Mercury levels in seabirds in the Gulf of Maine

(BRI 2006-08)

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BioDiversity Research Institute
19 Flaggy Meadow Raod
Gorham, Maine 04105

Wing.goodale@briloon.org
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Mercury levels in seabirds in the Gulf of Maine
(Report BRI 2006-08)

Final Report

Submitted to:

Gulf of Maine Council
PO Box 2246
South Portland, ME 04116

Submitted by:

W. Goodale,[1*] D. Evers, [1] B. Allen, [2] J. Ellis, [3] S. Hall, [4] S. Kress, [4] S. Mierzykowski, [5] and L. Welch[6]
*corresponding author

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[1*] Wing Goodale and David Evers, BioDiversity Research Institute, 19 Flaggy Meadow Road, Gorham, Maine 04038. 207-839-7600; wing.goodale@briloon.org.

[2]Brad Allen, Maine Inland Fisheries and Wildlife 650 State St., Bangor, Maine 04401.

[3]Julie C. Ellis, Shoals Marine Laboratory, Cornell University, Ithaca, NY 14853

[4]Steve Kress and Scott Hall, National Audubon Society, 159 Sapsucker Woods, Ithaca, New York 14850.

[5]Steve Mierzykowski, U.S. Fish and Wildlife Service, Maine Ecological Field Office, 1033 S. Main St., Old Town, Maine 04468.

[6]Linda Welch, Maine Coastal Islands NWR, P.O. Box 279, Milbridge, ME 04658

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Abstract

We conducted a pilot study to screen mercury (Hg) levels in Gulf of Maine seabirds in an effort to determine which species are most at risk, are the most appropriate bioindicators, and to refine sampling methods. From 13 Gulf of Maine islands, we evaluated Hg levels in the eggs or blood of seven species of seabirds: razorbill (*Alca torda*), black guillemot (*Cepphus grille*), Atlantic puffin (*Fratercula arctica*), double-crested cormorant (*Phalacrocorax auritus*), common eider (*Somateria mollissima*), Leach's storm-petrel (*Oceanodroma leucorhoa*), and common tern (*Sterna hirundo*). We found: (1) black-guillemots (egg mean = 0.66 ppm; juvenile blood mean = 0.11) and double-crested cormorants (egg mean = 0.28; juvenile blood mean = 0.18) had the highest Hg levels; (2) a suggestive relationship between cormorant levels and proximity to river outflows, but not statistically significant (r^2 0.17); (3) no significant relationship between cormorant Hg levels and proximity to the mainland (r^2 0.007); (4) low cormorant intra-clutch and island variation; and (5) a significant relationship between within cormorant clutch mean egg Hg levels and standard deviation (linear, $r^2 = 0.67$; 2nd degree polynomial, $r^2 = 0.99$). These results indicate that black guillemots, double-crested cormorants, and Leach's storm-petrels are effective bioindicators of Hg and other containments in the marine environment.

Introduction

The increase of global mercury (Hg) levels since the 1900 is of concern because mercury is a persistent toxic heavy metal that both bioaccumulates and biomagnifies in wildlife. To evaluate mercury accumulation, birds are often used as bioindicators of mercury levels in both the marine and freshwaster environments (Fimreite, 1974; Barr, 1986; Scheuhammer, 1987; Wolf *et al.*, 1998; Cohen *et al.*, 2000; Rumbold *et al.*, 2001; Henny *et al.*, 2002; Evers *et al.*, 2003; and Evers *et al.* 2005).

Although mercury is a naturally occurring element, studies on seabirds have found mercury above background levels in many parts of the world, specifically in Antarctica (Norheim *et al.*, 1982), North America (Braune *et al*. 2001), Europe (Furness *et al.*, 1995), Russia (Stout *et al.*, 2002), and Asia (Kim *et al.*, 1996). Moreover, researchers have found mercury in species with diverse foraging strategies (Elliot *et al.*, 1992; and Thompson *et al.*, 1992). Collectively, while these studies indicate that mercury is prevalent in the global environment, it does appear to be accumulating at a higher rate in seabirds that feed offshore: pelagic seabirds typically have levels of heavy metals higher than inshore feeders unless there is a known local pollution source (Nisbet, 1994). These findings are supported by recent evaluations of long-term Hg trends in seabirds, which indicate Hg is increasing in species that feed and winter offshore (Braune *et al.*, 2001 and Burgess and Braune 2001).

While there has been a significant effort to characterize Hg levels in seabirds in North America, few studies have sampled seabirds concurrently on multiple sites in the Gulf of Maine. Therefore, in order to create a baseline dataset, screen multiple species, and refine sampling methods, the Gulf of Maine Seabird Containment Assessment Network (GOMSCAN)[1] collected seabird eggs and blood from nesting colonies along the coast of Maine. We picked species and sites to provide insight into inshore verses offshore differences, within island species variation, within clutch variation, and the influence of major rivers.

[1] GOMSCAN is a standardized, long-term investigation to determine acute and chronic changes in contaminant profiles. Overall emphasis is on persistent bioaccumulative toxins with an initial, three-year focus on profiling the spatial and temporal distributions of mercury. GOMSCAN is comprised of state and federal agencies as well as NGOs. Members of this group are the authors of this paper.

Methods

Sample collection

During the summer of 2004 and 2005 we collected egg and blood samples from 13 islands in the Gulf of Maine (Figure 1, Table 1). We collected viable eggs from guillemots, cormorants, and eiders and nonviable eggs from puffins, razorbills, and terns (Table 1). We collected five complete cormorant clutches from Bluff Island, Egg Rock, No Man's Land, Sugarloaf Islands, and Thrumcap Island to analyze for intra-clutch Hg variation. Additionally, from Duck Island, Egg Rock, No Man's Land, Stratton Island, Sugar Loaf Island, and Thrumcap Island, we collected 15 cormorant eggs from individual nests and created three composites of five eggs for each island (only two for No Man's Land). We collected one complete common eider clutch from Eastern Egg Rock, Hardhead Island, Flag Island, Green Island, Metinic Island, and Petit Manan as well as 15 eggs from Stratton Island that were consolidated into three composites of five eggs each (at this time we only have results from Stratton Island). We opportunistically collected nonviable eggs from the other species that were washed out by storms or failed to hatch. Common tern eggs were collected in 2000, 2001, and 2003 from Stratton and Petit Manan.

Juvenile birds were captured by hand within their breeding colony, blood taken, and standard morphotmetrics collected (weight, tarsus width, bill length). Adult petrels were captured using 72mm nets. Blood was collected systematically from juvenile cormorants on Bluff (n = 12), Sugarloaf (n = 6), and Thrumcap (n = 12) islands (at this time we only have partial results from Bluff and Sugarloaf islands) and opportunistically collected from other species. Depending on the species, blood was collected by either pricking the bronchial wing vein with a 26-gage needle and collecting the blood in a capillary tube or by directly drawing the blood with a syringe. Egg and blood samples were collected with all required state and federal permits.

Table 1. Sampling effort for 2004 and 2005.

Island	Species*	Tissue	Longitude	Latitude	Total # Sample
Bluff Island	DCCO	blood	-70.317340	43.508250	3
		egg	-70.317340	43.508250	4
Duck Island	DCCO	egg	-70.626667	42.977000	15
Egg Rock	DCCO	egg	-67.868667	44.406733	18
Little Duck	BLGU	blood	-68.243730	44.173940	3
	LHSP	blood	-68.243730	44.173940	17
Matinicus Rock	ATPU	egg	-68.854167	43.785833	4
	RAZO	egg	-68.854167	43.785833	7
No Man's Land	DCCO	egg	-68.869767	43.884450	11
Petit Manan Island	ATPU	blood	-67.866060	44.366980	6
	COTE	egg	-67.866060	44.366980	11
Seavey Island	COTE	blood	-70.615500	42.984250	13
Stratton Island	COEI	egg	-70.311833	43.505083	15
	COTE	blood	-70.311833	43.505083	11
		egg	-70.311833	43.505083	4
	DCCO	egg	-70.311833	43.505083	15
Sugarloaf Island	DCCO	blood	-69.771790	43.748330	2

		egg	-69.771790	43.748330	18
Thrumcap Island	DCCO	egg	-68.758180	44.320980	27
Western Island	BLGU	egg	-68.822417	44.291217	3
Total					**207**

*ATPU (Atlantic puffin), BLGU (black guillemot), COEI (common eider), COTE (common tern), DCCO (double-crested cormorant), LHSP (Leach's storm-petrel), RAZO (razorbill)

Sample Processing

After the eggs were collected, they were placed in plastic-bags and frozen until processing. BioDiversity Research Institute processed all the eggs with the exception of six guillemot and two puffin eggs from Petit Manan that were processed by U.S. Fish and Wildlife Service, which are still being analyzed. During processing we collected morphometrics (width, depth, weight, and volume), determined embryo development, opened the eggshell with a scalpel, placed the contents into labeled chemically clean jars, and refroze the samples. Frozen samples were shipped overnight to Texas A & M Trace Element Research Laboratory (TERL) of College Station, Texas. After the blood was collected it was labeled, frozen, and shipped to TERL.

Sample Analysis

The eggs were homogenized with an OMNI Mixer, lyophilized in a Labconco Lyph Lock 12 freeze dryer, and powdered in a Spex Mixer Mill. The lab determined the percent moisture by the weight lost in freeze-drying. The egg and blood were then analyzed for total mercury with cold vapor atomic absorption using methods of Hatch and Ott (1968). To determine quality assurance and quality control (QA/QC), the lab used procedural blanks, duplicates, certified reference materials, and spike recoveries. We received the results from the lab in dry weight that we converted to wet weight using [(dry weight*(100-% moisture))/100]. Fresh weight was not determined at this time.

Statistical Analysis

We summarized the results in Microsoft Excel Pivot Tables, performed statistics with JMP, and spatial analysis with ESRI ArcGIS. Distance from the island to the mainland was calculated in ArcMap with the rulers tool in the coordinate system UTM NAD 83 Zone 19, using line-of-sight to nearest mainland as defined as having vehicular access. Distance to river outflow was also calculated in ArcMap as line-of-site to river outflow, defined as draining watersheds greater than 5,000 square kilometers.

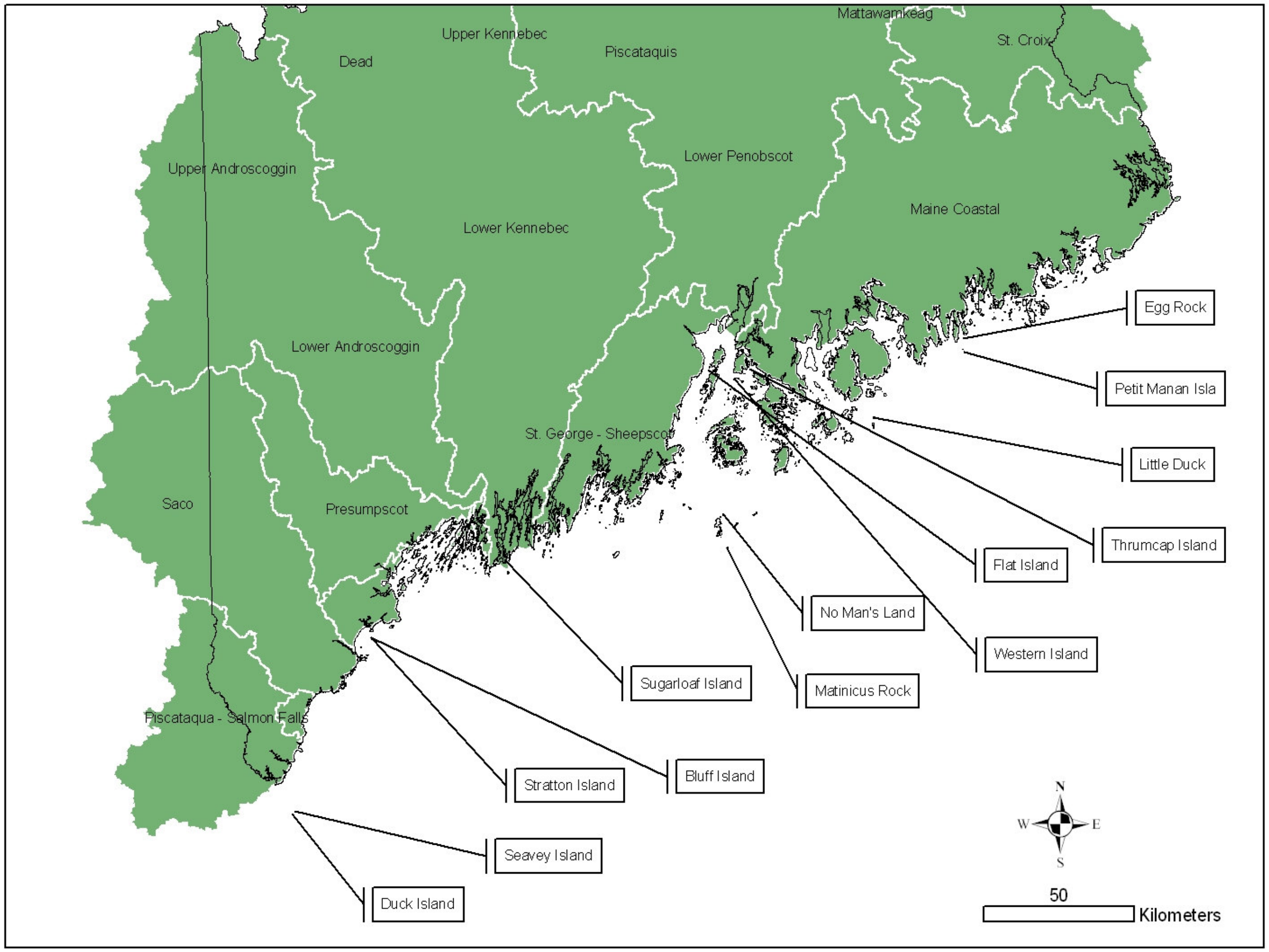

Figure 1. Sampling locations and riversheds.

Results

Guillemot egg Hg levels were significantly higher than all other species (ANOVA, Tukey HSD, F = 10.04, df = 5, 78, p < 0.0001) (Table 2). Duck island had the highest cormorant egg Hg levels (0.42 ppm) but was not significant different from the other islands (ANOVA, F = 2.03, df = 5, 11, p = 0.15) (Figure 2). There was low within-clutch (Table 3) and within-island differences for cormorants (Table 4). There was a significant positive relationship between cormorant whole clutch mean Hg level and standard deviation (linear, $r^2 = 0.67$, df = 4, p = 0.08; 2nd degree polynomial, $r^2 = 0.99$, df =4, p = 0.007) (Figure 3), no significant negative relationship between Hg levels and distance from river outflows (r^2 0.17, df = 16, p = 0.10,) (Figure 4), and no significant relationship between Hg levels and distance to the mainland (r^2 0.007, df = 16, p = 0.75) (Figure 5). There is currently insufficient data to determine within-island species relationships.

Table 2. Variation of egg total Hg (wet weight) levels.

Species*	Island	Composite	N	Mean	Min	Max	StdDev
ATPU	Matinicus Rock	No	4.00	0.21	0.08	0.42	0.14
BLGU	Western Island	No	3.00	0.66	0.47	0.78	0.16
COEI	Old Hump	No	1.00	0.20	0.20	0.20	
	Stratton Island	Yes	3.00	0.11	0.10	0.13	0.02
COEI Average			0.14	0.14	0.14	0.14	0.14
COTE	Petit Manan Island	No	11.00	0.19	0.07	0.25	0.07
	Stratton Island	No	4.00	0.12	0.07	0.17	0.04
COTE Average			0.17	0.17	0.17	0.17	0.17
DCCO	Bluff Island	No	4.00	0.12	0.11	0.13	0.01
	Duck Island	Yes	3.00	0.42	0.40	0.45	0.03
	Egg Rock	Yes	3.00	0.30	0.26	0.34	0.04
		No	3.00	0.24	0.23	0.25	0.01
	No Man's Land	Yes	2.00	0.26	0.14	0.38	0.17
		No	3.00	0.30	0.25	0.33	0.04
	Stratton Island	Yes	3.00	0.35	0.31	0.40	0.04
	Sugarloaf Island	Yes	3.00	0.36	0.32	0.42	0.06
		No	4.00	0.24	0.23	0.26	0.02
	Thrumcap Island	Yes	3.00	0.27	0.21	0.36	0.08
		No	12.00	0.28	0.17	0.43	0.09
DCCO Average			0.28	0.28	0.28	0.28	0.28
RAZO	Matinicus Rock	No	7.00	0.14	0.10	0.23	0.05

*ATPU (Atlantic puffin), BLGU (black guillemot), COEI (common eider), COTE (common tern), DCCO (double-crested cormorant), LHSP (Leach's storm-petrel), RAZO (razorbill)

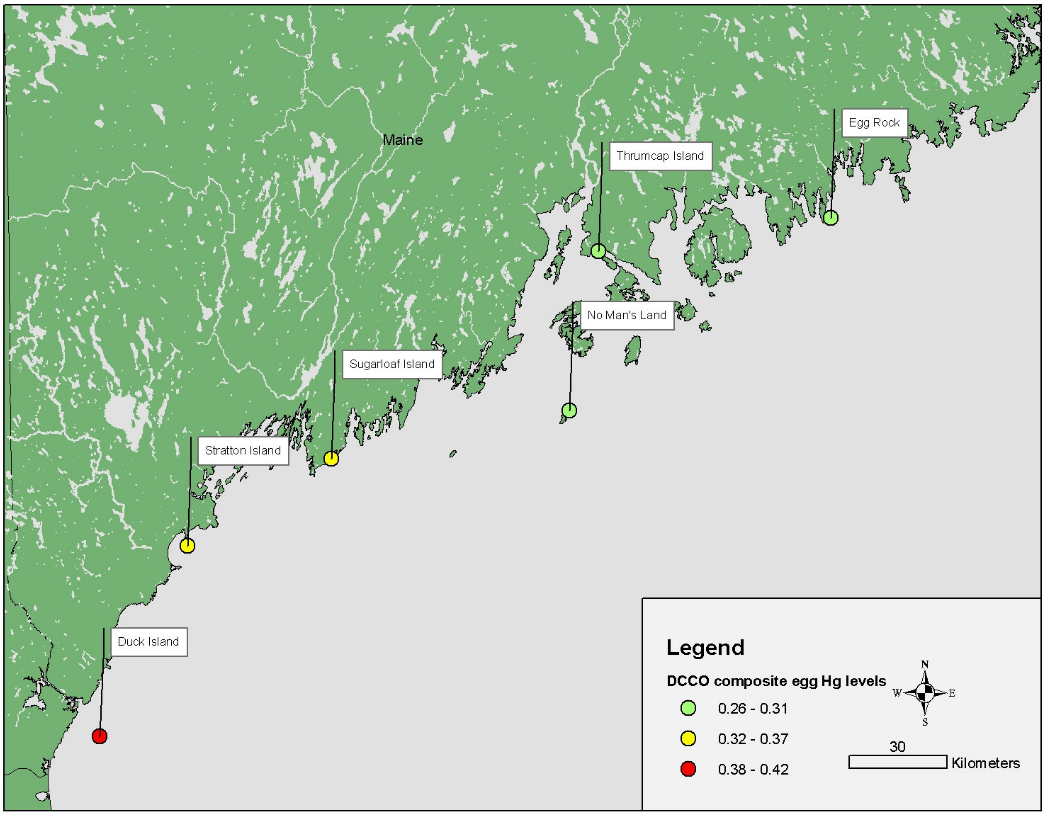

Figure 2. Locations of total Hg (wet weight) levels in egg composites of cormorants.

Table 3. Within-clutch total Hg (wet weight) variation of cormorant eggs.

Island	N	Mean	Min	Max	StdDev
Bluff Island	4.00	0.12	0.11	0.13	0.01
Egg Rock	3.00	0.24	0.23	0.25	0.01
No Man's Land	3.00	0.30	0.25	0.33	0.04
Sugarloaf Island	4.00	0.24	0.23	0.26	0.02
Thrumcap Island	3.00	0.32	0.28	0.40	0.06

Table 4. Within-island total Hg (wet weight) variation of cormorant eggs in composite.

Island	N	Mean	Min	Max	StdDev
Duck Island	3.00	0.42	0.40	0.45	0.03
Egg Rock	3.00	0.30	0.26	0.34	0.04
No Man's Land	2.00	0.26	0.14	0.38	0.17
Stratton Island	3.00	0.35	0.31	0.40	0.04
Sugarloaf Island	3.00	0.36	0.32	0.42	0.06
Thrumcap Island	3.00	0.27	0.21	0.36	0.08

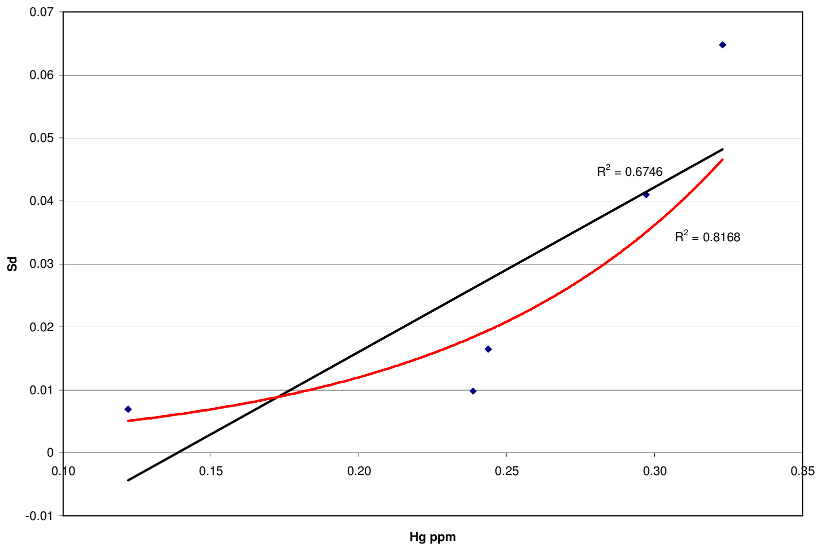

Figure 3. Relationship of mean egg total Hg (wet weight) levels and their variation within a clutch for cormorants.

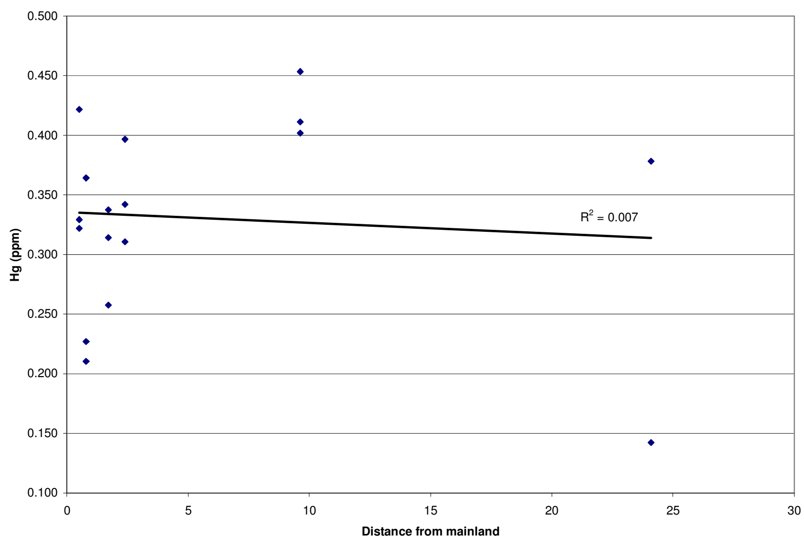

Figure 4. Relationship of cormorant egg total Hg (wet weight) levels and distance from mainland.

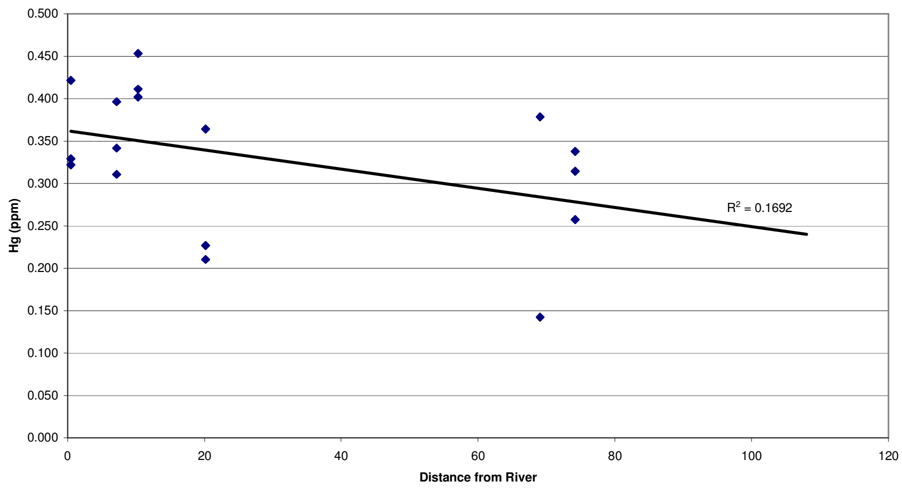

Figure 5. Relationship of cormorant egg composite total Hg (wet weight) levels to distance from river outflow.

The mean juvenile blood levels in descending order are cormorant (0.18 ppm), guillemot (0.11 ppm), puffin (0.05 ppm), petrel (0.03 ppm), and tern (0.03 ppm). The mean adult petrel Hg blood level was 0.62 ppm and using the 0.4 to 1 ratio of egg to blood developed for loons (Evers *et al.* 2005) we modeled an egg equivalent of 0.25 ppm.

Table 5 Blood total Hg (wet weight) levels in target seabirds.

Species*	Island	Age	N	Mean	Min	Max	StdDev
ATPU	Petit Manan Island	Juvenile	6.00	0.05	0.01	0.21	0.08
BLGU	Little Duck	Juvenile	3.00	0.11	0.09	0.13	0.02
COTE	Seavey Island	Juvenile	13.00	0.05	0.02	0.10	0.03
	Stratton Island	Juvenile	11.00	0.02	0.01	0.04	0.01
COTE Average			0.03	0.03	0.03	0.03	0.03
DCCO	Bluff Island	Juvenile	3.00	0.12	0.06	0.19	0.07
	Sugarloaf Island	Juvenile	2.00	0.26	0.15	0.37	0.16
DCCO Average			0.18	0.18	0.18	0.18	0.18
LHSP	Little Duck	Adult	15.00	0.62	0.35	0.89	0.16
		Juvenile	2.00	0.03	0.03	0.04	0.01

*ATPU (Atlantic puffin), BLGU (black guillemot), COTE (common tern), DCCO (double-crested cormorant), LHSP (Leach's storm-petrel)

Discussion

The results from this pilot study indicate that three species are best suited as bioindicators of marine Hg levels: guillemot, cormorants, and petrel. These species have multiple attributes that lend themselves as bioindicators of Hg and other contaminants: (1) wide distribution in the Gulf of Maine, (2) abundance, (3) represent different foraging guilds, (4) feed in geographically distinct areas, (5) often found breeding on the same site, and (6) have Hg levels higher than other Gulf of Maine seabirds.

Eggs

With the exception of the guillemot egg, total Hg levels (seabirds egg Hg levels are >90% MeHg; Fimi) not exceed established thresholds of 0.5 – 2.0 ppm, indicating the Maine seabirds are not accumulating Hg levels that would reduce egg viability, hatch ability, embryo survival, and chick survival in nonmarine birds (Thompson 1996; Henny *et al*. 2002). Guillemots, puffins, and cormorants were higher relative to terns, razorbills, and common eiders. This difference between these two groups is likely a result of their different feeding strategies and feeding at different trophic levels. Puffin levels compare directly to the 30-year Canadian Wildlife Service study that has documented a temporal increase in Hg levels. The mean value (0.21 ppm) observed in this study is nearly identical to puffin eggs collected in the Bay of Fundy (0.20 ppm) and lower than those in Newfoundland (0.38 ppm) (Burgess and Baune 2001).

Although our sample of guillemot eggs were limited to one site and had a small samples size (n = 3), their highest levels were more than twice that of the highest cormorant on a nearby island (Thrumcap Island, 6km away). This significant difference may be associated with the guillemot's benthic foraging strategy, which is primarily composed of rock gunnels (*Pholus gunnellus*)(Butler and Buckley, 2002). The gunnels may have Hg levels higher than similarly sized mid-water fish because they are benthic feeding organisms (Bigelow and Schroeder 2002), which could better relate to more biologically available Hg. Although other studies measured Hg levels in other tissue types, making direct comparison difficult, guillemots had one of the lowest levels relative to fulmar, albatross, skua, and gull species in Scotland (Thompson et al, 1990), were similar to other alcids along the British Coast (Dale and Baxter 1973), and were similar to gulls in Scotland (Furness *et al.*, 1995). Since guillemots tend not to have the highest levels relative to other seabirds in other studies, our results suggest that Hg levels may be elevated in the coastal Maine benthic ecosystem relative to other regions. This conclusion is supported by the analysis of four guillemot eggs on Petit Manan that had a mean Hg fresh wet weight of 0.31, nearly twice that of the eggs of six other species (Mierzykowski *et al.*, 2005).

With the geographically diverse and robust cormorant sample size, we were able to investigate how mercury levels were affected by difference in distance from the mainland, distance from major river outflows, inter- and intra-island variation, and intra-clutch variation. The cormorant Hg levels fell within the 30-year range seen in the Bay of Fundy and the St. Lawrence Estuary (Burgess and Braune, 2001).

We expected that offshore islands would have lower Hg levels as they would be further from coastal sources, but we found no significant correlation, suggesting no difference between inshore and offshore sites. However, the distance from large river outflows showed a trend, suggesting that Hg levels are higher closer to the rivers. This indicates that river deltas may have higher Hg levels than other areas of the coast and perhaps explains why Duck, Stratton, and Sugarloaf islands—close to large rivers—had higher Hg levels than the other islands.

When interpreting egg Hg levels, an important confounding variable is within-clutch variation. Generally the first laid egg has the highest Hg levels and the last the lowest (Evers *et al.*, 2005). Our analysis clearly shows little within clutch variation, signifying that in future studies we can analyze one egg from a clutch and accurately characterize the Hg level for the female that laid the egg. We did find however, that as the Hg increases, so does the intra-clutch variation, indicating that in a known contaminated site that a full clutch analysis is necessary. These results are supported by a multi-species study that found 89% of the within-clutch variance could be explained by the Hg level (Goodale et al, in preparation).

Another factor critical to research design is within-colony variation, which determines the number of samples needed from each site. Similar to within-clutch variation, we found little within-colony Hg variation in cormorant eggs. However, within colony variation would likely follow the same pattern as intra-clutch variation, exhibiting an increase in standard deviation with an increase in Hg level. Consequently, future studies should first conduct a pilot study to determine general Hg levels and if they fall below the effects threshold of 1.3 ppm wet weight for piscivorous birds, then 1-3 composite samples would be sufficient to characterize a site (Goodale *et al.*, in preparation).

Blood

The Hg blood levels of juveniles followed similar patterns as the eggs with cormorants and guillemots having the highest levels and the terns, puffin, and petrels having the lowest. However, because of small sample sizes and differences in the pharmacokinetics among species related to molt, it is difficult to draw conclusions.

The adult petrel blood data from Little Duck revealed a significant range from 15 birds caught in one evening (Table 5). This contrasted with our predication of little variation because while handling the birds we recorded the food items vomited by the birds, which were for all individuals was euphausiids (krill). This individual variation in Hg levels indicates potential differences between sex, age, and foraging location. Additionally, because some of the Hg levels were nearing 1.0 ppm, a level for cause of concern for birds foraging on invertebrates, further efforts are needed. Results from other studies have documented a significant Hg increase in this species (Burgess and Braune, 2001).

Future study

This pilot study has revealed a number of key areas where further study is need. In the Gulf of Maine additional sampling is need in the following areas: guillemot eggs (coast wide) and petrel eggs (coast wide); blood of adult seabirds; and Hg levels rock gunnels and euphausiids. Moreover, systematic within-island sampling is needed to determine between species difference and an intensive adult petrel study with know age and sex birds that tests for both Hg as well as stable isotopes to provide insight into variation in Hg levels. Ultimately, we contend that because of their offshore feeding habits, Leach's storm-petrel is one of the best indicators of circulating global Hg levels and related deposition.

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