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

(Report BRI 2006-02)

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Submitted on:

March 31, 2006

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1.0 Executive Summary

A recent US Fish and Wildlife Service proposal to list the Bald Eagle (*Haliaeetus leucocephalus*) from the Endangered Species List noted lasting concerns for the potential impacts of contaminants on some populations. Previous and ongoing toxicological assessments highlight specific contaminant concerns for Maine's Bald Eagle population, and warrant consideration in upcoming management decisions.

This report summarizes findings from an ongoing eagle mercury monitoring and impacts study supported by 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) organizations. Substantial support for this project was provided by the Maine Department of Environmental Protection.

We collected and analyzed mercury concentrations in Bald Eagle nestling blood, shed adult feathers, and abandoned eggs from freshwater-based Bald Eagle nests in Maine (2001-2005) to (1) evaluate dietary exposure to mercury (Hg), (2) assess if Hg exposure might be negatively impacting eagle productivity in Maine, and (3) evaluate spatial and temporal Hg trends in Maine. The following is a summary of current findings:

- *Nestling eagle Hg exposure:* Maine Bald Eagle nestlings and adults are exposed to elevated levels of methylmercury via the freshwater foodweb. Eagles in lacustrine habitats are particularly at risk. Blood mercury exposure levels of Maine eaglets is higher than many regional comparisons, and most similar to populations associated with significant point source pollution problems (e.g., Hg mines, dredging).   [Fig. 2; p. 14]

- *Adult eagle Hg exposure - feathers:* Exposure levels in Maine's adult Bald Eagles (as indicated by shed adult feathers) is elevated in comparison to virtually all comparison populations. As found in eaglet blood, mean Hg concentrations in Maine adult eagle feathers are most comparable to levels found at a site associated with a Hg mine (Pinchi Lake, BC).   [Fig. 3; p. 17]

- *Hg in Eggs:* Hg in abandoned Bald Eagle eggs from Maine study sites is elevated compared to most populations in the U.S.   [Table 4; p. 19]

- *Hg-Productivity Relationships: potential impacts:* We document significant negative relationships between eagle blood Hg and 3,5, and 10- year eagle productivity (chicks fledged/occupied nest). This has not been documented in other eagle populations, suggesting Maine's eagle population may be experiencing reproductive impacts due to Hg exposure despite population growth. [Fig. 4; p. 20]

- *Spatial Patterns:* Eaglet blood mercury levels were significantly different among 10 Maine watersheds, but sample sizes preclude powerful analyses. Eaglet mercury exposure in Maine highlights geographic mercury "hot spots" that demonstrate a general agreement with Hg findings in common loons and fish.   [Figs. 6-8; pps. 24-6]

- *Long-term trends:* Mercury bioavailability as indicated by nestling blood does not appear to be markedly different in lacustrine habitats during 2001-2005 in comparison to 1991-1992. Riverine comparisons suggest that levels are likely the same or higher than 1991-1992 levels. We recommend long-term monitoring of temporal Hg trends in Maine by periodic sampling (i.e., 1—15-yr intervals) as is currently conducted in other regions.   [Fig. 5; p. 22]

- *Proportion of sampled eaglets at levels of concern:* Our findings suggest that Maine's Bald Eagle population is within the range of negative impacts; that between 19-30% of eaglets sampled in lacustrine habitats contain blood mercury levels designated as elevated or higher (>0.70 ppm), and 4-9% of those sampled are highly elevated.   [Fig. 9; p. 28]

- *Proportions of adult feathers at levels of concern:* Feather mercury concentrations up to 87 ppm indicate a substantial proportion of Maine's adult eagle population are bioaccumulating mercury; 78% of feathers are >20 ppm, 38% are >40 ppm, and 21% were at or above 60 ppm; these levels are highly elevated and are suggestive of impacts.   [Fig. 11; p. 29]

2.0 Introduction

Bald Eagle (*Haliaeetus leucocephalus*) populations became locally extirpated throughout 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 removal of the species from the from Endangered Species List is being considered. 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). While some local populations in the Midwest remain 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, allowing further evaluations of Hg impact thresholds.

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 Sampling

Sampling strategy. Since freshwater habitats in Maine are at the greatest risk from mercury contamination (Welch 1994, Evers et al. 2005), we have focused this study on Bald Eagle nesting territories within lacustrine and riverine habitats only. Marine and estuarine habitats are associated with different limiting factors (i.e., organochlorine contaminant exposure), and are less comparable to inland populations biologically due to differences in diet, trophic level, and habitat. Sampling efforts were prioritized to: (1) obtain 2-3 nests per watershed, (2) sample regions/watersheds with previously undocumented mercury exposure in previous eagle studies, (3) resample territories from which historical eagle blood mercury baselines exist, and (4) obtain samples in regions where exposure has been documented in loon populations (for which exposure interpretations are more clearly understood).

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 for mercury analysis, other analyses, and sample archives. 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 age 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.

Indexing Blood Hg - background and use in analyses. We present information on eaglet exposure using three different blood exposure measures, or blood mercury profiles: (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.

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 length 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 blood 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. Despite the lack of a significant difference, blood mercury can vary substantially between siblings at some sites (BRI unpubl. data), and confound interpretations.

4.3 Adult Eagle Exposure

We analyzed Hg concentrations in two tissues, eggs and shed feathers, to gain insights on adult Bald 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.

4.5 Spatial and temporal mercury patterns in Maine

We evaluated spatial mercury trends aby comparing current (2001-2005) eaglet mercury exposure to levels previously reported by Welch (1994) for the 1991-1992 period. Spatial mercury patterns in Maine were evaluated by plotting mercury exposure (eaglet blood, adult eagle feather) spatially, and further quantified by analyzing by comparing mean eaglet territory mercury exposure among 10 Maine watersheds. Watersheds are a combination of HUC-8 and HUC-10 GIS coverages used in Maine statewide eagle monitoring efforts (C. Todd, MDIFW, unpubl. data). Sample size limits meaningful spatial comparisons using eagle eggs.

4.6 Evaluations of mercury risk to Maine's eagle population

We assess what proportion of Maine's sampled (nestling blood, adult feathers) eagle population falls within different mercury exposure ranges for nestling and adult populations. Delineations of different mercury exposure groups (i.e., low, moderate, high, extra high) are designated by evaluating and partitioning the distribution of mercury values in our study population based on (a) published literature values, (b) known mercury exposure levels for sympatric Common Loons, and (c) distribution of the

data. It would be premature to interpret these delineations as definitive mercury threshold impact levels.

4.7 Laboratory Analyses

Eaglet blood samples and egg aliquots were homogenized and analyzed for total Hg using Direct Mercury Analysis (DMA) 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 at the Savannah River Ecology Laboratory, Aiken, SC, University of Georgia, under the supervision of Dr. Christopher Romanek. All feathers were cleaned and lipid extracted prior to analysis. We analyzed the distal 5 cm of one shed feather per territory following techniques outlined in Evans (1993) and Bowerman et al. (1994).

4.8 Statistical Analyses

We compared means using a t-test or ANOVA for normally distributed datasets; non-normally distributed data was either log-transformed prior to analysis or compared using non-parametric tests (i.e., Wilcoxon test). Productivity-mercury relationships were analyzed using a Spearman Rank Correlation test. We performed all statistical tests using JMP version 4.0.0 Statistical Software (SAS 2001).

5.0 Results and Discussion

5.1 Eaglet Sampling Efforts

We sampled 100 nestling eagles from 77 nests in Maine during 2005 sampling visits (Table 1), totaling 208 birds from 104 Maine nesting territories (150 nest-years) over the course of this study (Figure 1). We additionally sampled 21 nestlings from 8 territories (13 territory-years) in New Hampshire (n = 5) and Massachusetts (n = 3) over the 2002-2005 period[1] (*These findings are not included in this summary*). Sixty-two percent of nests sampled have been visited once (n=62), 35% (n = 37) have been visited twice over the period (e.g., 1 visit /season), and 2% have been visited three (n = 2) and four (n = 2) times. These repeat visits over time aid in site-specific interpretations of dietary Hg exposure and variability. Statewide, we obtained blood samples from approximately 80% of the available sampling opportunities from freshwater Maine habitats during the 2005 season. 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 to gain increased resolution of geographic Hg exposure patterns, however sampling scale 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 in Maine, 2001-2005.

Year	Individuals Sampled	No. nests sampled
2001	10	5
2002	7	5
2003	9	7
2004	82[*]	56
2005	100[*]	77
Total	**208**	**150**

* Focal sampling years funded by MDEP.
Nests have also been sampled in: MA, n = 3 nests (2004 only); NH, n = 5 (2001-2005). Nests in NH and ME have been sampled in multiple years. Total sampling efforts in ME, NH, MA, 2001-2005: 229 nestlings, 85 territories, 163 territory-years.

[1] In collaboration with New Hampshire Audubon Society and Massachusetts Division of Wildlife.
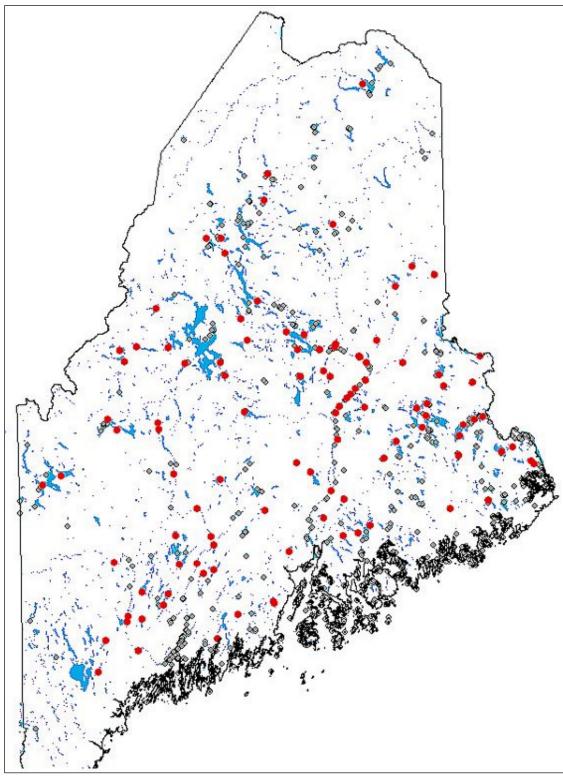
Figure 1. Bald Eagle nest sites in Maine sampled in 2001-2005.

Small gray dots represent Maine nest sites, red dots represent those sampled during 2001-2005. Nest site information courtesy of Maine Dept. Inland Fisheries and Wildlife.

5.2 Eaglet Mercury Exposure

Overall and habitat-specific blood Hg exposure levels are presented in Table 2.   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/weight) (Table 2; $p < 0.05$). These differences in eaglet mercury exposure by habitat type are consistent with those reported by Welch (1994) and Evers et al. (2005): 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	0.59 ± 0.23 (82)	1.45 ± 0.63 (81)	0.16 ± 0.09 (81)
Riverine	0.42 ± 0.17 (22)	0.92 ± 0.32 (22)	0.12 ± 0.05 (21)
BOTH	0.55 ± 0.23 (104)	1.34 ± 0.62 (103)	0.15 ± 0.08 (102)

[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) or weight data from sampled individuals. Findings changed minimally when using smaller siblings (vs. older siblings), blood Hg means using smaller siblings: lacustrine = 0.59 ± 0.24, riverine = 0.41 ± 0.17, both = 0.55 ± 0.24.
[b] No index, blood Hg, (ww).

Eaglet blood comparisons:

Figure 2. Blood mercury concentrations (ppm, ww) in nestling Bald Eagles from Maine and comparison populations.

[1] Regions: Florida eutrophic and mesotrophic lakes (Wood et al. 1996); Washington (WA: Wiemeyer et al. 1989); Maine lakes/rivers (ME: this study); "Col. Riv. Est." = Columbia River Estuary (Anthony et al. 1993) a site associated with extensive point source pollution inputs suspectedly exacerbated by numerous anthropogenic activities (e.g., dredging, hydroelectric dams); Pinchi L. (Pinchi Lake, BC, Canada, Weech 2003), a site associated with a Hg mine; Oregon, and Montana (OR, MT; Wiemeyer et al. 1989) populations reflect exceptionally high levels of mercury exposure due to a combination of (1) high concentrations of mercury in parent material (e.g., cinnabar) forming a "mercuriferous belt" throughout portions of western Canada and northwestern U.S. states, and (2) increased bioavailability due to anthropogenic activities. Error bars represent standard deviations and were not available in several comparison studies. Siblings and repeat sampling between years averaged/nest.

Comparisons with eagles. Blood mercury exposure levels for individual Maine eaglets sampled in our study ranged from 0.08 ppm to 1.27 ppm (0.59 ppm lacustrine, 0.42 ppm riverine; Table 2). These levels are elevated in comparison to several populations (Figure 2). 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) and 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 influences in that region (Anthony et al. 1993).

The only population displaying higher eaglet blood mercury exposure than Maine populations are those in southcentral Oregon and Montana (Figure 2), 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). These populations represent an extreme case in exposureand should be used cautiously when comparing to other regions.

Nestling blood is a suitable surrogate for short-term adult dietary mercury exposure and intake. 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. 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). Thus, post-fledged eagle nestlings in Maine are likely at the greatest risk to mercury impacts (Spaulding et al. 2000, Fournier et al. 2002), especially if they were born or feed heavily on a prey base high in mercury contamination like many throughout Maine (Evers et al. 2004). One nestling sampled in this study fledged in 2005 was recovered alive and resampled prior to euthanasia in New Jersey in November 2005. Initial mercury levels at approximately 5 weeks of age was 0.58; at 25 weeks of age, blood mercury levels rose 93% to 1.12 ppm.

Comparisons with 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, Evers et al. 2005) 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.

5.3 Adult Exposure - Feather

Shed adult eagle feathers collected at nestling sampling sites displayed highly elevated Hg concentrations (Table 3, Figure 3). Similar to nestling blood exposure levels, adult feathers indicated significantly higher mercury exposure on lacustrine vs. riverine habitats (p = 0.0084, Wilcoxon test). Feather mercury concentrations varied widely in both habitat types, ranging from 0.94 to 93.5 ppm (fw) overall. Findings are highly indicative of bioaccumulation in adults with age and are suggestive of impacts for a portion of the population (see section 5.8).

Table 3. Mercury exposure in adult feathers within two habitat types sampled in Maine.

Habitat type	Adult feather Hg ± SD (n)[a]	Range
Lacustrine	42.6 ± 21.5 (51)	0.94 – 93.5
Riverine	27.7 ± 12.3 (18)	1.4 – 48.1
BOTH	37.3 ± 21.4 (42)	0.94 – 93.5

[a] Habitat means are significantly different (p = 0.0084, Wilcoxon test). Feather Hg was averaged at sites represented in multiple years.

Eagle population comparisons: 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). Our mean feather Hg concentrations from Maine adult eagles is higher than the level found at Pinchi Lake, BC, a site associated with a mercury mine (Weech 2003; feathers ranged from 10.1 to 65.0 ppm (mean = 18.7 ppm, n = 13). Mercury concentrations for adult Bald Eagle feathers collected in New Hampshire increased dramatically from a minimal sample size in 2004 (n = 2, now n = 5), reflecting (1) one feather from the Connecticut River with an exceedingly high mercury concentration (91.54 ppm), the second highest off all samples analyzed in this study, (2) high between-year variability at two sites, and (3) One of NH feather was noted in DeSorbo and Evers (2005) to be from a winter roost (Wilcox Point), which may have inadequately represented the individual in that territory sampled in 2005 (i.e., a non-resident). A greater sample size for NH territories at more sites over on repeated years to properly evaluate high variability in the samples collected there.
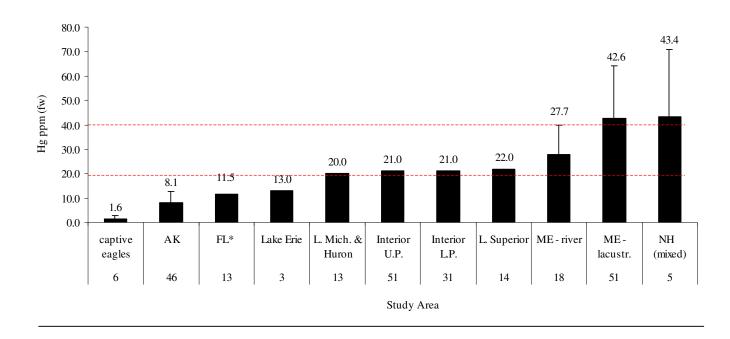
Figure 3. Concentrations of Hg (ppm, fw) in adult Bald Eagle feathers collected in the United States.

Error bars (SD) given when available. Sample sizes below study area names. Feathers analyzed are primaries, secondaries, and tail in most studies. Upper dotted red line represents level at which Spaulding et al. (2000) found some effects from feeding egrets fish dosed with 0.5 ppm Hg. Lower dotted red line represents level at which Scheuhammer (1991) suggested that toxic effects should be considered. 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; **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); ; **NH** = New Hampshire (BRI unpubl. data), Nubanusit Lake and Wilcox Point (feather collected from perch in winter), Umbagog Lake, Squam Lake, Connecticut River. Connecticut River sample is the second highest in all feathers analyzed in this study (91.54 ppm), and introduces significant variability into the NH mean. Exclusion of this feather results in a mean = 30.08 ± 1.5, n = 4. Exclusion of Lake Umbagog, which is hydrologically connected to the Androscoggin River Watershed in Maine results in a mean = 29.8 ±1.7 ppm.

Other species: 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 effects from other contaminants (i.e., organochlorines) are in question. These concentrations provide a guideline for literature comparisons, however impact thresholds remain unknown for adult or nestling eagle feathers.

Interpreting adult feather Hg: Wood et al. (1996) found strong correlations between feather mercury levels in adults and nestlings from the same nest. 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.

Greater sample sizes achieved after the 2005 sampling season resulted in a significant correlation between adult feather mercury and non-indexed nestling blood mercury (r = 0.27, p = 0.02), and marginally significant correlations between adult feather Hg and nestling blood Hg / weight (r = 0.25, p = 0.052). There was no significant correlation between adult feather Hg and Hg / age (r = 0.20, p = 0.11).

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 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 species that undergo a full remigial molt on the ocean (i.e., common loons). A variety of factors, however, should be considered when interpreting adult feather mercury values. First, although studies suggest that mercury does not vary significantly within individual feathers (Berg et al. 1966, Evans 1993, Dauwe et al. 2003), Weech (2003) reported evidence indicating that analysis of only a portion of feathers may overestimate mercury in some cases. 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 moderate to low 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. 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 ±12.3 ppm (riverine) and ± 21.5 ppm (lacustrine) (Table 3). Within-territory variations in feather mercury concentrations are unknown and would aid in future interpretations of adult feather tissues; several feathers may be required to best represent exposure levels for an eagle pair/territory.

5.4 Adult Exposure - Egg

We collected seven unhatched Bald Eagle eggs from six territories in 2004, and 8 eggs from 7 territories in 2005. 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).

Eggs Hg concentrations were significantly correlated with adult feather mercury (r = 0.84, p = 0.018, n = 7; pearson correlation, normally distributed datasets). This preliminary relationship was noted using smaller sample sizes from 2004. 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.

Table 4. Mercury concentrations in Bald Eagle eggs collected in Maine, 2004-2005.

Nest Site	Year	Nest Location	Township	Hg ppm (fw)[a]
ME 83D	2004	Tomah Stream	Codyville Plt	0.18
ME 439A	2004	Pemadumcook Lake	T1 R10	0.29
ME 289C	2004	Dolby Pond	Millinocket	0.30
ME 149	2004	Penobscot River	Chester	0.44
ME 336A1	2004	Quantabicook Lake	Searsmont	0.54*
ME 336A2	2004	Quantabicook Lake	Searsmont	0.68*
ME 161A	2004	Boyden Lake	Perry	0.90*
ME075D	2005	Brandy Pond		0.87*
ME081C	2005	West Grand Lake		0.52*
ME083D	2005	Tomah Stream	Codyville Plt	0.16
ME176A	2005	Mattamiscontis Lake	T3R8 NWP	0.35
ME252C	2005	Richardson Lake		0.34
ME412A 1	2005	Kennebec River	Livermore Falls	0.42
ME412A 2	2005	Kennebec River	Livermore Falls	0.33
ME436A	2005	Long Pond	Somerset	0.41
(15 eggs)		**(12 nests)**	**Mean Hg ± SD:**	[b] **0.46 ± 0.23**

[a] Additional analyses of Organochlorine compounds being conducted by Steve Mierzykowski, USFWS.
[b] Eggs within the same nest and nests sampled in different years were averaged to produce one Hg value per territory (n = 12). The mean of all eggs (n = 15) was 0.49 ± 0.22.
* Noted for eggs exceeding proposed Hg threshold impact level of 0.50 ppm (Wiemeyer et al. 1984, 1993).

Comparison of egg Hg to other populations: Our findings of 0.46 ± 0.23 in eagle eggs collected in this study are higher than most population comparisons at a national level. Several studies have found significantly higher Hg levels in Bald Eagle eggs from Maine in comparison to other populations in the U.S (Wiemeyer et al. 1984, 1993). Eggs during the early 1980s 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 in Maine freshwater habitats 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.

5.5 Relationships between Eagle Productivity and Mercury Exposure

Eaglet Blood Hg vs. Productivity. We found significant correlations between mean 3, 5, and 10-year productivity (young fledged / occupied nest) and eaglet blood mercury exposure levels (Tables 5, 6; Figure 4). This relationship has not been previously reported in other eagle populations, and few populations of wild birds.
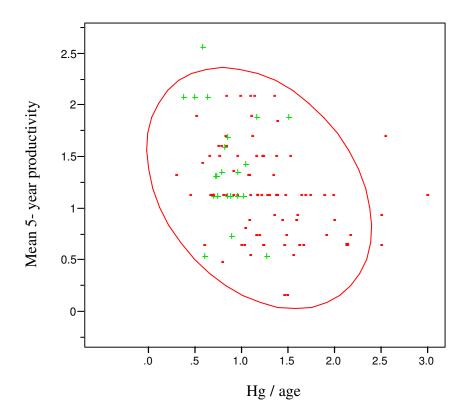
Figure 4. Correlation between an index of eaglet mercury exposure (Hg/age) and 5-year territory productivity (chicks fledged/occupied territory).

Red (dots) = lacustrine, green (+'s) = riverine samples. Spearman's Rho = -0.37, p<0.0001; 0.95 density ellipse, n=103.

Most blood mercury (Hg [no index], Hg/age, Hg/weight) measures indicated significant negative correlations with productivity. Relationships between mercury exposure and productivity were significantly negatively correlated for lacustrine and riverine nest combined (Table 5) and exclusively lacustrine nests (Table 5). Riverine nests were not significantly correlated to productivity measures (p > 0.05), however analyses are limited by sample size (n = 22). 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 (Tables 5, 6); indexes by age and weight appeared to show stronger relationships with mercury and retained significance to a greater extent after reductions in sample size.

Poor productivity in 2005 may have influenced mercury-productivity relationships; 2005 productivity was approximately 30% lower at a statewide level (i.e., including coastal/estuarine nests; 251 chicks fledged / 382 pairs = 0.66 in 2005) and within lakes and rivers (100 nests successful in fledging young / 185 nesting pairs = 54% nesting success) than what is typical for Maine (i.e., 2004 was approximately 0.9 chicks fledged/nesting territory statewide; C. Todd, MDIFW, pers. Com.). River habitats in this dataset generally display higher productivity than lacustrine nests. Habitat type is a variable that should be accounted for in future analyses by either (1) inclusion in a model or (2) exclusion of riverine nests from analyses. River territories are also more likely to be exposed to high levels of organochlorine contaminants which confound Hg-productivity relationships. Therefore, 2006 sampling efforts should prioritize sampling at lacustrine sites.

Table 5. 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 = -0.10 (0.31)	r = -0.23 (0.020)	r = -0.22 (0.024)
Hg/age	r = -0.29 (0.001) [a]	*r = -0.37 (0.0001) [a]	r = -0.31 (0.0013) [a]
Hg/weight	r = -0.20 (0.049)	r = -0.32 (0.001)[a]	r = -0.30 (0.0020) [b]

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 occupied <3 years.
[b] Relationships remained significant at P = 0.10 after removing territories occupied < 3 years.
* Displayed in Figure 4.

Table 6. 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 = 0.0043 (0.97)	r = -0.16 (0.15)	r = -0.14 (0.20)
Hg/age	r = -0.23 (0.036) [b]	r = -0.35 (0.001) [a]	r = -0.26 (0.19) [b]
Hg/weight	r = -0.15 (0.17) [b]	r = -0.32 (0.003) [b]	r = -0. 29 (0.009) [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.

Feather Hg and Egg Hg vs. Productivity. We did not find significant relationships between adult feather mercury concentrations and 3-year, (r = 0.03, p>0.05) 5-year (r = 0.028, p>0.05), or 10-year productivity (r = 0.07, p>0.05) (Spearman's rank correlation). We did not find significant correlations between egg mercury concentrations and 3-year, 5-year, or 10-year territory productivity (Spearman Rank Correlation, p>0.05).

5.6 Temporal Mercury Trends: 1991-1992 vs. 2001-2005.

Our findings indicate that current (2001-2005) mercury bioavailability as indicated by Bald Eagle nestlings in freshwater Maine habitats is similar or potentially higher than temporal comparisons (1991-1992; Welch 1994) (Figure 5). Robust temporal comparisons are limited by sample size for 1991-1992 sampling efforts, reflecting fewer sampling opportunities available during the earlier period. Statistical comparisons of eaglet mercury exposure limited to sites sampled during both periods were not found to be significantly different in lacustrine (p > 0.05, n = 12) or riverine (p > 0.05, n = 4) habitats.

> **Riverine:** Mean mercury exposure in riverine habitats in our study during 2001-2005 (territory mean = 0.42 ± 0.17 ppm, n = 22; nestling Hg range: 0.11 – 0.93) tended to be higher than those reported by Welch (1994) during 1991 (0.27 ± 0.06) and 1992 (0.28 ± 0.17) (Figure 5).

> **Lacustrine:** Mean mercury exposure in lacustrine habitats in our study during 2001-2005 (territory mean =0.59 ± 0.23 ppm, n = 82; nestling Hg range: 0.08 – 1.27) were similar those reported by Welch (1994) during 1991 (0.55 ± 0.30) and 1992 (0.62 ± 0.30) (Figure 5).

These findings should be noted by regulatory officials, as there is no evidence of declining bioavailability of mercury among nestling bald eagles raised at freshwater habitat in Maine during the last 11 – 15 years. These findings are consistent with other studies also indicating that mercury is

persistent in aquatic ecosystems (Wiener et al. 2003). 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.
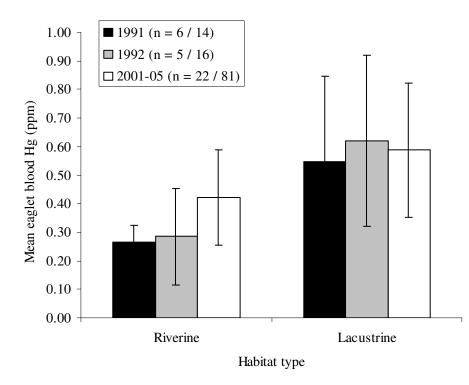

Figure 5. Mercury exposure for eagle nestlings sampled in riverine and lacustrine habitats, 1991, 1992, and 2001-2005.

Mean mercury exposure (ppm, ww) ± SD (error bars) presented. Sample sizes in legend correspond to sample sizes within riverine, and lacustrine habitats, respectively. Findings presented from Welch (1994) (Welch 1991 and 1992) and this study (2001-2005). 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. Siblings were averaged within nests and nests sampled in multiple years were averaged. Four riverine nests and 12 lacustrine nests sampled by Welch (1994) during 1991 – 1992 were sampled during 2001-2005.

5.7 Spatial comparisons: Mercury among Maine watersheds

Eaglet blood mercury. Greater sample sizes gathered during 2005 field efforts enabled spatial evaluations of eaglet mercury exposure within 10 Maine watersheds. Findings indicated significant differences in eaglet mercury exposure in lacustrine habitats among watersheds (Figures 6 & 7, Wilcoxon test, $p = 0.03$, $n = 81$). Limited sample sizes in some watersheds and resulting unequal variances among watershed groups preclude more powerful and potentially insightful statistical comparisons (i.e., ANOVA, Tukey HSD test) of mercury differences among watersheds.   Differences in Hg exposure were not detected in riverine habitats among watersheds (Figure 6, Wilcoxon test, $p = 0.12$, $n = 22$), however sample sizes/watershed again limit robust statistical comparisons. Sampling opportunities remain limited in freshwater regions within specific watersheds (*i.e., Southern Midcoast, inland Penobscot Bay area, Cobscook Bay*) due to few active nesting territories and poor nesting success (likely related to weather) during 2004-2005 nesting seasons. Comparisons of eaglet mercury among Maine watersheds indicate highest mercury bioavailability in lacustrine sites within Downeast, Penobscot, and Saint Croix River Basin Watersheds. Lacustrine habitats generally exhibited higher exposure levels in comparison to rivers within watersheds, with the exception of the Androscoggin

River watershed. High variability in mercury exposure within lacustrine and riverine habitats within watersheds may be the result of low sample sizes in some cases (e.g., river nests in the Saint Croix River Watershed and lakes within inland midcoast/coastal watersheds; Figure 6). Some well-sampled watersheds (i.e., lakes and rivers in the Penobscot River Basin) exhibit high variability in exposure; analyses of exposure within subdrainages would allow for improved resolution and interpretations of site-specific mercury contamination problems.

Adult feather Hg. We found no significant differences in mean adult feather Hg among 10 Maine watersheds in lacustrine, riverine, or combined habitats ($p > 0.05$). Small sample sizes of adult feathers / watershed limit meaningful analyses of this data (e.g., 6 watersheds with ≤3 feathers [lacustrine], 6 watersheds with no feathers represented, 3 of remaining 4 watersheds represented by ≤3 feathers).
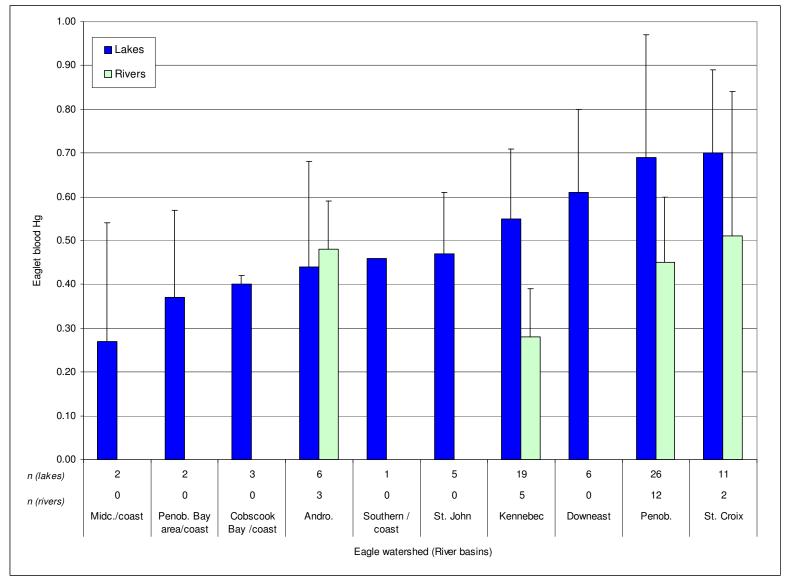
Figure 6. Bald Eagle mercury exposure in 10 Maine watersheds.

Eaglet blood mercury levels (ppm, ww) averaged for siblings and between years at repeat sampling sites. Watersheds correspond to regions delineated in Figure 7. Watershed delineations represent a modification of HUC-8 and HUC-10 GIS coverages. Note higher Hg exposure in Androscoggin Rivers vs. lakes.
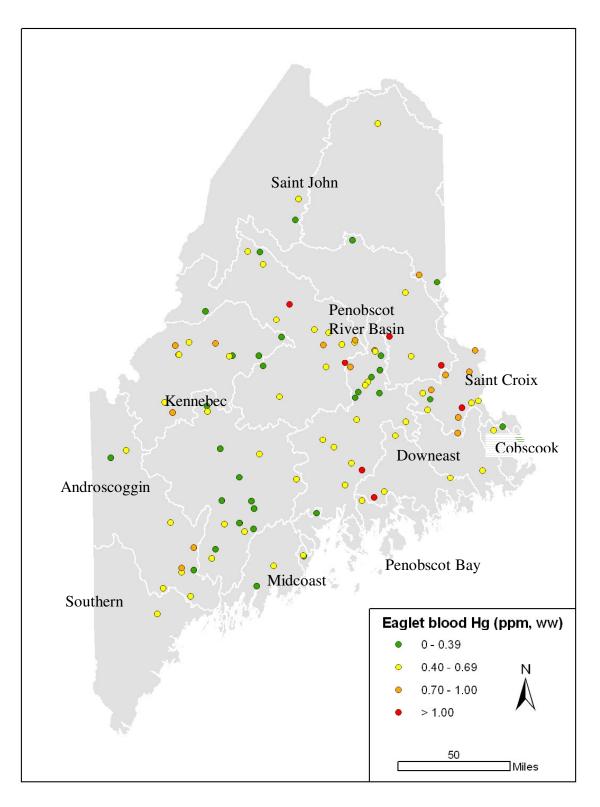
Figure 7. Nestling Bald Eagle blood mercury within ten Maine watersheds.

Names straddling watershed boundary lines in include both subregions (e.g., St. John constitutes all of northern Maine.)
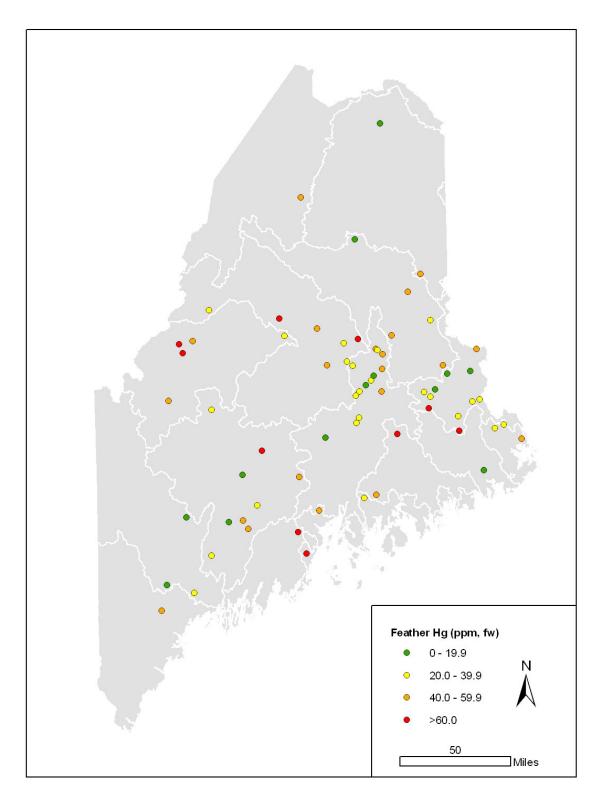
Figure 8. Adult Bald Eagle feather mercury within ten Maine watersheds.

5.8 Evaluations of Mercury Exposure risk 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. Other studies finding blood mercury levels at similar or considerably lower levels in comparison to Maine's eagle population have suggested that exposure was within the range of reproductive impacts (Figure 9). 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 assess what proportion of Maine's sampled eagle population falls within different mercury exposure ranges for nestling and adult populations by habitat type (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 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.

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).

Our blood mercury profiles suggest that between 19-30% of eaglets in lacustrine habitats contain blood mercury levels designated as elevated or higher (>0.70 ppm) (Figure 9). Between 4 – 9% of sampled eaglets are at levels designated as highly elevated (>1.0 ppm). Between 4-13% of eaglets in riverine habitats were designated as elevated or higher; no riverine eaglets were considered highly elevated (Figure 10).
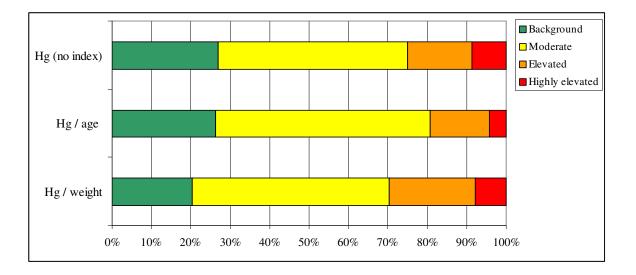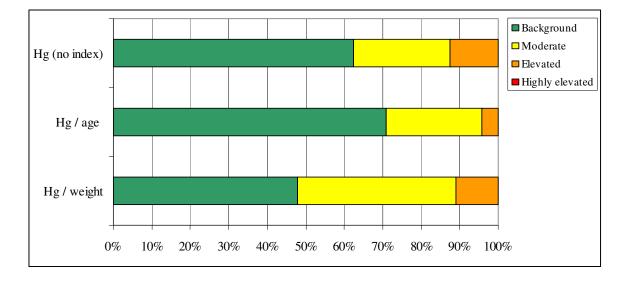
Figure 9. Proportion of sampled lacustrine eaglets falling into different dietary mercury exposure groups.

Three different blood mercury exposure profiles for eagle nestlings are shown (see text).

Figure 10. Proportion of sampled riverine eaglets falling into different dietary mercury exposure groups.

Three different blood mercury exposure profiles for eagle nestlings are shown (see text).

Evaluating adult exposure based on adult feathers: We analyzed 89 feathers from 69 Maine Bald Eagle territories in Maine, and included 8 feathers from 5 territories in NH. Eighty-four percent of feathers averaged/site were at a level where toxic effects should be considered ($\geq$20 ppm; Scheuhammer 1991) (Figure 11). Fifty-five percent of shed feathers from nesting territories were at or above the level designated here as highly elevated (>40 ppm) based on findings by Spaulding et al. (2000), and 21% were at or above the level we designate as very highly elevated (>60 ppm). Concentrations $\geq$60 ppm are uncommonly reported in literature (Burger 1993, DesGranges et al. 1998); most are generally associated with significant point source pollution problems such as application of alkylmercuric compounds on seed dressings in the 1940s in Sweeden (Berg et al. 1966,

Westmark et al. 1975, Burger 1993) or other sources (DesGranges et al. 1998, Weech 2003). Our highest feather values, 85 ppm (Great Moose, ME#231), and 87 ppm (Sysladobsis, ME#200), are substantially 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 that 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 in Maine's adult eagle population are unknown; however, rapid accumulation found by Weech (2003) is likely similarly occurring in Maine's population given high exposure levels.
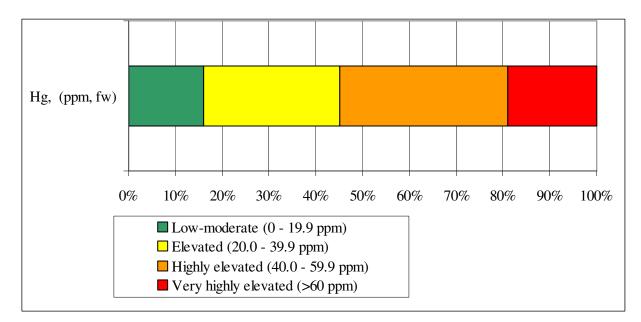

Figure 11. Proportion of adult eagle feathers within four mercury exposure groups.

Feathers averaged at sites from multiple years, n = 74 territories.

Evaluating adult exposure based on eggs: One third (33%; 5/15) of eagle eggs collected have mercury concentrations exceeding 0.50 ppm (fw), and 13% (2/15) exceed 0.8 ppm (Table 6). No eggs in our collections exceeded 1.0 ppm. The adverse impact threshold level for eagle eggs was once considered at 0.50 ppm based on studies analyzing eggs from eagles (Wiemeyer et al. 1984, 1993) and Mallards (Heinz 1979). Recent mallard studies suggest that the threshold level for that species may be at approximately 0.80 ppm (Heinz and Hoffman 2003). Evers et al. (2003) used an impact threshold level of 1.3 ppm for Common Loons. 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. Evaluations of adult mercury exposure based on eggs is limited due to a low sample size. Egg collections are a very limited, skewed sample and are inadequate for speculations on population impacts.

6.0 Recommendations

1. This study is timely given the proposed delisting of the Bald Eagles from the Endangered Species List and potential to understand factors limiting recovery of eagle populations in the northeastern U.S., which constitute 73% of the resident breeding eagle population in the region (C. Todd, MDIFW, pers. com.). Project findings raise significant concerns about contaminants in Maine's Bald Eagle population, and should be considered a research priority despite little indication that contaminants are limiting overall population expansion.

2. Findings of this study do not demonstrate any significant reduction of Hg over a 14-year period in sampled Maine habitats. Periodic long-term contaminant monitoring over a 10-15 year interval is recommended for Bald Eagle populations in Maine as well as other northeastern states, as is being conducted in other states (i.e., Bowerman et al. 2002) in order to evaluate temporal Hg trends observed during this study.

3. Gather sufficient nestling blood samples sizes within Maine watersheds to conduct viable statistical analyses comparing exposure among watersheds. Sampling opportunities were 20% lower, primarily due to weather, in 2005 compared to 2004, resulting in poor sampling representation in some regions with low nest densities (e.g., York county). Additional sampling will provide Hg baselines in currently underrepresented areas.

4. Revisit 2-4 nests to allow for better interpretations of nestling blood and feather changes during the prefleding period.

5. Continue collection and analysis of adult feather samples within previously unsampled regions and between years at previously sampled sites to allow for (1) better evaluation of mercury exposure risk to Maine's adult eagle population, (2) improved interpretation of feather mercury values (by repeat sampling at sites), (3) more powerful spatial analyses of mercury exposure patterns in Maine, (4) statistically viable comparisons to other tissues (i.e., eggs).

6. Findings of elevated adult feather mercury levels at a site near the Maine coast may indicate that coastal adult eagles are also exposed to high mercury levels despite low short-term dietary exposure indicated by nestlings (Welch 1994). Mercury exposure has never been assessed in Maine's coastal adult eagle population. We recommend analysis of feathers from adult eagle carcasses delivered to the Maine Department of Inland Fisheries and Wildlife to provide preliminary mercury exposure assessments for coastal populations.

7. PCB and DDE compounds confound relationships between mercury and productivity found in this study, especially on rivers. No studies have evaluated these compounds in nestling blood at detection levels comparable to current studies due to improvements in analytical techniques. We recommend analysis of organochlorine compounds in a subset of archived blood samples in order to adequately address this confounder.

7.0 Acknowledgements

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