unique individuals. Due to small sample sizes (2009: $n = 10$; 2010: $n = 2$), storm-petrel feather samples from both years were pooled for analyses. Breast feathers of adult snowy owls were collected from roost sites across the mountains and lowland areas of Agattu during May–August. Individual roost sites were determined based on plumage differences and territorial behaviors of owls. During a given year, all breast feathers from a territory were pooled to represent a single individual. In total, we collected feather samples representing four snowy owls each year during 2008–2011. Feathers were stored in sterile Whirl Paks until analytical processing.

Nearly all Hg in feathers is made up of MeHg (Thompson and Furness, 1989); thus, we analyzed all feather samples for total Hg (THg). Each feather sample was washed in a dilute (1%) alconox solution and sonicated for 10 min to remove foreign material, then rinsed in deionized water and dried at 50 °C for 24–48 h. Once dried, breast feathers were held at ambient temperature and allowed to reach equilibrium with ambient humidity, then composited together for each bird and homogenized to a fine powder in a cryogenic grinding mill. Following Environmental Protection Agency method 7473 (EPA, 2000), we measured THg concentrations in each feather on a Milestone DMA-80 total Hg analyzer as described in Eagles-Smith et al. (2008). Recoveries certified reference materials (DORM-3) averaged 97.4% and absolute relative percent difference for all duplicates averaged 9.2%.

We used the Shapiro–Wilke's test to determine normality of the data and $\log_{10}$-transformed breast feather mercury concentrations to improve normality and variance homogeneity. One-way analysis of variance (ANOVA) with Tukey's honestly significant difference (HSD) was used to test for differences in breast feather THg concentrations among species and among years for Kittlitz's murrelets and snowy owls (significance level = 0.05). Mercury data are presented as geometric mean values ± standard error (SE) in ng/g fresh weight (fw), unless otherwise specified.

There were no significant differences in breast feather THg concentrations among years for Kittlitz's murrelets adults ($F_{3,25} = 1.24$, $P = 0.315$) nor snowy owls ($F_{2,9} = 0.33$, $P = 0.726$), therefore, data for all years for a species were pooled for subsequent inter-species comparisons. Mercury concentrations in breast feathers from one snowy owl in 2009 were exceptionally high (Fig. 2), but the results of our statistical tests did not change with this data point included ($F_{3,57} = 14.98$, $P < 0.001$) or omitted ($F_{3,56} = 14.79$, $P < 0.001$) from analysis, so we included this data point in all subsequent analysis. There were significant differences in breast feather THg concentrations among species ($F_3 = 14.98$, $P < 0.001$). Post-hoc comparisons indicate that mean THg concentrations of fork-tailed storm-petrel were higher (6703 ± 1635 ng/g) than all other species ($P < 0.05$; Fig. 2). Post-hoc comparisons indicated no differences in mean THg concentrations of Kittlitz's murrelet adults (1658 ± 1276 ng/g) and chicks (1475 ± 671 ng/g; $P = 0.969$), between Kittlitz's murrelet adults and snowy owl (2105 ± 1631 ng/g; $P = 0.996$), or between Kittlitz's murrelet chicks and snowy owl ($P = 0.944$; Fig. 2).

Overall, the pattern of THg concentrations in breast feathers at Agattu was: fork-tailed storm-petrel >> snowy owl ≈ Kittlitz's murrelet adults ≈ Kittlitz's murrelet chicks. We found that

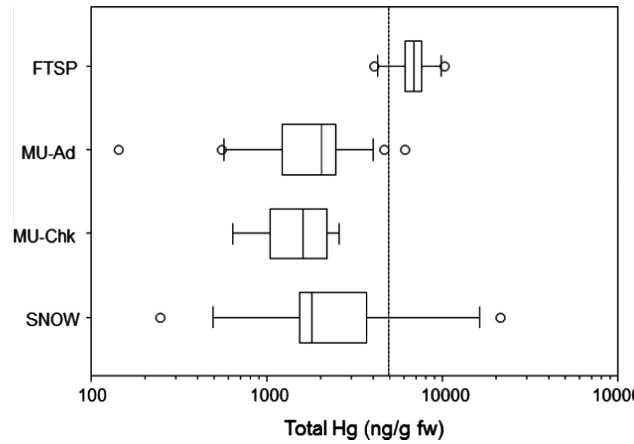

Fig. 2. Box plots depicting total mercury (Hg) concentrations ng/g fresh weight (fw) in breast feathers of fork-tailed storm-petrel (FTSP), Kittlitz's murrelet adults (MU-ad), Kittlitz's murrelet chicks (MU-Chk), and snowy owl (SNOW) from Agattu Island, Aleutian archipelago, Alaska. The box represents the interquartile range (r), the whiskers indicate the farthest data points within 1.5r from the 25th and the 75th percentiles. Outliers are shown as open circles. Vertical dashed line represents the hypothesized effects threshold of 5000 ng/g fw.

fork-tailed storm-petrels had THg concentrations that were four times greater than those in snowy owls or Kittlitz's murrelet adults and chicks. Mean THg concentrations in feathers of all species, except fork-tailed storm-petrel, were below 5000 ng/g, the effect level that has been hypothesized to result in adverse reproductive success in birds (Eisler,1987; Burger and Gochfeld, 2000).

Mean THg concentrations in breast feathers of fork-tailed storm-petrel at Agattu were 1.3 times greater than the effects threshold of 5000 ng/g (Fig. 2) and 83% (10 of 12) of individuals sampled exceeded this value. In addition to reproductive effects, Hg concentrations >5000 ng/g have been related to impaired territorial fidelity and reduced incubation behavior in other species (Furness et al., 1986; Evers et al., 2008). Elevated Hg concentrations in tissues of fork-tailed storm-petrel and its congener, Leach's storm-petrel (*Oceanodroma leucorhoa*), have been reported for western Canada (Elliot and Scheuhammer, 1997), the Aleutians (Ricca et al., 2008), and the Gulf of Maine (Goodale et al., 2008; Bond and Diamond, 2009) and has largely been attributed to high Hg concentrations in their prey (Monteiro et al., 1996; Lahaye et al., 2006). Diet samples from adults at Buldir Island (~150 km east of Agattu; Fig. 1) were largely composed of macrozooplankton (amphipods, copepods) and lantern-fishes (Myctophidae; Dragoo et al., 2012). While we found no published values of Hg concentrations in either prey type for the Aleutians, elevated Hg concentrations have been reported for myctophids in the North Atlantic (Thompson et al., 1998; Martin et al., 2006). Leach's storm-petrels have been used as indicators of Hg pollution due to their mesopelagic diets and vast feeding areas which focus on the surface layer where pollutants accumulate (Goodale et al., 2008; Bond and Diamond, 2009). Our findings concur with other studies that have documented high concentrations of Hg in tissues of storm-petrels and recommend this species as a biomonitoring sentinel to help quantify patterns of Hg exposure in marine environments across the North Pacific Ocean and Bering Sea.

Snowy owl diets based on pellet analysis at Agattu (Kenney, unpublished data; Williams and Frank, 1979) indicated that storm-petrels were the most common prey item (61% occurrence) and the second most frequent prey item (21% occurrence), respectively. Since Hg is known to biomagnify through food webs, it was unexpected that fork-tailed storm-petrels had greater mean THg concentrations than one of their primary predators at Agattu, the snowy owl. However, Burger and Gochfeld (2009), found a similar pattern in that bald eagles (a high trophic level species) had lower levels of Hg than pigeon guillemots (*Cepphus columba*), a comparatively lower trophic level species. Overall, the mean THg concentrations for snowy owls sampled at Agattu were within the 1000–5000 ng/g range of normal background concentrations of Hg in feathers estimated for other raptor species (Scheuhammer, 1991; Wood et al., 1996) with one exception; one individual had THg concentrations >20,000 ng/g (Fig. 2) and is difficult to interpret without specific knowledge of age, feather molt patterns, and specific diet habits. Further study of Hg dynamics within the snowy owl population at Agattu could benefit from studies focused on molt patterns and differences in diet during the breeding and non-breeding season.

Sources of Hg contamination in remote regions are difficult to identify and monitor, but understanding differences in effects within local food webs helps to elucidate patterns of exposure and provides insight into how to monitor future trends. Projections of climate models indicate that upper latitude regions such as the Aleutian archipelago will be disproportionately impacted by climate change (AMAP, 2011) with a general trend toward warmer and wetter weather patterns, conditions which would enhance Hg deposition through precipitation (Lin and Pehkonen, 1999) and an increase in MeHg production associated with warmer temperatures. Data from the present study serve as a reference point to monitor future temporal trends in global Hg deposition to this remote region and its effects on avian populations.

Author contributions

R.S.A.K and L.A.K. conceived and designed the study. R.S.A.K and L.A.K. collected samples. C.A.E. performed mercury analyses. R.S.A.K performed statistical analyses. R.S.A.K and L.A.K drafted the manuscript. R.S.A.K and L.A.K., C.A.E and A.L.B. contributed to manuscript development and preparation.

Conflict of interest

The authors declare that they have no conflict of interest.

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