Environmental Science & Technology

March 3, 2020
Volume 54
Number 5
pubs.acs.org/est

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Environmental Science & Technology

Article

Cite This: Environ. Sci. Technol. 2020, 54, 2878−2891

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Synthesis of Maternal Transfer of Mercury in Birds: Implications for Altered Toxicity Risk

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Supporting Information

ABSTRACT: Maternal transfer is a predominant route of methylmercury (MeHg) exposure to offspring. We reviewed and synthesized published and unpublished data on maternal transfer of MeHg in birds. Using paired samples of females' blood ($n = 564$) and their eggs ($n = 1814$) from 26 bird species in 6 taxonomic orders, we conducted a meta-analysis to evaluate whether maternal transfer of MeHg to eggs differed among species and caused differential toxicity risk to embryos. Total mercury (THg) concentrations in eggs increased with maternal blood THg concentrations; however, the proportion of THg transferred from females to their eggs differed among bird taxa and with maternal THg exposure. Specifically, a smaller proportion of maternal THg was transferred to eggs with increasing female THg concentrations. Additionally, the proportion of THg that was transferred to eggs at the same maternal blood THg concentration differed among taxonomic orders, with waterfowl (Anseriformes) transferring up to 382% more THg into their eggs than songbirds (Passeriformes). We provide equations to predict THg concentrations in eggs using female blood THg concentrations, and vice versa, which may help translate toxicity benchmarks across tissues and life stages. Our results indicate that toxicity risk of MeHg can vary among bird taxa due to differences in maternal transfer of MeHg to offspring.

INTRODUCTION

Mercury (Hg) contamination of the environment is prevalent throughout the world,[1−3] and methylmercury (MeHg), the

Received: October 24, 2019
Revised: December 19, 2019
Accepted: December 23, 2019
Published: December 24, 2019

form of Hg that biomagnifies and is most toxic, poses a significant risk to human and wildlife health.[4−6] Reproduction is a sensitive endpoint when MeHg exposure can lead to toxicity.[5] In birds, most examples of MeHg toxicity have been in ovo, including deformed embryos,[7] malpositioned embryos,[8] and reduced egg hatchability,[9−13] as well as latent effects of in ovo MeHg exposure on reduced chick growth, health, and survival.[14−19] Therefore, MeHg contamination of eggs represents a critical exposure period for MeHg toxicity to birds and other oviparous animals.[20,21]

The maternal transfer of MeHg is the predominant route of exposure to developing offspring and, in the case of bird eggs, is the only mechanism for MeHg contamination of the embryo until the chick hatches and begins feeding.[22] Thus, the transfer of MeHg from mothers to eggs is an important mechanism, which can result in the toxic impairment of offspring while simultaneously reducing MeHg contamination of adult females. For example, female birds can deposit 13−24% of their body burden of MeHg into their clutch of eggs.[23,24] Despite its important role in MeHg toxicity of animals, it is unknown whether the maternal transfer rate of MeHg to offspring is consistent among species or whether the transfer rate varies with the amount of maternal contamination. If maternal transfer rates vary among taxa or with environmental exposure, then this would suggest that MeHg toxicity to animals depends, at least in part, on this maternal transfer mechanism.

Herein, we reviewed and summarized the available data on maternal transfer of MeHg in birds using original datasets from both published[25−30] and unpublished research. Over a wide range of MeHg concentrations, we conducted a meta-analysis using paired data for incubating females and their eggs for 26 bird species from 6 taxonomic orders. Our objectives were to: (1) evaluate whether increased MeHg contamination of adult female birds directly results in increased MeHg contamination of their eggs; (2) determine whether the proportion of maternal MeHg transferred to eggs differs among bird taxonomic groupings or varies with the MeHg contamination level of the mother; (3) assess whether the maternal transfer relationship is sensitive to study methodology; and (4) develop equations to predict MeHg concentrations in bird eggs using female blood MeHg concentrations and vice versa.

■ MATERIALS AND METHODS

Data Compilation. We compiled all of the available datasets on paired Hg concentrations in female birds and their eggs (Table 1). First, we conducted a comprehensive literature review to find the published datasets on maternal transfer of Hg in birds and then contacted authors to include their original data in this synthesis. Second, we searched for unpublished datasets by contacting scientists that study Hg in birds. Previously published datasets used in this synthesis included American avocet,[25] black-necked stilt,[25] Forster's tern,[25] tree swallow,[26,27] house wren,[27] mallard,[28] and common loon.[29,30] We excluded only one published dataset (captive zebra finch[31]) because egg processing and Hg determination were substantially different than the other datasets. Unpublished datasets used in this synthesis included common loon, common merganser, hooded merganser, common goldeneye, mallard, wood duck, tree swallow, Carolina wren, indigo bunting, northern cardinal, red-winged blackbird, and song sparrow (Evers); zebra finch, tree swallow, Carolina wren, house wren, eastern phoebe, eastern bluebird, and belted kingfisher (Cristol); black-legged kittiwake and northern fulmar (Mallory, Provencher, and Braune); common eider, black-legged kittiwake, herring gull, and great black-backed gull (Lavoie); and yellow-billed loon (Matz and Schmutz).

Once the datasets were compiled, we proofed the data and made the following decisions (see Table S1 for each study's methods). First, we included data for both captive and free-living birds. For captive birds that were dosed with MeHg through their diet, we excluded data within the control treatments for mallard ($n = 5$)[28] and zebra finch ($n = 7$; Cristol) because these females' blood or egg total mercury (THg) concentrations were very low [$\ll 0.01$ μg/g wet weight or fresh wet weight] and these control birds had substantial leverage influencing the slope of the relationship for females within treatment groups. Second, we included maternal blood THg concentrations that were sampled at various times during breeding. Preferably, the mother's blood would have been sampled immediately before egg laying to precisely relate THg concentrations in blood to those in her subsequently laid eggs.[27] However, for field studies, this often is not practical. Instead, most field studies attempted to capture and bleed the nesting female during early incubation, near the time of clutch completion.[25−27,30] Captive bird studies typically bled the female on the day the egg was laid (Table S1).[28] We also included datasets where females were bled ≤28 days before or after clutch completion (except common loons where we did not have precise nest initiation dates; see Table S1). The inclusion of these data likely adds variability to results because the time at which the female's blood is sampled can influence the intercept, but not the slope, of the relationship between THg concentrations in eggs and maternal blood.[27] Third, we included datasets that sampled egg THg concentrations in either the female's complete clutch of eggs or from a random subset of eggs from her clutch (Table 1). Fourth, we included egg THg concentrations estimated using several approaches. Whenever possible, we estimated egg THg concentrations on a fresh wet weight basis using an individual egg's morphometrics and percent moisture following the methods of Ackerman et al.[32] using published egg densities and egg shape coefficients.[33−42] When individual egg morphometric data was not available (Table S1), we used egg THg concentrations on a wet weight basis instead of the preferred fresh wet weight basis. When individual egg percent moisture data was not available (Table S1), we used an average moisture content of 75.4% for zebra finch (Cristol, unpublished) and 75.5%[43] for yellow-billed loon. Fifth, we included female blood THg concentrations that were either analytically determined or mathematically estimated on a wet weight basis for whole blood (Table S1). For most datasets, whole blood was analyzed directly on a wet weight basis. However, in some cases, whole blood was analyzed on a dry weight basis and converted into a wet weight basis using the individual blood sample's moisture content[27] or, when moisture content for each individual blood sample was not available, we used an average blood moisture content from the literature; specifically, we used 79.1%[44] for northern fulmar and black-legged kittiwake and 75.9%[43] for yellow-billed loon. For herring gulls, black-legged kittiwakes, common eiders, and great black-backed gulls sampled at Corossol Island, Quebec, Canada, THg concentrations were determined on a dry weight basis in red blood cells and converted to THg concentrations in whole blood on a wet weight basis (details in the Supporting Information).

Table 1. Summary of Available Datasets on the Maternal Transfer of Mercury from Female Birds to Their Eggs in 26 Species across 6 Taxonomic Orders from Sites across North America[a]

citation	common name	species	order	wild or captive population	year	site	sample size (female and her eggs)	complete clutch or single egg
Ackerman et al.[25]	American avocet	*Recurvirostra americana*	Charadriiformes	wild	2005−2006	San Francisco Bay, California	25	complete clutch
Ackerman et al.[25]	black-necked stilt	*Himantopus mexicanus*	Charadriiformes	wild	2005−2006	San Francisco Bay, California	29	complete clutch
Ackerman et al.[25]	Forster's tern	*Sterna forsteri*	Charadriiformes	wild	2005−2006	San Francisco Bay, California	17	complete clutch
Ackerman et al.[27]	tree swallow	*Tachycineta bicolor*	Passeriformes	wild	2013−2015	Central Valley, California	34	complete clutch
Ackerman et al.[27]	house wren	*Troglodytes aedon*	Passeriformes	wild	2013−2015	Central Valley, California	44	complete clutch
Ackerman et al.[27]	tree swallow	*Tachycineta bicolor*	Passeriformes	wild	2013−2015	Central Valley, California	52	single egg
Kenow et al.[30]	common loon	*Gavia immer*	Gaviiformes	wild	2005−2006	northern Wisconsin	15	complete clutch
Heinz et al.[28]	mallard	*Anas platyrhynchos*	Anseriformes	captive	2007	pens, Patuxent Wildlife Research Center	15	single egg
Heinz et al.[28]	mallard	*Anas platyrhynchos*	Anseriformes	captive	2007	pens, Patuxent Wildlife Research Center	15	single egg
Mallory, Provencher, Braune; this paper	northern fulmar	*Fulmarus glacialis*	Procellariiformes	wild	2013	Prince Leopold Island, Nunavut, Canada	3	complete clutch (one egg)
Mallory, Provencher, Braune; this paper	black-legged kittiwake	*Rissa tridactyla*	Charadriiformes	wild	2013	Prince Leopold Island, Nunavut, Canada	5	single egg
Lavoie; this paper	herring gull	*Larus argentatus*	Charadriiformes	wild	2006	Corossol Island, Quebec, Canada	12	single egg
Lavoie; this paper	black-legged kittiwake	*Rissa tridactyla*	Charadriiformes	wild	2006	Corossol Island, Quebec, Canada	10	single egg
Lavoie; this paper	common eider	*Somateria mollissima*	Anseriformes	wild	2006	Corossol Island, Quebec, Canada	18	single egg
Lavoie; this paper	great black-backed gull	*Larus marinus*	Charadriiformes	wild	2006	Corossol Island, Quebec, Canada	2	single egg
Brasso et al.[26]	tree swallow	*Tachycineta bicolor*	Passeriformes	wild	2008	South River, Shenandoah Valley, Virginia	28	complete clutch
Cristol; this paper	zebra finch	*Taeniopygia guttata*	Passeriformes	captive	2011	pens, College of William and Mary	28	complete clutch
Cristol; this paper	tree swallow	*Tachycineta bicolor*	Passeriformes	wild	2006−2007	South River, Shenandoah Valley, Virginia	25	complete clutch
Cristol; this paper	house wren	*Troglodytes aedon*	Passeriformes	wild	2006	South River, Shenandoah Valley, Virginia	1	single egg
Cristol; this paper	eastern phoebe	*Sayornis phoebe*	Passeriformes	wild	2006	South River, Shenandoah Valley, Virginia	1	complete clutch
Cristol; this paper	eastern bluebird	*Sialia sialis*	Passeriformes	wild	2006−2007	South River, Shenandoah Valley, Virginia	3	complete clutch
Cristol; this paper	Carolina wren	*Thryothorus ludovicianus*	Passeriformes	wild	2006	South River, Shenandoah Valley, Virginia	3	single egg
Cristol; this paper	belted kingfisher	*Megaceryle alcyon*	Coraciiformes	wild	2006	South River, Shenandoah Valley, Virginia	7	complete clutch
Evers; this paper	Carolina wren	*Thryothorus ludovicianus*	Passeriformes	wild	2007	North Fork Holston River, Virginia	3	both
Evers et al.,[29] and additional unpublished data for this paper	common loon	*Gavia immer*	Gaviiformes	wild	1993−2014	northeastern United States	78	both
Evers; this paper	indigo bunting	*Passerina cyanea*	Passeriformes	wild	2006−2007	North Fork Holston River, Virginia	10	both

Table 1. continued

citation	common name	species	order	wild or captive population	year	site	sample size (female and her eggs)	complete clutch or single egg
Evers; this paper	northern cardinal	*Cardinalis cardinalis*	Passeriformes	wild	2006	North Fork Holston River, Virginia	1	complete clutch
Evers; this paper	red-winged blackbird	*Agelaius phoeniceus*	Passeriformes	wild	2007	North Fork Holston River, Virginia	1	complete clutch
Evers; this paper	song sparrow	*Melospiza melodia*	Passeriformes	wild	2006–2007	North Fork Holston River, Virginia	7	complete clutch
Evers; this paper	tree swallow	*Tachycineta bicolor*	Passeriformes	wild	2008–2009	Onondaga Lake and Oneida Lake, New York	26	both
Evers, Savoy; this paper	common goldeneye	*Bucephala clangula*	Anseriformes	wild	2001–2003	Rangeley Lakes, Maine	3	both
Evers, Savoy; this paper	common merganser	*Mergus merganser*	Anseriformes	wild	2002–2003	Rangeley Lakes, Maine	4	both
Evers, Savoy; this paper	hooded merganser	*Lophodytes cucullatus*	Anseriformes	wild	2001–2005	Rangeley Lakes, Maine and Sudbury River, Massachusetts	17	both
Evers, Savoy; this paper	mallard	*Anas platyrhynchos*	Anseriformes	wild	2006–2008	North Fork Holston River, North River, and South River, Virginia	24	both
Evers, Savoy; this paper	wood duck	*Aix sponsa*	Anseriformes	wild	2003	Sudbury River, Massachusetts	8	single egg
Matz, Schmutz; this paper	yellow-billed loon	*Gavia adamsii*	Gaviiformes	wild	2017	Bering Land Bridge National Park and Preserve, Alaska	5	single egg

[a] Table 1 is continued in the Supporting Information as Table S1 and has additional details on each dataset's methods.

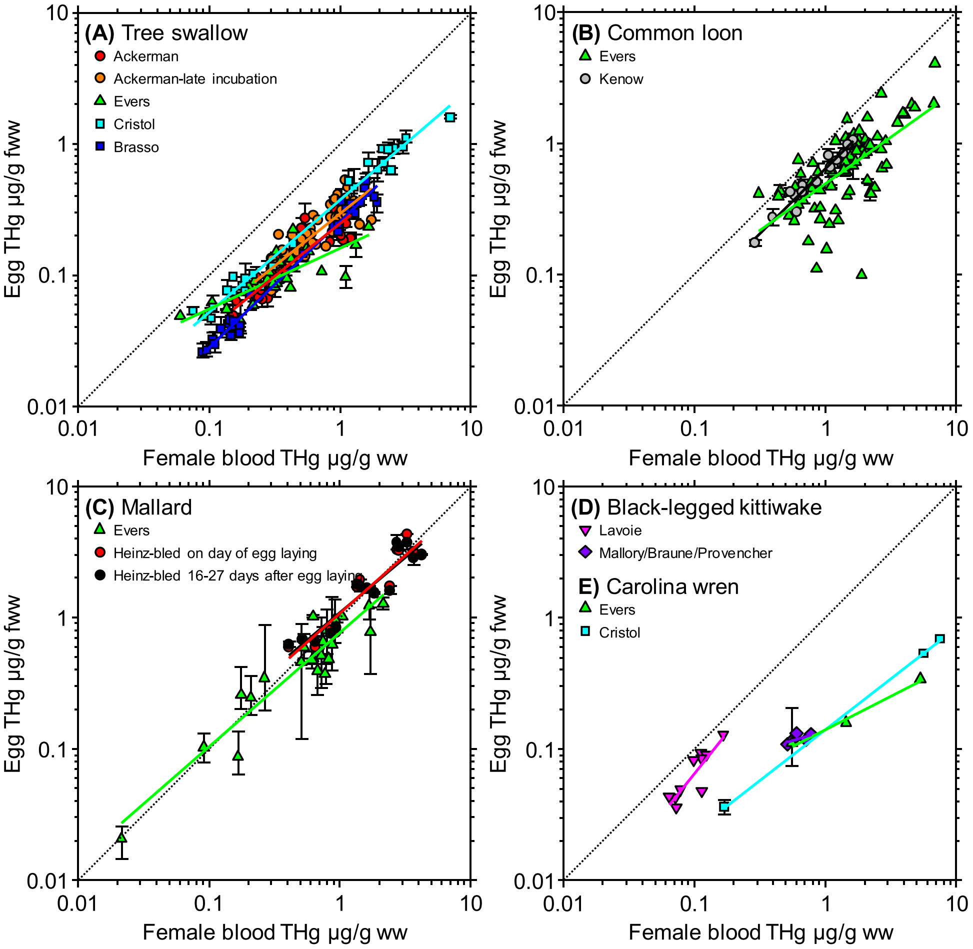

Figure 1. Total mercury (THg) concentrations in eggs were highly correlated with maternal THg concentrations in blood for (A) five studies on tree swallows, (B) two studies on common loons, (C) three studies on mallards, (D) two studies on black-legged kittiwakes, and (E) two studies on Carolina wrens. *Y*-axis values are either (1) geometric mean egg THg concentrations for each clutch and the error bars represent the minimum and maximum THg concentrations for individual eggs within the clutch or (2) THg concentrations in a single egg that was randomly sampled from a clutch. Symbols and colors within each panel represent different studies. The stippled line in each panel represents the one-to-one line. Regression equations are available in the Results section and Table S2, and Table 1 provides details about each dataset.

Mercury Determination. We used THg concentrations as a surrogate for MeHg concentrations because 96% [±7.8% standard deviation (SD)] of THg in bird eggs[32] and ≥90% (18.9−37.2% SD) of THg in bird blood[45] are in the more toxic MeHg form. THg content was determined using several analytical instruments and methods that are described in previously published studies.[25−30,46,47]

Statistical Analysis. We used linear mixed-effect and fixed-effect models to examine the relationship between THg concentrations in mothers' blood and their eggs. We conducted a series of six main statistical analyses (subheadings in Results) that are detailed in the Supporting Information. In general, the models were structured so that THg concentration in individual eggs was the dependent variable, THg concentration in the maternal blood was a fixed effect, and unique nest identification was included as a random effect. Study (dataset), species, and taxonomic order (and their interactions with the maternal blood THg concentration) were included as fixed or random effects depending on the specific test. Each individual egg was statistically nested within the clutch, study, and species it came from. If the interaction with the maternal blood THg concentration was not significant, we removed the interaction from the model structure and reran the analysis. Egg and blood THg concentrations were $\log_e$-transformed prior to analysis. In the figures, we present either the individual egg THg concentration (when only one egg was sampled from the clutch) or the geometric mean THg concentration and the range (minimum to maximum) of THg concentrations of all of the eggs within the clutch (when the complete clutch was collected) versus the maternal blood THg concentration. Table S2 provides test statistics, predictive equations, and variance for the egg to maternal blood models. The statistics and equations for predicting maternal blood THg concentrations from egg THg concentrations are presented only in Table S3 and are used for the predictions in Table 3.

■ RESULTS

We sampled the blood from 564 females and collected either her complete clutch or a subset of eggs (n = 1814 eggs) from 26 species in 6 taxonomic orders (Table 1). THg concentrations ranged from 0.02 to 17.53 μg/g wet weight (hereafter ww) in mothers' blood and 0.01 to 8.92 μg/g fresh wet weight (hereafter fww) in eggs.

Egg to Maternal Blood Relationship: Differences among Studies within the Same Species. First, we examined the potential differences within the same species but

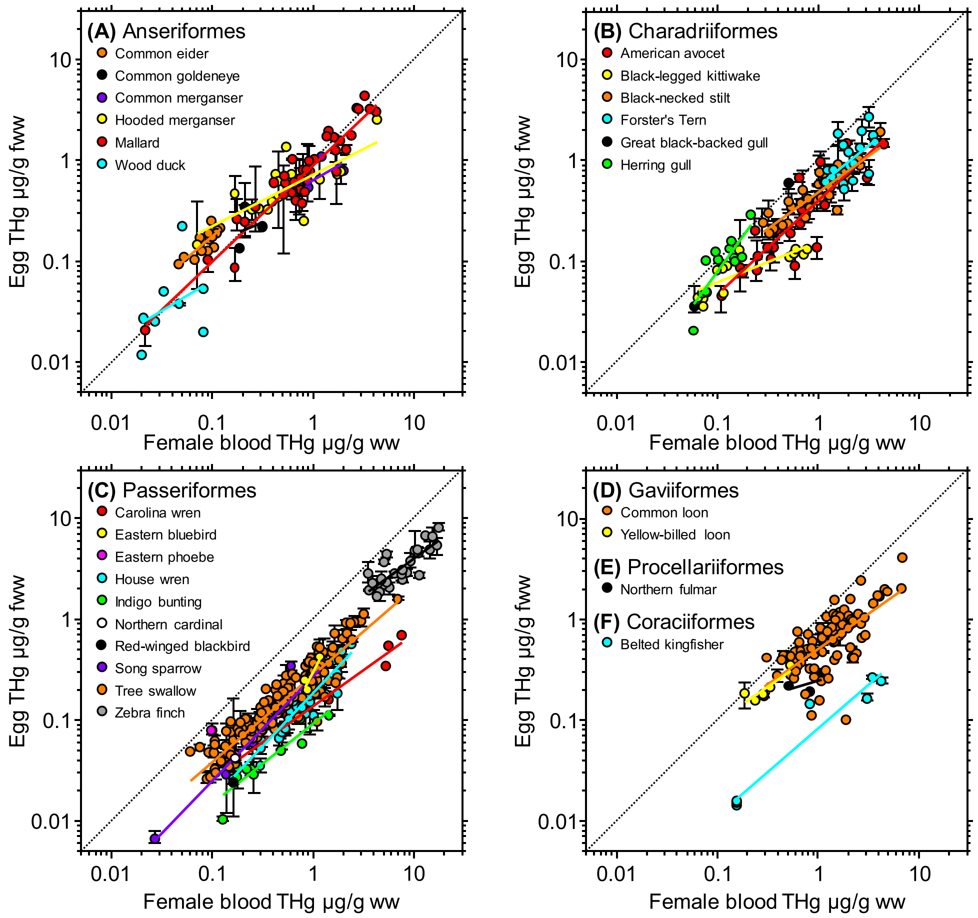

Figure 2. Total mercury (THg) concentrations in eggs were highly correlated with maternal THg concentrations in blood among taxonomic orders for (A) Anseriformes, (B) Charadriiformes, (C) Passeriformes, (D) Gaviiformes, (E) Procellariiformes, and (F) Coraciiformes. *Y*-axis values are either (1) geometric mean egg THg concentrations for each clutch and the error bars represent the minimum and maximum THg concentrations for individual eggs within the clutch or (2) THg concentrations in a single egg that was randomly sampled from a clutch. Different colors within each panel represent different bird species. The stippled line in each panel represents the one-to-one line. Regression equations are available in the Results section and Table S2, and Table 1 provides details about the data collected for each species.

among studies in five species that each had two to five unique datasets (Table 1). Detailed results are available in Supporting Information and Table S2 for tree swallows (eqs 1–5, Supporting Information; Figure 1A), common loons (eqs 6 and 7, Supporting Information; Figure 1B), mallards (eqs 8–10, Supporting Information; Figure 1C), Carolina wrens (eqs 11 and 12, Supporting Information; Figure 1E), and black-legged kittiwakes (eqs 13 and 14, Supporting Information; Figure 1D). In these five tests, the slope between THg concentrations in eggs and maternal blood differed among studies only once within the same species (tree swallows), and the effect of the study was significant in three species (tree swallows, mallards, and black-legged kittiwakes). We, therefore, included study as a random effect in all further models that included data from one of these five species where there was more than one study.

Egg to Maternal Blood Relationship: By Species. Second, we examined whether the relationship between THg concentrations in eggs and maternal blood differed among species. THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood ($F_{1,614.6}$ = 73.87, $p < 0.0001$), but there were significant effects of species ($F_{21,15.5}$ = 10.95, $p < 0.0001$) and blood THg concentration × species interaction ($F_{21,450.3}$ = 2.78, $p < 0.0001$; final model: n = 1787, R^2_m = 0.89). The significant blood THg concentration × species interaction and species effect indicated that the relationship between THg concentrations in eggs and maternal blood differed for some species.

We repeated the same analysis separately within each of four taxonomic orders where multiple species were studied: Anseriformes, Charadriiformes, Passeriformes, and Gaviiformes. Species had different slopes within Anseriformes and Passeriformes, whereas species had similar slopes within Charadriiformes and Gaviiformes. Within Anseriformes, THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood ($F_{1,109.2}$ = 6.56, p = 0.01), there was no effect of species ($F_{5,5.3}$ = 0.47, p = 0.79), but there was a significant blood THg concentration × species interaction ($F_{5,102.3}$ = 3.97, p = 0.003; final model: n = 317, R^2_m = 0.80; Figure 2A). Within Charadriiformes, THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood ($F_{1,91.5}$ = 210.95, $p < 0.0001$), and there were no significant effects of species ($F_{4,0.9}$ = 0.26, p = 0.88) after removing the nonsignificant blood THg concentration × species interaction ($F_{4,36.38}$ = 1.38, p = 0.26; final model: n = 278, R^2_m = 0.57; Figure 2B). Within Passeriformes, THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood

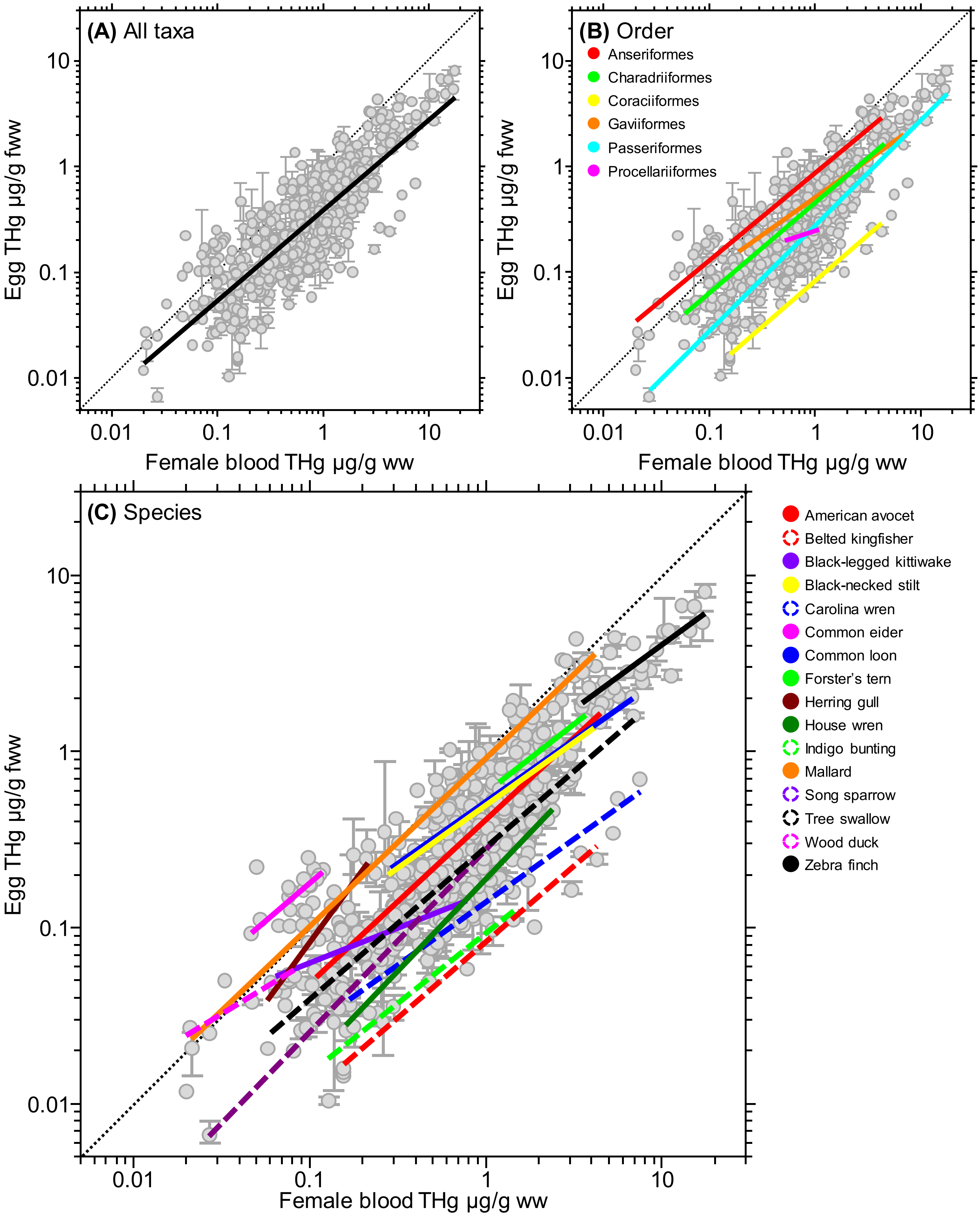

Figure 3. Total mercury (THg) concentrations in eggs were highly correlated with maternal THg concentrations in blood for (A) all data ($n = 564$ females and their eggs from 26 species), (B) 6 taxonomic orders ($n = 564$ females and their eggs from 26 species), and (C) 16 representative bird species ($n = 530$ females and their eggs). *Y*-axis values are either (1) geometric mean egg THg concentrations for each clutch and the error bars represent the minimum and maximum THg concentrations for individual eggs within the clutch or (2) THg concentrations in a single egg that was randomly sampled from a clutch. For (B) and (C), different colored lines represent different bird taxa; legend colors for filled circles indicate colors for solid lines, whereas colors for open circles indicate colors for dashed lines. The stippled line in each panel represents the one-to-one line. Regression equations are available in the Results section and Table S2.

($F_{1,310.8} = 43.20$, $p < 0.0001$), but there were significant effects of species ($F_{6,13.3} = 8.71$, $p = 0.0006$) and blood THg concentration × species interaction ($F_{6,252.0} = 3.41$, $p = 0.003$; final model: $n = 1040$, $R^2_m = 0.93$; Figure 2C). Within Gaviiformes, THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood ($F_{1,79.8} = 72.58$, $p < 0.0001$), and there were no significant effects of species ($F_{1,5.4} = 0.08$, $p = 0.79$) after removing the nonsignificant blood THg concentration × species interaction ($F_{1,89.3} = 0.01$, $p = 0.99$; final model: $n = 125$, $R^2_m = 0.53$; Figure 2D). Thus, the proportion of THg transferred to eggs at the same maternal blood THg concentration differed among species within Passeriformes and Anseriformes, but not within Charadriiformes and Gaviiformes. For example, within Passeriformes, predicted egg THg concentrations in tree swallows were greater than house wrens at any observed female blood THg concentration (Figure 2C).

Because some species differed in their relationships within taxonomic orders, we conducted separate models for each species to estimate the specific equations to predict THg concentrations in eggs from THg concentrations in maternal blood (Figure 3C). Species equations are available in the Supporting Information (eqs 15−36, Supporting Information). Although we present all species equations, we caution against using species-specific equations with low sample sizes and poor R^2_m values and instead suggest using the order-specific or general bird equations below (Table S2).

Egg to Maternal Blood Relationship: By Taxonomic Order. Third, we examined whether the relationship between THg concentrations in eggs and maternal blood differed among taxonomic orders. After dropping the nonsignificant blood THg concentration × order interaction ($F_{5,553.5} = 1.72$, $p = 0.13$), THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood ($F_{1,486.0} = 1938.21$, $p < 0.0001$), but there also was a significant effect of taxonomic order ($F_{5,18.94} = 9.19$, $p = 0.0001$; final model: $n = 1799$, $R^2_m = 0.77$). The nonsignificant blood THg concentration × order interaction indicated that the relationship between THg concentrations in eggs and maternal blood had a similar slope among orders, but the significant order effect indicated that the proportion of THg transferred to eggs at the same maternal blood THg concentration differed among orders (Figure 3B). Specifically, at the same maternal blood THg concentration, Passeriformes and Coraciiformes females transferred relatively lower amounts of THg to their eggs, whereas Anseriformes females transferred the most THg to their eggs (Figure 3B).

To estimate the specific equations by taxonomic order, we conducted separate models for each order (except Procellariiformes because $n = 3$ eggs) with the same model structure as the above test except that the species and study random effects were removed from Coraciiformes because only one species and study were conducted within that order (and therefore the Coraciiformes equation matches the species-specific equation for belted kingfishers). The specific equations to predict THg concentrations in eggs from the maternal blood among taxonomic orders are as follows (Table S2)

$$\ln(\text{egg THg}_{\mu g/g\,fww}) = 0.7661 \times \ln(\text{female Anseriformes blood THg}_{\mu g/g\,ww}) - 0.2470\ (n = 317\ \text{eggs},\ R^2_m = 0.72) \quad (37)$$

$$\ln(\text{egg THg}_{\mu g/g\,fww}) = 0.8761 \times \ln(\text{female Charadriiformes blood THg}_{\mu g/g\,ww}) - 0.7961\ (n = 280\ \text{eggs},\ R^2_m = 0.71) \quad (38)$$

$$\ln(\text{egg THg}_{\mu g/g\,fww}) = 0.8602 \times \ln(\text{female Coraciiformes blood THg}_{\mu g/g\,ww}) - 2.4879\ (n = 24\ \text{eggs},\ R^2_m = 0.87) \quad (39)$$

$$\ln(\text{egg THg}_{\mu g/g\,fww}) = 0.7312 \times \ln(\text{female Gaviiformes blood THg}_{\mu g/g\,ww}) - 0.6307\ (n = 125\ \text{eggs},\ R^2_m = 0.54) \quad (40)$$

$$\ln(\text{egg THg}_{\mu g/g\,fww}) = 0.8560 \times \ln(\text{female Passeriformes blood THg}_{\mu g/g\,ww}) - 1.4942\ (n = 1050\ \text{eggs},\ R^2_m = 0.71) \quad (41)$$

Egg to Maternal Blood Relationship: Captive Studies. Fourth, because Passeriformes females appeared to transfer less THg to their eggs than Anseriformes females at the same blood THg concentration, we used captive studies to confirm this relationship under controlled conditions. We included data from the two captive dosing studies on mallard and zebra finch. The blood THg concentration × species interaction was nonsignificant ($F_{1,42.4} = 1.70$, $p = 0.20$), indicating that the relationship between THg concentrations in eggs and maternal blood had a similar slope among the two captive bird species and we removed this interaction from the model. THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood ($F_{1,43.3} = 144.78$, $p < 0.0001$), but there was an influence of species ($F_{1,44.5} = 16.91$, $p = 0.0002$; final model: $n = 119$, $R^2_m = 0.78$; Figure 4). As with the mainly wild bird data, the captive songbirds (zebra finch) transferred less THg to their eggs than captive mallards did at the same maternal blood THg concentration (Figure 4). The captive study-specific equations are displayed above for mallard (eq 8, Supporting Information) and zebra finch (eq 36 and Table S2, Supporting Information).

Egg to Maternal Blood Relationship: All Taxa. Fifth, although it is preferable to use a species-specific or order-specific equation whenever appropriate, a general equation for all birds could be useful when these alternatives are unavailable. This general equation to estimate THg concentrations in eggs from maternal blood ($F_{1,484.9} = 1863.27$, $p < 0.0001$; Figure 3A) was (Table S2)

$$\ln(\text{egg THg}_{\mu g/g\,fww}) = 0.8220 \times \ln(\text{female bird blood THg}_{\mu g/g\,ww}) - 0.9947\ (n = 1799\ \text{eggs},\ R^2_m = 0.58) \quad (42)$$

Maternal Blood To Egg Relationship: All Taxa. Sixth, because many investigators sample eggs and may want to predict maternal blood THg concentrations (rather than the above egg predictions using blood), we restructured and reran the statistical models. Please see Table S3 for a complete list of species- and order-specific equations for predicting THg

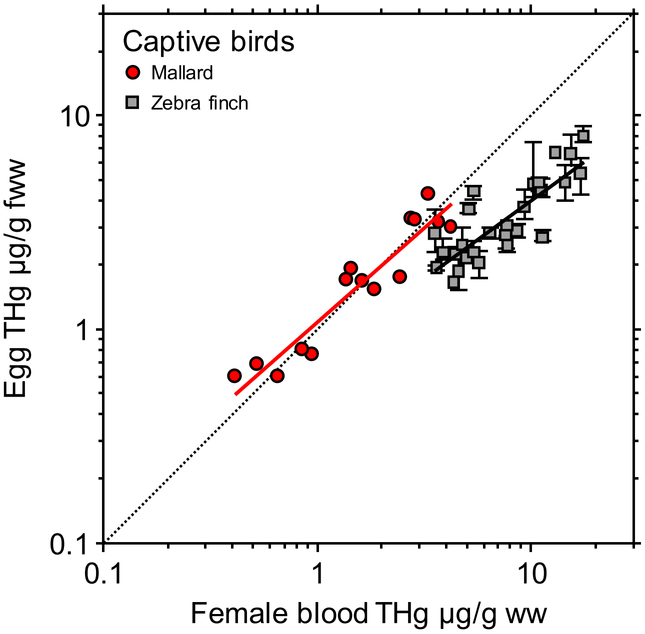

Figure 4. Total mercury (THg) concentrations in eggs were highly correlated with maternal THg concentrations in blood for studies on captive mallard (red circles) and captive zebra finch (gray squares). *Y*-axis values are either (1) geometric mean egg THg concentrations for each clutch and the error bars represent the minimum and maximum THg concentrations for individual eggs within the clutch or (2) THg concentrations in a single egg that was randomly sampled from a clutch. The stippled line represents the one-to-one line. Regression equations are available in the Supporting Information and Table S2, and Table 1 provides details about each captive study.

concentrations in female blood using egg THg concentrations. The general equation to estimate THg concentrations in maternal blood from the geometric mean egg THg concentrations in a clutch was as follows ($F_{1,564.0} = 1727.45$, $p < 0.0001$)

$$\ln(\text{female bird blood THg}_{\mu\text{g/g ww}}) = 0.9179 \times \ln(\text{egg THg}_{\mu\text{g/g fww}}) + 0.7244\ (n = 564\text{ nests},\ R_m^2 = 0.65) \quad (43)$$

■ DISCUSSION

THg concentrations in eggs were positively correlated with THg concentrations in maternal blood in all cases. In general, this result demonstrates that MeHg transferred from females to offspring was predictable and that increased MeHg contamination of the female directly increased MeHg contamination of eggs. However, the proportion of THg transferred from females to their eggs differed among bird taxa and with maternal THg concentrations.

The slope of the $\log_e$–$\log_e$ regression between THg concentrations in eggs and female blood was <1 for the majority of bird taxa (Figure 3). The general bird equation's slope was 0.82 on a natural log scale (eq 42) and indicated that, although egg THg concentrations increased with greater maternal blood THg concentrations, the proportion of maternal THg that was transferred to eggs decreased as THg concentrations in the female increased. The slope did not differ significantly among taxonomic orders, which ranged from 0.73 in Gaviiformes to 0.88 in Charadriiformes. Within orders, the slope differed for a few species of Anseriformes and Passeriformes, whereas it was similar among species for Charadriiformes and Gaviiformes. At the species level, only 5 of 22 bird species had a slope that was ≥1. For example, the proportion of THg transferred from mothers to eggs increased with maternal blood THg concentrations in house wrens, whereas it decreased with increasing maternal blood THg concentrations in most other Passeriformes. However, the standard error of the slope overlapped 1.0 for four of these five species. Thus, for most bird species, a smaller proportion of maternal THg was transferred to eggs with increasing female THg concentrations. A possible mechanism for this reduction in the proportional amount of MeHg transferred to bird eggs at higher exposure levels may be due to the increased demethylation of MeHg in the liver at higher maternal THg concentrations[48] and hence proportionately lower MeHg concentrations available for transfer to the egg. A reduction in the proportion of maternal THg transferred to eggs at greater female blood THg concentrations has also been observed in frogs.[49,50] THg concentrations in fish eggs also were not a consistent proportion of maternal THg concentrations; however, unlike birds and frogs, the proportion of THg transferred to eggs increased with female THg concentrations in fishes.[51−54]

Not only did the proportion of THg that was transferred from mother to offspring vary with female THg concentrations, but also the proportion of THg that was transferred to eggs at the same maternal blood THg concentration differed among taxonomic orders (Figure 3B) and, to a lesser extent, among species but only within the order Passeriformes (Figure 2). At the same maternal blood THg concentration, Passeriformes and Coraciiformes females transferred relatively lower amounts of THg to their eggs, whereas Anseriformes females transferred the most THg to their eggs (Figure 3B). We confirmed this result using MeHg-dosed birds held in captivity under more controlled conditions, demonstrating that captive zebra finch also transferred relatively less THg to their eggs than captive mallards did at the same maternal blood THg concentration (Figure 4). In fishes, the proportion of THg transferred to ova also differed among taxonomic orders of elasmobranchs that had different reproductive modes.[55]

Together, our results indicate that (1) increased MeHg contamination of the female resulted in increased MeHg contamination of eggs, (2) for most bird species, a smaller proportion of the female's MeHg was transferred to her eggs at higher maternal MeHg concentrations, (3) the proportion of maternal MeHg that was transferred to eggs differed among taxonomic orders even when maternal blood MeHg concentrations were the same, and (4) Anseriformes females transferred relatively more MeHg to their eggs than did Passeriformes females. To illustrate the difference in maternal transfer of MeHg to eggs among taxa, we used our equations (Table S2) to translate common toxicity benchmarks used for bird blood (review by ref 56) into expected THg concentrations in bird eggs (Table 2). For example, a female blood THg concentration of 1.0 µg/g ww (moderate risk) or 3.0 µg/g ww (high risk) would result in an average egg THg concentration of 0.08 or 0.21 µg/g fww in Coraciiformes, 0.22 or 0.57 µg/g fww in Passeriformes, 0.45 or 1.18 µg/g fww in Charadriiformes, 0.53 or 1.19 µg/g fww in Gaviiformes, and 0.78 or 1.81 µg/g fww in Anseriformes. At a given maternal blood THg concentration, ranging from 0.027 to 4.273 µg/g

Table 2. Model-Predicted Egg Total Mercury Concentrations (THg μg/g fww) Based on Female Blood THg Concentrations (μg/g ww) for All Taxa, 6 Taxonomic Orders, and 22 Species of Birds[a]

			predicted mean egg THg μg/g fww when female blood THg =					
taxa	sample size of eggs	model R^2_m	0.2 μg/g ww	0.5 μg/g ww	1.0 μg/g ww	2.0 μg/g ww	3.0 μg/g ww	4.0 μg/g ww
all taxa	1799	0.58	0.10	0.21	0.37	0.65	0.91	1.16
Anseriformes	317	0.72	0.23	0.46	0.78	1.33	1.81	2.26
common eider	18	0.64	0.32	–	–	–	–	–
common goldeneye	11	0.01	0.22	–	–	–	–	–
common merganser	5	0.29	–	–	0.65	0.96	–	–
hooded merganser	34	0.22	0.36	0.50	0.63	0.80	0.92	1.01
mallard	240	0.81	0.22	0.50	0.91	1.68	2.41	3.10
wood duck	9	0.11	0.10	–	–	–	–	–
Charadriiformes	280	0.71	0.11	0.25	0.45	0.83	1.18	1.52
American avocet	97	0.73	0.09	0.21	0.41	0.78	1.13	1.48
black-legged kittiwake	15	0.49	0.07	0.19	0.40	–	–	–
black-necked stilt	105	0.69	0.15	0.30	0.49	0.81	1.09	1.34
Forster's tern	49	0.26	–	–	0.58	0.99	1.36	1.70
herring gull	12	0.67	0.21	–	–	–	–	–
Coraciiformes	24	0.87	0.02	0.05	0.08	0.15	0.21	0.27
belted kingfisher	24	0.87	0.02	0.05	0.08	0.15	0.21	0.27
Gaviiformes	125	0.54	0.16	0.32	0.53	0.88	1.19	1.47
common loon	119	0.47	0.17	0.32	0.53	0.88	1.18	1.45
yellow-billed loon	6	0.50	0.16	0.29	–	–	–	–
Passeriformes	1050	0.71	0.06	0.12	0.22	0.41	0.57	0.74
Carolina wren	9	0.90	0.05	0.09	0.14	0.23	0.31	0.38
eastern bluebird	5	0.71	–	–	0.30	–	–	–
house wren	306	0.82	0.04	0.09	0.19	0.39	0.59	0.80
indigo bunting	23	0.78	0.03	0.05	0.10	0.17	–	–
song sparrow	25	0.87	0.05	0.14	0.29	–	–	–
tree swallow	568	0.87	0.07	0.16	0.28	0.49	0.69	0.88
zebra finch	104	0.64	–	–	–	–	1.71	2.10
Procellariiformes	3	0.17	–	0.20	0.25	–	–	–
northern fulmar	3	0.17	–	0.20	0.25	–	–	–

[a] Predictive equations and variances are available in Table S2. The blood THg concentrations referenced are based on background levels (0.2 μg/g ww) and span the range of common toxicity benchmarks for moderate risk (1.0 μg/g ww), high risk (3.0 μg/g ww), and extra high risk (4.0 μg/g ww) in birds.[56] Dashes indicate that there were no taxa-specific data within that range of the female blood THg concentration and, therefore, was outside of the model's predictive ability for egg THg concentrations. Because there were no other fixed-effects in the models, marginal R^2_m values indicated the explanatory power of THg concentrations in female bird blood for predicting THg concentrations in eggs.

ww, THg concentrations in eggs were 382% to 205% higher in Anseriformes than in Passeriformes (using eqs 37 and 41; Figure 3B).

These differences in maternal transfer of MeHg to eggs have important implications for toxicity risk to both the offspring and mother. Transferring proportionately more MeHg to eggs can reduce a female's body burden of MeHg and lower her own risk to MeHg toxicity, but this maternal transfer of MeHg increases the risk of MeHg toxicity to offspring. Species sensitivities of MeHg toxicity to embryos are known to differ among taxa, and it is thought that Anseriformes are among the least sensitive, and Passeriformes among the most sensitive, groups of birds.[9] It is interesting, therefore, that Anseriformes females transferred a much larger proportion of their THg burden to their eggs than did Passeriformes females. It is unclear whether this is a trait evolved to reduce the potential for embryonic toxicity in sensitive bird taxa or a physiological limitation due to a transfer mechanism. In fact, one might have expected that proportionately more, not less, MeHg would have been transferred to Passeriformes than Anseriformes eggs due to the differences in egg composition among altricial and precocial species. Specifically, MeHg is more prevalent in albumen than in the yolk portion of the egg[57−59] and precocial species (such as Anseriformes) have eggs with a larger proportion of yolk relative to egg size than do altricial species (such as Passeriformes).[60−62] Hence, it might be expected that altricial species would transfer a relatively greater proportion of MeHg to their eggs due to the higher albumen content of eggs and known affinity of MeHg to egg albumen. However, this was not the case because the observed trend was that altricial species transferred proportionately less MeHg to their eggs than precocial species. This proportionally smaller transfer of maternal MeHg to eggs in Passeriformes may also help explain the apparent lack of a substantial decline in egg MeHg concentrations with egg-laying order in songbirds, compared to the average decline of 16% between the first and second laid egg among all bird species.[63]

To compare studies and integrate MeHg toxicity risk across avian tissues, we developed maternal transfer equations to predict THg concentrations in bird eggs based on THg concentrations in maternal blood. We suggest using a species-specific equation, or that of a closely related species, when available and when there is confidence in the predictive equation (eqs 15−36 and Table S2, Supporting Information). However, for most bird species in the world, a species-specific maternal transfer equation is not available or is inadequate. In

Table 3. Model-Predicted Female Blood Total Mercury Concentrations (THg μg/g ww) Based on Egg THg Concentrations (μg/g fww) for All Taxa, 6 Taxonomic Orders, and 22 Species of Birds[a]

			predicted mean female blood THg μg/g ww when egg THg =							
taxa	sample size of nests	model R^2_m	0.1 μg/g fww	0.2 μg/g fww	0.4 μg/g fww	0.6 μg/g fww	0.8 μg/g fww	1.0 μg/g fww	1.4 μg/g fww	1.8 μg/g fww
all taxa	564	0.65	0.25	0.47	0.89	1.29	1.68	2.06	2.81	3.54
Anseriformes	89	0.79	0.11	0.21	0.39	0.56	0.72	0.89	1.20	1.51
common eider	18	0.64	0.06	0.10	–	–	–	–	–	–
common goldeneye	11	0.03	0.21	0.23	0.25	–	–	–	–	–
common merganser	5	0.27	–	–	–	1.04	1.24	1.44	–	–
hooded merganser	34	0.55	0.09	0.18	0.40	0.62	0.86	1.10	1.59	2.10
mallard	39	0.91	0.11	0.22	0.43	0.65	0.86	1.07	1.50	1.93
wood duck	8	0.13	0.05	–	–	–	–	–	–	–
Charadriiformes	100	0.65	0.27	0.47	0.81	1.12	1.40	1.67	2.18	2.67
American avocet	25	0.76	0.28	0.50	0.88	1.23	1.56	1.87	2.48	3.05
black-legged kittiwake	15	0.07	0.27	0.41	–	–	–	–	–	–
black-necked stilt	29	0.77	0.18	0.37	0.79	1.22	1.67	2.12	3.05	4.01
Forster's tern	17	0.30	–	–	–	1.65	1.86	2.03	2.33	2.57
herring gull	12	0.67	0.11	0.16	–	–	–	–	–	–
Coraciiformes	7	0.93	1.20	2.57	5.50	–	–	–	–	–
belted kingfisher	7	0.93	1.20	2.57	5.50	–	–	–	–	–
Gaviiformes	98	0.35	0.27	0.42	0.66	0.87	1.05	1.21	1.51	1.78
common loon	93	0.38	0.35	0.55	0.85	1.11	1.33	1.54	1.91	2.24
yellow-billed loon	6	0.73	0.13	0.29	0.62	–	–	–	–	–
Passeriformes	267	0.81	0.41	0.83	1.69	2.56	3.44	4.32	6.09	7.87
Carolina wren	6	0.96	0.66	1.67	4.23	7.30	–	–	–	–
eastern bluebird	5	0.67	–	0.84	1.12	–	–	–	–	–
house wren	45	0.87	0.57	1.01	1.80	2.52	–	–	–	–
indigo bunting	10	0.82	0.91	1.87	–	–	–	–	–	–
song sparrow	7	0.92	0.37	0.69	–	–	–	–	–	–
tree swallow	165	0.87	0.31	0.65	1.36	2.09	2.85	3.62	5.19	6.79
zebra finch	28	0.69	–	–	–	–	–	2.42	3.33	4.22
Procellariiformes	3	0.17	–	0.68	–	–	–	–	–	–
northern fulmar	3	0.17	–	0.68	–	–	–	–	–	–

[a] Predictive equations and variances are available in Table S3. The egg THg concentrations referenced span the range of commonly cited toxicity benchmarks for egg hatchability.[56] Dashes indicate that there were no taxa-specific data within that range of egg THg concentrations and, therefore, was outside of the model's predictive ability for female blood THg concentrations. Because there were no other fixed-effects in the models, marginal R^2_m values indicated the explanatory power of THg concentrations in eggs for predicting THg concentrations in the female bird blood.

these instances, we suggest using the order-specific maternal transfer equations (eqs 37–41) because the slopes were generally the same and most of the variation we observed occurred among taxonomic orders, rather than among species. For species within taxonomic orders that were not included in this paper, we suggest using the more general bird equation (eq 42) but caution that the estimate may lack precision.

Because many investigators sample eggs rather than the blood, we also developed equations to predict THg concentrations in female bird blood based on THg concentrations in eggs (eq 43 and equations in Table S3). These equations might be particularly useful in translating the more readily available toxicity benchmarks that have been developed for reproductive impairment, such as egg hatchability, into an equivalent female blood THg concentration.

For example, an average egg THg concentration of 0.6 μg/g fww, which has been proposed as an indicative value for reproductive impairment in birds (meta-analysis[64]), or 1.0 μg/g fww, which is another common toxicity benchmark (review[6]), would be equivalent to a mother's blood THg concentration of 0.56 or 0.89 μg/g fww in Anseriformes, 0.87 or 1.21 μg/g fww in Gaviiformes, 1.12 or 1.67 μg/g fww in Charadriiformes, and 2.56 or 4.32 μg/g fww in Passeriformes (Table 3).

When applying these maternal transfer equations, it is important to consider the sampling methodology. We found that the timing of maternal blood sampling was one issue, which influenced the estimated relationship between egg and blood THg concentrations. Specifically, the short time difference (<2 weeks) in sampling a female's blood during incubation can have a small influence on the predicted egg THg concentrations.[27] In that case, female tree swallows bled during early incubation had lower blood THg concentrations than females bled during late incubation, indicating that females acquired additional THg after egg laying. However, these differences in predicted egg THg concentrations based on the timing of female blood sampling were relatively small compared to the larger differences driven by bird taxonomy and overall maternal THg concentrations.

Our results have both useful applications and important implications for the interpretation of the toxicity risk of MeHg to animals. Due to differences in the proportion of maternal MeHg that is transferred to eggs, even when actual environmental exposure of birds to MeHg is similar, the toxicity risk of MeHg to offspring varies among taxa. The maternal transfer equations we provide can be applied to integrate MeHg toxicity risk across avian life stages and tissues, and, ultimately, may advance the development of a more unified toxicity benchmark for birds.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.9b06119.

> Datasets and methods (Table S1); equations and variance for predicting egg THg from female blood THg (Table S2); equations and variance for predicting female blood THg from egg THg (Table S3) (PDF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This synthesis was funded by the U.S. Geological Survey Environmental Health Mission Area's Contaminant Biology Program. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Supporting Information for

A Synthesis of Maternal Transfer of Mercury in Birds: Implications for Altered Toxicity Risk

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Total pages (including cover): 22
Tables: 3
Figures: 0

MATERIALS AND METHODS

Data compilation

For herring gulls, black-legged kittiwakes, common eiders, and great black-backed gulls sampled at Corossol Island, Quebec, Canada, THg concentrations were determined on a dry weight basis in red blood cells rather than in whole blood (Table S1). Therefore, we converted THg concentrations in red blood cells on a dry weight basis to THg concentrations in whole blood on a wet weight basis. We first transformed THg concentrations in red blood cells on a dry weight basis to a wet weight basis using individual-specific moisture content of red blood cells. We then estimated the THg concentration in the plasma portion of the whole blood using the equation: THg plasma µg/g ww = 0.0119 × THg red blood cells µg/g ww + 0.0019 (R^2=0.60, n=30; Lavoie, unpublished). Finally, we estimated the THg concentration in whole blood by adding the THg concentrations in the red blood cell and plasma portions of whole blood by assuming that red blood cells accounted for 44.2% of the whole blood volume (which is a weighted average from the literature) using the equation: THg whole blood µg/g ww = (THg red blood cells µg/g ww × 0.442) + (THg plasma µg/g ww × [1-0.442]).

Mercury determination

THg content was determined using several analytical approaches (Milestone DMA-80 Direct Mercury Analyzer, Milestone, Monroe, Connecticut, USA; Nippon MA-3000 Direct Mercury Analyzer, Nippon Instruments North America, College Station, Texas, USA; Nippon Instruments MA-2000 Mercury Analysis System, Nippon Instruments North America, College Station, Texas, USA; Nippon Instruments Mercury SP-3D Analyzer, Nippon Instruments, Osaka, Japan; AMA254 Advanced Mercury Analyzer, St. Joseph, Michigan, USA; PerkinElmer ELAN 6000/6100, Waltham, Massachusetts, USA) and methods are available in previously published studies.[1–8]

Statistical analysis

We conducted most statistical analyses using JMP® (version 14.3.0; SAS Institute Inc.) statistical software. We used linear mixed-effect and fixed-effect models to examine the relationship between THg concentrations in mothers' blood and their eggs. For the mixed-effect models, the Satterthwaite method was used to estimate the denominator degrees of freedom.

Using R (version 3.6.0; www.r-project.org) statistical software, we calculated the marginal R^2 values (hereafter R_m^2) to describe the proportion of variance explained by the fixed-effects,[9,10] which, for models where there were no other fixed-effects in the models, specifically assessed the explanatory power of THg concentrations in blood for predicting THg concentrations in eggs (Table S2) and vice versa (Table S3). Conditional R^2 values (hereafter R_c^2) also were included in Tables S2 and S3 and describe the proportion of variance explained by both the fixed- and random-effects in the model. Egg and blood THg concentrations were $\log_e$-transformed prior to analysis. In the figures, we present either the individual egg THg concentration (when only one egg was sampled from the clutch) or the geometric mean THg concentration and the range (minimum to maximum) of THg concentrations of all the eggs within the clutch (when the complete clutch was collected) versus the maternal blood THg concentration. Table S2 provides test statistics, predictive equations, and variance for the following egg to maternal blood models.

Egg to maternal blood relationship: differences among studies within the same species

The relationship between THg concentrations in eggs and maternal blood might differ among studies of the same species due to factors such as differences among sites[11] or the timing of female blood sampling.[3] Therefore, we first examined the potential differences in this relationship within the same species but among studies in five species that each had 2-5 unique datasets (collected by separate researchers or using different methods), including tree swallows (five datasets), common loons (two datasets), mallards (three datasets), Carolina wrens (two datasets), and black-legged kittiwakes (two datasets; Table 1). We conducted separate analyses for each of these five species where THg concentration in individual eggs was the dependent variable and THg concentration in maternal blood and study (dataset) were fixed effects, THg concentration in maternal blood × study was included as an interaction, and unique nest identification was included as a random effect. In this model we statistically nested individual eggs within the clutch it came from when >1 egg was collected from the same nest (complete clutches). If the interaction between maternal blood THg concentration and study was non-significant, we removed the interaction from the model structure and reran the analysis. After using this model structure to test whether the relationship differed among studies, we conducted separate models for each study to estimate the species- and study-specific equations to predict THg concentrations in eggs from maternal blood.

Egg to maternal blood relationship: by species

Second, we examined whether the relationship between THg concentrations in eggs and maternal blood differed among species. THg concentration in individual eggs was the dependent variable and THg concentration in maternal blood and species were fixed effects, THg concentration in maternal blood × species was included as an interaction, and unique nest identification and study were included as random effects. Each individual egg was statistically nested within the clutch and study (when more than one study was conducted on the same species). If the interaction between maternal blood THg concentration and species was non-significant, we removed the interaction from the model structure and reran the analysis. We excluded four species with small sample sizes (n=1 nest and n≤4 eggs each for eastern phoebe, northern cardinal, and red-winged blackbird; and n=2 nests and n=2 eggs for great black-backed gull). To determine specific differences among species within the same taxonomic order, we repeated the analysis within each of the four orders where multiple species were studied (Anseriformes, Charadriiformes, Passeriformes, and Gaviiformes). After using this model structure to test whether the slopes and intercepts differed among species overall and within each taxonomic order, we conducted separate models for each species to estimate the species-specific equations to predict THg concentrations in eggs from maternal blood. These models were similar to the global model, but did not include species or maternal blood × species interaction (because models were conducted separately for each species) and study was included as a random effect only for the five species where >1 study per species was conducted (tree swallow, common loon, mallard, Carolina wren, and black-legged kittiwake).

Egg to maternal blood relationship: by taxonomic order

Third, we examined whether the relationship between THg concentrations in eggs and maternal blood differed among taxonomic orders. THg concentration in individual eggs was the dependent variable and THg concentration in maternal blood and taxonomic order were fixed effects, THg concentration in maternal blood × order was included as an interaction, and unique nest identification, study, and species were included as random effects. Each individual egg was statistically nested within the clutch, study, and species it came from. If the interaction between maternal blood THg concentration and order was not significant, we removed the interaction from the model structure and reran the analysis. After using this model structure to test whether the slopes and intercepts differed among orders, we conducted separate models for each order (except Procellariiformes because *n*=3 eggs) to estimate the order-specific equations to predict THg concentrations in eggs from maternal blood. The structures of these models were similar to the global model, but did not include order or maternal blood × order interaction (because models were conducted separately for each order). These models also excluded species as a random effect from taxonomic orders without more than one species sampled (Coraciiformes) and excluded study as a random effect from orders without more than one study conducted within a species (Coraciiformes).

Egg to maternal blood relationship: captive studies

Fourth, we used data from only the captive bird studies to investigate if the relationship between THg concentrations in eggs and maternal blood differed among captive birds kept in controlled conditions. We included data from two captive dosing studies, one on mallard[4] and one on zebra finch (Cristol). THg concentration in individual eggs was the dependent variable and THg concentration in maternal blood and species were fixed effects, THg concentration in maternal blood × species was included as an interaction, and unique nest identification was included as a random effect. If the interaction between maternal blood THg concentration and species was not significant, we removed the interaction from the model structure and reran the analysis.

Egg to maternal blood relationship: all taxa

Fifth, because of the utility for a more universal equation across species to predict THg concentrations in eggs from THg concentrations in female bird blood for any species, we also produced a general equation using a model where THg concentration in individual eggs was the dependent variable and THg concentration in maternal blood was a fixed effect and unique nest identification, study, and species were included as random effects.

Maternal blood to egg relationship: by species, order, and all taxa

Finally, because many investigators sample eggs and may want to predict maternal blood THg concentrations (rather than the above egg predictions using blood), we restructured the statistical models and conducted separate tests for each 1) species: where female blood THg concentration was the dependent variable and geometric mean egg THg concentration in a clutch was a fixed effect and study was a random effect; 2) order: where female blood THg concentration was the dependent variable and geometric mean egg THg concentration in a clutch was a fixed effect and species and study were random effects; and 3) all taxa: where female blood THg concentration was the dependent variable and geometric mean egg THg concentration in a clutch was a fixed effect and species and study were random effects. The statistics and equations for predicting maternal blood THg concentrations from egg THg concentrations are presented only in Table S3 and are used for the predictions in Table 3.

RESULTS

Egg to maternal blood relationship: differences among studies within the same species

First, we examined the potential differences within the same species but among studies in five species that each had 2-5 unique datasets (Table 1).

Tree swallows

We had five unique datasets for tree swallows where the geographic location or timing of female blood sampling differed among studies. THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood in tree swallows ($F_{1,158.5}$=1101.46, p<0.0001), but there were significant effects of study ($F_{4,146.0}$=26.69, p<0.0001) and blood THg concentration × study interaction ($F_{4,148.3}$=14.15, p<0.0001; final model: n=568 eggs, R^2_m=0.94; Figure 1a). The significant blood THg concentration × study interaction and study effect indicated that the relationship between THg concentrations in eggs and maternal blood differed among the tree swallow studies. The most noteworthy difference among these studies was a shallower slope in the study by Evers (Eq. 5; green triangles) which predicted relatively lower egg THg concentrations at higher blood THg concentrations (Figure 1a). However, three of the five studies had similar slopes (Eqs. 1, 2, and 4). Additionally, the short time difference in sampling a female's blood during incubation had a small influence on the predicted egg THg concentrations in the two studies by Ackerman et al.[3] Specifically, for any predicted egg THg concentration, females bled immediately after clutch completion (early incubation) had lower blood THg concentrations than females bled after 6-10 days in incubation (mid to late incubation), indicating that females acquired additional THg after egg laying during incubation. The specific equations among these five studies to predict THg concentrations in eggs from maternal blood were (Table S2):

(1) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.8091 \times \ln\left(Female\ Tree\ Swallow\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 1.3740$ (females bled during early incubation,[3] n=171 eggs, R_m^2=0.80)

(2) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.7892 \times \ln\left(Female\ Tree\ Swallow\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 1.2195$ (females bled during late incubation,[3] n=52 eggs, R_m^2=0.70)

(3) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.9598 \times \ln\left(Female\ Tree\ Swallow\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 1.3412$ (females bled at clutch completion,[2] n=162 eggs, R_m^2=0.97)

(4) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.8568 \times \ln\left(Female\ Tree\ Swallow\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.9689$ (Cristol) (females bled throughout incubation, n=137 eggs, R_m^2=0.97)

(5) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.4549 \times \ln\left(Female\ Tree\ Swallow\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 1.8412$ (Evers) (females bled throughout incubation and nestling rearing, n=46 eggs, R_m^2=0.63)

Common loons

We had two unique datasets for common loons. After removing the non-significant blood THg concentration × study interaction term ($F_{1,80.6}$=1.08, p=0.30), THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood in common loons ($F_{1,88.8}$=82.67, p<0.0001) and there was no influence of study ($F_{1,83.1}$=2.18, p=0.14; final model: n=119, R_m^2=0.46; Figure 1b). This indicates that the relationship of THg concentrations in eggs and blood did not statistically differ between studies because there was substantially more variation in the study by Evers (Figure 1b). The study-specific equations between THg concentrations in eggs and maternal blood were (Table S2):

(6) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.9753 \times \ln\left(Female\ Common\ Loon\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.4318$ (Wisconsin,[7] n=29 eggs, R^2_m=0.91)

(7) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.7116 \times \ln\left(Female\ Common\ Loon\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.6937$ (Evers, northeastern USA, n=90 eggs, R^2_m=0.42)

Mallard

We had three unique datasets for mallards, including one field study and two captive studies where the timing of female blood sampling differed. The blood THg concentration × study interaction was non-significant ($F_{2,89.1}$=0.08, p=0.92), indicating that the relationship between THg concentrations in eggs and blood had a similar slope among the three mallard studies and we removed this interaction from the model. THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood in mallards ($F_{1,45.8}$=330.64, p<0.0001), but there was an influence of study ($F_{2,80.4}$=6.07, p=0.004; final model: n=255, R^2_m=0.87; Figure 1c). The data derived from dosed captive mallards (Eqs. 8 and 9) resulted in greater predicted egg THg concentrations than wild mallards (Eq. 10) at any given female blood THg concentration. Also noteworthy was that there were no significant differences in the modeled relationships between the two captive mallard datasets,[4] despite the difference in the timing of female blood sampling between studies where females were bled either on the day of egg laying or after she had laid an additional 16-27 eggs (which was approximately 16-27 days after the initial egg was laid that was assessed for THg concentrations). The study-specific equations to predict THg concentrations in eggs from maternal blood were (Table S2):

(8) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.8837 \times \ln\left(Female\ Mallard\ Blood\ THg\ \frac{\mu g}{g}ww\right) + 0.0878$ (captive females bled on day of egg laying,[4] n=15 eggs, R^2_m=0.89)

(9) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.8140 \times \ln\left(Female\ Mallard\ Blood\ THg\ \frac{\mu g}{g}ww\right) + 0.1075$ (captive females bled after laying an additional 16-27 eggs,[4] n=15 eggs, R^2_m=0.83)

(10) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.8690 \times \ln\left(Female\ Mallard\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.2574$ (Evers, wild females bled prior to and during incubation, n=225 eggs, R^2_m=0.83)

Carolina wren

We had two unique datasets for Carolina wrens. Due to the limited sample size for Carolina wrens (*n*=6 nests), we could not include the blood THg concentration × study interaction. THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood in Carolina wrens ($F_{1,3.2}$=66.36, *p*=0.003) and there was no influence of study ($F_{1,1.7}$=0.02, *p*=0.91; final model: *n*=9, R_m^2=0.88; Figure 1e). The study-specific equations between THg concentrations in eggs and maternal blood were (Table S2):

(11) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.7736 \times \ln\left(Female\ Carolina\ Wren\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 1.9399$ (Cristol, South River, Shenandoah Valley, Virginia, *n*=4 eggs, R_m^2=0.99)

(12) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.4801 \times \ln\left(Female\ Carolina\ Wren\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 1.9153$ (Evers, North Fork Holston River, Virginia, *n*=5 eggs, R_m^2=0.54)

Black-legged kittiwake

We had two unique datasets for black-legged kittiwakes where the geographic location differed between studies. After removing the non-significant blood THg concentration × study interaction term ($F_{1,11}$=2.38, *p*=0.15), THg concentrations in eggs were positively correlated with THg concentrations in the mother's blood in black-legged kittiwakes ($F_{1,12}$=27.40, *p*=0.0002), but there was an influence of study ($F_{1,12}$=12.53, *p*=0.004; final model: *n*=15, R_m^2=0.81; Figure 1d). In particular, the larger dataset for black-legged kittiwakes from Corossol Island, Quebec (Eq. 14) had much higher explanatory power than the smaller dataset from Prince Leopold Island, Nunavut (Eq. 13). The study-specific equations to predict THg concentrations in eggs from maternal blood were (Table S2):

(13) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.2751 \times \ln\left(Female\ Black-legged\ Kittiwake\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 1.9807$ (Mallory, Provencher, Braune; Prince Leopold Island, Nunavut, *n*=5 eggs, R_m^2=0.27)

(14) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 1.2601 \times \ln\left(Female\ Black-legged\ Kittiwake\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) + 0.1930$ (Lavoie, Corossol Island, Quebec, *n*=10 eggs, R_m^2=0.73)

Egg to maternal blood relationship: by species

Second, we examined whether the relationship between THg concentrations in eggs and maternal blood differed among species. Because some species differed in their relationships within taxonomic orders, we conducted separate models for each species to estimate the specific equations to predict THg concentrations in eggs from THg concentrations in maternal blood (Figure 3c).

(15) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.9295 \times \ln\left(Female\ American\ Avocet\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.8965$ (n=97 eggs, R_m^2=0.73)

(16) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.8602 \times \ln\left(Female\ Belted\ Kingfisher\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 2.4879$ (n=24 eggs, R_m^2=0.87)

(17) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 1.0835 \times \ln\left(Female\ Black\text{-}legged\ Kittiwake\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.9112$ (n=15 eggs, R_m^2=0.49)

(18) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.7225 \times \ln\left(Female\ Black\text{-}necked\ Stilt\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.7075$ (n=105 eggs, R_m^2=0.69)

(19) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.7090 \times \ln\left(Female\ Carolina\ Wren\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 1.9443$ (n=9 eggs, R_m^2=0.90)

(20) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.8531 \times \ln\left(Female\ Common\ Eider\ Blood\ THg\ \frac{\mu g}{g}ww\right) + 0.2416$ (n=18 eggs, R_m^2=0.64)

(21) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.2827 \times \ln\left(Female\ Common\ Goldeneye\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 1.0441$ (n=11 eggs, R_m^2=0.01)

(22) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.7218 \times \ln\left(Female\ Common\ Loon\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.6271$ (n=119 eggs, R_m^2=0.47)

(23) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 0.5618 \times \ln\left(Female\ Common\ Merganser\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 0.4308$ (n=5 eggs, R_m^2=0.29)

(24) $\ln\left(Egg\ THg\ \frac{\mu g}{g}fww\right) = 1.9391 \times \ln\left(Female\ Eastern\ Bluebird\ Blood\ THg\ \frac{\mu g}{g}ww\right) - 1.2038$ (n=5 eggs, R_m^2=0.71)

(25) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.7785 \times \ln\left(Female\ Forster's\ Tern\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 0.5465$ (n=49 eggs, R_m^2=0.26)

(26) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 1.3734 \times \ln\left(Female\ Herring\ Gull\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) + 0.6525$ (n=12 eggs, R_m^2=0.67)

(27) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.3425 \times \ln\left(Female\ Hooded\ Merganser\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 0.4600$ (n=34 eggs, R_m^2=0.22)

(28) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 1.0444 \times \ln\left(Female\ House\ Wren\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 1.6690$ (n=306 eggs, R_m^2=0.82)

(29) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.8263 \times \ln\left(Female\ Indigo\ Bunting\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 2.3433$ (n=23 eggs, R_m^2=0.78)

(30) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.8802 \times \ln\left(Female\ Mallard\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 0.0892$ (n=240 eggs, R_m^2=0.81)

(31) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.3227 \times \ln\left(Female\ Northern\ Fulmar\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 1.3870$ (n=3 eggs, R_m^2=0.17)

(32) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 1.0289 \times \ln\left(Female\ Song\ Sparrow\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 1.2475$ (n=25 eggs, R_m^2=0.87)

(33) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.8327 \times \ln\left(Female\ Tree\ Swallow\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 1.2819$ (n=568 eggs, R_m^2=0.87)

(34) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.6007 \times \ln\left(Female\ Wood\ Duck\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 1.3460$ (n=9 eggs, R_m^2=0.11)

(35) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.6472 \times \ln\left(Female\ Yellow-billed\ Loon\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 0.7751$ (n=6 eggs, R_m^2=0.50)

(36) $\ln\left(Egg\ THg\ \frac{\mu g}{g}_{fww}\right) = 0.7133 \times \ln\left(Female\ Zebra\ Finch\ Blood\ THg\ \frac{\mu g}{g}_{ww}\right) - 0.2478$ (n=104 eggs, R_m^2=0.64)

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TABLES

Table S1. Summary of available datasets on the maternal transfer of mercury from females to her eggs in 26 species and 6 taxonomic orders of birds in North America. Table S1 is an extension of Table 1 in the main manuscript and includes additional details about the methods used to estimate blood and egg total mercury concentrations (THg) and the timing of egg and female blood sampling for each dataset (denoted by the citation and species).

Citation	Common Name	Female Blood THg Estimation Method	Egg THg Estimation Method	Timing of egg sampling	Timing of female blood sampling
Ackerman et al. 2016a	American avocet	whole blood in wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected during early incubation, on same day when female blood was collected	female captured on nest and bled during early incubation, ≤12 days after clutch completion
Ackerman et al. 2016a	Black-necked stilt	whole blood in wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected during early incubation, on same day when female blood was collected	female captured on nest and bled during early incubation, ≤12 days after clutch completion
Ackerman et al. 2016a	Forster's tern	whole blood in wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected during early incubation, on same day when female blood was collected	female captured on nest and bled during early incubation, ≤12 days after clutch completion
Ackerman et al. 2017	Tree swallow	whole blood in wet weight: estimated using whole blood in dry weight with specific percent mositure to calculate wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected immediately after clutch completion, on same day when female blood was collected	female captured on nest and bled ≤3 days after clutch completion
Ackerman et al. 2017	House wren	whole blood in wet weight: estimated using whole blood in dry weight with specific percent mositure to calculate wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected immediately after clutch completion, on same day when female blood was collected	female captured on nest and bled ≤3 days after clutch completion
Ackerman et al. 2017	Tree swallow	whole blood in wet weight: estimated using whole blood in dry weight with specific percent mositure to calculate wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	egg was collected during late incubation, on same day when female blood was collected	female captured on nest and bled during late incubation, 6-10 days after clutch completion
Kenow et al. 2015	Common loon	whole blood in wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected during early incubation, on same day when female blood was collected	female captured on nest and bled ≤8 days after clutch completion
Heinz et al. 2010b	Mallard	whole blood in wet weight	wet weight; no egg morphometrics; assumed THg fww = THg ww because eggs were collected fresh on day they were laid	egg was collected on day it was laid, on same day when female blood was collected	female captured on nest and bled the day the single egg was collected, egg was one of 33 to 44 eggs laid in a clutch
Heinz et al. 2010b	Mallard	whole blood in wet weight	wet weight; no egg morphometrics; assumed THg fww = THg ww because eggs were collected fresh on day they were laid	egg was collected on day it was laid, which was 16-27 days before female blood was collected	female captured on nest and bled 16 to 27 days after egg was laid
Mallory, Provencher, Braune; this paper	Northern fulmar	whole blood in wet weight: estimated using whole blood in dry weight; used 79.1% (Eagles-Smith et al. 2008) average percent mositure to calculate THg in wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected during incubation, on same day when female was collected	female was collected ≤28 days after clutch completion, frozen, and then blood was sampled from heart during necropsy

Mallory, Provencher, Braune; this paper	Black-legged kittiwake	whole blood in wet weight: estimated using whole blood in dry weight; used 79.1% (Eagles-Smith et al. 2008) average percent mositure to calculate THg in wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	egg was collected during incubation, on same day when female was collected	female was collected ≤10 days after clutch completion, frozen, and then blood was sampled from heart during necropsy
Lavoie; this paper	Herring gull	whole blood in wet weight: estimated using red blood cells in dry weight, converting to wet weight, then estimating whole blood wet weight based on ratio of red blood cells to plasma	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	egg was collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤28 days after clutch completion
Lavoie; this paper	Black-legged kittiwake	whole blood in wet weight: estimated using red blood cells in dry weight, converting to wet weight, then estimating whole blood wet weight based on ratio of red blood cells to plasma	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	egg was collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤27 days after clutch completion
Lavoie; this paper	Common eider	whole blood in wet weight: estimated using red blood cells in dry weight, converting to wet weight, then estimating whole blood wet weight based on ratio of red blood cells to plasma	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	egg was collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤26 days after clutch completion
Lavoie; this paper	Great black-backed gull	whole blood in wet weight: estimated using red blood cells in dry weight, converting to wet weight, then estimating whole blood wet weight based on ratio of red blood cells to plasma	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	egg was collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤28 days after clutch completion
Brasso et al. 2010	Tree swallow	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected immediately after clutch completion, on same day when female blood was collected	female captured on nest and bled ≤3 days after clutch completion
Cristol; this paper	Zebra finch	whole blood in wet weight	wet weight: estimated from dry weight assuming an average percent moisture of 75.4% in eggs; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤7 days after clutch completion
Cristol; this paper	Tree swallow	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤7 days after clutch completion

Cristol; this paper	House wren	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	egg was collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤7 days after clutch completion
Cristol; this paper	Eastern phoebe	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤7 days after clutch completion
Cristol; this paper	Eastern bluebird	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤7 days after clutch completion
Cristol; this paper	Carolina wren	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	egg was collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤7 days after clutch completion
Cristol; this paper	Belted kingfisher	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤7 days after clutch completion
Evers; this paper	Carolina wren	whole blood in wet weight	wet weight; no egg morphometrics; assumed THg fww = THg ww	egg was collected during incubation, ≤6 days after when female blood was collected	female captured on nest and bled ≤6 days before egg collection
Evers et al. 2003, and additional unpublished data for this paper	Common loon	whole blood in wet weight	fresh wet weight: estimated from either 1) dry weight using individual egg's percent moisture and egg morphometrics or 2) wet weight and individual egg morphometrics	eggs were collected from abandoned nests, ≤69 days after egg laying	female captured in territory and bled ≤69 days before or after clutch completion
Evers; this paper	Indigo bunting	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, ≤3 days of when female blood was collected	female captured on nest and bled ≤16 days after clutch completion
Evers; this paper	Northern cardinal	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤13 days after clutch completion
Evers; this paper	Red-winged blackbird	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤12 days after clutch completion

Evers; this paper	Song sparrow	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	eggs were collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤14 days after clutch completion
Evers; this paper	Tree swallow	whole blood in wet weight	wet weight: estimated from dry weight using individual egg's percent moisture; no egg morphometrics; assumed THg fww = THg ww	egg was collected during incubation, ≤16 days before when female blood was collected	female captured on nest and bled ≤28 days after clutch completion
Evers, Savoy; this paper	Common goldeneye	whole blood in wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected from abandoned nests, ≤12 days after when female blood was collected	female captured on nest and bled ≤12 days before egg collection
Evers, Savoy; this paper	Common merganser	whole blood in wet weight	fresh wet weight: estimated from dry weight using individual egg's percent moisture and egg morphometrics	eggs were collected from abandoned nests, ≤28 days before or after after when female blood was collected	female captured in territory and bled ≤28 days before or after clutch completion
Evers, Savoy; this paper	Hooded merganser	whole blood in wet weight	fresh wet weight or wet weight: estimated from either 1) dry weight using individual egg's percent moisture and egg morphometrics or 2) wet weight and assumed THg fww = THg ww	eggs were collected from abandoned nests, ≤28 days before or after after when female blood was collected	female captured in territory and bled ≤28 days before or after clutch completion
Evers, Savoy; this paper	Mallard	whole blood in wet weight	fresh wet weight: estimated from either 1) dry weight using individual egg's percent moisture and egg morphometrics or 2) wet weight and individual egg morphometrics	eggs were collected during incubation, ≤20 days of when female blood was collected	female captured, bled, transmittered, and than followed to locate nest; female bled ≤20 days before clutch completion
Evers, Savoy; this paper	Wood duck	whole blood in wet weight	fresh wet weight or wet weight: estimated from either 1) wet weight and individual egg morphometrics or 2) wet weight and assumed THg fww = THg ww	egg was collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤28 days after clutch completion
Matz, Schmutz; this paper	Yellow-billed loon	whole blood in wet weight: estimated using whole blood in dry weight; used 75.9% (Ackerman et al. 2015) average percent mositure to calculate THg in wet weight	wet weight: estimated from dry weight assuming an average percent moisture of 75.5% (Ackerman et al. 2015) in eggs; no egg morphometrics; assumed THg fww = THg ww	egg was collected during incubation, on same day when female blood was collected	female captured on nest and bled ≤28 days after clutch completion

Table S2. Equations (both on the natural log scale and back-transformed), model fit, and variance for predicting egg total mercury concentrations (THg µg/g fww) based on female blood THg concentrations (µg/g ww) for all taxa, 6 taxonomic orders, 22 species of birds, and by study. The equation number from the text is provided for reference. Because there were no other fixed-effects in the models, marginal R_m^2 values indicated the explanatory power of THg concentrations in female bird blood for predicting THg concentrations in eggs. Conditional R_c^2 values described the proportion of variance explained by both the fixed- and random-effects in the model.

Taxa	Sample Size of Eggs	R_c^2	R_m^2	Slope ± SE (log scale)	Intercept ± SE (log scale)	Equation Reference Number	Equation (log scale)	Equation (back-transformed)
All taxa	1799	0.97	0.58	0.8220 ± 0.0190	-0.9947 ± 0.1441	42	ln(Egg THg)=0.8220×ln(Female Blood THg)-0.9947	Egg THg=0.3698×Female Blood THg$^{0.8220}$
Anseriformes	317	0.91	0.72	0.7661 ± 0.0564	-0.2470 ± 0.1994	37	ln(Egg THg)=0.7661×ln(Female Blood THg)-0.2470	Egg THg=0.7811×Female Blood THg$^{0.7661}$
Common eider	18	0.64	0.64	0.8531 ± 0.1548	0.2416 ± 0.3812	20	ln(Egg THg)=0.8531×ln(Female Blood THg)+0.2416	Egg THg=1.2733×Female Blood THg$^{0.8531}$
Common goldeneye	11	0.61	0.01	0.2827 ± 1.8426	-1.0441 ± 2.7439	21	ln(Egg THg)=0.2827×ln(Female Blood THg)-1.0441	Egg THg=0.3520×Female Blood THg$^{0.2827}$
Common merganser	5	0.98	0.29	0.5618 ± 0.5306	-0.4308 ± 0.1859	23	ln(Egg THg)=0.5618×ln(Female Blood THg)-0.4308	Egg THg=0.6500×Female Blood THg$^{0.5618}$
Hooded merganser	34	0.22	0.22	0.3425 ± 0.1125	-0.4600 ± 0.1088	27	ln(Egg THg)=0.3425×ln(Female Blood THg)-0.4600	Egg THg=0.6313×Female Blood THg$^{0.3425}$
Mallard	240	0.93	0.81	0.8802 ± 0.0560	-0.0892 ± 0.1729	30	ln(Egg THg)=0.8802×ln(Female Blood THg)-0.0892	Egg THg=0.9147×Female Blood THg$^{0.8802}$
Heinz et al. 2010; captive females bled on day of egg laying	15	0.89	0.89	0.8837 ± 0.0840	0.0878 ± 0.0696	8	ln(Egg THg)=0.8837×ln(Female Blood THg)+0.0878	Egg THg=1.0918×Female Blood THg$^{0.8837}$
Heinz et al. 2010; captive females bled 16-27 days after egg laying	15	0.83	0.83	0.8140 ± 0.0996	0.1075 ± 0.0825	9	ln(Egg THg)=0.8140×ln(Female Blood THg)+0.1075	Egg THg=1.1135×Female Blood THg$^{0.8140}$
Evers; wild females bled prior to and during incubation	225	0.92	0.83	0.8690 ± 0.0651	-0.2574 ± 0.0788	10	ln(Egg THg)=0.8690×ln(Female Blood THg)-0.2574	Egg THg=0.7731×Female Blood THg$^{0.8690}$
Wood duck	9	0.99	0.11	0.6007 ± 0.5956	-1.3460 ± 1.9506	34	ln(Egg THg)=0.6007×ln(Female Blood THg)-1.3460	Egg THg=0.2603×Female Blood THg$^{0.6007}$
Charadriiformes	280	0.95	0.71	0.8761 ± 0.0569	-0.7961 ± 0.1742	38	ln(Egg THg)=0.8761×ln(Female Blood THg)-0.7961	Egg THg=0.4511×Female Blood THg$^{0.8761}$
American avocet	97	0.94	0.73	0.9295 ± 0.0995	-0.8965 ± 0.1003	15	ln(Egg THg)=0.9295×ln(Female Blood THg)-0.8965	Egg THg=0.4080×Female Blood THg$^{0.9295}$
Black-legged kittiwake	15	0.98	0.49	1.0835 ± 0.2438	-0.9112 ± 0.7970	17	ln(Egg THg)=1.0835×ln(Female Blood THg)-0.9112	Egg THg=0.4020×Female Blood THg$^{1.0835}$
Mallory, Provencher, Braune; Prince Leopold Island, Nunavut	5	0.27	0.27	0.2751 ± 0.2277	-1.9807 ± 0.1106	13	ln(Egg THg)=0.2751×ln(Female Blood THg)-1.9807	Egg THg=0.1380×Female Blood THg$^{0.2751}$
Lavoie; Corossol Islands, Quebec	10	0.73	0.73	1.2601 ± 0.2532	0.1930 ± 0.5943	14	ln(Egg THg)=1.2601×ln(Female Blood THg)+0.1930	Egg THg=1.2129×Female Blood THg$^{1.2601}$
Black-necked stilt	105	0.85	0.69	0.7225 ± 0.0720	-0.7075 ± 0.0475	18	ln(Egg THg)=0.7225×ln(Female Blood THg)-0.7075	Egg THg=0.4929×Female Blood THg$^{0.7225}$
Forster's tern	49	0.78	0.26	0.7785 ± 0.2788	-0.5465 ± 0.2216	25	ln(Egg THg)=0.7785×ln(Female Blood THg)-0.5465	Egg THg=0.5790×Female Blood THg$^{0.7785}$
Herring gull	12	0.67	0.67	1.3734 ± 0.2916	0.6525 ± 0.6508	26	ln(Egg THg)=1.3734×ln(Female Blood THg)+0.6525	Egg THg=1.9203×Female Blood THg$^{1.3734}$
Coraciiformes	24	0.99	0.87	0.8602 ± 0.0945	-2.4879 ± 0.1395	39	ln(Egg THg)=0.8602×ln(Female Blood THg)-2.4879	Egg THg=0.0831×Female Blood THg$^{0.8602}$
Belted kingfisher	24	0.99	0.87	0.8602 ± 0.0945	-2.4879 ± 0.1395	16	ln(Egg THg)=0.8602×ln(Female Blood THg)-2.4879	Egg THg=0.0831×Female Blood THg$^{0.8602}$
Gaviiformes	125	0.94	0.54	0.7312 ± 0.0858	-0.6307 ± 0.0946	40	ln(Egg THg)=0.7312×ln(Female Blood THg)-0.6307	Egg THg=0.5322×Female Blood THg$^{0.7312}$
Common loon	119	0.95	0.47	0.7218 ± 0.0879	-0.6271 ± 0.1115	22	ln(Egg THg)=0.7218×ln(Female Blood THg)-0.6271	Egg THg=0.5341×Female Blood THg$^{0.7218}$
Kenow et al. 2015; Wisconsin	29	0.91	0.91	0.9753 ± 0.0546	-0.4318 ± 0.0296	6	ln(Egg THg)=0.9753×ln(Female Blood THg)-0.4318	Egg THg=0.6493×Female Blood THg$^{0.9753}$
Evers; northeastern USA	90	0.94	0.42	0.7116 ± 0.0931	-0.6937 ± 0.0671	7	ln(Egg THg)=0.7116×ln(Female Blood THg)-0.6937	Egg THg=0.4997×Female Blood THg$^{0.7116}$
Yellow-billed loon	6	0.50	0.50	0.6472 ± 0.2889	-0.7751 ± 0.3878	35	ln(Egg THg)=0.6472×ln(Female Blood THg)-0.7751	Egg THg=0.4607×Female Blood THg$^{0.6472}$
Passeriformes	1050	0.98	0.71	0.8560 ± 0.0198	-1.4942 ± 0.1911	41	ln(Egg THg)=0.8560×ln(Female Blood THg)-1.4942	Egg THg=0.2244×Female Blood THg$^{0.8560}$
Carolina wren	9	0.90	0.90	0.7090 ± 0.0867	-1.9443 ± 0.0104	19	ln(Egg THg)=0.7090×ln(Female Blood THg)-1.9443	Egg THg=0.1431×Female Blood THg$^{0.7090}$
Cristol; South River, Shenandoah Valley, Virginia	4	0.99	0.99	0.7736 ± 0.0183	-1.9399 ± 0.0325	11	ln(Egg THg)=0.7736×ln(Female Blood THg)-1.9399	Egg THg=0.1437×Female Blood THg$^{0.7736}$
Evers; North Fork Holston River, Virginia	5	0.54	0.54	0.4801 ± 0.1524	-1.9153 ± 0.0949	12	ln(Egg THg)=0.4801×ln(Female Blood THg)-1.9153	Egg THg=0.1473×Female Blood THg$^{0.4801}$
Eastern bluebird	5	0.71	0.71	1.9391 ± 0.9690	-1.2038 ± 0.1510	24	ln(Egg THg)=1.9391×ln(Female Blood THg)-1.2038	Egg THg=0.3001×Female Blood THg$^{1.9391}$
House wren	306	0.96	0.82	1.0444 ± 0.0620	-1.6690 ± 0.0410	28	ln(Egg THg)=1.0444×ln(Female Blood THg)-1.6690	Egg THg=0.1884×Female Blood THg$^{1.0444}$
Indigo bunting	23	0.91	0.78	0.8263 ± 0.1274	-2.3433 ± 0.1690	29	ln(Egg THg)=0.8263×ln(Female Blood THg)-2.3433	Egg THg=0.0960×Female Blood THg$^{0.8263}$
Song sparrow	25	0.96	0.87	1.0289 ± 0.1293	-1.2475 ± 0.2198	32	ln(Egg THg)=1.0289×ln(Female Blood THg)-1.2475	Egg THg=0.2872×Female Blood THg$^{1.0289}$
Tree swallow	568	0.98	0.87	0.8327 ± 0.0225	-1.2819 ± 0.0887	33	ln(Egg THg)=0.8327×ln(Female Blood THg)-1.2819	Egg THg=0.2775×Female Blood THg$^{0.8327}$
Ackerman et al. 2017; females bled during early incubation	171	0.96	0.80	0.8091 ± 0.0619	-1.3740 ± 0.0628	1	ln(Egg THg)=0.8091×ln(Female Blood THg)-1.3740	Egg THg=0.2531×Female Blood THg$^{0.8091}$
Ackerman et al. 2017; females bled during late incubation	52	0.70	0.70	0.7892 ± 0.0718	-1.2195 ± 0.0490	2	ln(Egg THg)=0.7892×ln(Female Blood THg)-1.2195	Egg THg=0.2954×Female Blood THg$^{0.7892}$
Brasso et al. 2010; females bled at clutch completion	162	0.99	0.97	0.9598 ± 0.0260	-1.3412 ± 0.0375	3	ln(Egg THg)=0.9598×ln(Female Blood THg)-1.3412	Egg THg=0.2615×Female Blood THg$^{0.9598}$
Cristol; females bled throughout incubation	137	0.99	0.97	0.8568 ± 0.0243	-0.9689 ± 0.0354	4	ln(Egg THg)=0.8568×ln(Female Blood THg)-0.9689	Egg THg=0.3795×Female Blood THg$^{0.8568}$
Evers; females bled throughout incubation	46	0.92	0.63	0.4549 ± 0.0728	-1.8412 ± 0.0984	5	ln(Egg THg)=0.4549×ln(Female Blood THg)-1.8412	Egg THg=0.1586×Female Blood THg$^{0.4549}$
Zebra finch	104	0.92	0.64	0.7133 ± 0.0954	-0.2478 ± 0.1944	36	ln(Egg THg)=0.7133×ln(Female Blood THg)-0.2478	Egg THg=0.7805×Female Blood THg$^{0.7133}$
Procellariiformes	3	0.17	0.17	0.3227 ± 0.5010	-1.3870 ± 0.2002	31	ln(Egg THg)=0.3227×ln(Female Blood THg)-1.3870	Egg THg=0.2498×Female Blood THg$^{0.3227}$
Northern fulmar	3	0.17	0.17	0.3227 ± 0.5010	-1.3870 ± 0.2002	31	ln(Egg THg)=0.3227×ln(Female Blood THg)-1.3870	Egg THg=0.2498×Female Blood THg$^{0.3227}$

Table S3. Equations (both on the natural log scale and back-transformed), model fit, and variance for predicting maternal blood total mercury concentrations (THg µg/g ww) based on geometric mean egg THg concentrations (µg/g fww) within her clutch for all taxa, 6 taxonomic orders, and 22 species of birds. Because there were no other fixed-effects in the models, marginal R_m^2 values indicated the explanatory power of THg concentrations in eggs for predicting THg concentrations in female bird blood. Conditional R_c^2 values described the proportion of variance explained by both the fixed- and random-effects in the model.

Taxa	Sample Size of Nests	R_c^2	R_m^2	Slope ± SE (log scale)	Intercept ± SE (log scale)	Equation (log scale)	Equation (back-transformed)
All taxa	564	0.93	0.65	0.9179 ± 0.0221	0.7244 ± 0.1511	ln(Female Blood THg)=0.9179×ln(Egg THg)+0.7244	Female Blood THg=2.0635×Egg THg$^{0.9179}$
Anseriformes	89	0.88	0.79	0.9066 ± 0.0954	-0.1203 ± 0.2086	ln(Female Blood THg)=0.9066×ln(Egg THg)-0.1203	Female Blood THg=0.8867×Egg THg$^{0.9066}$
Common eider	18	0.64	0.64	0.7677 ± 0.1393	-1.0308 ± 0.2601	ln(Female Blood THg)=0.7677×ln(Egg THg)-1.0308	Female Blood THg=0.3567×Egg THg$^{0.7677}$
Common goldeneye	3	0.03	0.03	0.1463 ± 0.5732	-1.2471 ± 0.9052	ln(Female Blood THg)=0.1463×ln(Egg THg)-1.2471	Female Blood THg=0.2873×Egg THg$^{0.1463}$
Common merganser	4	0.27	0.27	0.6379 ± 0.6013	0.3613 ± 0.2801	ln(Female Blood THg)=0.6379×ln(Egg THg)+0.3613	Female Blood THg=1.4352×Egg THg$^{0.6379}$
Hooded merganser	17	0.55	0.55	1.1063 ± 0.2505	0.0912 ± 0.2258	ln(Female Blood THg)=1.1063×ln(Egg THg)+0.0912	Female Blood THg=1.0955×Egg THg$^{1.1063}$
Mallard	39	0.92	0.91	0.9971 ± 0.0702	0.0709 ± 0.1093	ln(Female Blood THg)=0.9971×ln(Egg THg)+0.0709	Female Blood THg=1.0735×Egg THg$^{0.9971}$
Wood duck	8	0.13	0.13	0.2457 ± 0.2397	-2.4231 ± 0.8144	ln(Female Blood THg)=0.2457×ln(Egg THg)-2.4231	Female Blood THg=0.0886×Egg THg$^{0.2457}$
Charadriiformes	100	0.90	0.65	0.7926 ± 0.0537	0.5148 ± 0.3950	ln(Female Blood THg)=0.7926×ln(Egg THg)+0.5148	Female Blood THg=1.6733×Egg THg$^{0.7926}$
American avocet	25	0.76	0.76	0.8272 ± 0.0887	0.6285 ± 0.1455	ln(Female Blood THg)=0.8272×ln(Egg THg)-0.6285	Female Blood THg=1.8748×Egg THg$^{0.8272}$
Black-legged kittiwake	15	0.98	0.07	0.6143 ± 0.1167	0.0928 ± 0.7918	ln(Female Blood THg)=0.6143×ln(Egg THg)+0.0928	Female Blood THg=1.0972×Egg THg$^{0.6143}$
Black-necked stilt	29	0.77	0.77	1.0808 ± 0.1101	0.7526 ± 0.1017	ln(Female Blood THg)=1.0808×ln(Egg THg)+0.7526	Female Blood THg=2.1225×Egg THg$^{1.0808}$
Forster's tern	17	0.30	0.30	0.4031 ± 0.1451	0.7088 ± 0.0685	ln(Female Blood THg)=0.4031×ln(Egg THg)+0.7088	Female Blood THg=2.0316×Egg THg$^{0.4031}$
Herring gull	12	0.67	0.67	0.5018 ± 0.1066	-1.0105 ± 0.2612	ln(Female Blood THg)=0.5018×ln(Egg THg)-1.0105	Female Blood THg=0.3640×Egg THg$^{0.5018}$
Coraciiformes	7	0.93	0.93	1.0954 ± 0.1207	2.7083 ± 0.3638	ln(Female Blood THg)=1.0954×ln(Egg THg)+2.7083	Female Blood THg=15.0037×Egg THg$^{1.0954}$
Belted kingfisher	7	0.93	0.93	1.0954 ± 0.1207	2.7083 ± 0.3638	ln(Female Blood THg)=1.0954×ln(Egg THg)+2.7083	Female Blood THg=15.0037×Egg THg$^{1.0954}$
Gaviiformes	98	0.67	0.35	0.6560 ± 0.0711	0.1921 ± 0.3549	ln(Female Blood THg)=0.6560×ln(Egg THg)+0.1921	Female Blood THg=1.2118×Egg THg$^{0.6560}$
Common loon	93	0.58	0.38	0.6436 ± 0.0712	0.4293 ± 0.2268	ln(Female Blood THg)=0.6436×ln(Egg THg)+0.4293	Female Blood THg=1.5362×Egg THg$^{0.6436}$
Yellow-billed loon	5	0.73	0.73	1.1209 ± 0.3405	0.5506 ± 0.5448	ln(Female Blood THg)=1.1209×ln(Egg THg)+0.5506	Female Blood THg=1.7343×Egg THg$^{1.1209}$
Passeriformes	267	0.96	0.81	1.0221 ± 0.0246	1.4625 ± 0.1937	ln(Female Blood THg)=1.0221×ln(Egg THg)+1.4625	Female Blood THg=4.3167×Egg THg$^{1.0221}$
Carolina wren	6	0.96	0.96	1.3426 ± 0.1372	2.6735 ± 0.2354	ln(Female Blood THg)=1.3426×ln(Egg THg)+2.6735	Female Blood THg=14.4906×Egg THg$^{1.3426}$
Eastern bluebird	3	0.67	0.67	0.4128 ± 0.2062	0.4871 ± 0.2758	ln(Female Blood THg)=0.4128×ln(Egg THg)+0.4871	Female Blood THg=1.6276×Egg THg$^{0.4128}$
House wren	45	0.87	0.87	0.8319 ± 0.0488	1.3481 ± 0.0995	ln(Female Blood THg)=0.8319×ln(Egg THg)+1.3481	Female Blood THg=3.8501×Egg THg$^{0.8319}$
Indigo bunting	10	0.82	0.82	1.0484 ± 0.1646	2.3146 ± 0.5422	ln(Female Blood THg)=1.0484×ln(Egg THg)+2.3146	Female Blood THg=10.1209×Egg THg$^{1.0484}$
Song sparrow	7	0.92	0.92	0.8976 ± 0.1101	1.0680 ± 0.3139	ln(Female Blood THg)=0.8976×ln(Egg THg)+1.0680	Female Blood THg=2.9096×Egg THg$^{0.8976}$
Tree swallow	165	0.90	0.87	1.0701 ± 0.0303	1.2858 ± 0.1002	ln(Female Blood THg)=1.0701×ln(Egg THg)+1.2858	Female Blood THg=3.6176×Egg THg$^{1.0701}$
Zebra finch	28	0.69	0.69	0.9461 ± 0.1234	0.8833 ± 0.1521	ln(Female Blood THg)=0.9461×ln(Egg THg)+0.8833	Female Blood THg=2.4189×Egg THg$^{0.9461}$
Procellariiformes	3	0.17	0.17	0.9088 ± 1.4107	1.0797 ± 2.0891	ln(Female Blood THg)=0.9088×ln(Egg THg)+1.0797	Female Blood THg=2.9438×Egg THg$^{0.9088}$
Northern fulmar	3	0.17	0.17	0.9088 ± 1.4107	1.0797 ± 2.0891	ln(Female Blood THg)=0.9088×ln(Egg THg)+1.0797	Female Blood THg=2.9438×Egg THg$^{0.9088}$