Evaluating exposure of Maine's Bald Eagle population to Mercury: assessing impacts on productivity and spatial exposure patterns.

(Report BRI 2005-08)

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(REPORT BRI – 2005-08)

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1.0 Executive Summary

This report summarizes year one findings from an ongoing eagle mercury monitoring and impacts study supported by a combination of non-profit (BioDiversity Research Institute), state (Maine Dept. of Inland Fisheries and Wildlife, Maine Dept. of Environmental Protection), federal (US Fish and Wildlife Service) and industry (FPL Energy Maine Hydro) collaborators. Findings and interpretations are still preliminary and will be strengthened by additional and repeated sampling in 2005-2006.

We sampled blood from freshwater-based Bald Eagle (*Haliaeetus leuccocephalus*) nestlings in Maine (2001-2004) to determine dietary exposure to mercury (Hg) and to assess if mercury exposure might be negatively impacting eagle productivity in Maine. We additionally collected and analyzed Hg in addled eggs and shed adult feathers to evaluate Hg exposure in adult eagles. Nestling blood Hg exposure was higher in Maine than most other bald eagle populations sampled in the US. The few populations displaying higher levels than those in Maine were generally attributed to elevated exposure related to a variety of anthropogenic activities (i.e., dredging, mining, hydroelectric dams) in areas with naturally abundant mercury in parent material and sediments.

Maine nestling blood Hg concentrations were significantly higher in lacustrine habitats (0.57 ± 0.23 ppm) than riverine habitats (0.41 ± 0.23 ppm). Mercury bioavailability in riverine and lacustrine systems as indicated by eagle nestling blood does not appear to have declined since 1991-1992; levels in riverine habitats may have increased. We found evidence of significant correlations between nestling mercury and site-specific eagle productivity; significant relationships existed between nestling blood Hg exposure and mean productivity over 3, 5, and 10-year- intervals.

Analysis of adult feathers suggests that adult eagles in Maine, especially those in lacustrine habitats (41.0 ± 21.8ppm), are highly exposed to Hg in comparison to other populations. Mercury concentrations in eagle feathers collected at lacustrine-based nests were higher than all US comparisons available, and were most comparable to a site in British Columbia associated with a mercury mine. A substantial portion of feather Hg values in our study were within the exposure range similar to levels found in Sweden in the 1940s due to the broad use of alkylmercuric compounds in agriculture. The mean mercury concentration in seven eagle eggs was 0.47 ± 0.25 ppm. Egg Hg concentrations from 2004 do not indicate that Hg bioavailability has decreased since sampling in the early 1970s. All eagle tissues sampled in this study similarly indicate that Maine contains higher levels of bioavailable Hg in comparison to most other regions in the U.S. Short-term growth of eagle nesting numbers inland is not grounds to speculate that mercury contamination is not a long-term limiting factor for eagle recovery in interior Maine.

Exposure impact thresholds for eagles are unreported, however relationships between mercury exposure and productivity in this study suggest that Maine eagles are within the range of impacts. Nestling blood profiles indicate that between 19% and 29% of Maine's eagle population contains elevated levels of mercury. Forty-three percent of collected eggs were elevated (>0.5), while 66% of adult feathers were >20 ppm, a level often associated with toxic effects. Thirty-eight percent of eagle feathers were >40 ppm. Adult and nestling exposure displayed occasional differences in spatial exposure patterns, and provide different insights into population exposure. Mercury exposure patterns in eagles were often consistent with patterns observed in Common Loons despite dietary differences. Bald Eagle nestling blood, adult feathers, and eggs are suitable monitors of spatial and temporal patterns of mercury exposure. Recommendations for further study and monitoring are provided.

Research efforts are closely coordinated with biologists from the Maine Department of Inland Fisheries and Wildlife (MDIFW) and U.S. Fish and Wildlife Service (USFWS) that have partnered throughout recovery efforts for Bald Eagles in Maine since 1976. Primary field investigators for this mercury study are affiliated with BioDiversity Research Institiute (BRI) and Florida Power and Light Energy Maine Hydro (FPLE).

2.0 Introduction

Bald Eagle (*Haliaeetus leucocephalus*) populations became locally extirpated thoughout much of North America during the mid 1900s due to human persecution, habitat loss, and perhaps most notably, the impacts of DDT (Buehler 2000). Subsequent legislation banning the use of DDT, and legal protection for eagles and their habitats has resulted in strong population recoveries in many North American populations to the extent that the species is being considered for removal from Endangered Species List (Jody Millar, USFWS, pers. comm.). Population recoveries are not uniform throughout the U.S, however, and contaminants are considered a primary cause for low productivity in many regions (Anthony et al. 1993, Bowerman et al. 2002). Some local populations in the Midwest are impacted by persistent residues of organochlorine compounds (i.e., Great Lakes, Columbia River Estuary), the cause for lowered productivity in Maine has remained largely unexplained. Numerous studies demonstrating that fish and piscivorous wildlife in Maine commonly display mercury levels exceeding those associated with reproductive and behavioral impairment warrant investigations into its effects on Bald Eagles.

Previous studies have documented particularly elevated mercury levels in Maine's freshwater-feeding eagle population, often surpassing levels in eggs (Wiemeyer et al. 1984, 1993) and nestling blood (Welch 1994, Evers et al. 2005) found elsewhere in the U.S and many populations in Canada. No studies, however, have been able to evaluate the effects of Hg on eagles due to (1) a general emphasis of most studies on marine populations, which display different feeding habits and lower exposure to mercury; (2) higher levels of confounding contaminants (i.e., DDE, PCBs) in most sampled populations which likely "mask" potential negative effects; (3) a low variability in exposure levels for the majority of freshwater-feeding eagle populations in North America, and (4) limited sample sizes previously available from sparse eagle numbers in freshwater habitats. Lacustrine eagle populations in Maine may represent the only U.S. eagle population in which mercury impacts can be evaluated since exposure levels are highly variable and exposure to other contaminants can be avoided (Welch 1994). Lastly, as this study and others demonstrate, eagles can be effectively used as long-term monitors of contaminant trends in aquatic ecosystems (Bowerman et al. 2002, Roe 2004). This study benefits from a rare opportunity to compare with sympatric populations Common Loons of known exposure and risk.

3.0 Purpose of Study

3.1. Determine current dietary mercury exposure of freshwater-feeding bald eagle nestlings in Maine.

3.2. Determine net mercury residues of freshwater-feeding bald eagle adults in Maine.

3.3. Determine if mercury exposure might be limiting the recovery of Maine's eagle population by analyzing relationships between dietary exposure and territory productivity.

3.4. Evaluate temporal and spatial trends of mercury among freshwater-feeding bald eagles in Maine.

4.0 Methods

4.1 Eagle Productivity Surveys

Seasonal nest occupancy and reproductive status was documented through ongoing aerial surveys using fixed-wing aircraft conducted by MDIFW and USFWS biologists (MDIFW 2004). Surveys of traditional nests and searches for new locations began in late-March / early April to determine nest occupancy and breeding activity. Interim checks of occupied nests during May identified nests with successful hatching, estimates of eaglet ages, and occasional encounters with addled eggs. Active nests were surveyed again in June/July to determine territory productivity (number chicks fledged / occupied nests). Older eaglets counted during late-season surveys are assumed to have fledged. Productivity summaries for the Maine eagle population can be found in MDIFW (2004).

4.2 Nestling Mercury exposure

Field Sampling. Biologists from BRI and FPLE Maine Hydro climbed Bald Eagle nest trees by rope and spike methods. Five to eight week-old eaglets from each nest were placed separately into a canvas bag and lowered to the ground for processing and banding. Blood was taken from the brachial vein of each eaglet (7-10 mL) using 23 ¾" butterfly needles attached to heparinized evacuated test tubes. Samples were labeled and placed into protective cases in a cooler, and were frozen within 10 hrs. Eaglets were weighed, and morphometrics were taken (bill length, culmen, footpad length, tarsus width, eighth primary length) and were used to determine nestling and sex following methods described in Bortolloti (1984). Prey remains were collected from within and below nests to gain insights on dietary emphasis and trophic level. Sampling efforts were not random and were prioritized to: a) obtain 2-3 nests per watershed, b) sample regions/watersheds with previously undocumented mercury exposure in previous eagle studies, and c) obtain samples in regions where exposure has been previously estimated in loons.

Blood Analyses. In an attempt to standardize chick size and age among sampled eaglets, we selected the oldest / largest chick from each nest to represent each territory. Nests sampled in multiple years were averaged. We present information on eaglet exposure using three different blood exposure measures (see "Blood Hg profiles" section in discussion): (a) blood Hg (no index), (b) Hg/age in days, and (c) Hg/ weight in grams. All measures will be used in statistical analyses, however only non-indexed blood will be compared to literature and will be the basis for discussions.

4.3 Adult Eagle Exposure

Shed adult feathers (mostly primaries, but also secondary tail,and body) were collected opportunistically from within and below eagle nests to gain insights on adult Hg exposure as in Bowerman et al. (1994) and Evans (1993). One whole feather in good condition was selected for analysis from each territory, others were archived for later analysis. Shed feathers were prioritized for analysis in the following order: primaries, secondaries, tail, and other (i.e., body). Unhatched or abandoned eggs discovered during aerial surveys or eaglet sampling visits were collected opportunistically from all nests.

4.4 Relationships between Eagle Productivity and Mercury Exposure

We analyzed relationships between eagle productivity over 3-year (2003-05), 5-year (2001-05), and 10-year (1996-2005) intervals with mercury exposure for all tissues sampled (e.g., eaglet blood, adult feather, egg). Eagle productivity is defined as the number of young fledged per occupied nest. Eagle territories/nests were considered occupied if a pair of eagles was present within the territory during aerial surveys and/or active nesting was documented by observations of nestling eaglets, eggs, shell fragments, or an adult eagle in incubation posture. We log-transformed non-normal datasets when necessary and analyzed relationships with productivity using a Spearman's Rank Correlation.

4.5 Laboratory Analyses

Eaglet blood samples and egg aliquots were homogenized and analyzed for total Hg using Cold Vapor Atomic Absorption (CVAA; see Evers et al. 2005 and Mierzykowski and Carr 2002 for details) at the Texas A & M Trace Element Research Laboratory (TERL), College Station, Texas, University of Texas, under the supervision of Dr. Bob Taylor. Adult eagle feathers were analyzed using DMA (Direct Mercury Analysis) at the Savannah River Ecology Laboratory, Alken, SC, University of Georgia, under the supervision of Dr. Christopher Romanek. All feathers were cleaned prior to analysis. We analyzed the distal 5 cm of one shed feather per territory as in studies by Evans (1993) and Bowerman et al. (1994).

5.0 Results and Discussion

5.1 Eaglet Sampling Efforts

We sampled 82 nestling eagles from 56 nests in Maine during 2004 sampling visits (Table 1). We obtained blood samples from approximately 60% of the available sampling opportunities from freshwater Maine habitats during the 2004 season. Sixty-three different nesting territories have been sampled in Maine over the 2001-2004 period (Figure 1).

Two key sampling criteria were employed in 2004 field studies. First, samples were obtained at all sites (100%) with eaglets in freshwater habitats where previous baselines on dietary mercury were available for temporal comparisons (Welch 1994, BRI unpubl. data). Secondly, sampling was distributed as equitably as possible over all major watersheds in Maine. At least 60% of candidate nests were sampled in all primary hydrology units except for the Saint John River watershed (29%) in northernmost Maine and "Downeast" river basins (33%) in eastern coastal Maine. Sampling intensity was 100% in both the "Southern coastal" drainages and the Androscoggin River watershed where previous Hg baselines are scant.

Bald eagles are a sensitivity indicator of Hg in aquatic food webs, and sampling opportunities have notably improved with expansion of the breeding population across interior Maine. Sample stratification by subdrainages is still desirable but a single year offers few options to do so except in large watersheds like the Penobscot River and Kennebec River.

Table 1. Sample sizes of Bald Eagle individuals and nests banded/sampled, 2001-2004.

Year	Banded	Sampled	No. nests
2001	10	10	5
2002	8	7	5
2003	9	9	7
2004	86	82	56
Total	**113**	**108**	**73***

* Represents nest-years due to repeat sampling at nest sites. Nests in NH and ME have been sampled in multiple years (6 Maine nests sampled twice, 2 Maine nests sampled three times). Nests were also sampled in MA (n = 3 nests 2004 only); NH, n = 3 nests, 2001-2004).

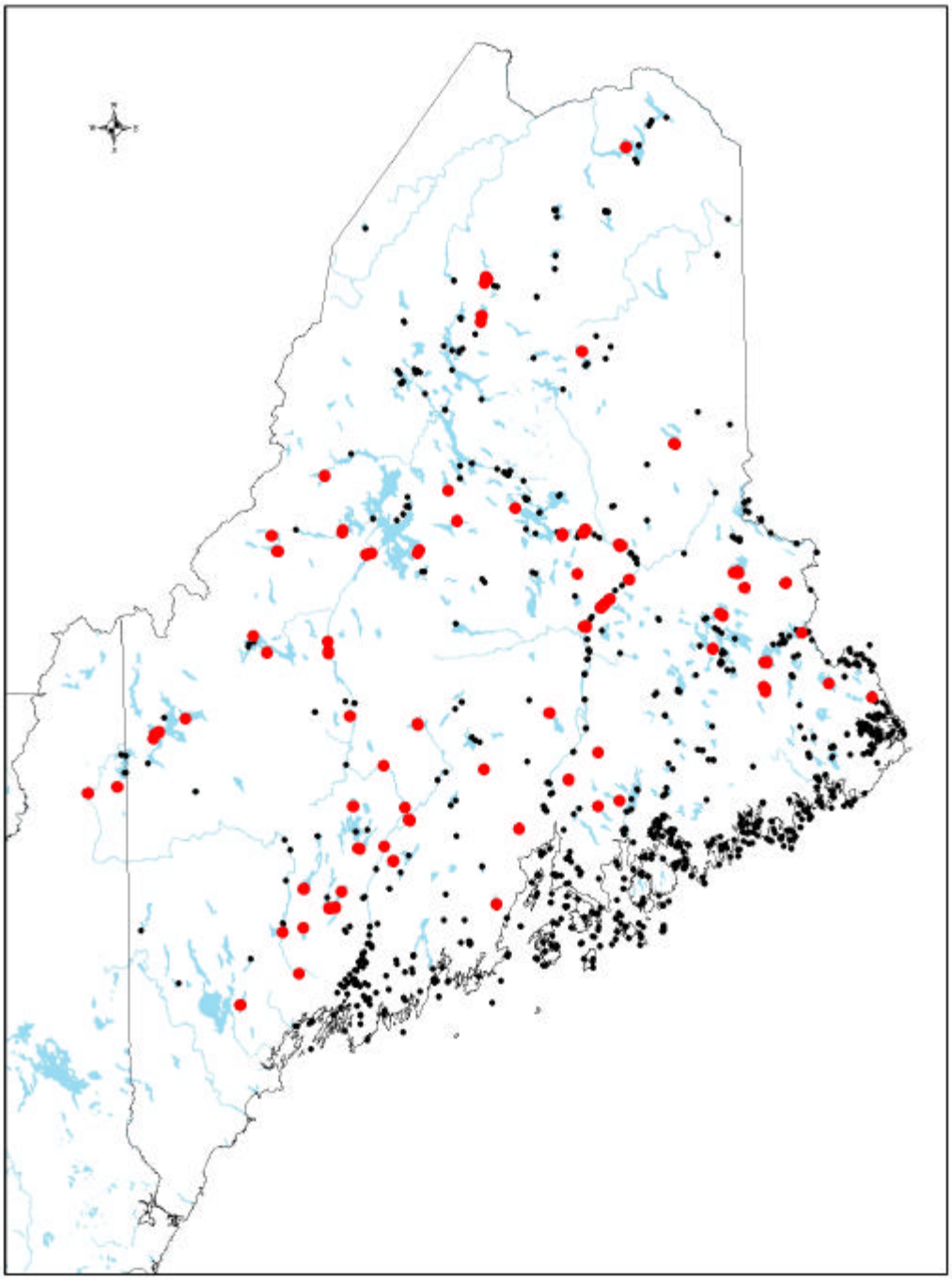

Figure 1. Bald Eagle nest sites in Maine sampled in 2001-2004.

Small black dots represent Maine nest sites, large red dots represent those sampled during 2001-2004. Nest site information courtesy of Maine Dept. Inland Fisheries and Wildlife.

5.2 Eaglet Mercury Exposure

Habitat Differences: We found significant differences in eaglet Hg exposure between lacustrine and riverine habitats using all three blood exposure profiles (blood Hg [no index], Hg/age, and Hg/wt) (Table 2). These differences in eaglet mercury exposure by habitat type are consistent with those reported by Welch (1994): lacustrine > riverine > estuarine > marine.

Table 2. Mercury exposure (ppm, ww) for Maine eaglets in two habitat types using three different exposure indicators.

	Mercury exposure profile[a]		
Habitat type	Blood Hg [b]	Hg / age	Hg / weight
Lacustrine	0.57 ± 0.23 (48)	1.55 ± 0.77 (46)	0.15 ± 0.06 (48)
Riverine	0.41 ± 0.23 (15)	0.97 ± 0.44 (15)	0.10 ± 0.06 (15)
BOTH	0.53 ± 0.23 (63)	1.41 ± 0.76 (61)	0.13 ± 0.067 (63)

[a] Means are presented ± SD (n). All means within columns were significantly different between habitat types at $\alpha = 0.05$. Older siblings were used for analyses in an attempt to standardize chick age; siblings from multiple years were averaged/territory. Sample sizes may differ between indices due to absence of age (8th primary, culmen) or weight data from sampled individuals.
[b] No index, blood Hg, (ww).

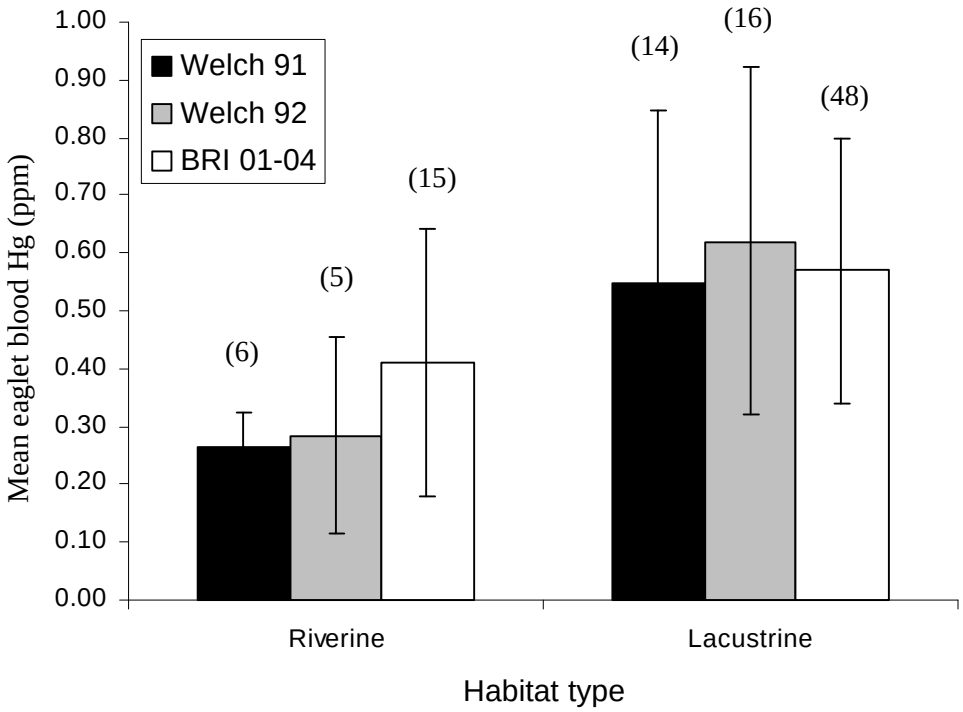

Figure 2. Mercury exposure for eagle nestlings sampled in riverine and lacustrine habitats, 1991, 1992, and 2001-2004.

Mean mercury exposure ± SD (sample sizes in parentheses) reported in Bald Eagle nestling blood sampled in riverine and lacustrine habitats. Findings presented from Welch (1994) (Welch 1991 and 1992) and this study (BRI 2001-2004). Some individual nests in Welch (1994) were sampled in both 1991 and 1992 (n=5, riverine, n=6 lacustrine) and are represented in means for both years. Exposure levels for 2001-2004 nests sampled in multiple years were averaged within territories. Two riverine nests and 10 lacustrine nests sampled by Welch (1994) during 1991 – 1992 were sampled during 2001-2004.

Riverine: Mean mercury exposure in riverine habitats in our study during 2001-2004 (0.41 ± 0.23 ppm) tended to be higher than those reported by Welch (1994) during 1991 (0.27 ± 0.06) and 1992 (0.28 ± 0.17). These findings suggest that mercury bioavailability has not decreased in riverine habitats during 2001-2004 in comparison to 1991-1992, and may have increased. Evaluations of temporal trends in mercury bioavailability, however, are limited by sample size and differences in sampling sites.

Lacustrine: Mean mercury exposure in lacustrine habitats in our study during 2001-2004 (0.57 ± 0.23 ppm) were similar those reported by Welch (1994) during 1991 (0.55 ± 0.30) and 1992 (0.62 ± 0.30). These findings suggest that mercury bioavailability has not declined in lacustrine habitats since the 1991-1992 period.

Biologists remain concerned that there is no evidence of declining exposure to dietary mercury among nestling bald eagles raised at freshwater habitat in Maine during the last 10 – 13 years. Short-term growth of eagle nesting numbers inland is not grounds to speculate that mercury contamination is not a long-term limiting factor for eagle recovery in interior Maine.

5.3 Comparison Populations - Eaglet Blood

Eagles. Blood mercury exposure levels for individual Maine eaglets sampled in our study ranged from 0.10 ppm to 1.20 ppm (0.57 ppm lacustrine, 0.41 ppm riverine; Table 2). These levels are elevated in comparison to several comparison populations. Wiemeyer et al. (1989) reported mean blood exposure levels from five captive eagles as 0.23 ppm (range 0.17 - 0.31 ppm) for background exposure level comparisons. Exposure levels for Maine freshwater-feeding nestlings were higher than populations in Florida (range 0.02 to 0.61 ppm, mean 0.13 ppm on eutrophic lakes, 0.20 ppm on mesotrophic lakes) (Wood et al. 1996). Wood et al. (1996) suggested that exposure levels in Florida eagles were similar to or lower than many comparison populations, but some individuals were within the exposure range associated with behavioral and reproductive impacts.

Mean eagle nestling mercury exposure in our study was higher than levels reported for populations in Washington State (mean 0.23 ppm, range 0.075 - 0.65 ppm; Wiemeyer et al. 1989). Other studies using nestling feathers indicate higher mercury exposure in Maine in comparison to the Great Lakes (Welch 1994). Mean eagle nestling mercury exposure in our study area was similar to levels found on Pinchi Lake, British Columbia, Canada (0.57 ppm), a site associated with mercury mining operations. No impacts on productivity were found in that study (Weech 2003). Anthony et al. (1993) reported 0.47 ppm Hg (range 0.19 – 1.40, n = 15) in eagle nestling blood from the Columbia River Estuary, a population displaying significantly elevated exposure to numerous other contaminants (PCBs, DDE, dioxin), many of which are blamed for low eagle productivity (0.56 young / occupied nest) in the region. Hydroelectric dams and dredged river sediments were suspected as contaminant sources in that region (Anthony et al. 1993).

Maine nestling eagles displayed lower mercury exposure than those in southcentral Oregon (mean 1.2 ppm, range <detection limit – 4.20), a population thought to be highly exposed to mercury due to a natural "mercuriferous belt" extending throughout the western U.S. states and British Columbia (Wiemeyer et al. 1989). Authors of that study indicated that exposure levels for some individuals in their study were cause for concern, yet reproduction for this population appeared to be normal (Frenzel 1985).

Weech (2003) found a strong relationship between nestling blood and adult blood mercury concentrations from birds at the same nest ($R^2 = 0.91$, $P = 0.004$, $n = 7$). Wood et al. (1996) found similar relationships between adult and nestling feathers. These findings support the use of nestlings,

which are much easier to capture than adults, as surrogates for adult dietary exposure. Nestling blood represents short-term dietary exposure, however, and body burdens will very likely increase after the completion of feather molt (Fournier et al. 2002). Adults and subadults are consistently reported to display higher blood mercury exposure than nestlings (Wiemeyer et al. 1989, Anthony et al. 1993, Wood et al. 1996, Weech 2003).

Other species. DesGranges et al. (1998) reported blood mercury concentrations for Osprey (*Pandion haliaetus*) nestlings as 0.39 ± 0.24 ppm on natural lakes (n = 60) and 1.94 ± 0.91 on reservoirs (n = 78) in James Bay and Hudson Bay, Quebec. These authors reported nestlings on reservoirs to be 6.5 times higher on reservoirs than natural lakes, but did not find evidence of exposure impacts on reproductive success. Evers et al. (1998) reported blood exposure levels for adult and juvenile Common Loons (*Gavia immer*) throughout North America. Exposure levels for juveniles, the most comparable to nestling eagles, were 0.07 ± 0.06 ppm in Alaska (lowest exposure in their study); levels varied widely in the Great Lakes (range 0.06 ± 0.01 to 0.20 ± 0.13 ppm), and were highest in the northeast (0.32 ± 0.19 ppm) and the Canadian Maritimes (0.35 ± 0.16 ppm). Loon populations in the northeast are exposed to levels of methylmercury considered elevated (>3.0 ppm in adults Burgess et al. 1998, Evers et al. 2004) and are associated with lower tendencies to incubate nests, and successfully hatch and fledge young in comparison to populations with low exposure levels (Evers et al. 2004). Direct comparisons of exposure levels between loons and eagles are complex, however, considering the differences in foraging habits, diet and trophic level between the two species. These differences would expectedly result in a wider variability in eaglet mercury exposure, especially considering the opportunistic foraging strategies and larger foraging areas for eagles. Since eagles tending nestlings often feed their young prey items caught from a perch near the nest (C. Todd, MDIFW, pers. com.), and lacustrine and riverine eagles' diets consist primarily of fish (Todd et al. 1982), eaglet mercury exposure likely often represents exposure of the aquatic foodweb located near the nest. Blood from other piscivorous birds such as Osprey and Common Loons are often highly correlated with mercury levels found in fish (DesGranges et al. 1998, Evers et al. 2004), demonstrating their effective use as contaminant bioindicators.

Indexing Blood Hg. Comparisons of mercury exposure in eaglets will be biased by differences in chick weight and/or age, in addition to other factors (e.g., recent dietary emphasis, extent of feather development). In other species, an index for mercury exposure has been used to more adequately allow for comparison between nestlings of different ages (and therefore size and feather development). Evers et al. 2004 addressed this issue in juvenile Common Loons by indexing Hg concentrations (ppm, ww) by chick weight. Studies with wading birds in Florida indexed blood mercury concentrations using culmen based on relationships developed in laboratory dosing experiments (Spaulding et al. 2000, Heath and Frederick 2005). DesGranges et al. (1998) significantly improved relationships between Osprey nestling blood and feather after accounting for age. No similar Hg index has been developed for eaglets despite knowledge of chick weights and an ability to accurately estimate chick age based on morphometrics (Bortolotti 1984). The need for such an index is supported by field- and laboratory-based findings showing that blood and feather mercury concentrations change in relation to physiological processes, especially molt (Welch 1994, Fournier et al. 2002). Welch (1994) found that eaglet feathers were 30% lower at nine weeks of age in comparison to samples obtained from the same individuals sampled three weeks earlier. Sibling eaglets from the same nest have not been found to have significantly different mercury levels (e.g., Welch 1994), prompting many to either use one chick to represent exposure at each nest or average siblings within a territory (Welch 1994). Despite the lack of a significant difference, blood mercury can vary substantially between siblings, and confound interpretations.

5.4 Relationships between eaglet mercury exposure and productivity

Eaglet Blood. We found significant correlations between mean 3, 5, and 10-year productivity (young fledged / occupied nest) and eaglet blood mercury exposure levels (Table 3, Figure 3). All blood measures indicated significant negative relationships between these two variables. This relationship has not been previously reported in other eagle populations. Since sample size limits some productivity means (e.g., mean territory productivity may be represented by only 1 or two years of nest occupation), data was also analyzed after excluding territories with less than three years nest occupancy. Relationships remained significant in many cases (Table 4); indexes by weight and age appeared to show stronger relationships with mercury and retained significance to a greater extent after reductions in sample size. Eaglet blood mercury (ww, no index) was normally distributed; Hg /age and Hg/weight were not normally distributed and were log-transformed for these analyses.

Table 3. Relationships between 3, 5, and 10-year productivity measures and three different indexes of eaglet blood mercury exposure (Lacustrine and riverine habitats combined).

Hg index	3yr productivity	5yr productivity	10yr productivity
Hg (no index)	r = -0.37 (0.0025)	r = -0.39 (0.0016)[b]	r = -0.35 (0.0046) [a]
log Hg/age	r = -0.48 (<0.0001)[a]	r = -0.50 (<0.0001)[b]	r = -0.38 (0.0025)
log Hg/weight	r = -0.46 (0.0002)[a]	r = -0.45 (0.0002)[a]	r = -0.37 (0.0029) [a]

Spearman's Rho correlation coefficient and significance values (in parentheses) for Hg exposure profiles and 3, 5, and 10-year productivity (young fledged/occupied nest).

[a] Relationships remained significant at P = 0.05 after removing territories not occupied for 3 years.

[b] Relationships remained significant at P = 0.10 after removing territories not occupied for 3 years.

Relationships between mercury exposure and productivity were significantly negatively correlated for lacustrine nests (Table 4). Riverine nests were not significantly correlated to productivity measures but limited by sample size.

Table 4. Relationships between 3, 5, and 10-year productivity measures and three different indexes of eaglet blood mercury exposure (Lacustrine only).

Hg index	3yr productivity	5yr productivity	10yr productivity
Hg (no index)	r = -0.29 (0.044)	r = -0.28 (0.053)	r = -0.22 (0.12)
log Hg/age	r = -0.41 (0.0043)[a]	r = -0.41 (0.0041)[a]	r = -0.25 (0.086)
log Hg/weight	r = -0.40 (0.0044)[a]	r = -0.39 (0.0055)[b]	r = -0.29 (0.048)

Spearman's Rho correlation coefficient and significance values (in parentheses) for Hg exposure profiles and 3, 5, and 10-year productivity (young fledged/occupied nest).

[a] Relationships remained significant at P = 0.05 after removing territories not occupied for 3 years.

[b] Relationships remained significant at P = 0.10 after removing territories not occupied for 3 years.

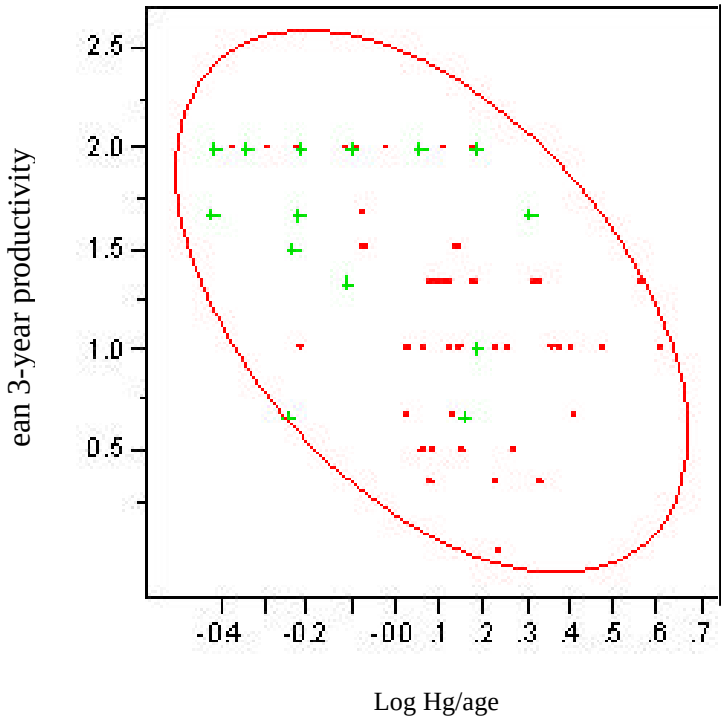

Figure 3. Correlation between an index of eaglet mercury exposure (Log Hg/age) and 3-year territory productivity (chicks fledged/occupied territory).

Red (dots) = lacustrine, green (+'s) = riverine samples. Spearman's Rho = -0.48, $p<0.0001$; 0.95 density ellipse, n=60.

5.5 Adult Exposure - Feather

We collected and analyzed shed adult feathers from 78% (44/56) of eagle territories during the 2004 season (we include one territory feather collected in 2003). Three feathers were from NH, Umbagog Lake was included in Maine comparisons; the other two were used in comparisons. Sixty-eight percent (28) of shed feathers were identified as primaries, 20% (8) as secondaries, 7% (3) as tail, and 4% (2) as other. Feather mercury concentrations varied widely in both habitat types, ranging from 0.94 to 87.4 ppm (fw). Similar to nestling blood exposure levels, adult feathers indicated significantly higher mercury exposure on lacustrine vs. riverine habitats (Table 5).

Table 5. Mercury exposure in adult feathers within two habitat types sampled in Maine.

Habitat type	Adult feather Hg ± SD (n)[a]	Range
Lacustrine	41.0 ± 21.8 (32)	0.94 – 87.4
Riverine	25.0 ± 15.0 (10)	1.4 – 46.7
BOTH	37.3 ± 21.4 (42)	0.94 – 87.4

[a] Means are significantly different (P = 0.035). These analyses include a) Umbagog, NH, and b) two suspicious values. Tomah Stream, (1.43 ppm) was a head feather, which biases comparability with other feather types. Scraggly Lake (0.94 ppm) was conspicuously low (e.g., to near background levels). Exclusion of these two values resulted in means as follows: 42.4± 3.5 (lacustrine, n=31); 27.6± 6.5 (riverine, n = 9) (P = 0.051).

5.6 Comparison Populations - Adult Feather

Adult eagle feathers sampled in riverine and especially lacustrine habitats in Maine are higher than most comparison study populations in the United States (Figure 3). Feathers from captive birds and populations in Alaska are considered to have background levels, and populations in the Great Lakes (mean 21.1 ppm, range: 3.6 – 48 ppm), are considered elevated (Bowerman et al. 1994). Weech (2003) reported adult eagle feather mercury exposure levels in British Colombia, Canada; values ranged from 10.1 to 65.0 ppm (mean = 18.7 ppm, n = 13), with the highest mean levels at a lake site associated with a mercury mine (39.9 ppm).

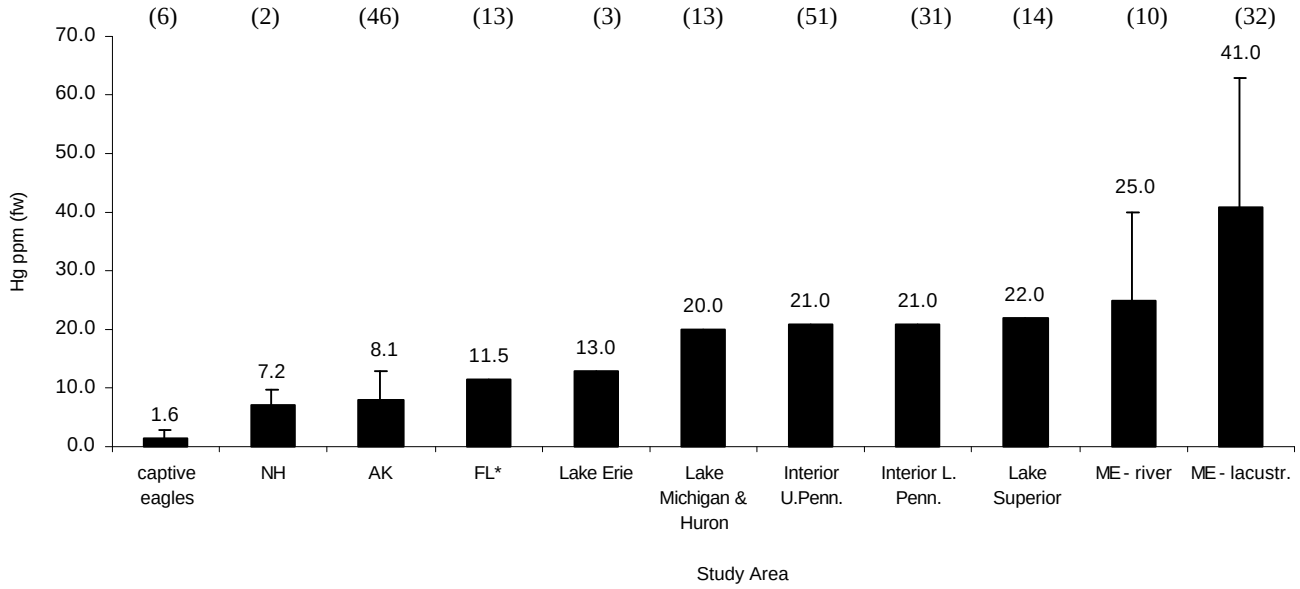

Figure 4. Concentrations of Hg (ppm, fw) in adult Bald Eagle feathers collected in the United States.

Error bars (SD) given when available. Sample sizes in parentheses above bars. Feathers analyzed are primaries, secondaries, and tail in most studies. Comparison populations given in figure include: **Captive** = captive eagles in zoos/wildlife clinics reported in Evans (1993), represent background levels, averaged for this figure, range: < 0.1 – 3.6; **NH** = New Hampshire (BRI unpubl. data), Nubanusit Lake and Wilcox Point (feather collected from perch in winter), range: 5.4 - 9.0, Umbagog Lake (33.4 ppm)included in Maine calculations for this report; **AK** = Alaska (Evans 1993), range: 1 - 20; **FL** = Florida (Wood et al. 1996), range: 2.01-34.7. *Florida study analyzed entire feathers, while other studies presented here analyzed only a portion of the feather (see discussion). All Midwest comparisons from Bowerman et al. (1994): **Lake Erie**, range: 9-19; **Lake Michigan/Huron**: range: 7.2 – 40; **Interior Upper Penninsula**, Michigan, range: 0.2 – 66; **Interior Lower Penninsula**, Michigan, range 6.1-62; **Lake Superior,** Wisconsin, range, 5.9 – 38; **ME river =** Maine riverine (this study), range, 1.4 – 46.7, **ME lacustr.** = Maine lacustrine (this study), range, 0.94 – 87.4 (Table 5).

Mean feather mercury concentrations for Common Loons sampled in New England were 10.2 ± 4.2 ppm (females) and 15.4 ± 5.1 ppm (males) (Evers et al. 1998). Some loon individuals within this population are considered to be at considerable risk from negative impacts of mercury exposure (Evers et al. 2004). DesGranges et al. (1998) reported feather mercury levels in adult Osprey to be highly variable (range = 1.2 – 193 ppm); 16.5 ± 12.8 (n=29) on natural lakes and 58.1 ± 51.3 on reservoirs (n = 31) in James Bay and Hudson Bay, Quebec.

Several studies consider that bird populations exhibiting concentrations > 20 ppm Hg in feathers should be considered for toxic effects (Scheuhammer 1991, Evers et al. 2004). Welch (1994) used this as the highest exposure group for evaluating nestling feather mercury exposure in Maine, as did Evers et al. (1998) for Common Loons. Berg et al. (1966) suggested 60 ppm or less in feathers could cause sterility, but other contaminants were not tested. These concentrations provide a guideline for literature comparisons, however impact thresholds remain unknown for adult or nestling eagle feathers.

Wood et al. (1996) found strong correlations between feather mercury levels in adults and nestlings from the same nest. We did not find such a relationship in our study. Assuming similarly aged populations, this finding suggests that adults in Florida are able to consistently depurate their body burden through natural mechanisms such as the feather molt and demethylation in liver and kidneys to avoid notable bioaccumulation in older individuals. Dietary intake of mercury for adult eagles in Maine likely exceeds the level that natural mechanisms can remove from their systems, placing older individuals on high mercury sites at substantial risk to negative impacts of mercury exposure.

Adult feathers will reflect dietary exposure over the period of feather growth and cumulative body burden of the molting adult. Adult feathers reflected differences in mercury exposure among Great Lakes subregions, following a similar gradient to that observed in fish flesh, supporting their use to monitor Hg exposure in aquatic habitats. Since adult eagles molt their flight feathers on their feathers on breeding grounds during the spring and summer (Buehler 2000), their feathers are more likely to reflect mercury exposure of their breeding grounds in comparison to other species such as loons that undergo a full remigial molt on the ocean (Weech 2003). A variety of factors, however, should be considered when interpreting adult feather mercury values. First, the populations presented in Figure 2 are comparable since they used similar methods of removing and analyzing the distal portion of the feathers as opposed to the entire feather (with the exception of Florida). Caution must be taken in comparing these values to other studies analyzing entire feathers. Many studies suggest that mercury does not vary significantly within individual feathers (Berg et al. 1966, Evans 1993, Dauwe et al. 2003). However, Weech (2003) reported evidence indicating that analysis of only a portion of feathers may overestimate mercury in some cases (This is less likely for the FL population given their low exposure). Second, older individuals, particularly those exposed to elevated mercury levels in prey, will likely display higher mercury levels in feathers due to bioaccumulation (see Evers et al. 1998 and Weech 2003 for cases in loons and eagles). Several adults in this study displayed clearly elevated feather mercury levels (e.g., 85 ppm, Great Moose, nest #231; 61 ppm, Little Sebago, nest #376) while nestling blood indicated low to moderate exposure levels (0.64 ppm and 0.33, respectively). Third, feathers molted early are likely to contain higher levels than those molted late in the season in individuals with elevated body burdens. Since feathers cannot be linked to individual adults within the pair, several feathers may be required to best represent exposure levels for an eagle pair/territory. Several studies have found no significant differences in mercury concentrations among feather types (Evans 1993, Bowerman et al. 1994, Wood et al. 1996). Feather mercury concentrations varied by ± 9.65 ppm SD (tail) to ±15.59 ppm (secondaries) within Great Lakes subregions (Evans 1993). Variation in feather Hg in our study was ±15.0 ppm (riverine) and ± 21.8 (lacustrine) (Table 5). Within-territory variations in feather mercury concentrations are unknown and would aid in future interpretations of adult feather tissues.

We did not find significant relationships between adult feather mercury and non-indexed nestling blood mercury ($r = 0.09$, $p = 0.55$), log Hg / age ($r = 0.044$, $p = 0.79$), or log Hg / weight ($r = 0.02$, 0.89). We did not find significant relationships between adult feather mercury concentrations and 3-year, ($r = 0.21$, $p = 0.18$) 5-year ($r = 0.17$, $p = 0.29$), or 10-year productivity ($r = 0.12$, $p = 0.44$).

5.7 Adult Exposure - Egg

We collected seven unhatched Bald Eagle eggs from six territories. Mean mercury exposure for all eggs was 0.47 ± 0.25 (ppm, fw, adjusted for moisture loss); values ranged from 0.18 to 0.90 (Table 6). Averaging multiple eggs/territory, mean = 0.45 ± 0.26 (n=6). Three eggs (from two territories) out of the seven (43% of eggs) were above the suggested adverse reproductive effect threshold of 0.50 ppm (Wiemeyer et al. 1984, 1993).

Table 6. Mercury concentrations in Bald Eagle eggs collected in Maine, 2004.

Nest Site	Drainage	Nest Location	Township	Hg ppm (fw)[a]
ME 83D	Coastal Lakes & Ponds	Tomah Stream	Codyville Plt	0.18
ME 439A	Penobscot	Pemadumcook Lake	T1 R10	0.29
ME 289C	Penobscot	Dolby Pond	Millinocket	0.30
ME 149	Penobscot	Penobscot River	Chester	0.44
ME 336A1	Coastal Lakes & Ponds	Quantabicook Lake	Searsmont	0.54
ME 336A2	Coastal Lakes & Ponds	Quantabicook Lake	Searsmont	0.68
ME 161A	Coastal Lakes & Ponds	Boyden Lake	Perry	0.90
(7 eggs)		**(6 nests)**	**Mean Hg ± SD:**	**0.47 ± 0.25**

[a] Additional analyses of Organochlorine compounds being conducted by Steve Mierzykowski, USFWS.

We did not find any significant correlations between egg mercury concentrations and 3-year, 5-year, or 10-year territory productivity. Eggs and adult feathers were not significantly correlated ($r = 0.80$, $P>0.05$), however sites where both eggs and feathers were collected were limited ($n = 4$). If both Quantabicook Lake eggs (Table 6) were used as independent samples and paired with the single feather analyzed from that lake (bringing the sample size for the analysis to $n = 5$), the correlation between eggs and feathers increases and becomes significant ($r = 0.89$, $P = 0.04$). In addition to low sample size, undocumented variations in within-territory feather Hg and differences in feather types limit our ability to assess the relationship between eggs and feathers. The only feather available to represent Tomah Stream was a head feather, while most other feathers analyzed were flight feathers. Evans (1993) reported similar feather Hg between body and flight feathers. Due to the ease and low expense involved with opportunistic collections of adult feathers in comparison to that of eggs, this relationship may warrant further exploration.

5.8 Comparison Populations - Egg

Several studies have found significantly higher Hg levels in Bald Eagle eggs from Maine in comparison to other populations in the U.S. Eggs during the early 80s displayed the following Hg levels by state (ppm, fw): 0.06 (OH), 0.07 (Chesapeake Bay), 0.17 (OR), 0.13 (WI), 0.18 (AZ), and 0.41 (ME). Similarly, Evers et al. (2003) reported the highest levels of Hg in loon eggs from Maine (0.91, $n = 186$) and New Hampshire (0.72, $n = 263$) in comparisons among eight U.S. states (other states ranged from 0.25 [AK, $n = 10$] to 0.54 [MI, $n = 24$]). Bioavailability of Hg as indicated by eagle eggs does not appear to be decreasing; Wiemeyer et al. (1993) reported a mean of 0.39 ($n = 7$) in 1974-1979, and a mean of 0.41 ($n = 11$) in 1980-1984. Welch (1994) reported a mean of 0.4 ($n = 7$) in 1991, and Mierzykowski and Carr (2002) reported a mean level of 0.17 ppm ($n = 4$) in 2000.

5.9 Evaluations of Mercury Exposure in Maine's Eagle Population

Threshold levels for mercury impacts on eagles are not clearly documented. Thus, it is difficult to evaluate impacts or risk to populations. Significant negative correlations between eaglet exposure using three blood profile measures in this study and 3, 5, and 10-year productivity strongly suggest that populations in Maine are within the range of exposure impacts. Mercury levels in Maine eagle eggs commonly exceed the adverse reproductive effect level of 0.5 ppm (Wiemeyer et al. 1984). Adult feather levels in our study likely span the threshold for negative impacts given the observed range of our values (<1 ppm to 87 ppm) and suggested thresholds for impact associated with 20 ppm in feathers (Scheuhammer 1991). As in most eagle populations, however, effects of mercury in that study were confounded by exposure to organochlorine compounds. Bald eagles resident at lacustrine territories in Maine are primarily fish eaters and thus less vulnerable to biomagnification of organochlorine contaminants relative to those in riverine and coastal habitats (Welch 1994), and therefore represent a unique population in which impacts of mercury can be assessed.

Evaluating exposure based on nestling blood. We attempted to assess the extent mercury exposure in Maine's nestling and adult eagle populations. Delineations of different mercury exposure groups that follow are performed by evaluating and partitioning the distribution of mercury values in our study population based on a) an equal interval numeric scale; b) published literature values, and c) known mercury exposure levels for sympatric Common Loons. It would be premature to interpret these delineations as definitive mercury threshold impact levels. All three blood Hg profiles were divided into four categories, so that proportions of territories falling within their ranges could be evaluated (Table 7). Wiemeyer et al. (1989) termed nests with non-indexed blood mercury exposure < 0.70 ppm as "low." In cases where both loons and eagles had been sampled sympatrically, approximately 100% (n = 10) of nestlings displaying blood mercury levels 0.70 resided in areas where sampled loons were found to be high (adults, > 3.0 ppm). This exposure level has been consistently linked with negative effects on loon productivity and behavior (Burgess et al. 1998, Evers et al. 2004), providing support for the use of 0.70 ppm to delineate "moderate" and "elevated" groups. Blood Hg / age and blood Hg / weight indexes have no comparisons in literature. We present the proportions of sampled populations falling within lacustrine and riverine habitats below (Tables 8 & 9).

Table 7. Four exposure level categories for three mercury exposure profiles of Bald Eagle nestling blood.

	Mercury exposure profile		
Exposure level	Blood Hg [a]	Hg / age (d)	Hg / weight (g)
Background	0 – 0.39	0 – 0.99	0 – 0.
Moderate	0.40 – 0.69	1.0 – 1.99	0.10 – 0.19
Elevated	*0.70 – 0.99*	*2.0 – 2.99*	*0.20 – 0.29*
Highly Elevated	*1.0*	*3.0*	*0.30*

[a] No index, blood Hg, (ww).

Table 8. Proportion of lacustrine eagle territories falling into different mercury exposure groups.

	Mercury exposure profile		
Exposure level	Blood Hg [a]	Hg / age (d)	Hg / weight (g)
Background	29 (14)	20 (9)	27 (13)
Moderate	42 (20)	57 (26)	54 (26)
Elevated	*25 (12)*	*17 (8)*	*17 (8)*
Highly Elevated	*4 (2)*	*7 (3)*	*2 (1)*
Total elevated:	**29 (14)**	**24 (11)**	**19 (9)**

Three different blood exposure profiles for eagle nestlings are shown. Numbers in parentheses indicate sample size.
[a] No index, blood Hg, (ww).

Twenty-five percent of sampled territories on lacustrine habitats were "elevated," 4 % of territories were considered "highly elevated" according to non-indexed blood measures (Table 8). Blood mercury exposure profiles indicate that between 19% and 29% of eagle territories sampled in lacustrine habitats are exposed to elevated mercury levels.

Table 9. Proportion of riverine eagle territories falling into different mercury exposure groups.

	Mercury exposure profile		
Exposure level	Blood Hg [a]	Hg / age (d)	Hg / weight (g)
Background	67 (10)	60 (9)	60 (9)
Moderate	20 (3)	33 (5)	33 (5)
Elevated	*13 (2)*	*7 (1)*	*7 (1)*
Highly Elevated	*0 (0)*	*0 (0)*	*0 (0)*
Total elevated:	**13 (2)**	**7 (1)**	**7 (1)**

Three different blood exposure profiles for eagle nestlings are shown. Numbers in parentheses indicate sample size.
[a] No index, blood Hg, (ww).

Thirteen percent of eagle nests sampled on riverine habitats were "elevated" (> 0.70 ppm); no riverine nests were placed in the "highly elevated" group. Evaluations of mercury exposure on riverine habitats is limited by sample size due to a greater emphasis on lacustrine habitats in this study. Blood mercury exposure profiles indicate that between 7% and 13% of eagle nests sampled in riverine habitats may contain elevated mercury levels, although evaluations are limited by sample size.

Evaluating adult exposure based on eggs: Eggs are laid in many cases before ice out on many lacustrine sites, and reflect recent dietary exposure and cumulative adult body burden of the laying female. Thus, eggs may not reflect mercury contamination in foodwebs associated with the nest, especially in lacustrine settings. We placed egg samples within four exposure groups (Table 10). Adult mercury exposure based on eggs is limited due to a low sample size. Forty-three percent of eggs analyzed were above the 0.50 ppm level associated with negative impacts (Wiemeyer et al. 1984, 1993). No eggs were above the highly elevated level 1.0 ppm. Of course, egg collections are a very limited, skewed sample and inadequate for speculation on population impacts.

Table 10. Proportion of sampled adult eagle eggs and feathers falling into different mercury exposure ranges.

Adult tissue					
Egg (ppm, ww)			Feather (ppm, fw)		
Exposure level	Exposure range	% (n)	Exposure level	Exposure range	% (n)
Low-moderate	0 – 0.50	57 (4)	Low-moderate	0 – 19.9	24 (10)
Elevated	0.5 – 1.0	43 (3)	*Elevated*	20 – 39.9	38 (16)
Highly elevated	*>1.0*	*0 (0)*	*Highly elevated*	40.0 – 59.9	*17 (7)*
-	-	-	*Very highly elevated*	*> 60*	*21 (9)*

Evaluating adult exposure based on feathers. Proportions of adult feathers falling into exposure level groups are listed in Table 10. Of the 42 adult eagle feathers analyzed for mercury in this study, a total of 66% (n = 32) were 20 ppm, a level a t which toxic effects should be considered (Scheuhammer 1991). Thirty-eight percent (n = 16) of feathers were 40 ppm, 21% (n = 9) were 60 ppm, and 7% (3) were 70 ppm (not shown). Concentrations 60 ppm are uncommonly reported in literature (Burger 1993); most are generally associated with dramatic increases (i.e., 10-20X) in Sweden after application of alkylmercuric compounds on seed dressings in the 1940s (Berg et al. 1966, Westmark et al. 1975,

Burger 1993). Our highest feather values, 85 ppm (Great Moose, ME#231), and 87 ppm (Sysladobsis, ME#200), are remarkably elevated, and should be a cause for concern.

Our analyses indicate that adult eagles are exposed to elevated dietary mercury levels during the period of feather molt. Mercury is likely bioaccumulating in a substantial proportion of the population to a level which outpaces natural mechanisms for excretion or demethylation. Weech (2003) found a roughly 2x increase (10.1 ppm in 2001, 21.9 ppm in 2002) in adult feather mercury concentrations in a recaptured adult eagle from Pinchi Lake, a site with mean adult feather concentrations similar to our lacustrine group. Recaptured adult Common Loons similarly showed increasing feather mercury concentrations (Evers et al. 1998, Evers et al. 2004). Accumulation rates in adult eagles in our population are unknown.

5.10 Spatial Patterns of Hg exposure in Maine Eagles

Bald eagle nestling blood reflects spatial Hg exposure patterns in freshwater aquatic ecosystems throughout Maine (Figure 5). Bald Eagle sampling indicates a general agreement with mercury exposure patterns found in fish and various piscivores in Maine (Evers et al. 2004, BRI unpubl. data). Spatial patterns of mercury exposure in adult eagle feathers were not always consistent with indications of short-term dietary exposure indicated by nestlings (Figure 6), demonstrating that adults with elevated body burdens may be residing on waterbodies that might otherwise be considered at low risk using other measures. Exposure levels in eggs may be influenced by Hg in foodwebs further from the nest if laid before ice out on adjacent waterbodies. As demonstrated by the lack of correlation between adult feather Hg and nestling blood Hg, these two measures may differ in terms of indicating exposure at some sites; nestling blood provides a measure of recent dietary exposure most likely related to the local foodweb, while eggs and feathers additionally reflect the cumulative body burdens of adults.

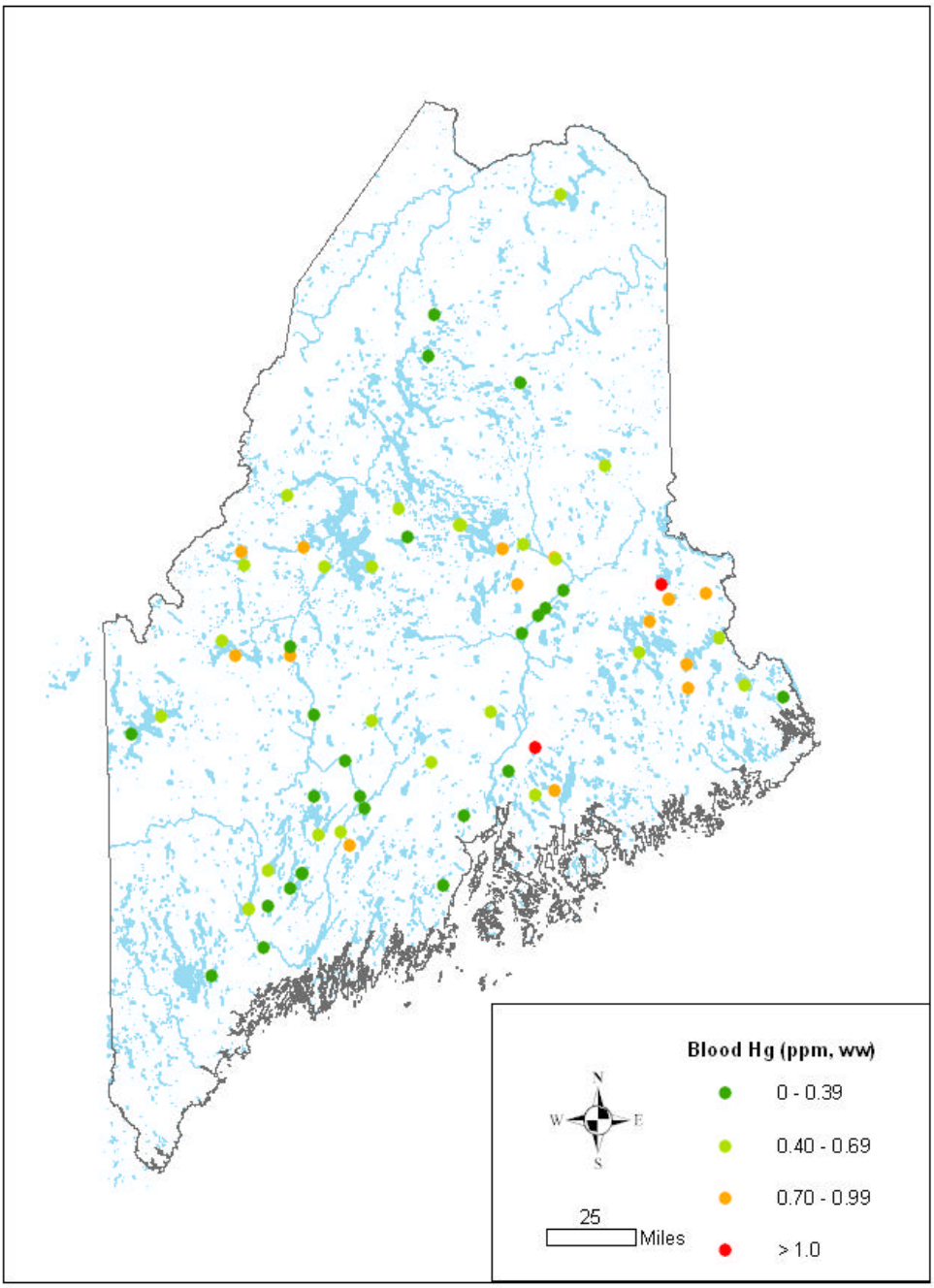

Figure 5. Blood mercury exposure in Maine Bald Eagle nestlings, 2001-2004.

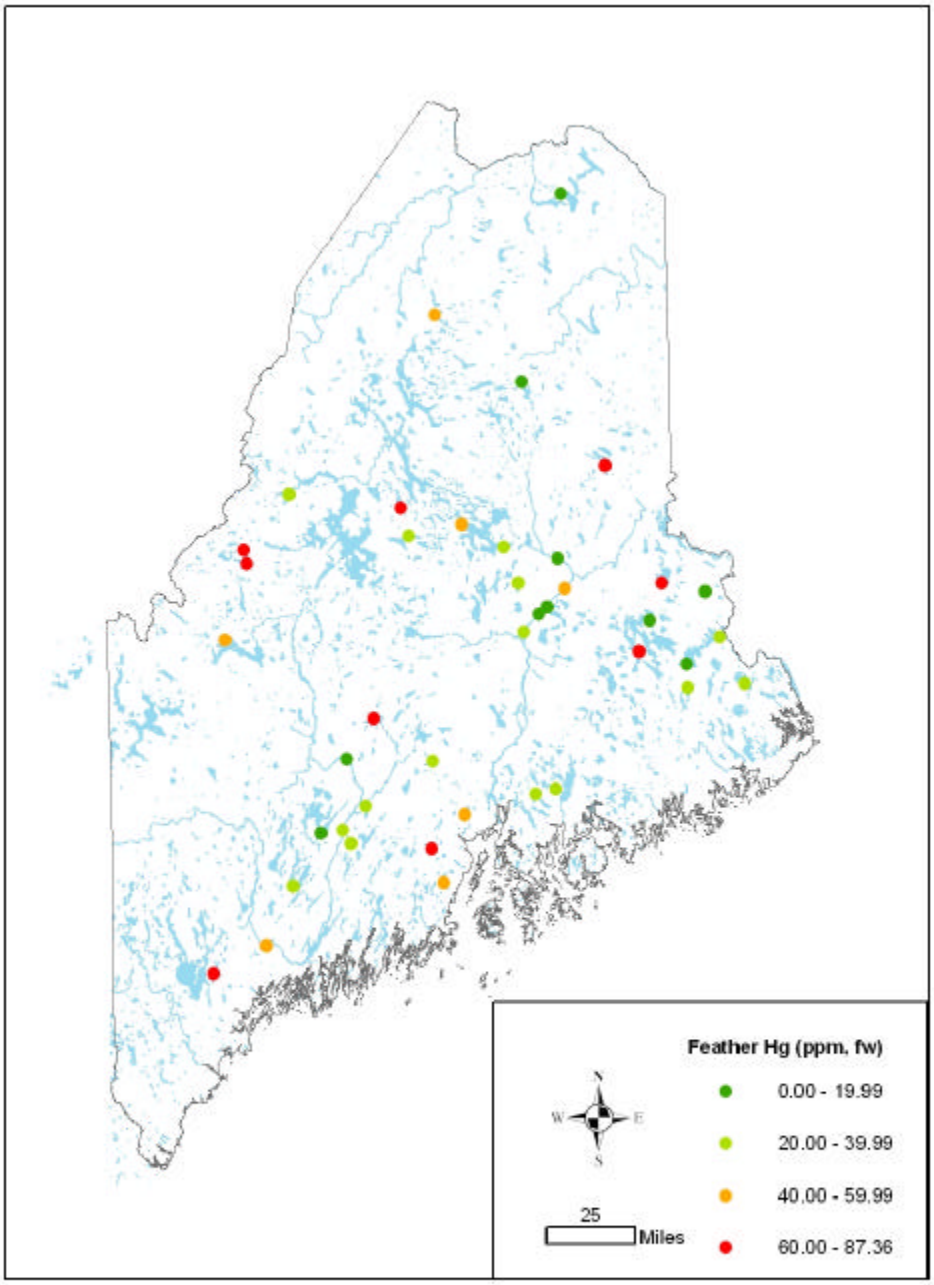

Figure 6. Mercury exposure indicated by shed adult Bald Eagle feathers in Maine.

6.0 Recommendations

1. *Develop a long-term eagle contaminants monitoring program in Maine.* Eagles have been demonstrated in this and other studies to be effective, sensitive monitors of spatial and temporal contaminant trends within aquatic ecosystems. We recommend that Maine implement a long-term mercury monitoring program by sampling eagles on freshwater habitats, following the template that has proven effective in the Great Lakes (Bowerman et al. 2002, Roe 2004). Broader statewide monitoring efforts could include organochlorine compounds, which are particularly elevated in Maine's marine and estuarine eagles (Welch 1994, Matz 1996).

Many have stressed the need for a thorough investigation of contaminant trends in Maine. Unique considerations include:

- atmospheric transport imparts high vulnerability to mercury in the Maine population;
- as yet, there is no evidence of declining dietary exposure to mercury;
- insights on mercury as a limiting factor are likely to accrue after declines in other contaminants, particularly DDE (Wiemeyer et al. 1984, 1993, Buehler 2000) and recent expansion of Maine eagles into freshwater habitats most threatened by mercury uptake;
- Maine is the only stronghold for bald eagles breeding in the northeastern U.S. and thus of particular concern given the proposed delisting of eagles from the Threatened Species List.

2. *Obtain eagle tissue samples from regions and watersheds not sampled previously.* We aggressively sampled eagles at freshwater habitats in 2004 to obtain samples to represent a diverse array of 93 sampling sites available. Baselines now exist in all major watersheds and habitats across Maine, but somesub-drainages are poorly represented due to low eagle productivity locally that year. Further sampling in 2005 will enable baselines with reduced variance, better distribution across poorly sampled sectors, evaluation of upstream – downstream trends, and optimize opportunities to compare to existing Hg data on other sympatric species such as Common Loons.

3. *Further evaluate the relationship between eagle productivity and mercury exposure by increasing sample size*. Findings of a negative correlation between eaglet mercury exposure and measures of productivity are the first to be reported in the U.S. We recommend collecting more samples throughout the state to further scrutinize the nature and robustness of this relationship. Due to the occurrence of organochlorine compounds documented in riverine habitats, this relationship will be less confounded by focusing on lacustrine nests.

4. Evaluate temporal mercury trends by resampling nest sites for tissues analyzed in previous studies. Findings in our study do not indicate decreasing bioavailability of mercury in Maine aquatic habitats, although comparisons were not territory specific. Eggs and nestling blood are reported in previous studies relative to specific nest sites throughout Maine; future sampling efforts should target these sites to obtain site-specific information on temporal trends.

5. *Improve understanding of Hg sources by analyzing nitrogen isotopes in eagle tissues.* Bird and/or terrestrial-based diets confound interpretations of mercury exposure. Roe (2004) successfully distinguished fish-based and bird-based diets using nitrogen isotope signatures in eaglet feathers. Such analyses are inexpensive and could substantially aid in interpreting observed mercury exposure levels.

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