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MERCURY CORRELATIONS AMONG SIX TISSUES FOR FOUR WATERBIRD SPECIES BREEDING IN SAN FRANCISCO BAY, CALIFORNIA, USA

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Abstract—Despite a large body of research concerning mercury (Hg) in birds, no single tissue has been used consistently to assess Hg exposure, and this has hampered comparisons across studies. We evaluated the relationships of Hg concentrations among tissues in four species of waterbirds (American avocets [*Recurvirostra americana*], black-necked stilts [*Himantopus mexicanus*], Caspian terns [*Hydroprogne caspia*; formerly *Sterna caspia*], and Forster's terns [*Sterna forsteri*]) and across three life stages (prebreeding adults, breeding adults, and chicks) in San Francisco Bay, California, USA. Across species and life stages, Hg concentrations (least square mean ± standard error) were highest in head feathers (6.45 ± 0.31 μg/g dry wt) and breast feathers (5.76 ± 0.28 μg/g dry wt), followed by kidney (4.54 ± 0.22 μg/g dry wt), liver (4.43 ± 0.21 μg/g dry wt), blood (3.10 ± 0.15 μg/g dry wt), and muscle (1.67 ± 0.08 μg/g dry wt). Relative Hg distribution among tissues, however, differed by species and life stage. Mercury concentrations were highly correlated among internal tissues ($r^2 \geq 0.89$). Conversely, the relationships between Hg in feathers and internal tissues were substantially weaker ($r^2 \leq 0.42$). Regression slopes sometimes differed among species and life stages, indicating that care must be used when predicting Hg concentrations in one tissue based on those in another. However, we found good agreement between predictions made using a general tissue-prediction equation and more specific equations developed for each species and life stage. Finally, our results suggest that blood is an excellent, nonlethal predictor of Hg concentrations in internal tissues but that feathers are relatively poor indicators of Hg concentrations in internal tissues.

Keywords—Mercury Tissue correlations Birds Blood Feathers

INTRODUCTION

Mercury (Hg) has been a contaminant of concern in birds for several decades [1–3], because it is widespread [4], has increased over time [5], and under specific exposure regimes, can be highly toxic [3]. These concerns have generated a large body of research reporting Hg concentrations in various bird tissues worldwide, resulting in a relatively good understanding of Hg dynamics in avian tissues [6,7]. Despite this focused research effort, no single tissue has been commonly used to assess Hg exposure, hampering the ability of investigators to compare results across studies. Instead, several bird tissues have been promoted for monitoring avian exposure and assessing risk, particularly feathers and liver [8–10], and more recently, blood [6,7,11], yet there have been few comprehensive studies that have simultaneously quantified the relationships among a suite of tissues in several bird species that would allow conversion of Hg concentrations in one tissue to those in another.

Blood often is a preferred tissue matrix for assessing Hg exposure, because it contains Hg almost entirely in the form of methylmercury (MeHg) [12,13], can be sampled nonlethally, correlates strongly with Hg concentrations in other internal tissues [14], and largely reflects recent dietary Hg exposure [6]. Conversely, feathers are discrete indicators of Hg exposure only during the period of feather growth [10,15], and interpretation of Hg in feathers depends on the timing of the most recent molt [8] and bird movements [16], including long-distance migration [17]. Although feathers also can be sampled nonlethally, feather Hg concentrations can be difficult to relate to toxic risk [18], because feathers are primarily a site for Hg depuration and sequestration and, thereafter, are inert.

Studies that focus on detoxification mechanisms and toxic effects of Hg commonly report Hg concentrations in liver tissue [3], presumably because the liver is the primary organ of xenobiotic detoxification and often contains the highest Hg levels among internal tissues [7,19,20]. Interpreting Hg concentrations in the avian liver relative to recent exposure, however, can be complicated by the process of demethylation [9,21]. Moreover, selenium (Se) can interact with hepatic MeHg and is thought to be an important contributor to the demethylation process [19,20,22,23]. Thus, proper interpretation of liver Hg contamination often requires a more extensive analytical examination, including total Hg (THg), MeHg, and Se concentrations.

With the abundance of tissues that have been examined to determine avian exposure and risk from Hg [7,24,25], substantial utility exists in the availability of conversion factors to estimate Hg concentrations in one tissue based on those in another. The 7:3:1 rule was proposed as a general ratio of Hg concentrations in feathers (fresh wt), liver (wet wt), and muscle

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Table 1. Total mercury concentrations (μg/g dry wt) in six tissues of adult and chick American avocets, black-necked stilts, Caspian terns, and Forster's terns collected at San Francisco Bay, California, USA[a]

Life stage	Tissue	Avocet	Stilt	Caspian tern	Forster's tern
Adults	Head feather	4.20 ± 0.39 A	12.16 ± 1.11 A	7.43 ± 0.97 A	7.34 ± 0.65 B
	Breast feather	2.23 ± 0.20 BC	8.45 ± 0.77 B	8.81 ± 1.15 A	9.63 ± 0.85 AB
	Kidney	2.64 ± 0.24 B	6.82 ± 0.62 BC	8.53 ± 1.11 A	11.60 ± 1.02 A
	Liver	2.59 ± 0.23 B	7.56 ± 0.69 B	8.22 ± 1.07 A	9.50 ± 0.84 AB
	Blood	1.49 ± 0.13 C	5.05 ± 0.46 C	6.83 ± 0.89 A	7.06 ± 0.62 B
	Muscle	0.98 ± 0.09 D	2.58 ± 0.23 D	2.97 ± 0.39 B	3.13 ± 0.28 C
Chicks	Head feather	6.76 ± 0.96 A	4.40 ± 0.39 A	NA	7.07 ± 0.76 A
	Breast feather	4.81 ± 0.69 A	4.05 ± 0.36 A	NA	7.19 ± 0.77 A
	Kidney	3.47 ± 0.49 AB	1.32 ± 0.12 BC	NA	2.74 ± 0.29 B
	Liver	3.80 ± 0.54 AB	1.41 ± 0.12 B	NA	2.37 ± 0.25 BC
	Blood	2.02 ± 0.29 BC	0.99 ± 0.09 C	NA	1.71 ± 0.18 C
	Muscle	1.58 ± 0.23 C	0.60 ± 0.05 D	NA	0.95 ± 0.10 D

[a] Values are presented as the geometric mean ± standard error. Capital letters that differ within a species and life stage indicate significant differences in mean tissue Hg concentrations (Tukey-Kramer, $p < 0.05$). See *Materials and Methods* for sample sizes. NA = no Caspian tern chicks were sampled.

(wet wt), respectively [26]. However, this ratio has not been widely used, because subsequent studies have disputed its generality [27]. Few researchers have presented regression equations for estimating Hg concentrations in one tissue based on those in another. Moreover, studies assessing Hg-tissue relationships generally are specific to a single species [6,14] and often are developed for only one life stage [14]; additionally, few tissues are examined simultaneously [28].

In the present study, we analyzed THg concentrations in six tissues (blood, liver, kidney, muscle, head feathers, and breast feathers) and MeHg concentrations in two tissues (liver and kidney) in each of four waterbird species that commonly breed in San Francisco Bay, California, USA, and examined the relationships of THg and MeHg concentrations between all pairs of tissues. We tested effects of both species and life stage (prebreeding adults, breeding adults, and chicks) on the relationships between tissues, and we provide both general (all species and life stages combined) and specific species and life stage regression equation parameters for the prediction of Hg concentrations in one tissue based on those in another. Finally, we evaluated the utility of several tissue matrices as bioindicators of avian Hg exposure.

MATERIALS AND METHODS

Sample collection

We captured and collected prebreeding and breeding American avocet (*Recurvirostra americana*; hereafter referred to as avocet), black-necked stilt (*Himantopus mexicanus*; hereafter referred to as stilt), Caspian tern (*Hydroprogne caspia*; formerly *Sterna caspia*), and Forster's tern (*Sterna forsteri*) adults as well as avocet, stilt, and Forster's tern chicks from several locations throughout the San Francisco Bay (37.8°N, 122.3°W). In 2005 and 2006, we collected prebreeding avocets (n = 77) and stilts (n = 65) during February and March and Caspian (n = 30) and Forster's terns (n = 55) during April and May using shotguns with steel shot or high-powered air rifles. We collected breeding avocets (n = 38), stilts (n = 46), and Forster's terns (n = 60) on their nests using self-triggered treadle traps or remotely detonated bow nets (Northwoods, Rainer, WA, USA) and net launchers (Coda Enterprises, Mesa, AZ, USA) during April and July of 2005 and 2006. Because of permit restrictions, we were required to collect breeding Caspian terns (n = 20) at off-colony sites; therefore, we collected Caspian terns within 400 m of known breeding colonies as the terns traveled from and arrived at their nesting colonies. Consequently, collected Caspian terns could not be confirmed as breeders, but they were collected during the breeding period in close proximity to breeding colonies. In 2005 and 2006, we also collected avocet (n = 46), stilt (n = 64), and Forster's tern (n = 100) chicks in or near their nesting colonies during July and August using hand nets or shotguns with steel shot.

Immediately upon collection, we sampled whole blood from all birds via cardiac puncture using sodium-heparinized needles (20–25 gauge) attached to polypropylene syringes. We immediately transferred blood to labeled polypropylene cryovials and used dry ice to freeze samples before transport to the laboratory for storage at −20°C. We conducted necropsies on all birds and used clean, acid-rinsed, stainless-steel scalpels, scissors, and forceps to excise the liver and kidneys for chemical analyses. We also excised a subsample of breast muscle (~4 g) from the anterior end of the pectoralis, within 3 cm of the keel, and feathers from both the crown (hereafter referred to as head feathers) and breast at the posterior end of the bird's keel (hereafter referred to as breast feathers). Necropsies were conducted primarily in the field immediately upon collection. However, in some instances, birds were frozen in the field on dry ice and necropsied in the laboratory within three months of collection. We placed all tissue samples in Whirl-Paks® (Nasco, Modesto, CA, USA) or I-CHEM glass vials (Chase Scientific Glass, Rockwood, TN, USA) and stored them frozen at −20°C until processing and analysis.

Sample processing and chemical determination

We thawed liver, kidney, and muscle samples at room temperature, after which we rinsed them in deionized water and blotted them dry with clean Kimwipes® (Kimberly-Clark, Roswell, GA, USA), then measured their wet mass to 0.0001 g on an analytical balance (Ohaus Adventurer Balance, model AR064; Ohaus, Pine Brook, NJ, USA). We oven-dried tissue samples at 50 to 60°C for 48 h or until they reached a constant mass. Once dried, we reweighed each tissue to the nearest 0.0001 g and then homogenized samples to a uniform consistency either using a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) or by hand using a porcelain mortar and pestle. We stored dry tissues in glass vials in an opaque dessicator before analyses.

We washed feathers in a 1% Alconox solution (Alconox, White Plains, NY, USA) while mechanically scrubbing each

Table 2. Matrix of linear regression parameters describing relationships in total mercury (THg) concentrations (μg/g dry wt except for blood [wet wt]) between each of six different tissue types over three life stages[a]

Species and life stage	Blood THg		Liver THg		Kidney THg	
	ln *y* = *b* + ln *x*	r^2	ln *y* = *b* + ln *x*	r^2	ln *y* = *b* + ln *x*	r^2
Blood						
All birds			ln *y* = −1.929 + 0.970(ln *x*)	0.88	ln *y* = −2.008 + 1.003(ln *x*)	0.87
Prebreeding adults			ln *y* = −1.962 + 0.958(ln *x*)	0.86	ln *y* = −2.218 + 1.076(ln *x*)	0.85
Breeding adults			ln *y* = −2.002 + 1.026(ln *x*)	0.90	ln *y* = −1.888 + 0.973(ln *x*)	0.92
Chicks			ln *y* = −1.863 + 0.905(ln *x*)	0.73	ln *y* = −1.872 + 0.908(ln *x*)	0.71
Avocets			ln *y* = −1.999 + 0.9254(ln *x*)	0.85	ln *y* = −2.148 + 1.063(ln *x*)	0.87
Stilts			ln *y* = −1.8491 + 0.899(ln *x*)	0.85	ln *y* = −1.857 + 0.969(ln *x*)	0.86
Caspian terns			ln *y* = −1.282 + 0.756(ln *x*)	0.57	ln *y* = −1.189 + 0.700(ln *x*)	0.45
Forster's terns			ln *y* = −1.945 + 1.012(ln *x*)	0.92	ln *y* = −2.088 + 1.005(ln *x*)	0.92
Liver THg						
All birds	ln *y* = 1.922 + 0.905(ln *x*)	0.88			ln *y* = −0.039 + 1.005(ln *x*)	0.93
Prebreeding adults	ln *y* = 1.967 + 0.893(ln *x*)	0.86			ln *y* = −0.200 + 1.075(ln *x*)	0.92
Breeding adults	ln *y* = 1.980 + 0.873(ln *x*)	0.90			ln *y* = 0.187 + 0.914(ln *x*)	0.93
Chicks	ln *y* = 1.716 + 0.810(ln *x*)	0.73			ln *y* = 0.010 + 1.000(ln *x*)	0.91
Avocets	ln *y* = 1.974 + 0.921(ln *x*)	0.85			ln *y* = −0.123 + 1.105(ln *x*)	0.96
Stilts	ln *y* = 1.968 + 0.949(ln *x*)	0.85			ln *y* = 0.028 + 1.044(ln *x*)	0.95
Caspian terns	ln *y* = 1.873 + 0.749(ln *x*)	0.57			ln *y* = 0.273 + 0.859(ln *x*)	0.68
Forster's terns	ln *y* = 1.904 + 0.913(ln *x*)	0.92			ln *y* = −0.096 + 0.973(ln *x*)	0.94
Kidney THg						
All birds	ln *y* = 1.935 + 0.872(ln *x*)	0.87	ln *y* = 0.134 + 0.929(ln *x*)	0.94		
Prebreeding adults	ln *y* = 1.986 + 0.788(ln *x*)	0.85	ln *y* = 0.298 + 0.853(ln *x*)	0.92		
Breeding adults	ln *y* = 1.961 + 0.945(ln *x*)	0.92	ln *y* = −0.030 + 1.014(ln *x*)	0.93		
Chicks	ln *y* = 1.684 + 0.785(ln *x*)	0.71	ln *y* = 0.059 + 0.913(ln *x*)	0.91		
Avocets	ln *y* = 1.875 + 0.814(ln *x*)	0.87	ln *y* = 0.147 + 0.866(ln *x*)	0.96		
Stilts	ln *y* = 1.841 + 0.891(ln *x*)	0.86	ln *y* = 0.043 + 0.911(ln *x*)	0.95		
Caspian terns	ln *y* = 1.945 + 0.639(ln *x*)	0.45	ln *y* = 0.479 + 0.793(ln *x*)	0.68		
Forster's terns	ln *y* = 2.056 + 0.916(ln *x*)	0.92	ln *y* = 0.203 + 0.966(ln *x*)	0.94		
Muscle THg						
All birds	ln *y* = 0.903 + 0.829(ln *x*)	0.90	ln *y* = −0.824 + 0.886(ln *x*)	0.94	ln *y* = −0.899 + 0.912(ln *x*)	0.92
Prebreeding adults	ln *y* = 0.845 + 0.805(ln *x*)	0.88	ln *y* = −0.858 + 0.864(ln *x*)	0.95	ln *y* = −1.078 + 0.960(ln *x*)	0.93
Breeding adults	ln *y* = 0.989 + 0.810(ln *x*)	0.91	ln *y* = −0.724 + 0.877(ln *x*)	0.92	ln *y* = −0.613 + 0.826(ln *x*)	0.90
Chicks	ln *y* = 0.826 + 0.785(ln *x*)	0.71	ln *y* = −0.792 + 0.865(ln *x*)	0.86	ln *y* = −0.786 + 0.863(ln *x*)	0.83
Avocets	ln *y* = 1.072 + 0.884(ln *x*)	0.90	ln *y* = −0.840 + 0.907(ln *x*)	0.94	ln *y* = −0.964 + 1.016(ln *x*)	0.92
Stilts	ln *y* = 0.929 + 0.865(ln *x*)	0.91	ln *y* = −0.775 + 0.857(ln *x*)	0.93	ln *y* = −0.812 + 0.931(ln *x*)	0.95
Caspian terns	ln *y* = 0.870 + 0.699(ln *x*)	0.52	ln *y* = −0.838 + 0.912(ln *x*)	0.89	ln *y* = −0.846 + 0.901(ln *x*)	0.80
Forster's terns	ln *y* = 0.843 + 0.854(ln *x*)	0.92	ln *y* = −0.863 + 0.893(ln *x*)	0.95	ln *y* = −1.037 + 0.905(ln *x*)	0.94
Breast feather THg						
All birds	ln *y* = 2.005 + 0.483(ln *x*)	0.32	ln *y* = 0.991 + 0.513(ln *x*)	0.34	ln *y* = 0.928 + 0.541(ln *x*)	0.34
Prebreeding adults	ln *y* = 2.114 + 0.657(ln *x*)	0.49	ln *y* = 0.724 + 0.688(ln *x*)	0.49	ln *y* = 0.506 + 0.794(ln *x*)	0.52
Breeding adults	ln *y* = 1.702 + 0.573(ln *x*)	0.27	ln *y* = 0.558 + 0.601(ln *x*)	0.28	ln *y* = 0.630 + 0.565(ln *x*)	0.28
Chicks	ln *y* = 2.389 + 0.539(ln *x*)	0.30	ln *y* = 1.330 + 0.506(ln *x*)	0.27	ln *y* = 1.266 + 0.600(ln *x*)	0.35
Avocets	ln *y* = 1.290 + 0.305(ln *x*)	0.16	ln *y* = 0.667 + 0.318(ln *x*)	0.17	ln *y* = 0.581 + 0.386(ln *x*)	0.20
Stilts	ln *y* = 0.372 + 0.453(ln *x*)	0.37	ln *y* = 1.250 + 0.439(ln *x*)	0.38	ln *y* = 1.259 + 0.458(ln *x*)	0.36
Caspian terns	ln *y* = 1.983 + 0.617(ln *x*)	0.18	ln *y* = 0.479 + 0.827(ln *x*)	0.31	ln *y* = 0.445 + 0.830(ln *x*)	0.29
Forster's terns	ln *y* = 2.230 + 0.335(ln *x*)	0.20	ln *y* = 1.475 + 0.397(ln *x*)	0.25	ln *y* = 1.426 + 0.385(ln *x*)	0.23
Head feather THg						
All birds	ln *y* = 2.144 + 0.497(ln *x*)	0.40	ln *y* = 1.0477 + 0.579(ln *x*)	0.49	ln *y* = 1.039 + 0.572(ln *x*)	0.43
Prebreeding adults	ln *y* = 2.287 + 0.704(ln *x*)	0.62	ln *y* = 0.762 + 0.796(ln *x*)	0.73	ln *y* = 0.577 + 0.874(ln *x*)	0.69
Breeding adults	ln *y* = 1.966 + 0.368(ln *x*)	0.15	ln *y* = 1.021 + 0.487(ln *x*)	0.24	ln *y* = 1.225 + 0.394(ln *x*)	0.17
Chicks	ln *y* = 2.467 + 0.559(ln *x*)	0.40	ln *y* = 1.344 + 0.553(ln *x*)	0.42	ln *y* = 1.309 + 0.608(ln *x*)	0.47
Avocets	ln *y* = 2.352 + 0.721(ln *x*)	0.76	ln *y* = 0.814 + 0.750(ln *x*)	0.77	ln *y* = 0.664 + 0.880(ln *x*)	0.82
Stilts	ln *y* = 2.475 + 0.586(ln *x*)	0.64	ln *y* = 1.286 + 0.598(ln *x*)	0.70	ln *y* = 1.294 + 0.630(ln *x*)	0.66
Caspian terns	ln *y* = 1.808 + 0.633(ln *x*)	0.19	ln *y* = 0.201 + 0880(ln *x*)	0.35	ln *y* = 0.169 + 0.881(ln *x*)	0.32
Forster's terns	ln *y* = 1.996 + 0.304(ln *x*)	0.14	ln *y* = 1.263 + 0.392(ln *x*)	0.20	ln *y* = 1.254 + 0.362(ln *x*)	0.16

[a] Tissues listed as column headings represent *x*-axis, and those within the body of the table represent the *y*-axis. See *Materials and Methods* for sample sizes.

feather to remove surface debris. We then dried feathers at 60°C for up to 24 h and stored them in a dessicator before analysis. We thawed blood samples to room temperature, inverted the cryovials several times, and thoroughly mixed the blood by stirring with a clean pipette tip to ensure sample homogeneity. Many stilt and tern blood samples were elevated in Hg to such an extent that to avoid saturation of the atomic absorbance cells or bias from carryover effects [29], we diluted the blood samples with deionized water at a ratio of four parts water to one part blood. We then pipetted a 200-μl aliquot of diluted blood into a quartz sample vessel for analysis.

We analyzed all samples for THg at the U.S. Geological Survey, Davis Field Station Mercury Lab (Davis, CA) following U.S. Environmental Protection Agency method 7473 [30] on a Milestone DMA-80 Direct Mercury Analyzer (Milestone, Monroe, CT, USA). We used an integrated sequence of drying, thermal decomposition, catalytic conversion, and then amalgamation, followed by atomic absorption spectroscopy. Drying and decomposition settings differed among tissue types. Muscle, kidney, and liver samples were dried at 150°C for 120 s and combusted at 850°C for 180 s. Feathers were dried at 300°C for 60 s and combusted at 850°C for 180 s. Blood was dried at 160°C for 140 s and combusted at 850°C for 240 s. Before analysis, we calibrated the analyzer over its entire operating range (0.5–600 ng of Hg) with dilutions of a certified Hg standard solution (SPEX CertiPrep, Metuchen, NJ, USA).

Quality-assurance measures included analysis of two certified reference materials (either dogfish muscle tissue, dogfish

Table 2. Extended

Species and life stage	Muscle THg		Breast feather THg		Head feather THg	
	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2
Blood						
All birds	$\ln y = -1.024 + 1.080(\ln x)$	0.90	$\ln y = -1.673 + 0.673(\ln x)$	0.32	$\ln y = -1.992 + 0.801(\ln x)$	0.40
Prebreeding adults	$\ln y = -0.988 + 1.092(\ln x)$	0.88	$\ln y = -1.855 + 0.749(\ln x)$	0.49	$\ln y = -2.214 + 0.880(\ln x)$	0.62
Breeding adults	$\ln y = -1.080 + 1.119(\ln x)$	0.91	$\ln y = -0.601 + 0.473(\ln x)$	0.27	$\ln y = -0.565 + 0.405(\ln x)$	0.15
Chicks	$\ln y = -1.062 + 0.904(\ln x)$	0.71	$\ln y = -2.239 + 0.552(\ln x)$	0.30	$\ln y = -2.583 + 0.721(\ln x)$	0.40
Avocets	$\ln y = -1.208 + 1.019(\ln x)$	0.90	$\ln y = -1.681 + 0.540(\ln x)$	0.16	$\ln y = -1.756 + 1.050(\ln x)$	0.76
Stilts	$\ln y = -1.025 + 1.057(\ln x)$	0.91	$\ln y = -2.083 + 0.821(\ln x)$	0.37	$\ln y = -2.883 + 1.088(\ln x)$	0.64
Caspian terns	$\ln y = -0.502 + 0.747(\ln x)$	0.52	$\ln y = -0.326 + 0.293(\ln x)$	0.18	$\ln y = -0.302 + 0.306(\ln x)$	0.19
Forster's terns	$\ln y = -0.916 + 1.077(\ln x)$	0.92	$\ln y = -1.426 + 0.593(\ln x)$	0.20	$\ln y = -0.925 + 0.452(\ln x)$	0.14
Liver THg						
All birds	$\ln y = 0.964 + 1.066(\ln x)$	0.94	$\ln y = 0.342 + 0.657(\ln x)$	0.34	$\ln y = -0.101 + 0.841(\ln x)$	0.49
Prebreeding adults	$\ln y = 1.016 + 1.100(\ln x)$	0.95	$\ln y = 0.221 + 0.714(\ln x)$	0.49	$\ln y = -0.298 + 0.912(\ln x)$	0.73
Breeding adults	$\ln y = 0.932 + 1.052(\ln x)$	0.92	$\ln y = 1.307 + 0.475(\ln x)$	0.28	$\ln y = 1.179 + 0.485(\ln x)$	0.24
Chicks	$\ln y = 0.896 + 0.994(\ln x)$	0.86	$\ln y = -0.195 + 0.529(\ln x)$	0.27	$\ln y = -0.621 + 0.757(\ln x)$	0.42
Avocets	$\ln y = 0.929 + 1.035(\ln x)$	0.94	$\ln y = 0.435 + 0.542(\ln x)$	0.17	$\ln y = -0.623 + 1.032(\ln x)$	0.77
Stilts	$\ln y = 0.945 + 1.089(\ln x)$	0.93	$\ln y = -0.170 + 0.873(\ln x)$	0.38	$\ln y = -1.051 + 1.169(\ln x)$	0.70
Caspian terns	$\ln y = 1.052 + 0.977(\ln x)$	0.89	$\ln y = 1.305 + 0.374(\ln x)$	0.31	$\ln y = 1.315 + 0.398(\ln x)$	0.35
Forster's terns	$\ln y = 1.009 + 1.062(\ln x)$	0.95	$\ln y = 0.400 + 0.639(\ln x)$	0.25	$\ln y = 0.843 + 0.521(\ln x)$	0.20
Kidney THg						
All birds	$\ln y = 1.031 + 1.009(\ln x)$	0.92	$\ln y = -0.428 + 0.630(\ln x)$	0.34	$\ln y = 0.098 + 0.755(\ln x)$	0.43
Prebreeding adults	$\ln y = 1.151 + 0.970(\ln x)$	0.93	$\ln y = 0.409 + 0.654(\ln x)$	0.52	$\ln y = 0.009 + 0.795(\ln x)$	0.69
Breeding adults	$\ln y = 0.879 + 1.095(\ln x)$	0.90	$\ln y = 1.263 + 0.495(\ln x)$	0.28	$\ln y = 1.274 + 0.434(\ln x)$	0.17
Chicks	$\ln y = 0.888 + 0.958(\ln x)$	0.83	$\ln y = -0.272 + 0.578(\ln x)$	0.35	$\ln y = -0.657 + 0.775(\ln x)$	0.47
Avocets	$\ln y = 0.954 + 0.905(\ln x)$	0.92	$\ln y = 0.510 + 0.507(\ln x)$	0.20	$\ln y = -0.441 + 0.932(\ln x)$	0.82
Stilts	$\ln y = 0.903 + 1.016(\ln x)$	0.96	$\ln y = -0.086 + 0.785(\ln x)$	0.36	$\ln y = -0.889 + 1.054(\ln x)$	0.66
Caspian terns	$\ln y = 1.184 + 0.892(\ln x)$	0.80	$\ln y = 1.402 + 0.347(\ln x)$	0.29	$\ln y = 1.414 + 0.368(\ln x)$	0.32
Forster's terns	$\ln y = 1.198 + 1.034(\ln x)$	0.94	$\ln y = 0.663 + 0.592(\ln x)$	0.23	$\ln y = 1.154 + 0.449(\ln x)$	0.16
Muscle THg						
All birds			$\ln y = -0.493 + 0.592(\ln x)$	0.34	$\ln y = -0.898 + 0.743(\ln x)$	0.47
Prebreeding adults			$\ln y = -0.694 + 0.632(\ln x)$	0.49	$\ln y = -1.140 + 0.799(\ln x)$	0.71
Breeding adults			$\ln y = 0.451 + 0.401(\ln x)$	0.24	$\ln y = 0.305 + 0.428(\ln x)$	0.22
Chicks			$\ln y = -1.027 + 0.545(\ln x)$	0.31	$\ln y = -1.418 + 0.720(\ln x)$	0.46
Avocets			$\ln y = -0.484 + 0.549(\ln x)$	0.20	$\ln y = -1.446 + 0.964(\ln x)$	0.78
Stilts			$\ln y = -0.919 + 0.758(\ln x)$	0.37	$\ln y = -1.724 + 1.022(\ln x)$	0.69
Caspian terns			$\ln y = 0.383 + 0.327(\ln x)$	0.25	$\ln y = 0.391 + 0.350(\ln x)$	0.29
Forster's terns			$\ln y = -0.267 + 0.516(\ln x)$	0.23	$\ln y = 0.030 + 0.419(\ln x)$	0.17
Breast feather THg						
All birds	$\ln y = 1.439 + 0.577(\ln x)$	0.34			$\ln y = 0.155 + 0.827(\ln x)$	0.59
Prebreeding adults	$\ln y = 1.417 + 0.774(\ln x)$	0.79			$\ln y = 0.110 + 0.843(\ln x)$	0.64
Breeding adults	$\ln y = 1.147 + 0.608(\ln x)$	0.24			$\ln y = 0.293 + 0.756(\ln x)$	0.45
Chicks	$\ln y = 1.709 + 0.573(\ln x)$	0.31			$\ln y = -0.075 + 0.990(\ln x)$	0.83
Avocets	$\ln y = 0.953 + 0.373(\ln x)$	0.20			$\ln y = 0.176 + 0.511(\ln x)$	0.32
Stilts	$\ln y = 1.649 + 0.484(\ln x)$	0.37			$\ln y = 0.201 + 0.781(\ln x)$	0.64
Caspian terns	$\ln y = 1.387 + 0.776(\ln x)$	0.25			$\ln y = 0.228 + 0.970(\ln x)$	0.94
Forster's terns	$\ln y = 1.815 + 0.451(\ln x)$	0.23			$\ln y = 0.520 + 0.837(\ln x)$	0.78
Head feather THg						
All birds	$\ln y = 1.594 + 0.631(\ln x)$	0.47	$\ln y = 0.671 + 0.719(\ln x)$	0.59		
Prebreeding adults	$\ln y = 1.569 + 0.887(\ln x)$	0.71	$\ln y = 0.612 + 0.756(\ln x)$	0.64		
Breeding adults	$\ln y = 1.472 + 0.515(\ln x)$	0.22	$\ln y = 0.977 + 0.596(\ln x)$	0.45		
Chicks	$\ln y = 1.840 + 0.646(\ln x)$	0.46	$\ln y = 0.349 + 0.841(\ln x)$	0.83		
Avocets	$\ln y = 1.508 + 0.806(\ln x)$	0.78	$\ln y = 0.930 + 0.628(\ln x)$	0.32		
Stilts	$\ln y = 1.843 + 0.672(\ln x)$	0.69	$\ln y = 0.612 + 0.824(\ln x)$	0.64		
Caspian terns	$\ln y = 1.164 + 0.828(\ln x)$	0.29	$\ln y = -0.094 + 0.969(\ln x)$	0.94		
Forster's terns	$\ln y = 1.657 + 0.409(\ln x)$	0.17	$\ln y = -0.048 + 0.934(\ln x)$	0.78		

liver, or lobster hepatopancreas [DORM-2, DOLT-3, and TORT-2, respectively; National Research Council of Canada, Ottawa, ON]), two system and method blanks, two duplicates, one matrix spike, and one matrix spike duplicate per batch. Recoveries averaged 102.1% ± 0.9% (n = 329; mean ± 95% confidence interval) and 99.9% ± 0.7% (n = 409) for certified reference materials and calibration checks, respectively. Matrix spike recoveries averaged 97.7% ± 1.3% (n = 154) overall (blood: 98.2% ± 2.1%, n = 34; feathers: 100.8% ± 3.5%, n = 38; kidney: 96.7% ± 3.2%, n = 22; liver: 95.1% ± 2.6%, n = 31; muscle: 96.7% ± 1.3%, n = 29). The absolute relative percentage difference (RPD) for duplicates in all tissues combined averaged 7.8% ± 1.9% (blood: 4.9% ± 1.1%, n = 68; feathers: 18.9% ± 5.9%, n = 78; kidney: 3.0% ± 0.9%, n = 42; liver: 2.6% ± 0.7%, n = 52; muscle: 2.5% ± 1.0%, n = 38), and absolute RPD for matrix spike duplicates averaged 5.0% ± 1.0% overall (blood: 2.7% ± 0.8%, n = 34; feathers: 10.7% ± 3.3%, n = 38; kidney: 4.4% ± 1.4%, n = 22; liver: 3.7% ± 1.0%, n = 31; muscle: 1.9% ± 1.7%, n = 29).

A subset of livers and kidneys (73% of all samples) also was analyzed for MeHg at Battelle Marine Sciences Laboratory (Sequim, WA, USA) using cold-vapor atomic fluorescence following U.S. Environmental Protection Agency method 1630 [31]. To assess accuracy and precision, certified reference materials for MeHg in tissues (DOLT-2), matrix spikes, duplicate samples, and blanks were analyzed. Recoveries averaged 106.2% ± 1.83% (n = 57) and 96.8% ± 1.83% (n =

Table 3. Matrix of linear regression parameters describing relationships between liver and kidney methylmercury (MeHg) and total mercury (THg) concentrations (μg/g dry wt except blood [wet wt]) in each of six different tissues over three life stages[a]

Species and life stage	Blood THg		Liver THg		Liver MeHg		Kidney MeHg	
	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2
Liver MeHg								
All birds	ln *y* = 1.744 + 0.833(ln *x*)	0.88	ln *y* = −0.049 + 0.925(ln *x*)	0.97			ln *y* = −0.088 + 0.932(ln *x*)	0.93
Prebreeding adults	ln *y* = 1.690 + 0.783(ln *x*)	0.83	ln *y* = −0.081 + 0.914(ln *x*)	0.97			ln *y* = −0.276 + 0.986(ln *x*)	0.92
Breeding adults	ln *y* = 1.837 + 0.813(ln *x*)	0.91	ln *y* = 0.014 + 0.912(ln *x*)	0.95			ln *y* = 0.160 + 0.848(ln *x*)	0.92
Chicks	ln *y* = 1.628 + 0.787(ln *x*)	0.71	ln *y* = −0.039 + 0.937(ln *x*)	0.95			ln *y* = −0.034 + 0.940(ln *x*)	0.86
Avocets	ln *y* = 1.777 + 0.848(ln *x*)	0.85	ln *y* = −0.133 + 0.957(ln *x*)	0.98			ln *y* = −0.241 + 1.050(ln *x*)	0.93
Stilts	ln *y* = 1.754 + 0.849(ln *x*)	0.88	ln *y* = 0.038 + 0.879(ln *x*)	0.96			ln *y* = 0.020 + 0.927(ln *x*)	0.94
Caspian terns	ln *y* = 1.667 + 0.654(ln *x*)	0.49	ln *y* = 0.029 + 0.867(ln *x*)	0.89			ln *y* = 0.098 + 0.822(ln *x*)	0.74
Forster's terns	ln *y* = 1.783 + 0.867(ln *x*)	0.93	ln *y* = 0.018 + 0.914(ln *x*)	0.98			ln *y* = −0.066 + 0.896(ln *x*)	0.93
Kidney MeHg								
All birds	ln *y* = 1.728 + 0.861(ln *x*)	0.88	ln *y* = −0.098 + 0.931(ln *x*)	0.90	ln *y* = −0.038 + 1.001(ln *x*)	0.92	ln *y* = −0.225 + 0.989(ln *x*)	0.95
Prebreeding adults	ln *y* = 1.677 + 0.808(ln *x*)	0.83	ln *y* = −0.089 + 0.905(ln *x*)	0.88	ln *y* = −0.010 + 0.990(ln *x*)	0.91	ln *y* = −0.388 + 0.914(ln *x*)	0.96
Breeding adults	ln *y* = 1.743 + 0.919(ln *x*)	0.89	ln *y* = −0.248 + 1.005(ln *x*)	0.89	ln *y* = −0.227 + 1.085(ln *x*)	0.91	ln *y* = −0.187 + 0.980(ln *x*)	0.95
Chicks	ln *y* = 1.685 + 0.835(ln *x*)	0.76	ln *y* = −0.013 + 0.852(ln *x*)	0.82	ln *y* = 0.034 + 0.902(ln *x*)	0.81	ln *y* = −0.090 + 0.941(ln *x*)	0.91
Avocets	ln *y* = 1.555 + 0.804(ln *x*)	0.88	ln *y* = −0.261 + 0.878(ln *x*)	0.93	ln *y* = −0.119 + 0.897(ln *x*)	0.90	ln *y* = −0.386 + 0.990(ln *x*)	0.94
Stilts	ln *y* = 1.630 + 0.836(ln *x*)	0.90	ln *y* = −0.025 + 0.847(ln *x*)	0.93	ln *y* = −0.047 + 0.954(ln *x*)	0.95	ln *y* = −0.102 + 0.927(ln *x*)	0.97
Caspian terns	ln *y* = 1.866 + 0.589(ln *x*)	0.37	ln *y* = 0.404 + 0.783(ln *x*)	0.65	ln *y* = 0.357 + 0.913(ln *x*)	0.74	ln *y* = −0.058 + 0.982(ln *x*)	0.94
Forster's terns	ln *y* = 1.876 + 0.860(ln *x*)	0.93	ln *y* = 0.166 + 0.887(ln *x*)	0.94	ln *y* = 0.159 + 0.967(ln *x*)	0.94	ln *y* = −0.003 + 0.910(ln *x*)	0.97

[a] Tissues listed as column headings represent the *x* axis, and those within the body of the table represent the *y* axis.

175) for certified reference materials and matrix spikes, respectively. Absolute RPD for duplicates averaged 7.8% ± 1.5% ($n = 42$), and absolute RPD for matrix spike duplicates averaged 7.3% ± 1.3% ($n = 87$).

Statistical analyses

Because moisture content in tissues can vary by several percent and may differ among tissue types, we analyzed liver, kidney, muscle, and feather Hg on a dry-weight basis. Because blood typically is measured and reported on a wet-weight basis, we analyzed and reported blood wet. We converted blood wet-weight concentrations to dry-weight values, however, using sample-specific moisture content for among-tissue comparisons. We also provide the moisture content (average ± standard error) for each tissue (liver: 67.04% ± 0.15%; muscle: 69.71% ± 0.11%; kidney: 73.60% ± 0.12%; blood: 79.13% ± 0.13%). Before analyses, we natural-log transformed all Hg data to better meet the assumptions of standard parametric statistical tests and to normalize residuals. We used multifactor analysis of variance (ANOVA) to test for differences in Hg concentrations among tissues and life stages for each species. We did not consider gender in our models, both because most of the sampled birds were females and because we lacked the sample size to assess gender differences in all species. In our initial model, we included species, life stage, and tissue type as independent categorical variables as well as species × tissue and tissue × life stage interactions. The species × life stage interaction caused a convergence failure in our model, because we did not sample Caspian tern chicks. Therefore, we excluded that interaction from all analyses. The tissue × life stage interaction in the global model was statistically significant (see *Results*); thus, we assessed differences in Hg concentrations among tissue types for each species separately. To examine the variability of Hg concentrations among tissues, we determined the coefficient of variation (CV) in tissue Hg concentrations for each individual bird using only those individuals for which we had the entire suite of tissues ($n = 435$). The CV was calculated as the mean/standard deviation of tissue-specific THg concentrations for each individual bird. We used two-way ANOVA to test for differences in CV among species and bird life stages (adult vs chick) and examined pairwise differences among categories using Tukey–Kramer post hoc tests.

We used linear regression to examine the relationships in Hg concentrations between all pairs of tissues for each species and life stage. For each tissue pair, we developed a set of equations for predicting Hg concentrations in one tissue based on those in another. These equations spanned a range of scales. First, we developed a general equation that included data for all species and life stages combined. Second, we developed life stage–specific equations for all species combined. Third, we developed species-specific equations for all life stages combined. Fourth, we developed life stage–specific equations for each species independently.

We tested differences in the slopes of tissue relationships among species and life stages (prebreeding adults, breeding adults, and chicks) using analysis of covariance (separate slopes model). We analyzed our data using a tiered approach. For each tissue pair, we first assessed a global model for factors influencing tissue Hg concentrations; in this global model, species and life stage were categorical factors, *x*-axis tissue Hg concentration was the covariate, and interactions between the covariate and each categorical factor were included to test for slope differences. For example, in assessing the relationship between THg concentrations in liver and blood, we constructed a global model with species and life stage as the main effects, blood THg as the covariate, and species × blood THg and life stage × blood THg interactions. Using backward stepwise elimination, we individually removed any nonsignificant ($p > 0.05$) covariate × main effect interaction in the global model. If the slopes differed among species or life stage, we then conducted a second-tier analysis, whereby we tested the correlation between the two tissue Hg concentrations separately for each species and life stage. Because we focused on relationships between tissue Hg concentrations, we do not report the results of main effects tests. Instead, we evaluated only the interaction effects related to differences in slopes. All statistical tests were conducted using JMP® 5.0 software (SAS Institute, Cary, NC, USA), and the Hg concentrations in the text are reported as the geometric mean ± standard error based on the back-transformed least square mean ± standard error from model output.

Table 3. Extended

Species and life stage	Kidney THg $\ln y = b + \ln x$	r^2	Muscle $\ln y = b + \ln x$	r^2	Breast feather $\ln y = b + \ln x$	r^2	Head feather $\ln y = b + \ln x$	r^2
Liver THg								
All birds	$\ln y = 0.151 + 0.916(\ln x)$	0.92	$\ln y = 0.819 + 0.987(\ln x)$	0.94	$\ln y = 0.375 + 0.583(\ln x)$	0.32	$\ln y = 0.004 + 0.723(\ln x)$	0.42
Prebreeding adults	$\ln y = 0.126 + 0.915(\ln x)$	0.91	$\ln y = 0.826 + 0.944(\ln x)$	0.94	$\ln y = 0.147 + 0.624(\ln x)$	0.49	$\ln y = -0.310 + 0.800(\ln x)$	0.70
Breeding adults	$\ln y = 0.382 + 0.839(\ln x)$	0.91	$\ln y = 0.840 + 0.974(\ln x)$	0.90	$\ln y = 1.239 + 0.436(\ln x)$	0.27	$\ln y = 1.190 + 0.413(\ln x)$	0.20
Chicks	$\ln y = 0.109 + 0.900(\ln x)$	0.81	$\ln y = 0.784 + 0.890(\ln x)$	0.93	$\ln y = -0.055 + 0.458(\ln x)$	0.23	$\ln y = -0.526 + 0.686(\ln x)$	0.38
Avocets	$\ln y = 0.192 + 1.023(\ln x)$	0.92	$\ln y = 0.746 + 0.978(\ln x)$	0.90	$\ln y = 0.415 + 0.433(\ln x)$	0.13	$\ln y = -0.621 + 0.944(\ln x)$	0.68
Stilts	$\ln y = 0.116 + 0.995(\ln x)$	0.95	$\ln y = 0.848 + 0.934(\ln x)$	0.95	$\ln y = 0.032 + 0.724(\ln x)$	0.34	$\ln y = -0.709 + 0.961(\ln x)$	0.65
Caspian terns	$\ln y = 0.204 + 0.810(\ln x)$	0.74	$\ln y = 0.882 + 0.902(\ln x)$	0.90	$\ln y = 1.176 + 0.318(\ln x)$	0.27	$\ln y = 1.186 + 0.338(\ln x)$	0.30
Forster's terns	$\ln y = -0.047 + 0.970(\ln x)$	0.94	$\ln y = 0.893 + 1.003(\ln x)$	0.96	$\ln y = 0.575 + 0.545(\ln x)$	0.20	$\ln y = 1.009 + 0.404(\ln x)$	0.13
Kidney MeHg								
All birds			$\ln y = 0.770 + 1.007(\ln x)$	0.89	$\ln y = 0.214 + 0.651(\ln x)$	0.36	$\ln y = -0.062 + 0.736(\ln x)$	0.40
Prebreeding adults			$\ln y = 0.799 + 1.022(\ln x)$	0.90	$\ln y = -0.008 + 0.700(\ln x)$	0.57	$\ln y = -0.380 + 0.827(\ln x)$	0.68
Breeding adults			$\ln y = 0.641 + 1.088(\ln x)$	0.87	$\ln y = 1.088 + 0.484(\ln x)$	0.25	$\ln y = 1.135 + 0.408(\ln x)$	0.15
Chicks			$\ln y = 0.750 + 0.835(\ln x)$	0.71	$\ln y = -0.302 + 0.577(\ln x)$	0.37	$\ln y = -0.650 + 0.734(\ln x)$	0.46
Avocets			$\ln y = 0.544 + 0.906(\ln x)$	0.87	$\ln y = 0.198 + 0.454(\ln x)$	0.16	$\ln y = -0.773 + 0.916(\ln x)$	0.72
Stilts			$\ln y = 0.746 + 0.920(\ln x)$	0.96	$\ln y = -0.037 + 0.703(\ln x)$	0.33	$\ln y = -0.738 + 0.919(\ln x)$	0.62
Caspian terns			$\ln y = 1.110 + 0.871(\ln x)$	0.74	$\ln y = 1.385 + 0.311(\ln x)$	0.22	$\ln y = 1.395 + 0.330(\ln x)$	0.25
Forster's terns			$\ln y = 1.035 + 0.974(\ln x)$	0.94	$\ln y = 0.666 + 0.545(\ln x)$	0.21	$\ln y = 1.096 + 0.410(\ln x)$	0.14

RESULTS

Mercury distribution among tissues

We found that across all species and life stages, THg concentrations differed among tissue type (ANOVA: $F_{5,2575} = 103.68$, $p < 0.0001$), with the highest concentrations in head feathers (6.45 ± 0.31 μg/g dry wt) and breast feathers (5.76 ± 0.28 μg/g dry wt), followed by kidney (4.54 ± 0.22 μg/g dry wt), liver (4.43 ± 0.21 μg/g dry wt), blood (3.10 ± 0.15 μg/g dry wt), and muscle (1.67 ± 0.08 μg/g dry wt). The tissue × species interaction (ANOVA: $F_{15,2575} = 4.38$, $p < 0.0001$), however, indicated that the relative rank of tissue THg concentrations differed among species (Table 1). Therefore, we analyzed each species separately to assess the relative rank of Hg concentrations among tissue types.

We found a significant tissue × life stage (adults vs chicks) interaction in stilts (ANOVA: $F_{5,835} = 10.01$, $p < 0.0001$) and Forster's terns (ANOVA: $F_{5,791} = 12.75$, $p < 0.0001$) but not in avocets (ANOVA: $F_{5,689} = 0.48$, $p = 0.79$); we did not sample Caspian tern chicks. In adults, THg concentrations were highest in head feathers of avocets and stilts, in breast feathers of Caspian terns, and in kidney of Forster's terns (Table 1). Total Hg concentrations were consistently lowest in muscle from adults of each species; in fact, THg in muscle was at least 34% lower than that in blood, the next-least-contaminated tissue, in each species (Table 1). Agreement in tissue THg concentrations was more consistent among species in chicks, where THg was always highest in feathers, followed by liver or kidney and then blood and muscle (Table 1).

The CV did not differ among species (ANOVA: $F_{3,430} = 0.02$, $p = 0.99$) but, rather, was higher in chicks (0.74 ± 0.02) than in adults (0.58 ± 0.01; ANOVA: $F_{1,430} = 46.80$, $p < 0.0001$). The notably elevated THg concentrations in feathers relative to internal tissues in chicks in comparison to adults likely accounted for this difference in CV among life stages (Table 1). Indeed, when we assessed the CV only for internal tissues (blood, liver, kidney, and muscle), we found that the CV was higher in adults (0.47 ± 0.01) than in chicks (0.40 ± 0.01; ANOVA: $F_{1,430} = 26.90$, $p < 0.0001$) and varied among species (ANOVA: $F_{3,430} = 5.53$, $p = 0.001$). The CV in Caspian terns (0.45 ± 0.02) did not differ from that of any other species, nor did the CV in avocets (0.42 ± 0.01) differ from that in stilts (0.41 ± 0.01). Forster's terns (0.46 ± 0.01), however, had higher CVs than both avocets and stilts.

Mercury correlations between tissues

To provide linear regression equations for each tissue pair, we examined pairwise relationships in Hg concentrations between all tissue pairs (Tables 2 and 3 and Appendix). Here, we focus on THg in three tissues in particular—liver, blood, and breast feathers—because they are most commonly used in monitoring and toxicological assessments of Hg exposure in birds. We first examined the relationships between THg in liver and all other tissue concentrations individually (MeHg in liver and kidney and THg in blood, kidney, muscle, breast feathers, and head feathers). We found that THg concentrations in liver were highly correlated with MeHg and/or THg concentrations in all other internal tissues ($r^2 \geq 0.88$) but not in feathers ($r^2 = 0.34$–0.49) (Fig. 1). Across all species and life stages, the correlation was the strongest between THg in liver and MeHg in liver ($r^2 = 0.97$), followed by the correlation of THg in liver with THg in kidney, THg in muscle, MeHg in kidney, and THg in blood, head feathers, and breast feathers (Tables 2 and 3). Examining each species and life stage separately, THg concentrations in liver explained a considerable proportion of the variation in Hg concentrations in other tissues (with the exception of feathers) (Tables 2 and 3). The r^2 values between THg in liver and THg or MeHg in other internal tissues, however, were substantially lower in Caspian terns than in the other species (Tables 2 and 3). This discrepancy likely resulted, at least in part, because the sample sizes for Caspian terns ($n = 30$ prebreeding and 20 breeding) were approximately half those of the other species.

Next, we assessed blood as a sampling matrix, both because THg in blood correlated strongly with THg in liver (Fig. 2 and Table 2) and because blood sampling is more rapid and less invasive than liver sampling. As with liver, THg concentrations in blood were strongly correlated with THg or MeHg in all tissues ($r^2 \geq 0.87$) except feathers ($r^2 = 0.32$–0.40), and Caspian terns, again, had the lowest r^2 values (Tables 2 and 3). Unlike liver, the strongest correlation for all species and life stages combined was between THg in blood and THg in muscle ($r^2 = 0.90$), followed by MeHg in liver and kidney and THg in kidney, head feathers, and breast feathers (Fig. 2

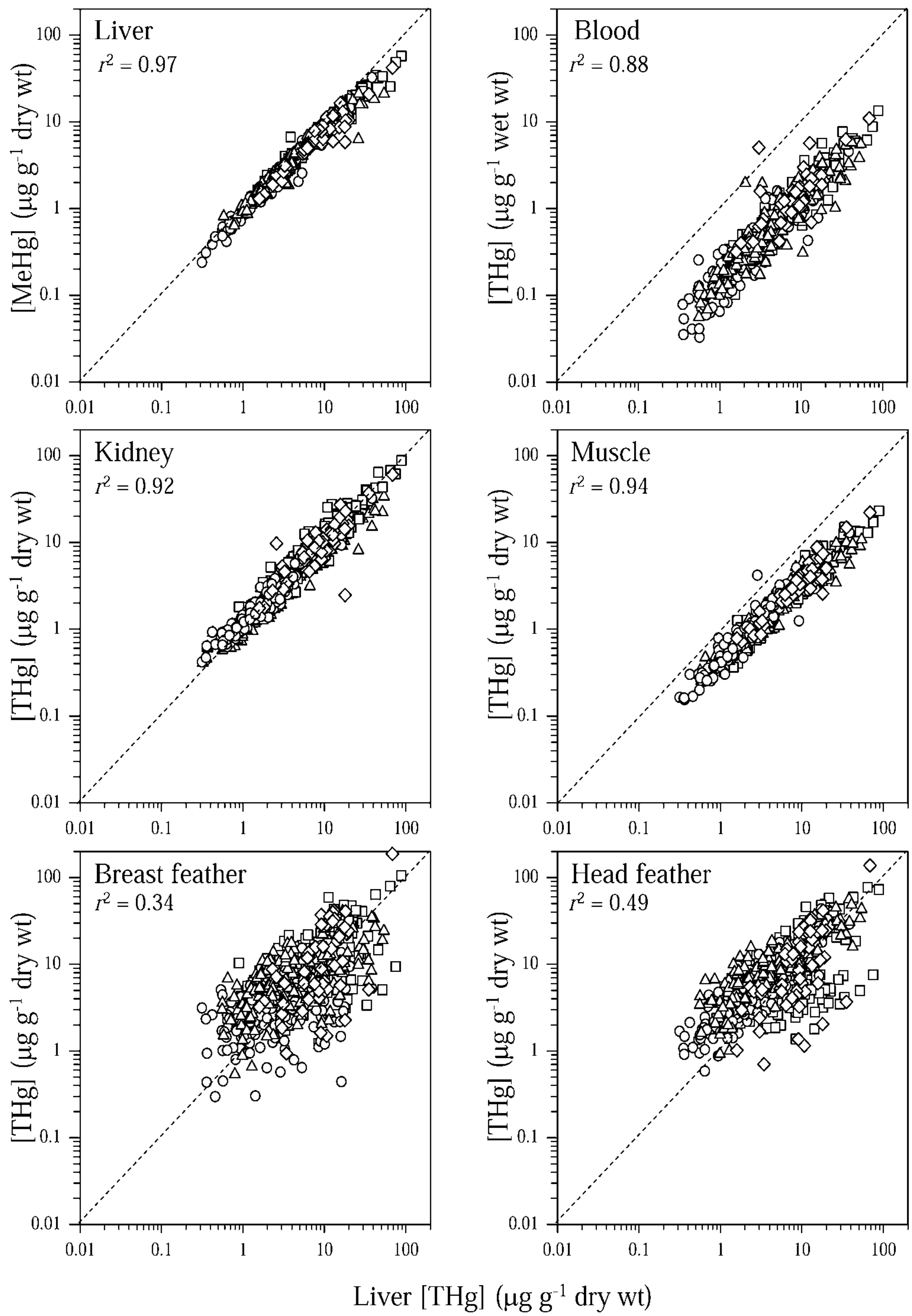

Fig. 1. Total mercury (THg) concentrations in liver versus methylmercury (MeHg) concentrations in liver and THg concentrations in blood, kidney, muscle, breast feather, and head feather in American avocets (○), black-necked stilts (△), Caspian terns (◇), and Forster's terns (□). Stippled line represents a 1:1 relationship.

and Table 2). Additionally, r^2 values for blood–tissue relationships were consistently lower in chicks than in either prebreeding or breeding adults of each species (Tables 2 and 3 and Appendix), which was not the case with liver.

Like blood, feathers represent a noninvasive sampling matrix for assessing Hg exposure, are one of the primary sites of Hg sequestration and elimination, and have been used as a monitoring tool in numerous avian contaminant studies worldwide. We found that although THg in breast feathers was correlated (all $p < 0.0001$) with THg and MeHg in all internal tissues, the variability explained by THg in breast feathers across all species and life stages was far weaker ($r^2 \leq 0.36$) than the variability explained by THg in internal tissues, such as liver or blood. Correlations were strongest between THg in breast feathers and THg in head feathers ($r^2 = 0.59$), followed by MeHg in kidney; THg in liver, kidney, muscle, and blood; and MeHg in liver (Tables 2 and 3). Among species, r^2 values for feathers were particularly low in avocets ($r^2 = 0.16$–0.32) relative to stilts, Caspian terns, or Forster's terns (Tables 2 and 3 and Appendix).

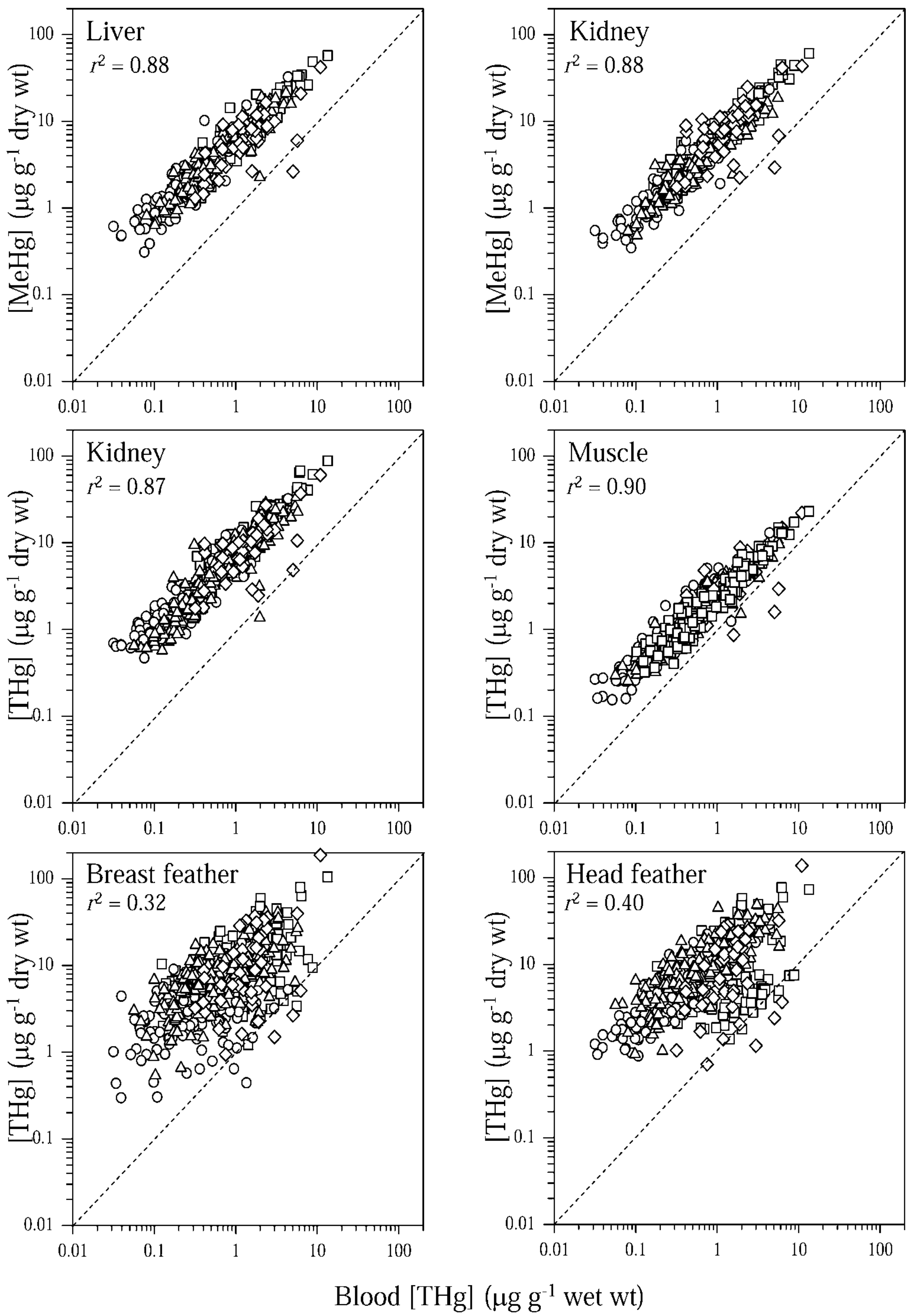

Fig. 2. Total mercury (THg) concentrations in blood versus methylmercury (MeHg) concentrations in liver and kidney and THg concentrations in kidney, muscle, breast feather, and head feather in American avocets (◯), black-necked stilts (△), Caspian terns (◇), and Forster's terns (□). Stippled line represents a 1:1 relationship.

Regression slopes among species and life stages

We found that for some tissue pairs, the slopes of the linear regression between THg in liver, blood, or breast feathers and THg or MeHg in other tissues did not differ among species or life stages, whereas for other tissue pairs, significant differences occurred in slopes among species and/or life stages (Figs. 3 and 4 and Table 4). This indicates that in many cases, the general equations derived from pooled species and life stage data likely are adequately predictive across species and life stages when more specific equations are not available. The matrix of slope interactions (Table 4), however, also suggests that circumstances existed in which the greater specificity of species- or life stage–based equations was more appropriate. The factors influencing slope differences among species or life stage differed with the covariate tissue. For example, the liver THg regressions with THg and MeHg in most tissues had significantly different slopes among species for prebreeding adults but not for breeding adults or chicks (Table 4). Prebreeding avocet slopes generally were steeper than slopes of other species (Tables 2 and 3 and Appendix), indicating that

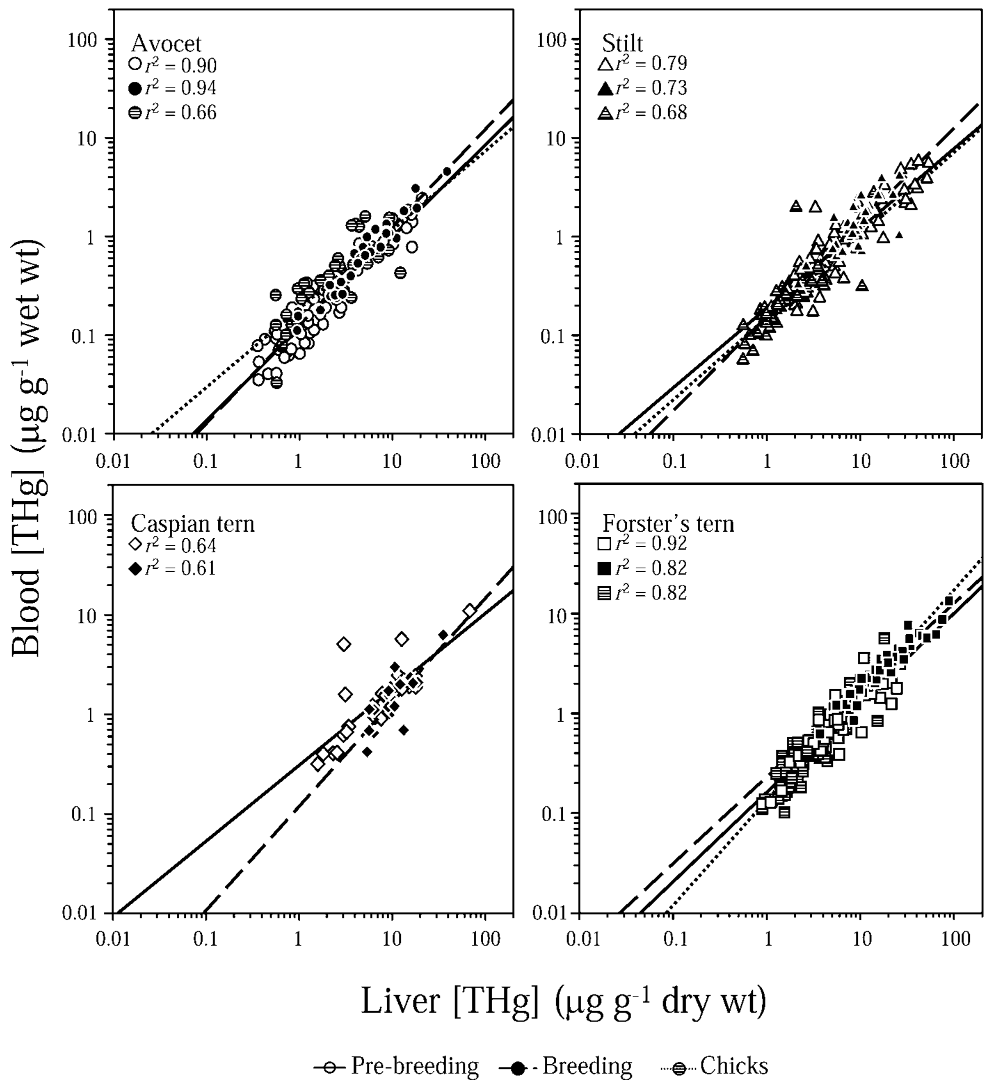

Fig. 3. Total mercury (THg) concentrations in liver versus THg concentrations in blood by life stages in American avocets, black-necked stilts, Caspian terns, and Forster's terns.

for each unit increase of THg in liver, a relatively greater increase occurred in the *y*-axis comparison tissue for avocets than for the other species during the prebreeding period. When assessed individually for each species, we found that slopes differed among life stage for stilts in five tissues, for Forster's terns in four tissues, and for avocets in one tissue but did not vary among life stages in Caspian terns (Table 4). For stilts and Forster's terns, tissue × life stage interactions generally were driven by chicks and had steeper slopes than those for prebreeding or breeding adults.

Contrary to our findings with liver, slopes of THg in blood with THg or MeHg in all other internal tissues (but not in breast feathers) did not differ among species for prebreeding adults or chicks but were different for breeding adults (Table 4). These interactions were driven by breeding Forster's terns, which had substantially steeper slopes between THg in blood and THg or MeHg in other tissues compared with those for breeding adults of other species (Tables 2 and 3 and Appendix). This indicates that with each unit increase in blood Hg concentrations, THg and MeHg concentrations in the tissues of breeding Forster's terns were higher than those for breeding adults of other species. When we examined each species individually, we found that slopes between THg in blood and other internal tissues differed among life stages only for Forster's terns (THg in liver, THg in kidney, and THg in muscle) (Table 4), with breeding adults having steeper slopes than prebreeding adults or chicks. However, for blood to feather correlations, we found life stage differences in slopes between THg in blood and breast feathers in stilts and between THg in blood and head feathers in Caspian terns (Table 4).

When controlling for species, the slopes between THg in breast feathers and MeHg or THg in other tissues differed among life stages for all tissues (all $p < 0.03$) except blood THg ($p = 0.06$), and slopes in prebreeding adults generally were steeper than those in breeding adults or chicks (Tables 2 and 3 and Appendix). Additionally, within each species, we found that slopes for THg in breast feathers differed among life stage for all species except avocets (Fig. 4 and Table 4). Slopes were steepest in prebreeding adults for stilts and Caspian terns, whereas chicks had the steepest slopes among life stages for Forster's terns (Tables 2 and 3). In general, slopes for breeding adults were lower than those for either chicks or prebreeding adults for stilts, Caspian terns, and Forster's terns (Tables 2 and 3). Within each life stage, however, very few differences in slopes were found among species (Table 4).

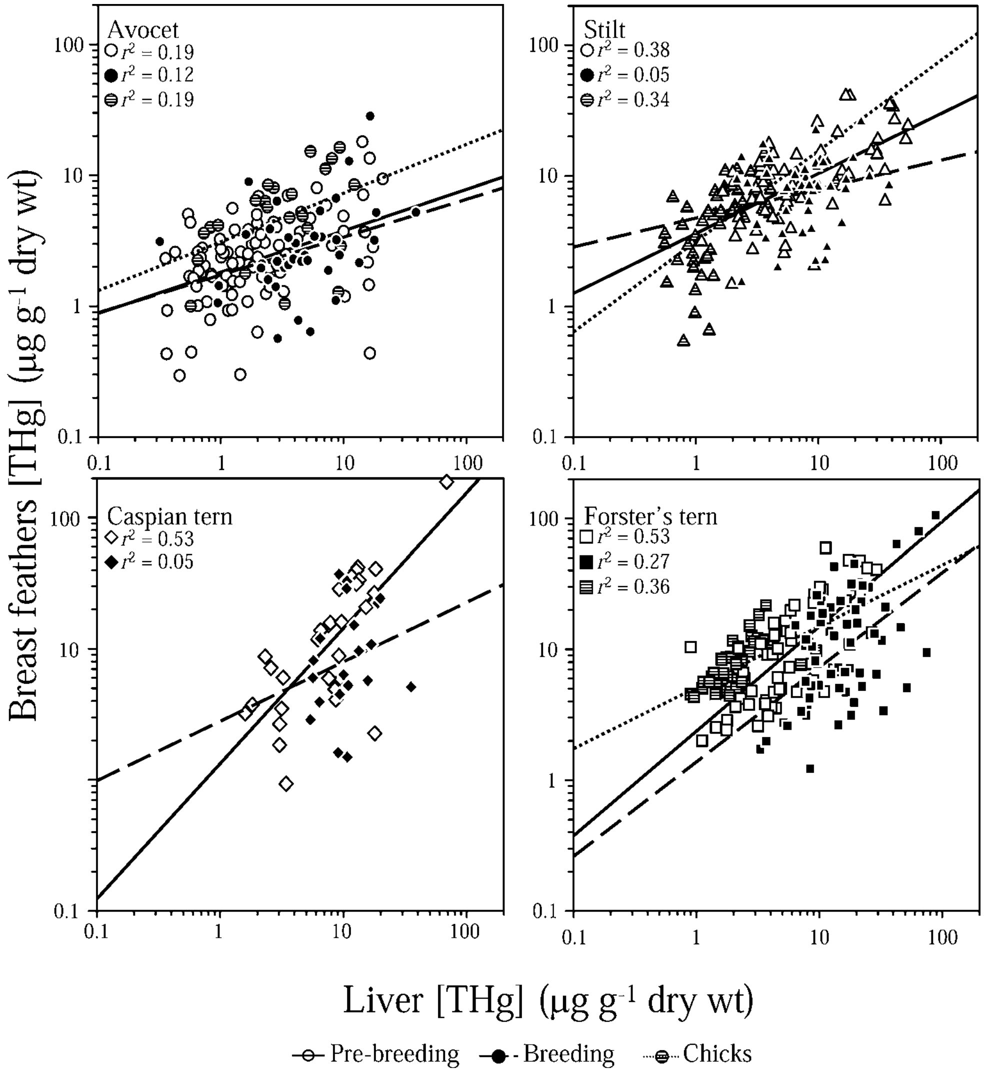

Fig. 4. Total mercury (THg) concentrations in liver versus THg concentrations in breast feather by life stages in American avocets, black-necked stilts, Caspian terns, and Forster's terns.

DISCUSSION

Total Hg concentrations generally were highest in feathers, followed by kidney and liver, and then blood and muscle. This pattern was especially prevalent in chicks, which had relatively higher levels of Hg in feathers compared to those in internal tissues, probably because of active depuration of Hg into growing feathers and dilution of the body burden of Hg as chicks grew in size [14]. However, the Hg distribution varied among tissues differently in each species of adult birds. For example, THg concentrations in livers and kidneys were similar to or exceeded those in feathers for adult Caspian terns and Forster's terns, whereas head feather concentrations were higher than those of internal tissues for adult avocets and stilts. Muscle consistently had the lowest THg concentrations among all tissues for both chicks and adults. These tissue Hg distribution patterns are consistent with other studies. We summarized ratios of THg concentrations between several tissues for 46 bird species and found that across species, THg concentrations in liver generally were higher than those in kidney and concentrations in both liver and kidney typically were higher than those in blood or muscle (Table 5). However, ratios between THg concentrations in feathers and other tissues were highly variable, indicating no clear patterns among species. This high variation in ratios among species has been noted elsewhere and generally is thought to be a result of timing and geographic location when feathers grow relative to when tissues were sampled, as well as demethylation of MeHg in the liver [27].

Total Hg concentrations in liver and blood were strongly related to THg and MeHg concentrations of other internal tissues for all species and life stages. Other studies also have shown strong correlations between blood or liver and other internal tissues [14,20]. These results are not surprising given that blood distributes MeHg throughout the body tissues and represents a dynamic equilibrium between dietary Hg assimilation and tissue Hg redistribution [32]. Although blood-to-tissue relationships were strong for all species and life stages combined ($r^2 \geq 0.87$), we found that relationships generally were weakest for chicks ($0.71 < r^2 < 0.76$), likely because of their rapid growth and feather production as they age [32]. For example, captive-reared common loon (*Gavia immer*) chicks that were fed a range of Hg-contaminated diets had blood THg concentrations that decreased rapidly during three to five weeks posthatch, remained constant between five to seven weeks, and thereafter increased substantially as body growth and feather production slowed [14,33]. Similar patterns with age also have been observed in Hg-dosed Cory's shearwater

Table 4. The p values for analysis-of-covariance models testing differences in slopes among species and life stage for total mercury (THg) in liver, blood, or breast feather as covariates[a]

	Interaction test	n	Dependent variable: Liver THg	Liver MeHg	Blood THg	Kidney THg	Kidney MeHg	Muscle THg	Breast feather THg	Head feather THg
Liver THg										
Prebreeding	Species × liver THg	238	—	*0.0003*	0.17	0.05	*0.04*	*0.007*	*0.0001*	*0.0001*
Breeding	Species × liver THg	164	—	*0.01*	0.36	0.82	0.54	0.93	0.10	0.62
Chicks	Species × liver THg	210	—	0.24	*0.02*	*0.04*	0.06	0.10	0.15	0.41
AMAV	Life stage × liver THg	172	—	0.19	0.13	*0.01*	0.06	*0.05*	0.92	0.12
BNST	Life stage × liver THg	175	—	*0.03*	0.42	*0.0003*	*0.004*	*0.02*	*0.04*	0.9
CATE	Life stage × liver THg	50	—	0.79	0.28	0.61	0.46	0.7	0.21	0.09
FOTE	Life stage × liver THg	215	—	*0.01*	*0.03*	*0.02*	0.43	0.96	0.29	*0.03*
Blood THg										
Prebreeding	Species × blood THg	238	0.38	0.34	—	0.17	0.12	0.18	*0.02*	0.16
Breeding	Species × blood THg	164	*0.0001*	*0.002*	—	*0.0002*	*0.02*	*0.005*	*0.02*	*0.01*
Chicks	Species × blood THg	210	0.76	0.91	—	0.98	0.25	0.08	0.24	0.13
AMAV	Species × blood THg	172	0.23	0.79	—	0.08	0.29	0.05	0.71	0.26
BNST	Species × blood THg	175	0.09	0.37	—	0.92	0.22	0.75	*0.01*	0.15
CATE	Species × blood THg	50	0.36	0.66	—	0.96	0.65	0.74	0.11	*0.02*
FOTE	Species × blood THg	215	*0.0005*	0.28	—	*0.0001*	0.15	*0.002*	0.23	0.09
Breast feather THg										
Prebreeding	Species × feather THg	238	0.39	0.19	0.24	0.94	0.59	0.81	—	*0.001*
Breeding	Species × feather THg	164	0.47	0.58	0.36	0.14	0.34	0.13	—	*0.001*
Chicks	Species × feather THg	210	0.52	0.56	0.40	0.14	0.44	*0.04*	—	*0.001*
AMAV	Species × feather THg	172	0.74	0.98	0.75	0.76	0.09	0.41	—	0.76
BNST	Species × feather THg	175	0.08	*0.003*	*0.003*	*0.03*	*0.01*	*0.009*	—	*0.0001*
CATE	Species × feather THg	50	*0.01*	*0.02*	0.09	*0.001*	*0.002*	*0.001*	—	0.37
FOTE	Species × feather THg	215	*0.01*	*0.009*	*0.03*	*0.03*	*0.008*	*0.02*	—	0.07

[a] Italics denote a significant difference ($p < 0.05$) in slopes among categories. AMAV = avocets; BNST = stilts; CATE = Caspian terns; FOTE = Forster's terns; MeHg = methylmercury.

(*Calonectris diomedea*) chicks [34] and wild Forster's tern and black-necked stilt chicks in the San Francisco Bay [35]. Even under controlled Hg exposure regimes, Hg concentrations in chick blood can change nearly 20-fold within just a few weeks [33,35]. Thus, relationships between tissues likely are highly variable and dependent on the age of the chick relative to the timing of feather production and organ growth.

Unlike with liver or blood, THg in breast feathers was poorly correlated with THg and MeHg in internal tissues ($r^2 \leq 0.36$). Feathers represent a discrete depuration and sequestration repository for Hg only during the period of feather growth [6] and do not reflect changes in tissue concentrations once the blood supply to the feathers atrophies [8,36]. This is particularly important, because complex molt patterns and migration strategies can convolute the interpretation and utility of feather THg concentrations as indicators of Hg exposure, especially in migratory adults [8,21]. For example, we found that breast feathers were much poorer indicators of Hg concentrations in internal tissues for breeding adults ($0.01 < r^2 < 0.30$) than they were for prebreeding adults ($0.14 < r^2 < 0.79$). In fact, no significant relationships were found between THg in blood and breast feathers for breeding avocets, stilts, or Caspian terns (all $r^2 \leq 0.10$ and all $p \geq 0.08$). Similarly, head feathers were poorly correlated with internal tissues, but concentrations differed from those in breast feathers for adult avocets and stilts. These results suggest a substantial temporal separation between when feathers were grown and when internal tissues were sampled, especially for breeding adults. In general, molt occurs in late winter to early spring, just before prebreeding sampling, and again after breeding in late summer to early fall [37–40]. Thus, Hg exposure in breeding bird tissues likely was several months removed from when their breast feathers were grown. Similar results have been observed in Bonaparte's gulls (*Larus philadelphia*), in which Hg levels in liver declined dramatically during fall molt, then began to increase again once molt was completed [36]. Correlations between Hg concentrations in feathers and internal tissues may be stronger if sampling occurs during times of active feather growth; however, it is unclear how much more reliable feathers are as indicators in those circumstances.

Although relationships between feather and tissue Hg concentrations were better in prebreeding than in breeding birds, they were weak in comparison to other tissue relationships. Migration likely influences these relationships, particularly for Forster's terns and Caspian terns, which largely do not overwinter in the San Francisco Bay [39,40]. Terns generally arrive in the estuary in early April (J. Takekawa, U.S. Geological Survey, Vallejo, CA, unpublished data), and their feathers are grown in late winter [39,40], indicating that prebreeding feather Hg concentrations may be more reflective of exposure outside San Francisco Bay. Indeed, for prebreeding Forster's terns, gender and calendar-year were far more important factors explaining feather THg concentrations than were capture site or date, whereas capture site and capture date were the most important predictors of THg in blood of prebreeding Forster's terns [16]. Additionally, THg in Forster's tern blood more than tripled during the 45-d prebreeding period after they arrived in the San Francisco Bay [16]. Thus, we would not expect a high correlation between feathers and internal tissues during the breeding season. Conversely, avocets and stilts largely overwinter in the San Francisco Bay [37,38], and capture date had no effect on THg concentrations in avocet or stilt blood during prebreeding [41]. Therefore, we would expect stronger relationships between Hg concentrations in feathers and internal tissues for avocets and stilts than for terns. That the relationships between feathers and internal tissues were just as weak for avocets and stilts as they were for terns highlights the difficulties in relating Hg concentrations in feathers to those of internal tissues in wild birds.

To our knowledge, the present study is the only one that

Table 5. Ratios between total mercury (THg) concentrations in feathers, liver, kidney, and muscle (dry wt) as well as blood (wet wt) from other studies

		Feather				Liver			Blood		
Species	Age	Liver	Kidney	Blood	Muscle	Kidney	Blood	Muscle	Kidney	Muscle	Reference
American avocet	Adult	0.86	0.84	1.50	2.28	0.98	1.74	2.64	0.58	1.52	Present study
	Chick	1.27	1.39	2.38	3.04	1.10	1.88	2.41	0.58	1.28	Present study
Black-necked stilt	Adult	1.12	1.24	1.67	3.28	1.11	1.50	2.93	0.74	1.96	Present study
	Chick	2.87	3.07	4.09	6.75	1.07	1.42	2.35	0.75	1.65	Present study
Caspian tern	Adult	1.07	1.03	1.29	2.97	0.96	1.20	2.77	0.80	2.30	Present study
Forster's tern	Adult	1.01	0.83	1.36	3.08	0.82	1.35	3.04	0.61	2.26	Present study
	Chick	3.03	2.62	4.20	2.30	0.86	1.39	2.49	0.62	1.80	Present study
Arctic tern	Adult	—	—	—	—	1.04	—	5.22	—	—	[47]
	Adult	0.18	0.25	—	1.00	1.36	—	5.44	—	—	[9]
Common tern	Adult	—	—	—	—	1.21	—	0.90	—	—	[47]
White-chinned petrel	Adult	0.83	1.28	—	12.00	1.54	—	14.50	—	—	[9]
Herring gull	Adult	—	—	—	—	1.37	—	4.80	—	—	[47]
	Adult	1.45	1.69	—	7.63	1.17	—	5.25	—	—	[9]
Audouin's gull	Adult	0.13	0.24	—	—	1.86	—	—	—	—	[48]
Black guillemot	Adult	—	—	—	—	1.05	—	4.66	—	—	[47]
Bonepart's gull	Adult	—	—	—	—	1.07	—	5.63	—	—	[36]
Black-legged kittiwake	Adult	—	—	—	—	1.54	—	9.25	—	—	[47]
Northern fulmar	Adult	0.34	0.72	—	3.13	2.12	—	10.14	—	—	[9]
Oldsquaw	Adult	0.00	0.12	—	0.47	5.23	—	20.93	—	—	[9]
Shag	Adult	0.38	0.34	—	—	0.88	—	—	—	—	[48]
Yellow-legged gull	Adult	0.58	0.73	—	—	1.24	—	—	—	—	[48]
Lysan albatross	Adult	0.19	—	—	—	—	—	—	—	—	[9]
Black-footed albatross	Adult	0.13	1.06	—	2.63	8.18	—	20.26	—	—	[9]
Royal albatross	Adult	0.12	0.46	—	2.83	3.90	—	24.21	—	—	[9]
Great egret	Chick	3.10	3.94	5.20	7.65	1.27	1.68	2.47	0.76	1.47	[24]
	Chick	0.53	0.95	0.67	0.44	1.79	1.25	0.83	1.43	0.67	[24]
	Chick	0.21	0.25	0.32	0.67	1.17	0.86	3.11	0.78	2.07	[24]
Black-crowned night heron	Juvenile	—	—	—	—	—	—	—	0.19	—	[7]
	Adult	—	—	—	—	2.23	2.07	—	1.08	—	[20]
	Adult	—	—	—	—	1.14	0.84	—	1.36	—	[20]
	Chick	1.76	2.06	2.17	—	1.17	1.23	—	0.95	—	[20]
	Chick	1.60	2.12	1.90	—	1.33	1.19	—	1.12	—	[20]
Great blue heron	Juvenile	—	0.55	2.12	—	—	—	—	0.26	—	[7]
Great egret	Adult	0.56	—	—	1.13	—	—	2.00	—	—	[49]
Cattle egret	Adult	0.09	—	—	0.23	—	—	2.43	—	—	[49]
Snowy egret	Adult	—	—	—	—	3.93	7.45	—	0.53	—	[20]
	Adult	—	—	—	—	2.53	2.53	—	1.00	—	[20]
	Chick	2.24	2.80	2.30	—	1.25	1.03	—	1.25	—	[20]
	Chick	3.89	5.01	5.18	—	1.29	1.33	—	0.97	—	[20]
Double-crested cormorant	Adult	—	—	—	—	1.94	9.53	—	0.25	—	[20]
	Adult	—	—	—	—	2.04	5.81	—	0.35	—	[20]
	Chick	1.23	2.15	2.45	—	1.75	1.99	—	0.88	—	[20]
	Chick	1.28	2.00	2.95	—	1.56	2.30	—	0.68	—	[20]
	Adult	—	—	—	—	1.32	—	11.56	—	—	[47]
Olivacous cormorant	Adult	0.61	—	—	2.82	—	—	4.64	—	—	[49]
Brown pelican	Adult	0.57	—	—	1.24	—	—	2.18	—	—	[49]
White-faced ibis	Adult	4.50	—	—	7.50	—	—	1.67	—	—	[49]
Red-necked phalarope	Adult	—	—	—	—	—	—	4.60	—	—	[47]
Bald eagle	Adult	1.27	0.30	—	7.00	0.24	—	5.50	—	—	[7]
	Juvenile	—	—	—	—	2.00	4.00	4.00	0.50	1.00	[7]
Osprey	Adult	0.29	0.20	2.20	2.08	0.68	7.46	7.07	0.09	0.95	[7]
	Juvenile	1.84	1.51	5.35	16.60	0.82	2.90	9.00	0.28	3.10	[7]
	Chick	0.23	0.67	—	2.00	2.92	—	8.75	—	—	[25]
	Hatch year	0.07	0.38	—	0.40	5.38	—	5.73	—	—	[25]
	Adult	0.06	0.94	—	0.44	15.25	—	7.18	—	—	[25]
Common loon	Adult	0.09	0.06	1.25	0.62	0.74	14.56	7.24	0.05	0.50	[7]
	Juvenile	0.07	0.03	4.00	1.20	0.42	55.19	16.56	0.01	0.07	[7]
	Chick	0.87	1.74	1.25	4.16	2.01	1.45	4.81	1.39	3.32	[14]
	Chick	1.61	2.72	2.04	5.97	1.69	1.26	3.70	1.33	2.93	[14]
	Chick	1.35	2.36	1.62	5.04	1.75	1.43	3.73	1.46	3.11	[14]
	Adult	0.75	—	—	—	—	—	—	—	—	[48]
American coot	Adult	1.47	—	—	5.50	—	—	3.75	—	—	[49]
Brown booby	Adult	0.40	0.45	—	0.76	1.11	—	1.89	—	—	[9]
Canada goose	Adult	0.60	—	—	1.50	—	—	2.50	—	—	[7]
American black duck	Adult	0.60	—	—	2.25	—	—	3.75	—	—	[7]
American green-winged teal	Adult	0.33	—	—	1.24	—	—	3.81	—	—	[7]
Black-bellied duck	Adult	2.00	—	—	20.00	—	—	10.00	—	—	[49]
Cinnamon teal	Adult	2.50	—	—	1.88	—	—	0.75	—	—	[49]
Ring-necked duck	Adult	0.50	—	—	1.76	—	—	3.53	—	—	[7]
Wood duck	Adult	1.07	—	6.40	—	—	1.20	—	—	—	[7]
Common goldeneye	Adult	0.37	—	2.67	1.70	—	7.14	4.55	—	0.64	[7]
Common eider	Adult	—	—	—	—	2.75	—	6.60	—	—	[47]
Great tit	Adult	9.04	3.20	—	11.00	0.35	—	1.22	—	—	[50]
Greenfinch	Adult	58.40	324.44	—	58.40	5.56	—	1.00	—	—	[50]

has developed general equations for estimating Hg concentrations in one tissue based on those in another, using several tissues for multiple species and life stages, and for which Hg concentrations range nearly three orders of magnitude (Fig. 1). These general equations showed strong relationships between Hg concentrations in internal tissues, indicating their utility when more specific conversion equations are not available. For example, we used our general equation to predict THg concentrations in liver from a range of simulated THg concentrations in blood, and we compared the results with those derived when we used the more specific species and life stage equations. We found relatively high agreement between the prediction from the general equation and the more specific species and life stage equations. In fact, all predictions with the exception of chicks and Caspian terns differed from the general equation by less than 8%. However, we also urge caution in using these general equations without proper consideration of factors, such as species-specific timing and locations of Hg exposure relative to sampling. Regression-line slopes sometimes varied among species or life stage, indicating that specific species or life stage equations may be more appropriate for some situations. For example, predictions from specific chick and Caspian tern equations differed from those of the general equation by as much as 21%.

We conclude that although feathers often have been promoted as a tool for biomonitoring, our data (as well as data from other studies) demonstrate that feathers are less accurate in predicting recent Hg exposure or whole-body burdens. We recognize that Hg studies using feathers remain valuable if their results are interpreted with caution. However, we concur with other recent studies [7,11] and recommend using blood as a preferred tissue matrix. Like feathers, blood can be sampled nonlethally, and unlike feathers, it is highly correlated with internal tissues. Nonlethal sampling is of obvious value for conservation, and it allows individual-based studies on topics such as Hg relationships with bird space use [16,41], behavior [42], survival [43,44], and reproduction [45,46] in relation to an individual's Hg levels. Additionally, nearly all Hg in blood is MeHg [13,32]; therefore, THg can be analyzed with relatively large cost savings compared to MeHg. Conversely, interpretation of Hg in internal tissues such as liver and kidney can be convoluted by demethylation processes [21] and sequestration of Se-bound inorganic Hg [23]. Total Hg in blood, on the other hand, is strongly related to MeHg in both liver and kidney, and our equations for converting THg in blood to MeHg in internal tissues are robust. Finally, effects thresholds also are being developed for blood Hg concentrations [42], which will further increase their utility for both monitoring and risk assessment.

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REFERENCES

1. Berg W, Johnels A, Sjostrand B, Westermark T. 1966. Mercury content in feathers of Swedish birds from the past 100 years. *Oikos* 17:71–83.
2. Fimreite N, Holsworth WN, Keith JA, Pearce PA, Gruchy IM. 1971. Mercury in fish and fish eating birds near sites of industrial contamination in Canada. *Can Field-Nat* 85:211–220.
3. Scheuhammer AM, Meyer MW, Sandheinrich MB, Murray MW. 2007. Effects of environmental methylmercury on the health of wild birds, mammals, and fish. *Ambio* 36:12–18.
4. Wiener JG, Krabbenhoft DP, Heinz GH, Scheuhammer AM. 2003. Ecotoxicology of mercury. In Hoffman DJ, Rattner BA, Burton GA, Cairns J, eds, *Handbook of Ecotoxicology.* Lewis, Boca Raton, FL, USA, pp 409–463.
5. Dietz R, Riget FF, Boertmann D, Sonne C, Olsen MT, Fjeldsa J, Falk K, Kirkegaard M, Egevang C, Asmund G, Wille F, Moller S. 2006. Time trends of mercury in feathers of west Greenland birds of prey during 1851–2003. *Environ Sci Technol* 40:5911–5916.
6. Bearhop S, Ruxton GD, Furness RW. 2000. Dynamics of mercury in blood and feathers of great skuas. *Environ Toxicol Chem* 19: 1638–1643.
7. Evers DC, Burgess NM, Champoux L, Hoskins B, Major A, Goodale WM, Taylor RJ, Poppenga R, Daigle T. 2005. Patterns and interpretation of mercury exposure in freshwater avian communities in northeastern North America. *Ecotoxicology* 14:193–221.
8. Furness RW, Muirhead SJ, Woodburn M. 1986. Using bird feathers to measure mercury in the environment: Relationship between mercury content and molt. *Mar Pollut Bull* 17:27–30.
9. Kim EY, Murakami T, Saeki K, Tatsukawa R. 1996. Mercury levels and its chemical form in tissues and organs of seabirds. *Arch Environ Contam Toxicol* 30:259–266.
10. Thompson DR, Bearhop S, Speakman JR, Furness RW. 1998. Feathers as a means of monitoring mercury in seabirds: Insights from stable isotope analysis. *Environ Pollut* 101:193–200.
11. Kahle S, Becker PH. 1999. Bird blood as bioindicator for mercury in the environment. *Chemosphere* 39:2451–2457.
12. DesGranges JL, Rodrigue J, Tardif B, Laperle M. 1998. Mercury accumulation and biomagnifications in ospreys (*Pandion haliaetus*) in the James Bay and Hudson Bay regions of Quebec. *Arch Environ Contam Toxicol* 35:330–341.
13. Rimmer CC, McFarland KP, Evers DC, Miller EK, Aubry Y, Busby D, Taylor RJ. 2005. Mercury concentrations in Bicknell's thrush and other insectivorous passerines in montane forests of northeastern North America. *Ecotoxicology* 14:223–240.
14. Kenow KP, Meyer MW, Hines RK, Karasov WH. 2007. Distribution and accumulation of mercury in tissues of captive-reared common loon (*Gavia immer*) chicks. *Environ Toxicol Chem* 26: 1047–1055.
15. Lewis SA, Furness RW. 1991. Mercury accumulation and excretion in laboratory reared black-headed gull *Larus ridibundus* chicks. *Arch Environ Contam Toxicol* 21:316–320.
16. Ackerman JT, Eagles-Smith CA, Takekawa JY, Bluso JD, Adelsbach TL. 2008. Mercury concentrations in blood and feathers of prebreeding Forster's terns in relation to space use of San Francisco Bay habitats. *Environ Toxicol Chem* 27:897–908.
17. Monteiro LR, Granadeiro JP, Furness RW, Oliveira P. 1999. Contemporary patterns of mercury contamination in the Portuguese Atlantic inferred from mercury concentrations in seabird tissues. *Mar Environ Res* 47:137–156.
18. Burger J, Gochfeld M. 1997. Risk, mercury levels, and birds: Relating adverse laboratory effects to field biomonitoring. *Environ Res* 75:160–172.
19. Scheuhammer AM, Wong AHK, Bond D. 1998. Mercury and selenium accumulation in common loons (*Gavia immer*) and common mergansers (*Mergus merganser*) from eastern Canada. *Environ Toxicol Chem* 17:197–201.
20. Henny CJ, Hill EF, Hoffman DJ, Spalding MG, Grove RA. 2002. Nineteenth century mercury: Hazard to wading birds and cormorants of the Carson River, Nevada. *Ecotoxicology* 11:213–231.
21. Thompson DR, Furness RW. 1989. The chemical form of mercury stored in south Atlantic seabirds. *Environ Pollut* 60:305–318.
22. Kim EY, Saeki K, Tanabe S, Tanaka H, Tatsukawa R. 1996. Specific accumulation of mercury and selenium in seabirds. *Environ Pollut* 94:261–265.
23. Scheuhammer AM, Basu N, Burgess NM, Elliot JT, Campbell GD, Wayland M, Champoux L, Rodrigue J. 2008. Relationships among mercury, selenium, and neurochemical parameters in common loons (*Gavia immer*) and bald eagles (*Haliaeetus leucocephalus*). *Ecotoxicology* 17:93–101.
24. Spalding MG, Frederick PC, McGill HC, Bouton SN, McDowell LR. 2000. Methylmercury accumulation and its effects on growth and appetite in captive great egrets. *J Wildl Dis* 36:411–422.
25. Hopkins WA, Hopkins LB, Unrine JM, Snodgrass J, Elliot JD.

2007. Mercury concentrations in tissues of osprey from the Carolinas, USA. *J Wildl Manag* 71:1819–1829.
26. Westermark T, Odsjo T, Johnels AG. 1975. Mercury content of bird feathers before and after Swedish ban on alkyl mercury in agriculture. *Ambio* 4:87–92.
27. Thompson DR, Stewart FM, Furness RW. 1990. Using seabirds to monitor mercury in marine environments: The validity of conversion ratios for tissue comparisons. *Mar Pollut Bull* 21:339–342.
28. Agusa T, Matsumoto T, Ikemoto T, Anan Y, Kubota R, Yasunaga G, Kunito T, Tanabe S, Ogi H, Shibata Y. 2005. Body distribution of trace elements in black-tailed gulls from Rishiri Island, Japan: Age-dependent accumulation and transfer to feathers and eggs. *Environ Toxicol Chem* 24:2107–2120.
29. Butala SJM, Scanlan LP, Chaudhuri SN. 2006. A detailed study of thermal decomposition, amalgamation/atomic absorption spectrophotometry methodology for the quantitative analysis of mercury in fish and hair. *J Food Prot* 69:2720–2728.
30. U.S. Environmental Protection Agency. 2000. Test methods for evaluating solid waste, physical/chemical methods. Method 7473. SW 846, Update IVA. National Technical Information Service, Springfield, VA.
31. U.S. Environmental Protection Agency. 2001. Methyl mercury in water by distillation, aqueous ethylation, purge and trap, and cold-vapor atomic fluorescence spectrometry. Method 1630. EPA-821-R-01-020. Office of Water and Office of Science and Technology, Washington, DC.
32. Fournier F, Karasov WH, Kenow KP, Meyer MW, Hines RK. 2002. The oral bioavailability and toxicokinetics of methylmercury in common loon (*Gavia immer*) chicks. *Comp Biochem Physiol A Mol Integr Physiol* 133:703–714.
33. Kenow KP, Gutreuter S, Hines RK, Meyer MW, Fournier F, Karasov WH. 2003. Effects of methyl mercury exposure on the growth of juvenile common loons. *Ecotoxicology* 12:171–182.
34. Monteiro LR, Furness RW. 2001. Kinetics, dose–response, excretion, and toxicity of methylmercury in free-living Cory's shearwater chicks. *Environ Toxicol Chem* 20:1816–1823.
35. Ackerman JT, Eagles-Smith CA, Heinz GH, Wainwright-De La Cruz SE, Takekawa JY, Adelsbach TL, Miles AK, Hoffman DJ, Schwarzbach SE, Suchanek TH, Maurer TC. 2007. Mercury in birds of the San Francisco Bay delta: Trophic pathways, bioaccumulation, and ecotoxicological risk to avian reproduction. 2006 Annual Administrative Report. U.S. Geological Survey, Western Ecological Research Center, Davis, CA.
36. Braune BM, Gaskin DE. 1987. Mercury levels in Bonaparte's gulls (*Larus philadelphia*) during autumn molt in the Quoddy regions, New Brunswick, Canada. *Arch Environ Contam Toxicol* 16:539–549.
37. Robinson JA, Oring LW, Skorupa JP, Boettcher R. 1997. American avocet (*Recurvirostra americana*). In Poole A, Gill F, eds, *The Birds of North America*, No. 275. The Academy of Natural Sciences, Philadelphia, PA, USA, and The American Ornithologists' Union, Washington, DC.
38. Robinson JA, Reed JM, Skorupa JP, Oring LW. 1999. Black-necked stilt (*Himantopus mexicanus*). In Poole A, Gill F, eds, *The Birds of North America*, No. 449. The Academy of Natural Sciences, Philadelphia, PA, USA, and The American Ornithologists' Union, Washington, DC.
39. Cuthbert FJ, Wires LR. 1999. Caspian tern (*Sterna caspia*). In Poole A, Gill F, eds, *The Birds of North America*, No. 403. The Academy of Natural Sciences, Philadelphia, PA, USA, and The American Ornithologists' Union, Washington, DC.
40. McNicholl MK, Lowther PE, Hall JA. 2001. Forster's tern (*Sterna forsteri*). In Poole A, Gill F, eds, *The Birds of North America*, No. 595. The Academy of Natural Sciences, Philadelphia, PA, USA, and The American Ornithologists' Union, Washington, DC.
41. Ackerman JT, Eagles-Smith CA, Takekawa JY, Demers SD, Adelsbach TL, Bluso JD, Miles AK, Warnock N, Suchanek TH, Schwarzbach SE. 2007. Mercury concentrations and space use of prebreeding American avocets and black-necked stilts in San Francisco Bay. *Sci Total Environ* 384:452–466.
42. Evers DC, Savoy LJ, DeSorbo CR, Yates DE, Hanson W, Taylor KM, Siegel LS, Cooley JH, Bank MS, Major A, Munney K, Mower BF, Vogel HS, Schoch N, Pokras M, Goodale MW, Fair J. 2008. Adverse effects from environmental mercury loads on breeding common loons. *Ecotoxicology* 17:69–81.
43. Sepúlveda MS, Williams GE Jr, Frederick PC, Spalding MG. 1999. Effects of mercury on health and first-year survival of free-ranging great egrets (*Ardea albus*) from southern Florida. *Arch Environ Contam Toxicol* 37:369–376.
44. Ackerman JT, Takekawa JY, Eagles-Smith CA, Iverson SA. 2007. Mercury contamination and effects on survival of American avocets and black-necked stilt chicks in San Francisco Bay. *Ecotoxicology* 17:103–116.
45. Weech SA, Scheuhammer AM, Elliott JE. 2006. Mercury exposure and reproduction in fish-eating birds breeding in the Pinchi Lake region, British Columbia, Canada. *Environ Toxicol Chem* 25:1433–1440.
46. Brasso RL, Cristol DA. 2007. Effects of mercury exposure on the reproductive success of tree swallows (*Tachycineta bicolor*). *Ecotoxicology* 17:133–141.
47. Braune BM. 1987. Comparison of total mercury levels in relation to diet and molt for nine species of marine birds. *Arch Environ Contam Toxicol* 16:217–224.
48. Arcos JM, Ruiz X, Bearhop S, Furness RW. 2002. Mercury levels in seabirds and their fish prey at the Ebro Delta (NW Mediterranean): The role of trawler discards as a source of contamination. *Mar Ecol Prog Ser* 232:281–290.
49. Ruelas-Inzunza J, Paex-Osuna F, Arvizu-Merin M. 2007. Mercury distribution in selected tissues of migratory and resident avifauna from Altata-Ensenada del Pabellon Lagoon, southeast Gulf of California. *Bull Environ Contam Toxicol* 78:39–43.
50. Deng H, Zhang Z, Chang C, Wang Y. 2007. Trace metal concentration in great tit (*Parus major*) and greenfinch (*Carduelis sinica*) at the Western Mountains of Beijing, China. *Environ Pollut* 148:620–626.

APPENDIX. Intraspecies life stage-specific regression equations for all pairwise tissue comparisons for total mercury (THg) and methylmercury (MeHg)[a]

Species	Life stage	Blood THg		Liver THg		Liver MeHg		Kidney THg	
		$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2
Blood THg									
Avocets	Prebreeding adults			$\ln y = -2.149 + 0.930(\ln x)$	0.90	$\ln y = -2.061 + 1.013(\ln x)$	0.86	$\ln y = -2.341 + 1.072(\ln x)$	0.91
	Breeding adults			$\ln y = -2.074 + 0.993(\ln x)$	0.94	$\ln y = -1.946 + 1.022(\ln x)$	0.90	$\ln y = -1.982 + 1.005(\ln x)$	0.95
	Chicks			$\ln y = -1.685 + 0.799(\ln x)$	0.66	$\ln y = -1.696 + 0.844(\ln x)$	0.68	$\ln y = -1.838 + 0.982(\ln x)$	0.74
Stilts	Prebreeding adults			$\ln y = -1.647 + 0.803(\ln x)$	0.79	$\ln y = -1.792 + 1.011(\ln x)$	0.86	$\ln y = -1.941 + 1.001(\ln x)$	0.79
	Breeding adults			$\ln y = -1.862 + 0.951(\ln x)$	0.73	$\ln y = -2.086 + 1.142(\ln x)$	0.83	$\ln y = -1.967 + 1.048(\ln x)$	0.85
	Chicks			$\ln y = -1.882 + 0.833(\ln x)$	0.69	$\ln y = -1.843 + 0.944(\ln x)$	0.71	$\ln y = -1.806 + 0.841(\ln x)$	0.65
Caspian terns	Prebreeding adults			$\ln y = -1.1785 + 0.763(\ln x)$	0.61	$\ln y = -1.025 + 0.799(\ln x)$	0.54	$\ln y = -1.070 + 0.693(\ln x)$	0.44
	Breeding adults			$\ln y = -2.132 + 1.046(\ln x)$	0.64	$\ln y = -2.215 + 1.168(\ln x)$	0.69	$\ln y = -2.025 + 0.986(\ln x)$	0.62
	Chicks			NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults			$\ln y = -1.816 + 0.896(\ln x)$	0.82	$\ln y = -1.817 + 0.953(\ln x)$	0.84	$\ln y = -2.467 + 1.097(\ln x)$	0.87
	Breeding adults			$\ln y = -1.460 + 0.870(\ln x)$	0.92	$\ln y = -1.554 + 0.979(\ln x)$	0.92	$\ln y = -1.574 + 0.869(\ln x)$	0.91
	Chicks			$\ln y = -2.002 + 1.054(\ln x)$	0.82	$\ln y = -1.815 + 0.925(\ln x)$	0.73	$\ln y = -2.024 + 0.986(\ln x)$	0.75
Liver THg									
Avocets	Prebreeding adults	$\ln y = 2.151 + 0.971(\ln x)$	0.90			$\ln y = 0.166 + 1.020(\ln x)$	0.98	$\ln y = -0.189 + 1.110(\ln x)$	0.96
	Breeding adults	$\ln y = 2.056 + 0.950(\ln x)$	0.94			$\ln y = 0.168 + 1.002(\ln x)$	0.96	$\ln y = 0.093 + 1.009(\ln x)$	0.96
	Chicks	$\ln y = 1.660 + 0.828(\ln x)$	0.66			$\ln y = 0.132 + 1.066(\ln x)$	0.96	$\ln y = -0.104 + 1.149(\ln x)$	0.94
Stilts	Prebreeding adults	$\ln y = 2.037 + 0.983(\ln x)$	0.79			$\ln y = -0.082 + 1.182(\ln x)$	0.96	$\ln y = -0.322 + 1.208(\ln x)$	0.93
	Breeding adults	$\ln y = 1.985 + 0.769(\ln x)$	0.73			$\ln y = -0.001 + 1.084(\ln x)$	0.87	$\ln y = 0.157 + 0.975(\ln x)$	0.88
	Chicks	$\ln y = 1.744 + 0.833(\ln x)$	0.69			$\ln y = 0.080 + 0.992(\ln x)$	0.93	$\ln y = 0.086 + 1.019(\ln x)$	0.95
Caspian terns	Prebreeding adults	$\ln y = 1.702 + 0.799(\ln x)$	0.61			$\ln y = 0.173 + 1.071(\ln x)$	0.91	$\ln y = 0.278 + 0.842(\ln x)$	0.64
	Breeding adults	$\ln y = 2.147 + 0.613(\ln x)$	0.64			$\ln y = 0.127 + 1.032(\ln x)$	0.84	$\ln y = 0.323 + 0.857(\ln x)$	0.75
	Chicks	NA	NA			NA	NA	NA	NA
Forster's terns	Prebreeding adults	$\ln y = 1.977 + 0.915(\ln x)$	0.82			$\ln y = 0.050 + 1.072(\ln x)$	0.95	$\ln y = -0.536 + 1.139(\ln x)$	0.89
	Breeding adults	$\ln y = 1.762 + 1.060(\ln x)$	0.92			$\ln y = -0.087 + 1.112(\ln x)$	0.94	$\ln y = -0.092 + 0.977(\ln x)$	0.90
	Chicks	$\ln y = 1.722 + 0.775(\ln x)$	0.82			$\ln y = 0.073 + 0.995(\ln x)$	0.97	$\ln y = -0.030 + 0.970(\ln x)$	0.87
Liver MeHg									
Avocets	Prebreeding adults	$\ln y = 1.814 + 0.847(\ln x)$	0.86	$\ln y = -0.152 + 0.955(\ln x)$	0.98			$\ln y = -0.234 + 1.056(\ln x)$	0.93
	Breeding adults	$\ln y = 1.854 + 0.881(\ln x)$	0.90	$\ln y = -0.111 + 0.961(\ln x)$	0.96			$\ln y = -0.019 + 0.966(\ln x)$	0.93
	Chicks	$\ln y = 1.600 + 0.801(\ln x)$	0.68	$\ln y = -0.088 + 0.901(\ln x)$	0.96			$\ln y = -0.191 + 1.041(\ln x)$	0.90
Stilts	Prebreeding adults	$\ln y = 1.750 + 0.850(\ln x)$	0.86	$\ln y = 0.130 + 0.813(\ln x)$	0.96			$\ln y = -0.217 + 0.996(\ln x)$	0.93
	Breeding adults	$\ln y = 1.841 + 0.731(\ln x)$	0.83	$\ln y = 0.256 + 0.802(\ln x)$	0.87			$\ln y = 0.207 + 0.869(\ln x)$	0.93
	Chicks	$\ln y = 1.564 + 0.755(\ln x)$	0.71	$\ln y = -0.033 + 0.937(\ln x)$	0.93			$\ln y = 0.032 + 0.949(\ln x)$	0.87
Caspian terns	Prebreeding adults	$\ln y = 1.460 + 0.676(\ln x)$	0.54	$\ln y = 0.014 + 0.846(\ln x)$	0.91			$\ln y = 0.064 + 0.802(\ln x)$	0.74
	Breeding adults	$\ln y = 1.982 + 0.589(\ln x)$	0.69	$\ln y = 0.241 + 0.816(\ln x)$	0.84			$\ln y = 0.432 + 0.729(\ln x)$	0.69
	Chicks	NA	NA	NA	NA			NA	NA
Forster's terns	Prebreeding adults	$\ln y = 1.875 + 0.885(\ln x)$	0.84	$\ln y = 0.040 + 0.886(\ln x)$	0.95			$\ln y = -0.495 + 1.059(\ln x)$	0.91
	Breeding adults	$\ln y = 1.684 + 0.936(\ln x)$	0.92	$\ln y = 0.225 + 0.849(\ln x)$	0.94			$\ln y = 0.112 + 0.840(\ln x)$	0.85
	Chicks	$\ln y = 1.671 + 0.787(\ln x)$	0.73	$\ln y = -0.042 + 0.975(\ln x)$	0.97			$\ln y = -0.033 + 0.912(\ln x)$	0.82
Kidney THg									
Avocets	Prebreeding adults	$\ln y = 2.057 + 0.850(\ln x)$	0.91	$\ln y = 0.193 + 0.869(\ln x)$	0.96	$\ln y = 0.339 + 0.885(\ln x)$	0.93		
	Breeding adults	$\ln y = 1.9401 + 0.942(\ln x)$	0.95	$\ln y = -0.035 + 0.952(\ln x)$	0.96	$\ln y = 0.116 + 0.964(\ln x)$	0.93		
	Chicks	$\ln y = 1.603 + 0.754(\ln x)$	0.74	$\ln y = 0.133 + 0.819(\ln x)$	0.94	$\ln y = 0.257 + 0.868(\ln x)$	0.90		
Stilts	Prebreeding adults	$\ln y = 1.928 + 0.787(\ln x)$	0.79	$\ln y = 0.384 + 0.747(\ln x)$	0.93	$\ln y = 0.328 + 0.936(\ln x)$	0.93		
	Breeding adults	$\ln y = 1.890 + 0.812(\ln x)$	0.85	$\ln y = 0.095 + 0.904(\ln x)$	0.88	$\ln y = -0.080 + 1.070(\ln x)$	0.93		
	Chicks	$\ln y = 1.559 + 0.770(\ln x)$	0.65	$\ln y = -0.056 + 0.933(\ln x)$	0.95	$\ln y = 0.049 + 0.915(\ln x)$	0.87		
Caspian terns	Prebreeding adults	$\ln y = 1.791 + 0.640(\ln x)$	0.44	$\ln y = 0.518 + 0.764(\ln x)$	0.64	$\ln y = 0.473 + 0.922(\ln x)$	0.74		
	Breeding adults	$\ln y = 2.175 + 0.630(\ln x)$	0.62	$\ln y = 0.316 + 0.875(\ln x)$	0.75	$\ln y = 0.342 + 0.942(\ln x)$	0.69		
	Chicks	NA	NA	NA	NA	NA	NA		
Forster's terns	Prebreeding adults	$\ln y = 2.218 + 0.791(\ln x)$	0.87	$\ln y = 0.635 + 0.784(\ln x)$	0.89	$\ln y = 0.615 + 0.858(\ln x)$	0.91		
	Breeding adults	$\ln y = 1.905 + 1.049(\ln x)$	0.91	$\ln y = 0.357 + 0.926(\ln x)$	0.90	$\ln y = 0.348 + 1.009(\ln x)$	0.85		
	Chicks	$\ln y = 1.777 + 0.763(\ln x)$	0.75	$\ln y = 0.154 + 0.901(\ln x)$	0.87	$\ln y = 0.229 + 0.897(\ln x)$	0.82		
Kidney MeHg									
Avocets	Prebreeding adults	$\ln y = 1.530 + 0.790(\ln x)$	0.89	$\ln y = -0.260 + 0.882(\ln x)$	0.95	$\ln y = -0.120 + 0.904(\ln x)$	0.94	$\ln y = -0.444 + 0.994(\ln x)$	0.95
	Breeding adults	$\ln y = 1.603 + 0.885(\ln x)$	0.91	$\ln y = -0.322 + 0.932(\ln x)$	0.93	$\ln y = -0.184 + 0.948(\ln x)$	0.93	$\ln y = -0.245 + 0.946(\ln x)$	0.92
	Chicks	$\ln y = 1.464 + 0.723(\ln x)$	0.70	$\ln y = -0.182 + 0.767(\ln x)$	0.84	$\ln y = -0.030 + 0.783(\ln x)$	0.76	$\ln y = -0.303 + 0.938(\ln x)$	0.88
Stilts	Prebreeding adults	$\ln y = 1.599 + 0.751(\ln x)$	0.81	$\ln y = 0.212 + 0.713(\ln x)$	0.91	$\ln y = 0.122 + 0.862(\ln x)$	0.91	$\ln y = -0.163 + 0.912(\ln x)$	0.96
	Breeding adults	$\ln y = 1.691 + 0.756(\ln x)$	0.77	$\ln y = 0.042 + 0.837(\ln x)$	0.80	$\ln y = -0.203 + 1.032(\ln x)$	0.90	$\ln y = -0.104 + 0.954(\ln x)$	0.95
	Chicks	$\ln y = 1.675 + 0.901(\ln x)$	0.87	$\ln y = -0.128 + 0.940(\ln x)$	0.94	$\ln y = -0.072 + 0.966(\ln x)$	0.92	$\ln y = -0.104 + 0.984(\ln x)$	0.96
Caspian terns	Prebreeding adults	$\ln y = 1.691 + 0.557(\ln x)$	0.35	$\ln y = 0.460 + 0.725(\ln x)$	0.61	$\ln y = 0.364 + 0.901(\ln x)$	0.76	$\ln y = -0.014 + 0.940(\ln x)$	0.93
	Breeding adults	$\ln y = 2.116 + 0.666(\ln x)$	0.62	$\ln y = 0.235 + 0.892(\ln x)$	0.67	$\ln y = 0.343 + 0.924(\ln x)$	0.57	$\ln y = -0.169 + 1.054(\ln x)$	0.96
	Chicks	NA	NA	NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults	$\ln y = 1.986 + 0.858(\ln x)$	0.86	$\ln y = 0.363 + 0.787(\ln x)$	0.85	$\ln y = -0.354 + 0.872(\ln x)$	0.86	$\ln y = -0.262 + 1.012(\ln x)$	0.94
	Breeding adults	$\ln y = 1.690 + 0.993(\ln x)$	0.87	$\ln y = 0.334 + 0.841(\ln x)$	0.84	$\ln y = 0.171 + 0.970(\ln x)$	0.84	$\ln y = -0.029 + 0.917(\ln x)$	0.91
	Chicks	$\ln y = 1.770 + 0.792(\ln x)$	0.72	$\ln y = 0.118 + 0.896(\ln x)$	0.83	$\ln y = 0.158 + 0.919(\ln x)$	0.82	$\ln y = 0.020 + 0.924(\ln x)$	0.95
Muscle THg									
Avocets	Prebreeding adults	$\ln y = 1.060 + 0.900(\ln x)$	0.92	$\ln y = -0.891 + 0.901(\ln x)$	0.96	$\ln y = -0.734 + 0.911(\ln x)$	0.93	$\ln y = -1.073 + 1.015(\ln x)$	0.96
	Breeding adults	$\ln y = 1.075 + 0.887(\ln x)$	0.92	$\ln y = -0.755 + 0.902(\ln x)$	0.91	$\ln y = -0.578 + 0.890(\ln x)$	0.84	$\ln y = -0.696 + 0.929(\ln x)$	0.91
	Chicks	$\ln y = 0.996 + 0.673(\ln x)$	0.61	$\ln y = -0.549 + 0.746(\ln x)$	0.81	$\ln y = -0.434 + 0.791(\ln x)$	0.76	$\ln y = -0.540 + 0.817(\ln x)$	0.74
Stilts	Prebreeding adults	$\ln y = 0.870 + 0.821(\ln x)$	0.84	$\ln y = -0.696 + 0.778(\ln x)$	0.92	$\ln y = -0.831 + 0.991(\ln x)$	0.93	$\ln y = -1.029 + 0.983(\ln x)$	0.93
	Breeding adults	$\ln y = 1.030 + 0.851(\ln x)$	0.88	$\ln y = -0.750 + 0.907(\ln x)$	0.85	$\ln y = -0.969 + 1.093(\ln x)$	0.89	$\ln y = -0.794 + 0.978(\ln x)$	0.92
	Chicks	$\ln y = 0.922 + 0.875(\ln x)$	0.85	$\ln y = -0.823 + 0.924(\ln x)$	0.90	$\ln y = -0.807 + 1.015(\ln x)$	0.88	$\ln y = -0.772 + 0.954(\ln x)$	0.90
Caspian terns	Prebreeding adults	$\ln y = 0.668 + 0.716(\ln x)$	0.57	$\ln y = -0.824 + 0.883(\ln x)$	0.89	$\ln y = -0.757 + 0.996(\ln x)$	0.90	$\ln y = -0.826 + 0.864(\ln x)$	0.78
	Breeding adults	$\ln y = 1.177 + 0.648(\ln x)$	0.66	$\ln y = -0.812 + 0.930(\ln x)$	0.86	$\ln y = -0.887 + 1.048(\ln x)$	0.86	$\ln y = -0.808 + 0.920(\ln x)$	0.86
	Chicks	NA	NA	NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults	$\ln y = 0.854 + 0.863(\ln x)$	0.86	$\ln y = -0.878 + 0.864(\ln x)$	0.92	$\ln y = -0.803 + 0.907(\ln x)$	0.94	$\ln y = -1.492 + 1.059(\ln x)$	0.95
	Breeding adults	$\ln y = 0.725 + 0.976(\ln x)$	0.95	$\ln y = -0.757 + 0.873(\ln x)$	0.94	$\ln y = -0.802 + 0.964(\ln x)$	0.91	$\ln y = -0.946 + 0.892(\ln x)$	0.92
	Chicks	$\ln y = 0.627 + 0.655(\ln x)$	0.55	$\ln y = 0.815 + 0.856(\ln x)$	0.78	$\ln y = -0.747 + 0.897(\ln x)$	0.79	$\ln y = -0.871 + 0.833(\ln x)$	0.76
Breast feather THg									
Avocets	Prebreeding adults	$\ln y = 1.291 + 0.332(\ln x)$	0.20	$\ln y = 0.599 + 0.316(\ln x)$	0.19	$\ln y = 0.678 + 0.265(\ln x)$	0.11	$\ln y = 0.515 + 0.377(\ln x)$	0.21
	Breeding adults	$\ln y = 0.992 + 0.241(\ln x)$*	0.10*	$\ln y = 0.550 + 0.289(\ln x)$	0.12	$\ln y = 0.695 + 0.254(\ln x)$*	0.10*	$\ln y = 0.549 + 0.311(\ln x)$	0.14
	Chicks	$\ln y = 1.983 + 0.428(\ln x)$	0.23	$\ln y = 1.132 + 0.382(\ln x)$	0.19	$\ln y = 1.191 + 0.370(\ln x)$*	0.14*	$\ln y = 0.897 + 0.582(\ln x)$	0.25
Stilts	Prebreeding adults	$\ln y = 2.249 + 0.530(\ln x)$	0.42	$\ln y = 1.313 + 0.454(\ln x)$	0.38	$\ln y = 1.033 + 0.648(\ln x)$	0.54	$\ln y = 1.229 + 0.518(\ln x)$	0.32
	Breeding adults	$\ln y = 1.995 + 0.126(\ln x)$*	0.02*	$\ln y = 1.560 + 0.221(\ln x)$*	0.05*	$\ln y = 1.471 + 0.275(\ln x)$*	0.06*	$\ln y = 1.689 + 0.168(\ln x)$*	0.03*
	Chicks	$\ln y = 2.484 + 0.675(\ln x)$	0.35	$\ln y = 1.148 + 0.692(\ln x)$	0.36	$\ln y = 1.150 + 0.714(\ln x)$	0.36	$\ln y = 1.170 + 0.761(\ln x)$	0.41

APPENDIX. Extended

		Kidney MeHg		Muscle		Breast feather		Head feather	
Species	Life stage	ln y = b + lnx	r^2	ln y = b + lnx	r^2	ln y = b + lnx	r^2	ln y = b + lnx	r^2
Blood THg									
Avocets	Prebreeding adults	ln y = −1.899 + 1.127(ln x)	0.89	ln y = −1.205 + 1.023(ln x)	0.92	ln y = −2.007 + 0.614(ln x)	0.20	ln y = −2.845 + 1.036(ln x)	0.80
	Breeding adults	ln y = −1.693 + 1.027(ln x)	0.91	ln y = −1.163 + 1.040(ln x)	0.92	ln y = −0.923 + 0.405(ln x)*	0.10*	ln y = −2.180 + 0.912(ln x)	0.71
	Chicks	ln y = −1.730 + 0.966(ln x)	0.70	ln y = −1.273 + 0.912(ln x)	0.61	ln y = −1.866 + 0.545(ln x)	0.23	ln y = −3.137 + 1.143(ln x)	0.66
Avocets	Prebreeding adults	ln y = −1.759 + 1.081(ln x)	0.81	ln y = −0.895 + 1.018(ln x)	0.84	ln y = −1.827 + 0.799(ln x)	0.42	ln y = −2.525 + 1.004(ln x)	0.59
	Breeding adults	ln y = −1.710 + 1.024(ln x)	0.77	ln y = −1.055 + 1.035(ln x)	0.88	ln y = −0.178 + 0.137(ln x)*	0.02*	ln y = −1.970 + 0.809(ln x)	0.30
	Chicks	ln y = −1.800 + 0.968(ln x)	0.87	ln y = −1.129 + 0.969(ln x)	0.85	ln y = −2.26 + 0.513(ln x)	0.35	ln y = −2.238 + 0.422(ln x)	0.29
Caspian terns	Prebreeding adults	ln y = −0.847 + 0.620(ln x)	0.34	ln y = −0.403 + 0.801(ln x)	0.57	ln y = −0.602 + 0.403(ln x)	0.33	ln y = −0.618 + 0.441(ln x)	0.40
	Breeding adults	ln y = −1.833 + 0.924(ln x)	0.62	ln y = −1.082 + 1.012(ln x)	0.66	ln y = 0.216 + 0.050(ln x)*	0.01*	ln y = 0.403 − 0.045(ln x)*	0.00*
	Chicks	NA	NA	NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults	ln y = −2.036 + 1.013(ln x)	0.87	ln y = −0.888 + 1.001(ln x)	0.86	ln y = −1.490 + 0.552(ln x)	0.38	ln y = −1.318 + 0.530(ln x)	0.45
	Breeding adults	ln y = −1.340 + 0.877(ln x)	0.87	ln y = −0.660 + 0.973(ln x)	0.95	ln y = 0.185 + 0.325(ln x)	0.26	ln y = 0.312 + 0.312(ln x)	0.24
	Chicks	ln y = −1.894 + 0.904(ln x)	0.72	ln y = −1.003 + 0.834(ln x)	0.55	ln y = −2.820 + 0.815(ln x)	0.34	ln y = −2.793 + 0.840(ln x)	0.27
Liver THg									
Avocets	Prebreeding adults	ln y = 0.316 + 1.074(ln x)	0.95	ln y = 0.980 + 1.070(ln x)	0.96	ln y = 0.214 + 0.605(ln x)	0.19	ln y = −0.683 + 1.015(ln x)	0.82
	Breeding adults	ln y = 0.421 + 1.004(ln x)	0.93	ln y = 0.893 + 1.007(ln x)	0.91	ln y = 1.041 + 0.430(ln x)	0.12	ln y = −0.242 + 0.957(ln x)	0.71
	Chicks	ln y = 0.382 + 1.092(ln x)	0.84	ln y = 0.829 + 1.086(ln x)	0.81	ln y = 0.328 + 0.499(ln x)	0.19	ln y = −0.794 + 1.067(ln x)	0.62
Stilts	Prebreeding adults	ln y = −0.100 + 1.271(ln x)	0.91	ln y = 0.984 + 1.178(ln x)	0.92	ln y = 0.124 + 0.835(ln x)	0.38	ln y = −0.954 + 1.196(ln x)	0.70
	Breeding adults	ln y = 0.384 + 0.955(ln x)	0.80	ln y = 1.017 + 0.937(ln x)	0.85	ln y = 1.607 + 0.239(ln x)*	0.05*	ln y = −0.209 + 0.893(ln x)	0.51
	Chicks	ln y = 0.160 + 1.005(ln x)	0.94	ln y = 0.842 + 0.969(ln x)	0.90	ln y = −0.365 + 0.527(ln x)	0.36	ln y = −0.306 + 0.914(ln x)	0.45
Caspian terns	Prebreeding adults	ln y = 0.388 + 0.845(ln x)	0.61	ln y = 1.047 + 1.013(ln x)	0.89	ln y = 0.786 + 0.515(ln x)	0.53	ln y = 0.830 + 0.537(ln x)	0.60
	Breeding adults	ln y = 0.599 + 0.754(ln x)	0.67	ln y = 1.086 + 0.923(ln x)	0.86	ln y = 2.123 + 0.119(ln x)*	0.05*	ln y = 2.174 + 0.102(ln x)*	0.04*
	Chicks	NA	NA	NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults	ln y = −0.099 + 1.074(ln x)	0.85	ln y = 1.076 + 1.062(ln x)	0.92	ln y = 0.239 + 0.666(ln x)	0.53	ln y = 0.462 + 0.626(ln x)	0.62
	Breeding adults	ln y = 0.122 + 1.00(ln x)	0.84	ln y = 0.984 + 1.073(ln x)	0.94	ln y = 1.873 + 0.367(ln x)	0.26	ln y = 2.012 + 0.356(ln x)	0.25
	Chicks	ln y = 0.045 + 0.932(ln x)	0.83	ln y = 0.945 + 0.913(ln x)	0.78	ln y = −0.744 + 0.761(ln x)	0.36	ln y = −0.879 + 0.870(ln x)	0.35
Liver MeHg									
Avocets	Prebreeding adults	ln y = 0.156 + 1.042(ln x)	0.94	ln y = 0.788 + 1.025(ln x)	0.93	ln y = 0.184 + 0.426(ln x)*	0.11*	ln y = −0.702 + 0.917(ln x)	0.69
	Breeding adults	ln y = 0.278 + 0.979(ln x)	0.93	ln y = 0.759 + 0.947(ln x)	0.84	ln y = 0.953 + 0.384(ln x)*	0.10*	ln y = −0.212 + 0.872(ln x)	0.66
	Chicks	ln y = 0.251 + 0.965(ln x)	0.76	ln y = 0.670 + 0.962(ln x)	0.76	ln y = 0.395 + 0.375(ln x)*	0.14*	ln y = −0.706 + 0.915(ln x)	0.55
Stilts	Prebreeding adults	ln y = 0.013 + 1.056(ln x)	0.91	ln y = 0.892 + 0.938(ln x)	0.93	ln y = −0.124 + 0.836(ln x)	0.54	ln y = −0.470 + 0.899(ln x)	0.72
	Breeding adults	ln y = 0.373 + 0.872(ln x)	0.90	ln y = 1.000 + 0.817(ln x)	0.89	ln y = 1.540 + 0.207(ln x)*	0.06*	ln y = 0.339 + 0.627(ln x)	0.37
	Chicks	ln y = 0.109 + 0.950(ln x)	0.92	ln y = 0.755 + 0.866(ln x)	0.88	ln y = −0.242 + 0.498(ln x)	0.36	ln y = −0.221 + 0.416(ln x)	0.25
Caspian terns	Prebreeding adults	ln y = 0.113 + 0.834(ln x)	0.76	ln y = 0.856 + 0.902(ln x)	0.90	ln y = 0.646 + 0.450(ln x)	0.51	ln y = 0.686 + 0.468(ln x)	0.58
	Breeding adults	ln y = 0.726 + 0.617(ln x)	0.57	ln y = 1.031 + 0.822(ln x)	0.86	ln y = 1.966 + 0.100(ln x)*	0.05*	ln y = 2.018 + 0.081(ln x)*	0.03*
	Chicks	NA	NA	NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults	ln y = −0.106 + 0.984(ln x)	0.86	ln y = 0.935 + 1.034(ln x)	0.94	ln y = 0.097 + 0.631(ln x)	0.46	ln y = 0.226 + 0.621(ln x)	0.64
	Breeding adults	ln y = 0.266 + 0.870(ln x)	0.84	ln y = 0.998 + 0.944(ln x)	0.91	ln y = 2.078 + 0.251(ln x)	0.19	ln y = 2.209 + 0.234(ln x)	0.18
	Chicks	ln y = 0.012 + 0.897(ln x)	0.82	ln y = 0.848 + 0.883(ln x)	0.79	ln y = −0.599 + 0.702(ln x)	0.25	ln y = −0.529 + 0.668(ln x)	0.22
Kidney THg									
Avocets	Prebreeding adults	ln y = 0.464 + 0.960(ln x)	0.95	ln y = 1.047 + 0.945(ln x)	0.96	ln y = 0.346 + 0.567(ln x)	0.21	ln y = −0.449 + 0.916(ln x)	0.86
	Breeding adults	ln y = 0.350 + 0.974(ln x)	0.92	ln y = 0.805 + 0.978(ln x)	0.91	ln y = 0.928 + 0.437(ln x)	0.14	ln y = −0.345 + 0.956(ln x)	0.75
	Chicks	ln y = 0.408 + 0.941(ln x)	0.88	ln y = 0.802 + 0.906(ln x)	0.74	ln y = 0.461 + 0.434(ln x)	0.25	ln y = −0.523 + 0.902(ln x)	0.73
Stilts	Prebreeding adults	ln y = 0.247 + 1.051(ln x)	0.96	ln y = 1.105 + 0.946(ln x)	0.93	ln y = 0.540 + 0.610(ln x)	0.32	ln y = −0.360 + 0.920(ln x)	0.64
	Breeding adults	ln y = 0.212 + 0.992(ln x)	0.95	ln y = 0.911 + 0.937(ln x)	0.92	ln y = 1.644 + 0.168(ln x)*	0.03*	ln y = 0.128 + 0.716(ln x)	0.35
	Chicks	ln y = 0.122 + 0.977(ln x)	0.96	ln y = 0.762 + 0.940(ln x)	0.90	ln y = −0.405 + 0.540(ln x)	0.41	ln y = −0.375 + 0.452(ln x)	0.33
Caspian terns	Prebreeding adults	ln y = 0.148 + 0.995(ln x)	0.93	ln y = 1.200 + 0.900(ln x)	0.78	ln y = 0.820 + 0.521(ln x)	0.60	ln y = 0.886 + 0.533(ln x)	0.65
	Breeding adults	ln y = 0.253 + 0.909(ln x)	0.96	ln y = 1.092 + 0.933(ln x)	0.86	ln y = 2.377 + 0.008(ln x)*	0.00*	ln y = 2.398 − 0.002(ln x)*	0.00*
	Chicks	NA	NA	NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults	ln y = 0.375 + 0.925(ln x)	0.94	ln y = 1.439 + 0.897(ln x)	0.95	ln y = 0.817 + 0.525(ln x)	0.48	ln y = 1.026 + 0.477(ln x)	0.52
	Breeding adults	ln y = 0.314 + 0.988(ln x)	0.91	ln y = 1.198 + 1.035(ln x)	0.92	ln y = 1.995 + 0.377(ln x)	0.30	ln y = 2.157 + 0.353(ln x)	0.26
	Chicks	ln y = 0.031 + 1.028(ln x)	0.95	ln y = 1.036 + 0.910(ln x)	0.76	ln y = −0.841 + 0.860(ln x)	0.41	ln y = −1.012 + 0.994(ln x)	0.40
Kidney MeHg									
Avocets	Prebreeding adults			ln y = 0.600 + 0.952(ln x)	0.93	ln y = −0.019 + 0.470(ln x)	0.16	ln y = −0.844 + 0.903(ln x)	0.76
	Breeding adults			ln y = 0.519 + 0.924(ln x)	0.83	ln y = 0.718 + 0.365(ln x)*	0.09*	ln y = −0.470 + 0.874(ln x)	0.68
	Chicks			ln y = 0.469 + 0.819(ln x)	0.56	ln y = 0.108 + 0.433(ln x)	0.24	ln y = −0.778 + 0.842(ln x)	0.60
Stilts	Prebreeding adults			ln y = 0.862 + 0.848(ln x)	0.93	ln y = 0.063 + 0.692(ln x)	0.45	ln y = −0.253 + 0.758(ln x)	0.60
	Breeding adults			ln y = 0.767 + 0.897(ln x)	0.91	ln y = 1.456 + 0.179(ln x)*	0.04*	ln y = 0.157 + 0.640(ln x)	0.32
	Chicks			ln y = 0.683 + 0.905(ln x)	0.93	ln y = −0.440 + 0.570(ln x)	0.44	ln y = −0.337 + 0.469(ln x)	0.34
Caspian terns	Prebreeding adults			ln y = 1.122 + 0.836(ln x)	0.71	ln y = 0.761 + 0.487(ln x)	0.55	ln y = 0.821 + 0.499(ln x)	0.60
	Breeding adults			ln y = 1.036 + 0.945(ln x)	0.76	ln y = 2.392 − 0.018(ln x)*	0.00*	ln y = 2.428 − 0.037(ln x)*	0.00*
	Chicks			NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults			ln y = 1.125 + 0.961(ln x)	0.91	ln y = 0.255 + 0.622(ln x)	0.51	ln y = 0.444 + 0.586(ln x)	0.64
	Breeding adults			ln y = 1.012 + 0.984(ln x)	0.90	ln y = 2.113 + 0.261(ln x)	0.19	ln y = 2.196 + 0.280(ln x)	0.24
	Chicks			ln y = 0.981 + 0.840(ln x)	0.71	ln y = −0.662 + 0.783(ln x)	0.30	ln y = −0.411 + 0.677(ln x)	0.23
Muscle THg									
Avocets	Prebreeding adults	ln y = −0.603 + 0.976(ln x)	0.93			ln y = −0.752 + 0.609(ln x)	0.23	ln y = −1.540 + 0.938(ln x)	0.83
	Breeding adults	ln y = −0.358 + 0.897(ln x)	0.83			ln y = 0.119 + 0.454(ln x)	0.15	ln y = −1.070 + 0.917(ln x)	0.73
	Chicks	ln y = −0.110 + 0.684(ln x)	0.56			ln y = −0.085 + 0.287(ln x)*	0.11*	ln y = −1.094 + 0.781(ln x)	0.51
Stilts	Prebreeding adults	ln y = −0.894 + 1.098(ln x)	0.93			ln y = −0.601 + 0.648(ln x)	0.34	ln y = −1.493 + 0.949(ln x)	0.65
	Breeding adults	ln y = −0.672 + 1.013(ln x)	0.91			ln y = 0.877 + 0.132(ln x)*	0.02*	ln y = −0.710 + 0.718(ln x)	0.34
	Chicks	ln y = −0.726 + 1.030(ln x)	0.93			ln y = −1.287 + 0.605(ln x)	0.49	ln y = −1.281 + 0.523(ln x)	0.45
Caspian terns	Prebreeding adults	ln y = −0.680 + 0.849(ln x)	0.71			ln y = −0.242 + 0.502(ln x)	0.58	ln y = −0.180 + 0.514(ln x)	0.63
	Breeding adults	ln y = −0.498 + 0.804(ln x)	0.86			ln y = 1.387 + 0.004(ln x)*	0.00*	ln y = 1.406 − 0.006(ln x)*	0.00*
	Chicks	NA	NA			NA	NA	NA	NA
Forster's terns	Prebreeding adults	ln y = −1.008 + 0.952(ln x)	0.91			ln y = −0.609 + 0.549(ln x)	0.44	ln y = −0.412 + 0.509(ln x)	0.50
	Breeding adults	ln y = −0.749 + 0.915(ln x)	0.90			ln y = 0.883 + 0.318(ln x)	0.24	ln y = 1.007 + 0.307(ln x)	0.23
	Chicks	ln y = −0.818 + 0.852(ln x)	0.71			ln y = −1.834 + 0.914(ln x)	0.45	ln y = −1.552 + 0.761(ln x)	0.35
Breast feather THg									
Avocets	Prebreeding adults	ln y = 0.692 + 0.338(ln x)	0.16	ln y = 0.919 + 0.378(ln x)	0.23			ln y = 0.228 + 0.437(ln x)	0.28
	Breeding adults	ln y = 0.765 + 0.249(ln x)*	0.09*	ln y = 0.780 + 0.341(ln x)	0.15			ln y = 0.160 + 0.456(ln x)	0.24
	Chicks	ln y = 1.129 + 0.556(ln x)	0.24	ln y = 1.441 + 0.383(ln x)*	0.11*			ln y = −0.332 + 1.007(ln x)	0.70
Stilts	Prebreeding adults	ln y = 1.103 + 0.650(ln x)	0.45	ln y = 1.767 + 0.530(ln x)	0.34			ln y = 0.167 + 0.833(ln x)	0.61
	Breeding adults	ln y = 1.644 + 0.201(ln x)*	0.04*	ln y = 1.877 + 0.127(ln x)*	0.02*			ln y = 0.538 + 0.576(ln x)	0.22
	Chicks	ln y = 1.171 + 0.773(ln x)	0.44	ln y = 1.761 + 0.807(ln x)	0.49			ln y = −0.061 + 0.987(ln x)	0.94

APPENDIX. Continued

Species	Life stage	Blood THg		Liver THg		Liver MeHg		Kidney THg	
		$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2	$\ln y = b + \ln x$	r^2
Caspian terns	Prebreeding adults	$\ln y = 2.001 + 0.811(\ln x)$	0.33	$\ln y = 0.287 + 1.034(\ln x)$	0.53	$\ln y = 0.407 + 1.143(\ln x)$	0.51	$\ln y = 0.002 + 1.150(\ln x)$	0.60
	Breeding adults	$\ln y = 2.018 + 0.113(\ln x)$*	0.01*	$\ln y = 0.033 + 0.454(\ln x)$*	0.05*	$\ln y = 1.057 + 0.484(\ln x)$*	0.05*	$\ln y = 2.043 + 0.028(\ln x)$*	0.00*
	Chicks	NA	NA	NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults	$\ln y = 2.425 + 0.683(\ln x)$	0.38	$\ln y = 0.865 + 0.800(\ln x)$	0.53	$\ln y = 1.295 + 0.731(\ln x)$	0.46	$\ln y = 0.428 + 0.915(\ln x)$	0.48
	Breeding adults	$\ln y = 1.551 + 0.802(\ln x)$	0.26	$\ln y = 0.324 + 0.722(\ln x)$	0.26	$\ln y = 0.332 + 0.767(\ln x)$	0.19	$\ln y = 0.026 + 0.784(\ln x)$	0.30
	Chicks	$\ln y = 2.483 + 0.412(\ln x)$	0.34	$\ln y = 1.632 + 0.468(\ln x)$	0.36	$\ln y = 1.725 + 0.355(\ln x)$	0.25	$\ln y = 1.577 + 0.477(\ln x)$	0.41
Head feather THg									
Avocets	Prebreeding adults	$\ln y = 2.451 + 0.772(\ln x)$	0.80	$\ln y = 0.795 + 0.809(\ln x)$	0.82	$\ln y = 0.932 + 0.758(\ln x)$	0.70	$\ln y = 0.612 + 0.936(\ln x)$	0.86
	Breeding adults	$\ln y = 2.201 + 0.782(\ln x)$	0.71	$\ln y = 0.697 + 0.740(\ln x)$	0.71	$\ln y = 0.768 + 0.757(\ln x)$	0.66	$\ln y = 0.716 + 0.784(\ln x)$	0.75
	Chicks	$\ln y = 2.438 + 0.580(\ln x)$	0.66	$\ln y = 1.155 + 0.585(\ln x)$	0.62	$\ln y = 1.258 + 0.601(\ln x)$	0.55	$\ln y = 0.926 + 0.808(\ln x)$	0.73
Stilts	Prebreeding adults	$\ln y = 2.505 + 0.588(\ln x)$	0.59	$\ln y = 1.302 + 0.583(\ln x)$	0.70	$\ln y = 1.032 + 0.805(\ln x)$	0.72	$\ln y = 1.138 + 0.696(\ln x)$	0.64
	Breeding adults	$\ln y = 2.487 + 0.367(\ln x)$	0.30	$\ln y = 1.367 + 0.571(\ln x)$	0.51	$\ln y = 1.387 + 0.914(\ln x)$	0.60	$\ln y = 1.582 + 0.494(\ln x)$	0.35
	Chicks	$\ln y = 2.587 + 0.677(\ln x)$	0.29	$\ln y = 1.262 + 0.637(\ln x)$	0.29	$\ln y = 1.298 + 0.598(\ln x)$	0.25	$\ln y = 1.280 + 0.723(\ln x)$	0.33
Caspian terns	Prebreeding adults	$\ln y = 1.795 + 0.911(\ln x)$	0.40	$\ln y = -0.055 + 1.117(\ln x)$	0.60	$\ln y = 0.078 + 1.232(\ln x)$	0.58	$\ln y = -0.318 + 1.220(\ln x)$	0.65
	Breeding adults	$\ln y = 1.930 - 0.091(\ln x)$*	0.01*	$\ln y = 1.117 + 0.358(\ln x)$*	0.04*	$\ln y = 1.182 + 0.360(\ln x)$*	0.03*	$\ln y = 1.986 - 0.008(\ln x)$*	0.00*
	Chicks	NA	NA	NA	NA	NA	NA	NA	NA
Forster's terns	Prebreeding adults	$\ln y = 2.235 + 0.854(\ln x)$	0.45	$\ln y = 0.322 + 0.991(\ln x)$	0.62	$\ln y = 0.626 + 1.027(\ln x)$	0.64	$\ln y = -0.145 + 1.097(\ln x)$	0.52
	Breeding adults	$\ln y = 1.266 + 0.771(\ln x)$	0.24	$\ln y = 0.063 + 0.709(\ln x)$	0.25	$\ln y = -0.063 + 0.790(\ln x)$	0.18	$\ln y = -0.124 + 0.734(\ln x)$	0.26
	Chicks	$\ln y = 2.314 + 0.324(\ln x)$	0.27	$\ln y = 1.617 + 0.404(\ln x)$	0.35	$\ln y = 1.743 + 0.335(\ln x)$	0.22	$\ln y = 1.572 + 0.405(\ln x)$	0.40

[a] NA = no data available for Caspian tern chicks. Asterisks indicate relationships between tissues that are not significant ($p > 0.05$).

APPENDIX. Continued (Extended)

Species	Life stage	Kidney MeHg $\ln y = b + \ln x$	r^2	Muscle $\ln y = b + \ln x$	r^2	Breast feather $\ln y = b + \ln x$	r^2	Head feather $\ln y = b + \ln x$	r^2
Caspian terns	Prebreeding adults	$\ln y = 0.181 + 1.139(\ln x)$	0.55	$\ln y = 1.267 + 1.156(\ln x)$	0.58			$\ln y = 0.271 + 0.957(\ln x)$	0.95
	Breeding adults	$\ln y = 2.245 - 0.057(\ln x)$*	0.00*	$\ln y = 2.091 + 0.014(\ln x)$*	0.00*			$\ln y = 0.149 + 0.998(\ln x)$	0.92
	Chicks	NA	NA	NA	NA			NA	NA
Forster's terns	Prebreeding adults	$\ln y = 1.044 + 0.814(\ln x)$	0.51	$\ln y = 1.751 + 0.809(\ln x)$	0.44			$\ln y = 618 + 0.801(\ln x)$	0.85
	Breeding adults	$\ln y = 0.382 + 0.719(\ln x)$	0.19	$\ln y = 1.044 + 0.769(\ln x)$	0.24			$\ln y = 0.571 + 0.857(\ln x)$	0.74
	Chicks	$\ln y = 1.667 + 0.379(\ln x)$	0.30	$\ln y = 1.997 + 0.491(\ln x)$	0.45			$\ln y = 0.171 + 0.922(\ln x)$	0.90
Head feather THg									
Avocets	Prebreeding adults	$\ln y = 1.026 + 0.838(\ln x)$	0.76	$\ln y = 1.594 + 0.890(\ln x)$	0.83	$\ln y = 0.826 + 0.644(\ln x)$	0.28		
	Breeding adults	$\ln y = 0.932 + 0.784(\ln x)$	0.68	$\ln y = 1.333 + 0.792(\ln x)$	0.73	$\ln y = 1.267 + 0.526(\ln x)$	0.24		
	Chicks	$\ln y = 1.303 + 0.713(\ln x)$	0.60	$\ln y = 1.636 + 0.658(\ln x)$	0.51	$\ln y = 0.789 + 0.691(\ln x)$	0.70		
Stilts	Prebreeding adults	$\ln y = 1.136 + 0.798(\ln x)$	0.60	$\ln y = 1.882 + 0.690(\ln x)$	0.65	$\ln y = 0.847 + 0.728(\ln x)$	0.61		
	Breeding adults	$\ln y = 1.641 + 0.504(\ln x)$	0.32	$\ln y = 2.016 + 0.747(\ln x)$	0.34	$\ln y = 1.792 + 0.376(\ln x)$	0.22		
	Chicks	$\ln y = 1.314 + 0.718(\ln x)$	0.34	$\ln y = 1.918 + 0.864(\ln x)$	0.45	$\ln y = 0.143 + 0.955(\ln x)$	0.94		
Caspian terns	Prebreeding adults	$\ln y = -0.131 + 1.210(\ln x)$	0.60	$\ln y = 1.023 + 1.228(\ln x)$	0.63	$\ln y = -0.157 + 0.992(\ln x)$	0.95		
	Breeding adults	$\ln y = 2.227 - 0.111(\ln x)$*	0.00*	$\ln y = 1.995 - 0.021(\ln x)$*	$0.00*	$\ln y = 0.026 + 0.919(\ln x)$	0.92		
	Chicks	NA	NA	NA	NA	NA	NA		
Foster's terns	Prebreeding adults	$\ln y = 0.364 + 1.094(\ln x)$	0.64	$\ln y = 1.428 + 0.990(\ln x)$	0.50	$\ln y = -0.338 + 1.057(\ln x)$	0.85		
	Breeding adults	$\ln y = -0.309 + 0.849(\ln x)$	0.24	$\ln y = 0.771 + 0.753(\ln x)$	0.23	$\ln y = 0.025 + 0.865(\ln x)$	0.74		
	Chicks	$\ln y = 1.693 + 0.340(\ln x)$	0.23	$\ln y = 2.004 + 0.459(\ln x)$	0.35	$\ln y = 0.023 + 0.977(\ln x)$	0.90		