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Short Communication

HIGH WITHIN-INDIVIDUAL VARIATION IN TOTAL MERCURY CONCENTRATION IN SEABIRD FEATHERS

ALEXANDER L. BOND* and ANTONY W. DIAMOND
Atlantic Cooperative Wildlife Ecology Research Network and Department of Biology, University of New Brunswick, P.O. Box 45111, Fredericton, New Brunswick E3B 6E1, Canada

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Abstract—To our knowledge, no rigorous assessment of the variation in mercury concentrations within individual seabirds has been made using multiple body feathers. We analyzed five feathers from individual Arctic terns (*Sterna paradisaea* Pontoppidan), common terns (*Sterna hirundo* L.), and Leach's storm-petrels (*Oceanodroma leucorhoa* Veillot) and found levels of within-individual variability higher than population or time-series variation. Using a randomization procedure, we found a large range of possible mercury concentrations if only one feather per individual had been sampled. Researchers should report within-individual variability in future studies.

Keywords—Mercury Variation Seabird Feather Monitoring

INTRODUCTION

Seabirds frequently have been used as indicators of contamination in the marine environment [1–3]. Feathers often are sampled, because they can be collected easily and without harming the bird [1,4]. Because mercury is bound to feather keratin and, therefore, is inert [5], feathers from museum specimens also may be used to monitor changes in contamination over time [6–8].

The high level of intraspecific variability in feather mercury concentrations [9] is influenced by such factors as progress of molting (i.e., replacing worn feathers with new ones [10]), sex [6], and age class [11], although the effects are not necessarily consistent [6,12]. Variation also has been documented within individual feathers [13], but researchers sampling multiple feathers per individual (e.g., E.K. MacIntosh, Honors thesis, University of New Brunswick, Fredericton, NB, Canada) have not tested explicitly for within-individual variation using body feathers.

Furness et al. [10] first recommended the use of body feathers to determine feather mercury levels because of differences in naming wing feathers among regions or studies and patterns of mercury deposition related to molt progression. Decreasing mercury concentration with increased molt progress in flight feathers has been recorded in seabirds [10] (MacIntosh, Honors thesis), to our knowledge differences among individual body feathers have not been shown.

Here, we report on the variation in total mercury concentrations of multiple feathers from individual Arctic terns (*Sterna paradisaea* Pontoppidan), common terns (*Sterna hirundo* L.), and Leach's storm-petrels (*Oceanodroma leucorhoa* Veillot). In addition, we present recommendations for future studies that analyze mercury burden using feathers.

* To whom correspondence may be addressed (abond@mun.ca). The current address of A.L. Bond is Department of Biology, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador A1B 3X9, Canada.

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MATERIALS AND METHODS

All samples were collected on Machias Seal Island (Bay of Fundy, Canada; 44°30′N, 67°06′W) [14] during the 2005 and 2006 breeding seasons. Five worn breast feathers were collected from five individuals of each species during routine banding or from freshly dead carcasses of birds that had collided with structures on the island. Worn feathers were those that exhibited fraying at the distal end and did not appear to be fresh and newly grown. Feathers were stored at −18°C in individual, sterile, polyethylene bags until analysis. Immediately before analysis, feathers were washed with a 0.25 M NaOH solution and three deionized water baths to remove external contamination. Mercury in feathers probably is not affected by such treatments [5], because mercury binds to disulfide bonds in keratin protein [15]. External contamination from inorganic mercury likely is low, because almost all mercury found in seabird feathers after washing is methylmercury [16] (A.L. Bond, MSc thesis, University of New Brunswick, Fredericton, NB, Canada).

Total mercury was analyzed at the Soils Lab, Faculty of Forestry and Environmental Management, University of New Brunswick. Full single feathers were loaded into a nickel boat and analyzed in a DMA-80 direct mercury analyzer (Milestone Science, Shelton, CT, USA), with a detection limit of 0.2 ng, by atomic absorption spectrometry. Dogfish muscle standard (DORM-2; National Research Council, Ottawa, ON, Canada) was used, in combination with blanks, to calibrate the results in each run. Recovery of total mercury from DORM-2 (mean ± standard deviation) was 87% ± 6.33%. Results are reported as parts per billion (ppb) on a fresh-weight basis.

To determine the possible estimates of mean feather mercury concentration for each species, we used a randomization procedure in Minitab 14 (Minitab, State College, PA, USA), whereby one mercury concentration per individual was selected and a mean generated for each species from the five randomly selected concentrations. This was iterated 1,000 times, and the distribution of the means was plotted to determine an overall mean and 95% confidence interval (CI) for

Table 1. Within-individual feather mercury concentrations of adult Arctic terns (*Sterna paradisaea* Pontoppidan; ARTE), common terns (*Sterna hirundo* L.; COTE), and Leach's storm-petrels (*Oceanodroma leucorhoa* Veillot; LHSP) from Machias Seal Island (NB, Canada)

Species[a]	Individual	Mercury (pbb) Min.	Max	Mean ± SD[b]	CV[c] (%)
ARTE	1	254	722	503 ± 185	37
ARTE	2	369	810	580 ± 173	30
ARTE	3	588	1,620	1,081 ± 491	45
ARTE	4	270	416	328 ± 54	17
ARTE	5	552	938	728 ± 141	19
COTE	1	582	2,066	1,075 ± 596	56
COTE	2	1,809	9,474	4,190 ± 3,209	77
COTE	3	1,663	3,441	2,207 ± 704	32
COTE	4	236	348	282 ± 42	15
COTE	5	247	1,403	503 ± 504	100
LHSP	1	4,898	11,526	6,614 ± 2,834	43
LHSP	2	5,961	10,823	7,844 ± 1,805	23
LHSP	3	3,828	5,867	5,084 ± 781	15
LHSP	4	3,491	4,971	4,167 ± 689	16
LHSP	5	350	462	409 ± 45	11

[a] ARTE = Arctic tern; COTE = common tern; LHSP = Leach's storm-petrel.
[b] $n = 5$ feathers/individual. SD = standard deviation.
[c] CV = coefficient of variation ([SD/mean]·100).

each species [17]. Parametric statistical analyses were conducted in SPSS® 11 (SPSS, Chicago, IL, USA), with results considered to be significant at $p < 0.05$.

RESULTS

Total feather mercury concentrations ranged from 236 to 11,526 ppb, with the highest levels recorded in Leach's storm-petrels (Table 1). Coefficients of variation ([SD/mean]·100, for SD = standard deviation) were not statistically different among species (analysis of variance: $F_{2,12} = 3.26$, $p = 0.07$) and were between 11 and 100% (Table 1). Coefficients of variation were not significantly correlated with minimum ($r = -0.17$, $p = 0.55$), maximum ($r = 0.14$, $p = 0.61$), or mean ($r = -0.05$, $p = 0.87$) total mercury concentration within individuals.

A significant difference was found between the minimum and maximum mercury levels within each individual (repeated-measures analysis of variance: $F_{1,12} = 11.03$, $p = 0.006$), with maximum concentrations from 32 to 424% higher than the minimum (Table 1).

Randomization produced concentrations (mean ± SD) of 645 ± 102 ppb for Arctic tern, 1,655 ± 622 ppb for common tern, and 4,798 ± 616 ppb for Leach's storm-petrel based on 1,000 iterations. Ranges of feather mercury concentrations were 434 to 901 ppb (95% CI: 497–809 ppb) in Arctic terns, 907 to 3,324 ppb (95% CI: 988–2,846) in common terns, and 3,705 to 6,712 ppb (95% CI: 4,024–5,930) in Leach's storm-petrels (Fig. 1).

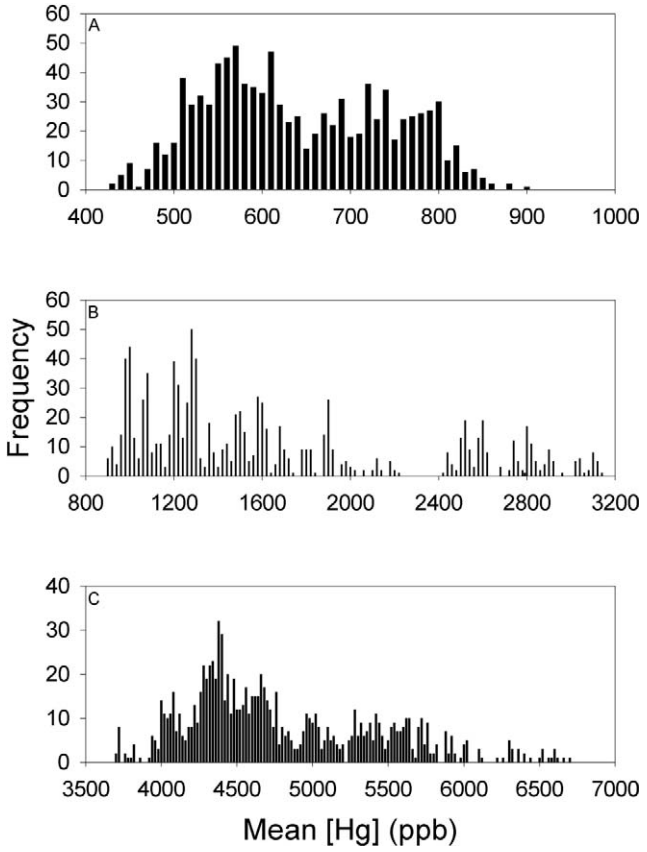

Fig. 1. Possible mean feather mercury concentrations in parts per billion (fresh wt) for Arctic terns (*Sterna paradisaea* Pontoppidan; **A**), common terns (*Sterna hirundo* L.; **B**) and Leach's storm-petrels (*Oceanodroma leucorhoa* Veillot; **C**) as determined by randomization (n = 1,000 iterations).

DISCUSSION

The amount of variability in feather total mercury concentration within individuals is high. Within-individual variation in the present study is larger than within-species variation from the same population when within-individual variation is not considered [18,19] (Bond, MSc thesis) and is greater or equal to increases documented over many years using museum specimens. In the case of Leach's storm-petrels, possible population mercury concentrations, as determined by randomization, straddled the hypothesized effect level of 5,000 ppb [20]. With such high within-individual variability, feather selection could have a profound effect on the reported means and contribute to the high within-species SDs that often are observed [9].

This intraindividual variation may result from body feathers being molted and replaced at different times, therefore reflecting greatly different body burdens of mercury. Body feather molt in many seabirds is poorly known [21–23], and as a result, intraindividual variability may be confounded by changes over time in mercury exposure and mobilization, especially in species with a protracted molting period [24].

The high variability within individuals is not surprising given that feathers may be grown over long periods of time or at different geographic locations where the availability of mercury is expected to differ. Variation in a bird's metabolic rate on a smaller scale (e.g., days) during feather formation and growth would alter mercury deposition [25,26]. Ultimately, mercury found in consumer tissues is derived from prey [27,28]; thus, changes in diet composition or mercury concentration in individual prey items also would contribute to variability in mercury in seabird body feathers.

Researchers may use feathers from chicks [29] to identify local mercury levels, because all chick feathers would be grown at the breeding site. The amount of mercury in chick feathers derived from local input (from prey items) or egg nutrients and the possible carryover effects, however, must be considered [30].

Feather mercury is representative of the internal body mer-

cury burden at the time of feather formation [4] and is dose-dependent [26,31], but it also may reflect the efficiency of converting toxic organic methylmercury into inorganic mercury (Bond, MSc thesis). A strong correlation has been found between total and organic mercury in seabird feathers [16,32], so we have no reason to believe that demethylation ability changes over the short term (i.e., within one molt cycle, or less than one year) and would cause high levels of variation in feather total mercury concentration within individuals.

We therefore recommend that researchers using feathers to monitor avian mercury burden examine multiple feathers from a subset of individuals to assess the level of intraindividual variability and report those results in a manner similar to repeatability analyses in other analytical processes [33], or that a homogenate of body feathers from the same individual be used to characterize mercury concentration.

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