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

(Report BRI 2007-02)

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(REPORT BRI – 2007-02)

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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 (2001-2006) to (1) evaluate dietary mercury (Hg) exposure, (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. 18]
- ***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. 7-8; pps. 25-6]
- ***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. 6; p. 23]
- ***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 Hg concentrations ranging to >93 ppm indicate a substantial proportion of Maine's adult eagle population are bioaccumulating mercury; these levels are highly elevated and 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.

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). Several studies have found similar mercury concentrations among feather types (Evans 1993, Bowerman et al. 1994, Wood et al. 1996), and within individual feathers (Berg et al. 1966, Evans 1993, Dauwe et al. 2003). 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.

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 (x 100) in days, and (c) Hg/ weight (x 1000) 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 may confound interpretations.

4.5 Spatial and Temporal Mercury Patterns in Maine

We evaluated spatial mercury trends aby comparing current (2001-2006) 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). Similarly, subdrainage delineations within watershed basins are adopted from MDIFW designations. 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 324 eaglets from 159 nesting territories in Maine, primarily during 2004-2006[1] period (226 territory-years) (Table 1,Figure 1). This total includes 20 eaglets sampled in 9 territories in estuarine habitats in 2006, as well as 22 nestlings from 5 territories in New Hampshire and 3 territories in Massachusetts[2]; these samples are not included in analyses herein. Maine field efforts often obtained blood samples from 80-95% of the available freshwater sampling opportunities annually. 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 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, 2001-2006.

Year	Individuals Sampled	No. nests sampled
2001	10	5
2002	7	5
2003	9	7
2004*	82	56
2005*	100	77
2006*	116	76
Total	**324**	**159**

* Focal sampling years funded by MDEP.

[1] Preliminary sampling occurred during 2001-2003 in collaboration with FPL Energy Maine Hydro.
[2] In collaboration with New Hampshire Audubon Society and Massachusetts Division of Wildlife, 2002-2006.

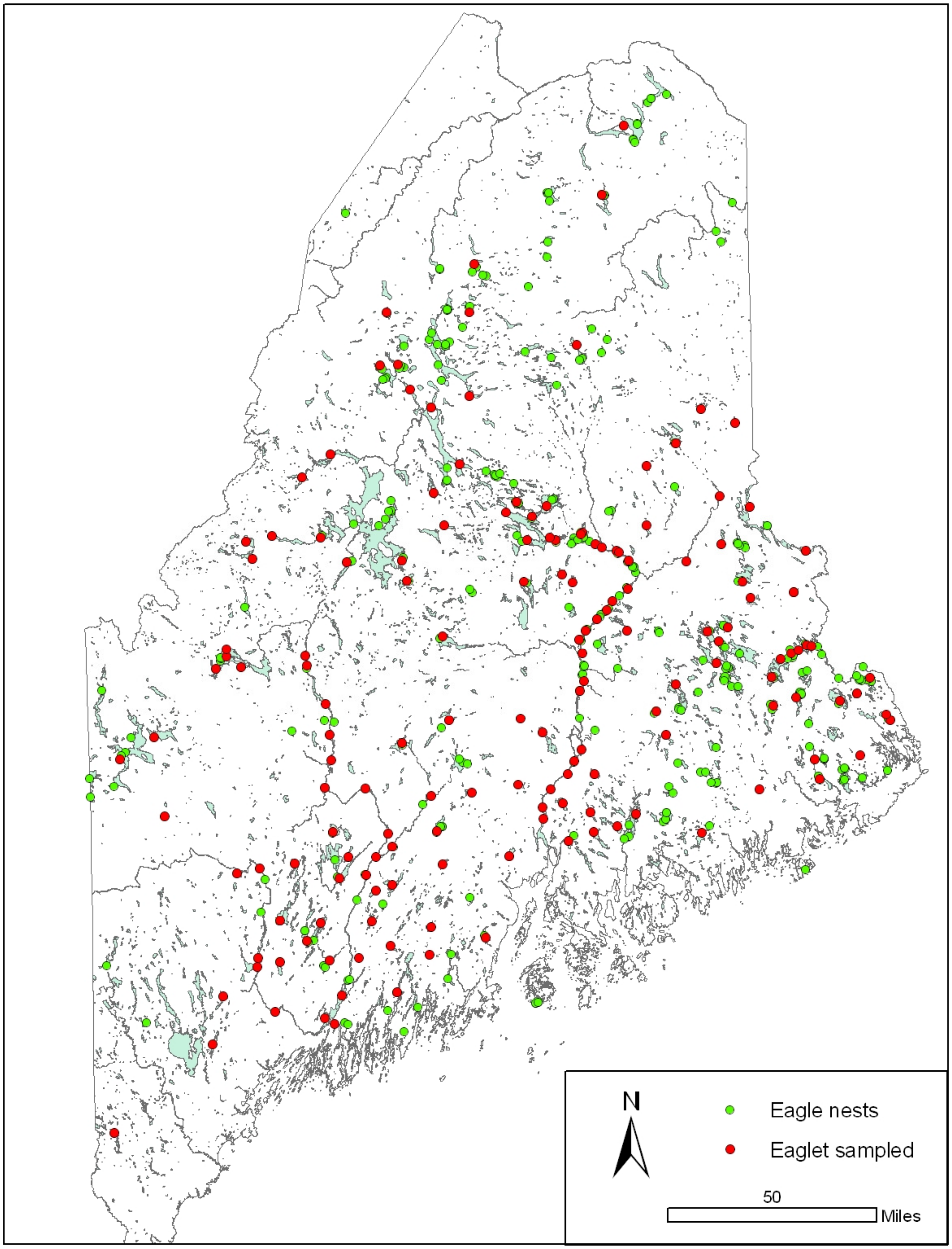


Figure 1. Bald Eagle nest sites in interior Maine visited for nestling blood sampling, 2001-2006.

Nest site information courtesy of Maine Dept. Inland Fisheries and Wildlife.

5.2 Eaglet Hg Exposure

Blood Hg concentrations for sampled Maine eaglets ranged from 0.08 ppm to 1.62 ppm (Table 2). Eaglet Hg exposure differed between lacustrine and riverine habitats ($p < 0.05$, Wilcoxon Test). Differences in eaglet blood Hg 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.

Habitat type	Blood Hg ± SD (n) [a]	Range [b]
Lacustrine	0.56 ± 0.24 (115)	0.08 - 1.62
Riverine	0.44 ± 0.18 (35)	0.11 – 1.19
BOTH	0.53 ± 0.24 (150)	0.08 - 1.62

[a] Means and sample sizes reflect territory averages (i.e., siblings averaged / nest; nests sampled in multiple years averaged).
[b] Range reflects Hg concentrations in individual eaglets.

Population comparisons for eaglet blood Hg

Eaglet blood Hg concentrations for Maine lacustrine and riverine habitats (0.56 ppm lacustrine, 0.44 ppm riverine; Table 2) are elevated compared to most inland population comparisons, including South Carolina (Jagoe et al. 2002), Florida (Wood et al. 1996), and Washington (Wiemeyer et al. 1989) (Figure 2). While neither the study in South Carolina or Florida detected evidence of negative impacts on local populations and exposure was considered generally low, both noted that a portion of these populations exhibited tissue concentrations that exceeded those associated with negative impacts in some studies, and periodic monitoring was recommended.

Eaglets in Maine's riverine habitats exhibited Hg concentrations in blood roughly twice the mean concentration reported for eaglets in Washington, and similar to concentrations reported for eaglets in the Columbia River Estuary (Anthony et al. 1993). The Columbia River Estuary is considered one of the more industrialized and polluted regions in the U.S. due to combined influences of industrialization, hydroelectric dams, and dredged river sediments. Populations there are exposed to several contaminants in addition to mercury (PCBs, DDE, dioxin), many of which are blamed for low eagle productivity (0.56 young / occupied nest) in the region.

Eaglets in lacustrine habitats sampled in Maine exhibited Hg concentrations (0.56 ppm) higher than those reported in Columbia River Estuary (0.47 ppm), and were most similar to concentrations reported from Pinchi Lake, British Columbia, Canada (0.57 ppm); a site associated with cinnabar Hg deposits and mercury mining operations (Weech et al. 2006). Mean eaglet blood Hg concentrations at reference lakes in that study ranged from 0.20 – 0.42 ppm.

Several Maine watersheds exhibited mean eaglet blood Hg concentrations on lakes similar to or higher than those observed at Pinchi Lake: (1) the Saint John (0.55 ppm), (2) The Penobscot River Basin (0.66 ppm), and the Saint Croix River Basin (0.70 ppm). These Maine subregions are compared in the spatial analysis section of this report.

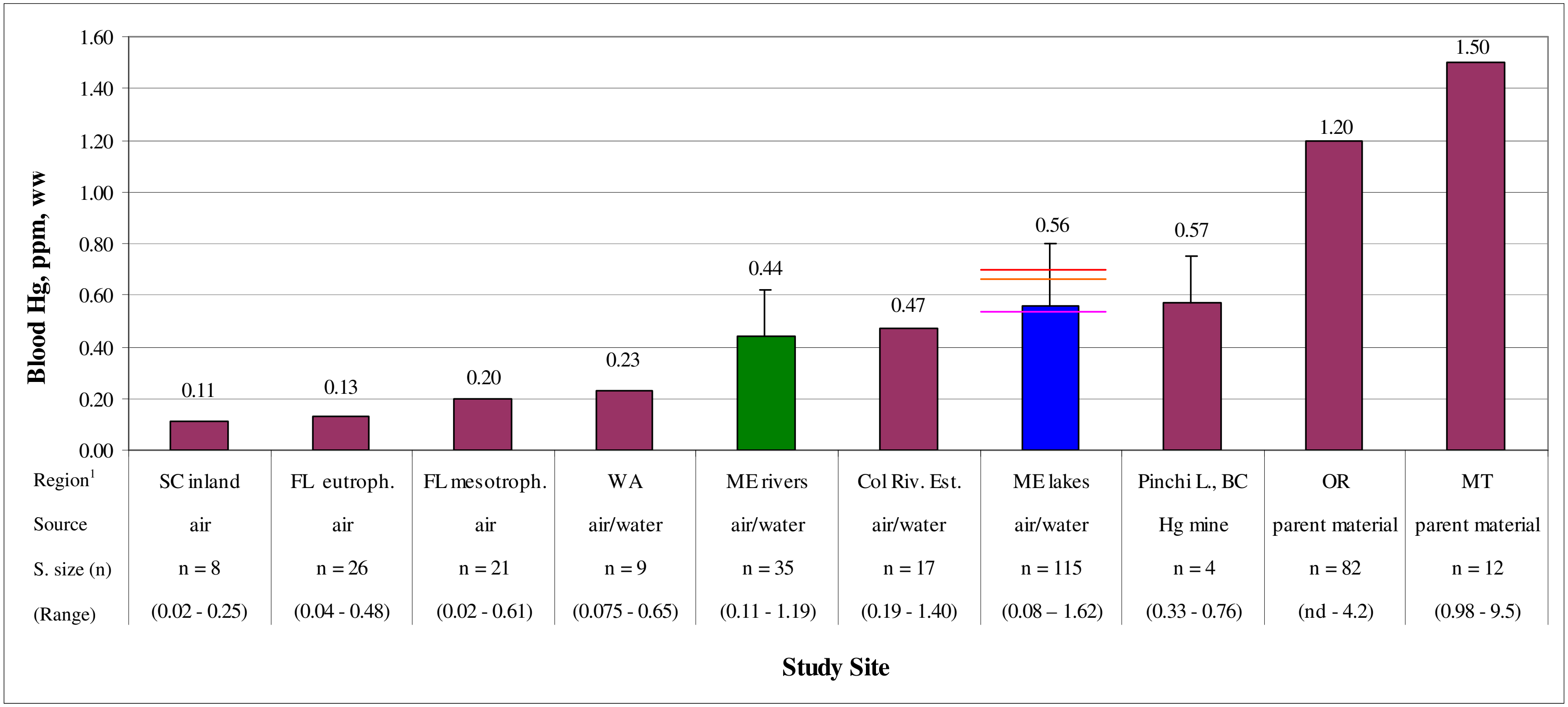


Figure 2. Blood mercury concentrations (ppm, ww) in nestling Bald Eagles from Maine and comparison populations[1].

[1] Horizontal lines on Maine Lakes bar reflect mean eaglet blood Hg concentrations for lacustrine-based eaglets in the following Maine River Basins (from highest to lowest): Red = Saint Croix (n=15), orange = Penobscot (n = 37), and pink = Saint John (n = 6). Comparison Regions: South Carolina (Jagoe et al. 2002; range reflects inland and coastal habitats); 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.

Only one study reports eaglet blood Hg concentrations higher than those reported for Maine lakes and at Pinchi Lake, B.C. Eaglets sampled in southcentral Oregon and Montana exhibited eaglet blood Hg concentrations of 1.20 ppm and 1.50 ppm, respectively (Figure 2). This population is considered to be highly exposed to mercury due to a natural "mercuriferous belt" extending throughout the western U.S. states and British Columbia made more bioavailable in many cases due to anthropogenic activities. While Wiemeyer et al. (1989) indicated that exposure levels for some individuals in their study were cause for concern; reproduction for this population appeared to be normal (Frenzel 1985). These populations represent an extreme upper case scenario in Hg exposure.

Interpreting eaglet blood Hg concentrations

Eagles tending nestlings often feed their young prey items caught from a perch near the nest, 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. 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).

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 contain 6.5 times higher Hg concentrations on reservoirs compared to natural lakes, but did not find evidence of reproductive impacts. Evers et al. (1998) reported blood exposure levels for adult and juvenile Common Loons (*Gavia immer*) throughout North America. Juvenile loons, which are more more comparable to nestling eagles compared to adults, were 0.07 ± 0.06 ppm in Alaska (lowest exposure in their study); concentrations 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). Adult loons in the northeast are commonly exposed to mercury concentrations associated with lower tendencies to incubate nests, and successfully hatch and fledge young (>3.0 ppm in adults; Burgess et al. 1998, Evers et al. 2004, Evers et al. 2005). 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.

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 = 0.01, Wilcoxon test). Feather mercury concentrations varied widely in both habitat types, ranging in individual feathers from 1.4 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	40.8 ± 20.0 (80)	7.5 – 93.5
Riverine	29.4 ± 14.6 (25)	1.4 – 48.1
BOTH	38.1 ± 19.4 (105)	1.4 – 93.5

[a] Habitat means are significantly different (p = 0.01, Wilcoxon test). Feather Hg was averaged at n = 29 sites represented by feathers collected in multiple years (n = 105 individual feathers analyzed).

Population comparisons for adult eagle feather Hg

Adult eagle feathers sampled in riverine (29.4 ppm) and especially lacustrine (40.8 ppm) habitats in Maine are higher than most population comparisons in the United States (Figure 3). Feathers from captive birds and populations in Alaska are considered to exhibit background levels, and populations in the Great Lakes (mean 21.1 ppm, range: 3.6 – 48 ppm), are considered elevated (Bowerman et al. 1994). While eaglet blood Hg concentrations in Maine lakes were comparable to those reported at Pinchi Lake, BC, (10.1 to 65.0 ppm, mean = 18.7 ppm, n = 13), adult feathers from eagles on Maine Lakes and several sites in New Hampshire[3] are notably higher. These findings indicate that adult eagles in Maine, particularly those on lacustrine sites, are bioaccumulating Hg in their bodies at a level that exceeds their natural mechanisms (i.e, feather molt, egg laying, demethylation in liver, kidneys) for elimination.

Interpreting adult feather Hg concentrations

Adult eagle feathers reflect chronic dietary Hg exposure over the period of feather growth and cumulative body burden of the molting adult. Bald eagles molt their flight feathers on their breeding grounds (Buehler 2000), thus 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). 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. Other studies have noted relationships between adult and nestling feather Hg concentrations (Wood et al. 1996), and nestling blood Hg concentrations (this study). Notable variability in adult feather Hg exposure is confounded by age, as Hg accumulates with age.

Mercury concentrations in shed adult eagle feathers from Maine (and New Hampshire) freshwater habitats exceed the level at which Scheuhammer (1991) suggested toxic effects should be considered. Feather Hg concentrations in feathers collected on lacustrine habitats in Maine and New Hampshire are slightly higher than regrown feather Hg concentrations (40 ppm) in egrets dosed with 0.5 ppm Hg, and provide some insights into dietary Hg intake through the freshwater foodweb. Berg et al. (1966) suggested 60 ppm or less in feathers could cause sterility, but effects related to other contaminants (i.e., organochlorines) remain in question. These concentrations provide a guideline for literature comparisons, however impact thresholds remain unknown for adult or nestling eagle feathers. Some adult eagles in Maine have bioaccumulated Hg concentrations in their tissues comparable to those in reported in various raptors in Sweden where alkylmercuric compounds were applied directly to the landscape (Berg et al. 1966, Westmark et al. 1975).

[3] Bald Eagle feathers collected in New Hampshire[3] reflect a small sample size, and high variability. Samples include: (1) a 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) One feather from a winter roost (Wilcox Point), which may have inadequately represented the individual in that territory sampled in 2005 (i.e., a non-resident).

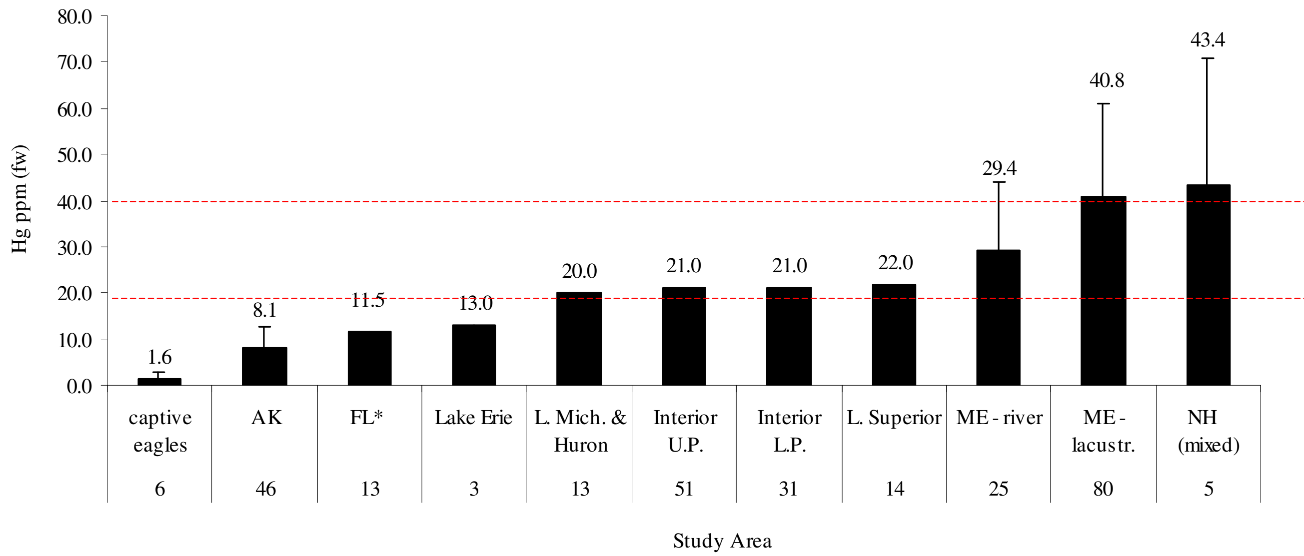


Figure 3. Concentrations of Hg (ppm, fw) in adult Bald Eagle feathers collected in the United States.

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, 7.5 – 93.5 (Table 3); ; **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 highly contaminated reservoirs (n = 31) in James Bay and Hudson Bay, Quebec.

5.4 Adult Exposure - Egg

We collected 22 unhatched Bald Eagle eggs from 19 territories over the 2004-2006 period. Egg collection sites and Hg concentrations are presented in Table 4. We did not detect significant differences in Hg concentrations in eggs among lacustrine, riverine and estuarine habitats (p>0.05, n = 18 territories[4]), or between lacustrine and riverine habitats (p>0.05).[5] Habitat differences have been

[4] Eggs from the same clutch averaged; sites sampled in >1 year (n=1)averaged.
[5] Categorizing Quantabicook as lacustrine and Kennebec as riverine did not change outcome of analyses..

noted, however, using a larger dataset of Maine eagle eggs (n=30, 2000-2005), including some of those listed below (Mierzykowski et al. 2006).

Table 4. Mercury concentrations in Bald Eagle eggs collected in Maine, 2004-2006.

Nest Site	Year	Nest Location/ twp	Habitat	Hg ppm (fw)[a]
ME 83D	2004	Tomah Stream/ Codyville Plt	riverine	0.18
ME 439A	2004	Pemadumcook Lake/ T1 R10	lacustrine	0.29
ME 289C	2004	Dolby Pond/ Millinocket	lacustrine	0.30
ME 149	2004	Penobscot River/ Chester	riverine	0.44
ME 336A1	2004	Quantabicook Lake/ Searsmont	estuarine	0.54*
ME 336A2	2004	Quantabicook Lake/ Searsmont	estuarine	0.68*
ME 161A	2004	Boyden Lake/ Perry	lacustrine	0.90^
ME075D	2005	Brandy Pond/ T39 MD	lacustrine	0.87^
ME081C	2005	West Grand Lake/ Pukakon	lacustrine	0.52*
ME083D	2005	Tomah Stream/ Codyville Plt	riverine	0.16
ME176A	2005	Mattamiscontis Lake/ T3R8 NWP	lacustrine	0.35
ME252C	2005	Richardson Lake/ Richardson TWP	lacustrine	0.34
ME412A 1	2005	Androscoggin River/ Livermore Falls	riverine	0.42
ME412A 2	2005	Androscoggin River/ Livermore Falls	riverine	0.33
ME436A	2005	Long Pond/ Somerset	lacustrine	0.41
ME397	2006	Pleasant Pond/ Litchfield	lacustrine	0.16
ME 404	2006	Washington Pond/ Washington	lacustrine	0.09
ME 491	2006	Kennebec River/ Winslow	estuarine	0.19
ME 392	2006	Hermon Pond/ Hermon	lacustrine	0.27
ME 141 1	2006	Quakish Lake/ T3 Indian Purchase	lacustrine	0.73*
ME 141 2	2006	Quakish Lake/ T3 Indian Purchase	lacustrine	0.67*
ME 186	2006	Chesuncook, Gero Island/ Chesuncook	lacustrine	0.30
(22 eggs)		**(19 nesting territories)**	**Mean Hg ± SD:**	[b] **0.39 ± 0.23**

[a] Hg analyses supported by USFWS. Additional analyses of Organochlorine compounds are also being conducted on egg samples (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 collected = 0.41 ± 0.23 (SD).
* Noted for eggs exceeding 0.50 ppm (Wiemeyer et al. 1984, 1993).
^ Eggs exceeding 0.80 ppm (Henny et al. 2002).

Population comparisons for eagle egg Hg

Mercury concentrations in Maine eagle eggs in this study are higher than many available 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). Evers et al. (2003) reported similar geographic trends in loon eggs; with 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. Mierzykowski et al. (2006) note little declines in Hg exposure as indicated by eagle eggs over the last several decades. Mierzykowski and Carr (2002) reported a mean level of 0.17 ppm in four eagle eggs collected in 2000. As with other tissues collected in this study, interpretations of egg Hg concentrations must consider location (i.e., region, watershed) and habitat.

Interpreting eagle egg Hg concentrations

Eggs reflect a combination of current dietary Hg exposure and chronic Hg accumulation in adult eagles. Adverse effect thresholds for eggs range from 0.50 to 1.00 ppm (ww) (Weech et al. 2006). Benchmarks of 0.50 ppm (Wiemeyer et al. 1984, 1993) and 0.80 ppm (Henny et al. 2002) are useful in evaluating Hg exposure in eagle eggs; 7 eggs representing 5 nesting territories (26%) exhibited Hg concentrations exceeding 0.50 ppm, and 2 eggs (2 territories; 10%) exceeded 0.80 ppm. Further assessments and evaluations of Hg exposure data in eagle eggs has been presented elsewhere (Mierzykowski et al. 2006).

5.5 Relationships between Eagle Productivity and Hg Exposure

Eaglet Blood Hg vs. Productivity

We detected 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.

In general, blood mercury measures displayed a significant negative correlation 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 6). Riverine nests were not significantly correlated to productivity measures ($p > 0.05$).

Categorical approaches comparing Hg exposure in 2 productivity groups (>1 or <1 chicks fledged per occupied nest) are similarly suggestive of reproductive impacts (Figure 5). The level of productivity of 1.0 chicks fledged per occupied nest is considered the level necessary to sustain populations.

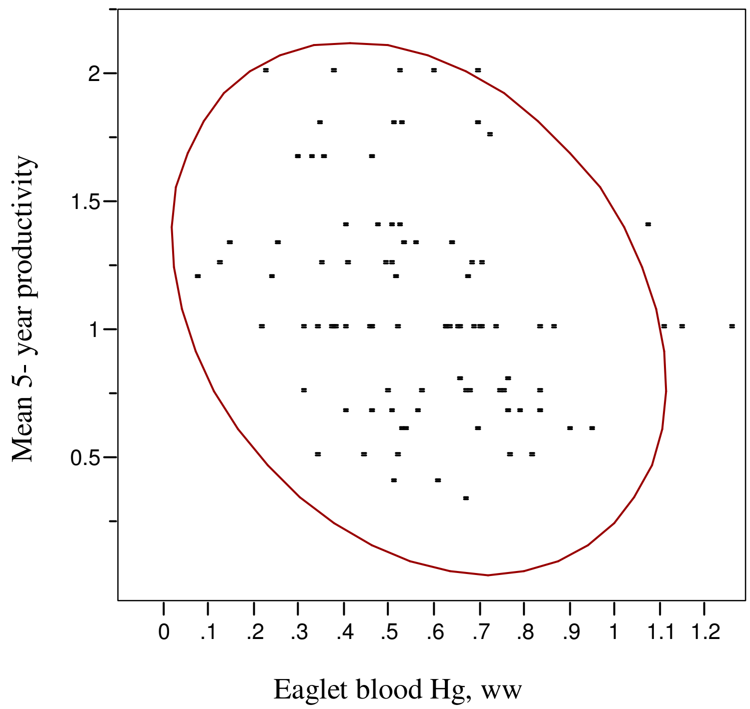


Figure 4. Correlation between eaglet blood mercury concentration (ppm) and 5-year territory productivity (chicks fledged/occupied territory) for lacustrine eagle nesting territories in Maine.

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 = -0.13 (0.11) [a]	r = -0.31 (0.0001) [a]	r = -0.26 (0.0014) [a]
Hg/age	r = -0.21 (0.017) [a]	r = -0.34 (0.0001) [a]	r = -0.33 (0.0001) [a]
Hg/weight	r = -0.16 (0.052) [a]	r = -0.29 (0.0004) [a]	r = -0.28 (0.0006) [a]

Spearman's Rho correlation coefficient and significance (in parentheses) for eaglet blood Hg exposure vs. 3, 5, and 10-year productivity (young fledged/occupied nest).
[a] Relationships remained or became significant at P = 0.05 after removing territories occupied <3 years from 3,5,10 yr datasets.

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 = -0.12 (0.20)	r = -0.32 (0.0004) [a]	r = -0.25 (0.0068) [a]
Hg/age	r = -0.23 (0.022) [a]	r = -0.35 (0.0003) [a] *	r = -0.34 (0.0005) [a]
Hg/weight	r = -0.16 (0.09) [a]	r = -0.31 (0.0007) [a]	r = -0. 30 (0.0012) [a]

Spearman's Rho correlation coefficient and significance (in parentheses) for eaglet blood Hg exposure vs. 3, 5, and 10-year productivity (young fledged/occupied nest).
[a] Relationships remained or became significant at P = 0.05 after removing territories occupied <3 years from 3,5,10 yr datasets.
* Displayed in Figure 4.

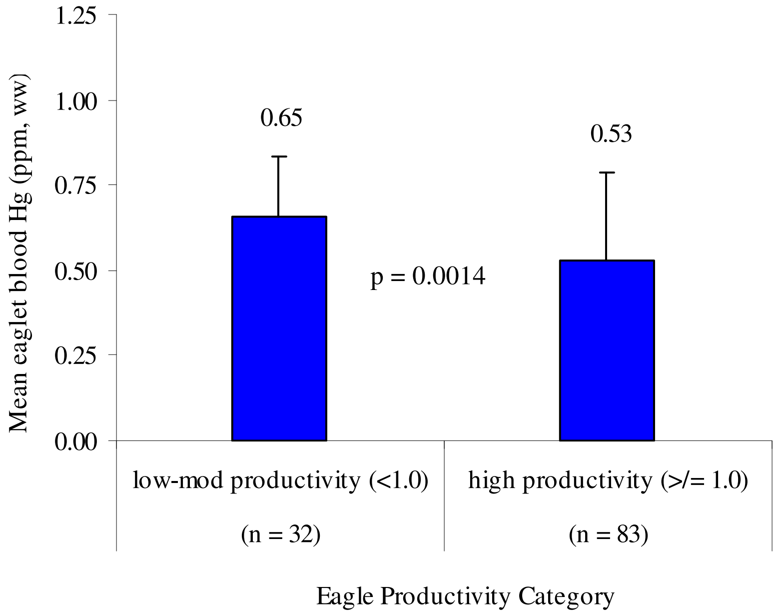


Figure 5. Mean eaglet blood Hg exposure in two categories of mean eagle productivity.

Siblings within nest and nests sampled within multiple years were averaged. Data includes lacustrine habitats only. Mean 5-year productivity used in analyses, 2002-2006.

Noteworthy observations and conclusions based on Tables 5 & 6 (and Figures 4 & 5) include:

- The majority of relationships detected between eaglet blood Hg and productivity remained significant after excluding territories with less than three years nest occupancy in 3, 5, and 10-year categories (noted by superscripts in Tables 5, 6).
- Five–year productivity measures often display the strongest relationships to Hg exposure in comparison to 3-year measures, likely reflecting increased variability in shorter term measures of productivity.
- Blood Hg measures that account for differences in chick age or weight generally result in stronger correlation coefficients and greater significance, suggesting these variables are important.
- Eaglets displaying productivity ≥1.0 productivity (the level considered necessary to sustain populations) exhibited lower mean blood Hg exposure compared to territories exhibiting <1.0 chicks fledged / occupied nest (Wilcoxon test, $p = 0.0014$). Note mean eaglet blood Hg exposure in the low-moderate productivity group approaches the 0.70 ppm Hg level used in this study and associated with potential negative impacts.

Adult tissues (shed feather and eggs) vs. productivity

Mean adult shed feather mercury concentrations were not significantly correlated with 3, 5, or 10-year productivity ($p>0.05$, Spearman Rank Correlation). Mean territory egg Hg concentrations were not related to mean 3-year, 5-year, or 10-year territory productivity measures in lacustrine or combined habitats (Pearson Correlation, $p>0.05$). Mean territory egg Hg concentrations were positively correlated to all 3 productivity measures in riverine habitats ($p < 0.05$, $r = 0.99$, for all 3 measures; Pearson Correlation nest #ME491 considered riverine) assumedly implying no effect; however, sample sizes is highly limited (n=4).

5.6 Temporal Mercury Trends in Maine, 1991-1992 vs. 2001-2006.

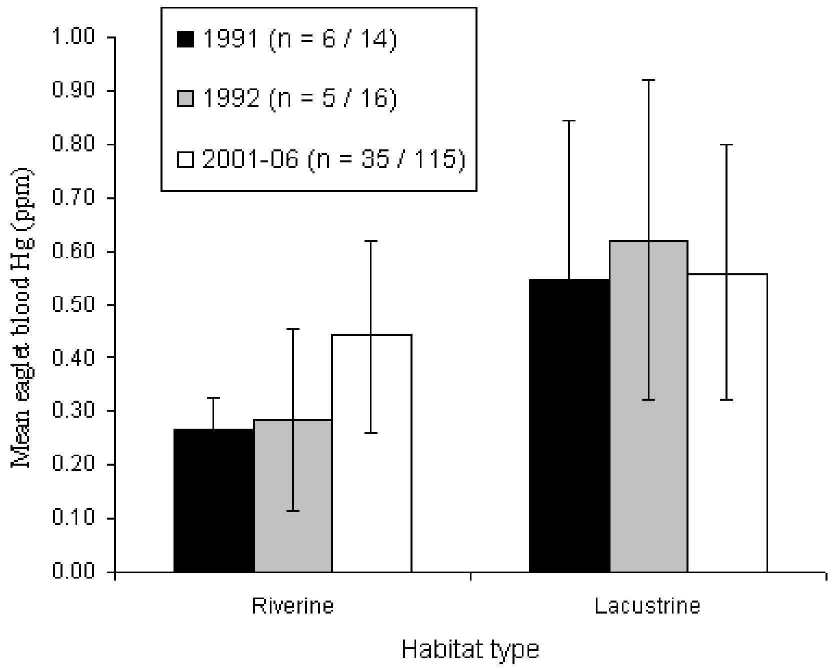
Our findings indicate that current (2001-2006) mercury bioavailability as indicated by Bald Eagle nestlings in freshwater Maine habitats is similar or potentially higher than temporal comparisons (1991-1992; Welch 1994) (Figure 6). Robust temporal comparisons are limited by sample size for 1991-1992 sampling efforts, reflecting fewer sampling opportunities available during the earlier period.

Riverine: Mean mercury exposure in riverine habitats in our study during 2001-2006 (territory mean = 0.44 ± 0.18 ppm, n = 35; nestling Hg range: 0.11 – 1.19 ppm) tended to be higher than those reported by Welch (1994) during 1991 (0.27 ± 0.06) and 1992 (0.28 ± 0.17) (Figure 6).

Lacustrine: Mean mercury exposure in lacustrine habitats in our study during 2001-2006 (territory mean =0.56 ± 0.24 ppm, n = 115; nestling Hg range: 0.08 – 1.62) were similar those reported by Welch (1994) during 1991 (0.55 ± 0.30) and 1992 (0.62 ± 0.30) (Figure 6).

Based on these findings, there is no evidence of declining bioavailability of mercury among nestling bald eagles based on freshwater nesting habitats in Maine during the last 11 – 16 years. These findings are consistent with other studies also indicating that mercury is persistent in aquatic ecosystems (Wiener et al. 2003). Policy makers should consider these findings when evaluating Hg emissions policies within local, regional, national, or global scales. 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 6. Mercury exposure for eagle nestlings sampled in riverine and lacustrine habitats, 1991- 1992, and 2001-2006.



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 (2001-2006). 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.

5.7 Spatial comparisons: Mercury among Maine watersheds

Eaglet blood mercury. Greater sample sizes gathered during 2006 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 (Figure 7). 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 7), however sample sizes/watershed/habitat 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 2004-2006 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, and potentially the Downeast region. Similarities between Hg exposure between lacustrine and riverine sites in Maine are unusual, and may reflect Hg inputs into riverine habitats in these regions. Additional sampling by habitat in these regions is necessary to evaluate habitat Hg patterns observed in this study.

Adult feather Hg. We found no significant differences in mean feather Hg among 10 watersheds in lacustrine, riverine, or combined habitats ($p > 0.05$, Wilcoxon test). Mean Hg concentrations for watersheds ranged from 31 to 71 ppm (Table 7). Of the watersheds represented by ≥3 samples, mean Hg exposure within watersheds appears to be fairly similar, ranging between 31 - 46 ppm. Samples representing Androscoggin River Basin lakes were among the highest means in the dataset; and this watershed may contain greater variability in adult Hg exposure compared to others (SD = 34.3).

Feather Hg exposure patterns observed among watersheds do not mirror patterns observed in eaglet blood (Figure 7), suggesting more uniform Hg bioaccumulation in adults regionally. For example, adult eagles within the Kennebec and Penobscot River basin watersheds display very similar mean feather Hg concentrations and variability, while mean eaglet blood Hg concentrations between these two watersheds differ ($p< 0.05$). Consistent with other patterns observed in this and other studies, adult feathers were generally higher in lacustrine vs. riverine habitats. Preliminary evaluations based on very few samples from the Saint John and Saint Croix River Basin rivers may suggest relatively low Hg accumulation compared to other riverine habitats in Maine. Some patterns of Hg exposure may relate to eagle age, as older individuals often exhibit higher body burdens of Hg.

Table 7. Mercury concentrations in adult eagle feathers collected within 10 Maine watershed basisns, 2004-2006.

	Lacustrine			Riverine		
Watershed	n	Mean	SD	n	Mean	SD
Saint John River basin	5	30.7	13.8	1	13.2	
Cobscook Bay area coastal waters	3	36.0	17.7			
Saint Croix River basin	12	37.6	19.2	2	13.6	17.2
Penobscot River basin	24	40.1	18.3			
Kennebec River basin	19	40.9	22.8	5	34.9	19.3
Downeast river basins	8	43.0	20.6	1	34.5	.
Androscoggin River basin	4	46.2	34.3	2	31.0	3.4
Penobscot Bay area coastal waters	2	51.6	12.1	14	30.2	13.5
Southern river basins & coastal waters	1	57.0				
Midcoast river basins and coastal waters	1	70.7				

Eagle feather Hg concentrations did not vary among watersheds within habitat types ($p>0.05$, Wilcoxon test). Table is sorted by increasing feather Hg in lacustrine sites.

One interesting pattern suggested in Table 7 that the 3 watersheds consisting of a greater proportion of coastal and estuarine habitats (i.e., Penobscot Bay, Midcoast River Basins, Southern River Basins) exhibited the highest mean Hg concentrations compared to most other watersheds. These patterns are based on very small sample sizes, but may suggest higher Hg exposure in coastal eagles than previously thought. No studies have evaluated Hg exposure in adult eagles along coastal Maine; these findings may indicate high exposure in coastal/estuarine eagles despite low short-term dietary Hg exposure indicated by nestling blood observed in other studies (Welch 1994, Evers et al. 2005). Patterns of eaglet blood Hg and adult feather Hg exposure are superimposed in Figure 8.

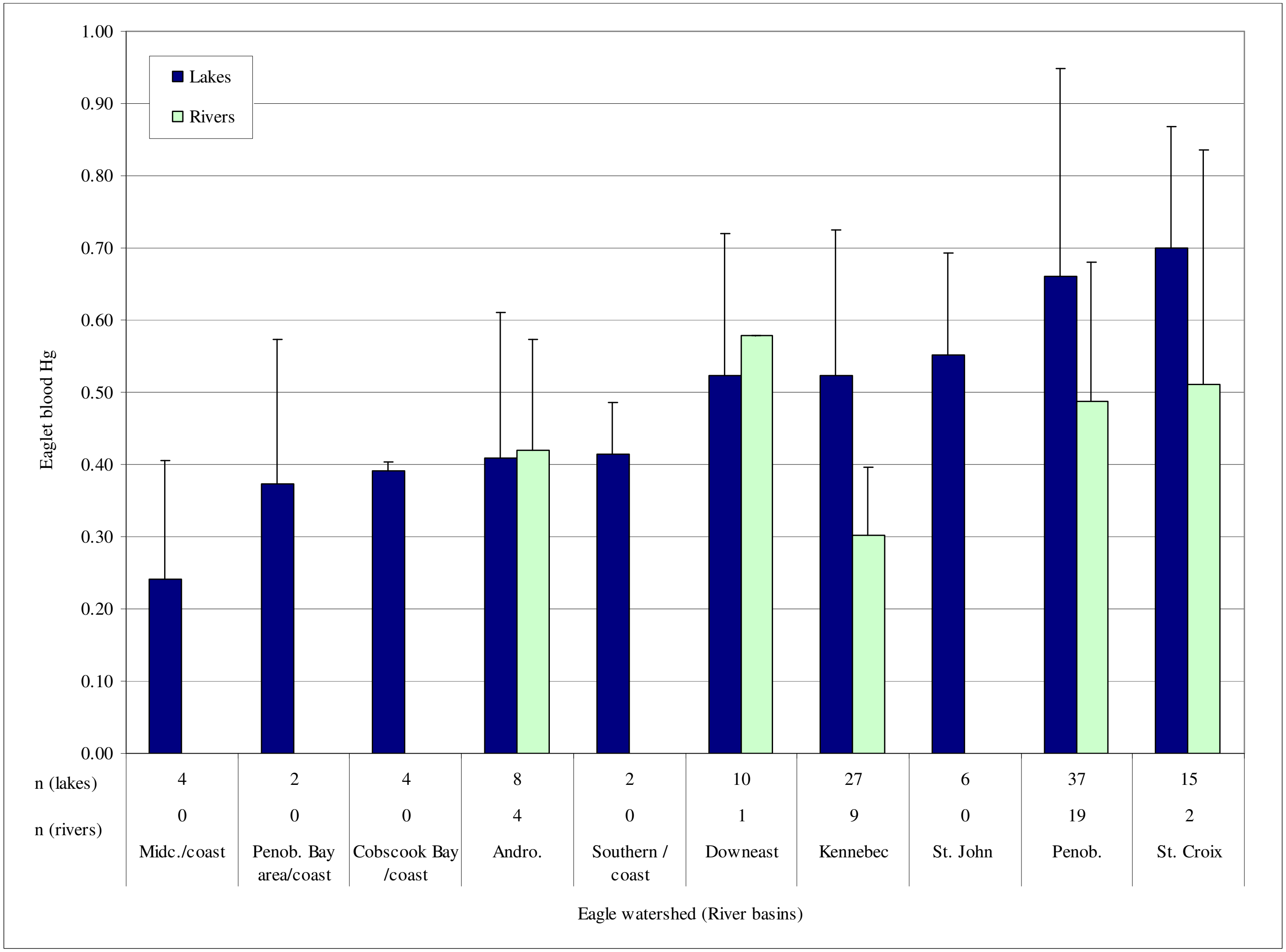


Figure 7. Bald Eagle nestling blood mercury exposure in 10 Maine watersheds.

Eaglet blood mercury levels (ppm, ww) averaged for siblings and between years at repeat sample sites (2001-2006; primary sampling 04-06).
Note (1) Hg exposure appears to be elevated in several watersheds in northeastern Maine (i.e., St. Croix, Penobscot, and St. John), (2) In most watersheds lakes exhibit higher Hg vs. rivers, except in the Androscoggin and Downeast regions.

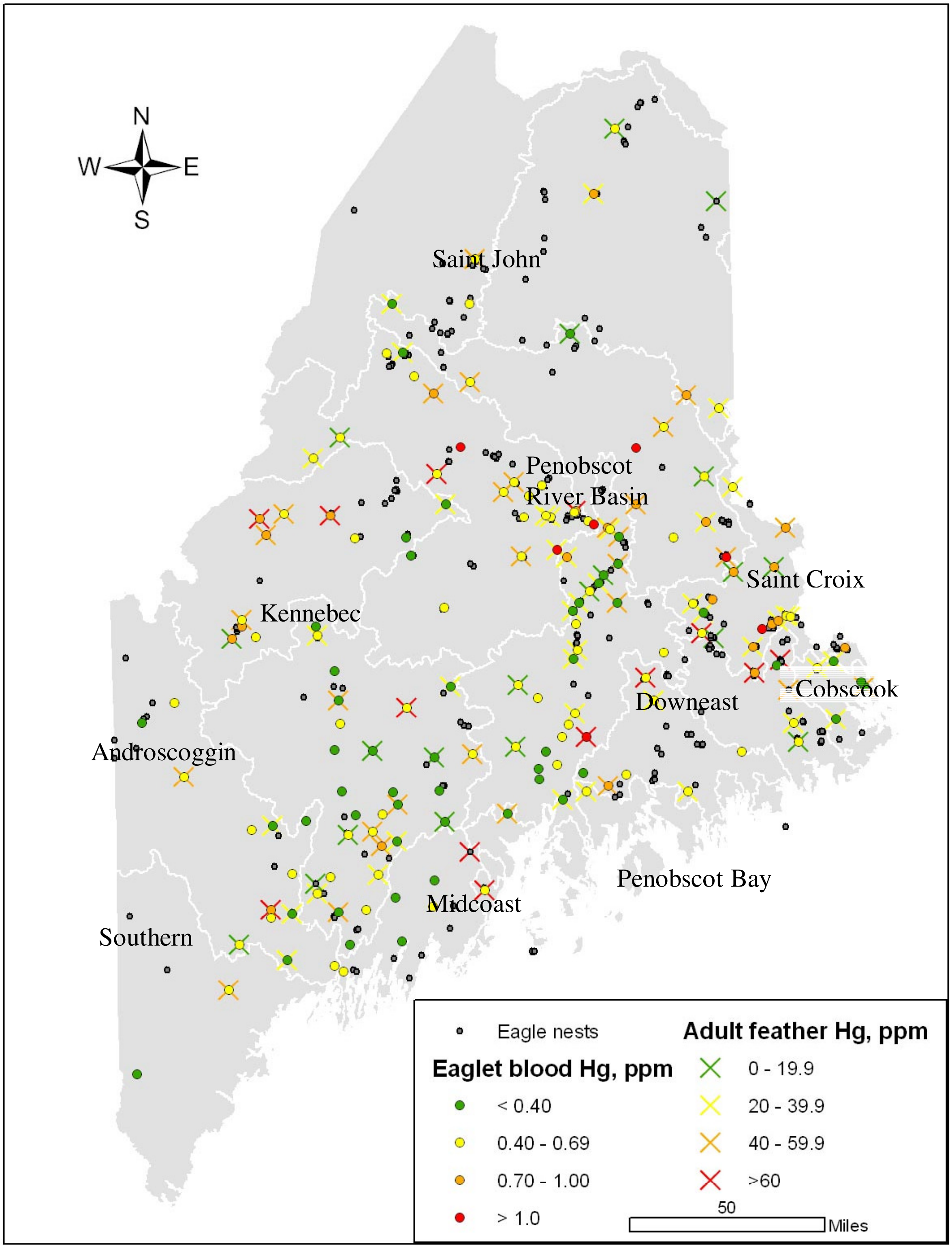


Figure 8. Mercury concentrations in eaglet blood and adult shed feathers in ten Maine watersheds, 2001-2006.

Names straddling watershed boundary lines in include both subregions (e.g., St. John constitutes all of northern Maine). Eaglets averaged within nests and between/among years at territories. Feathers (collected 2004-2006), averaged when multiple samples collected / site or year.

5.8 Proportional Assessments of Hg 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 blood Hg blood Hg exposure and 3, 5, and 10-year productivity. A portion of all tissues sampled in this study exceeded most comparison populations in North America, many of which are considered highly contaminated, industrial regions. Hg is not spatially homogenous in Maine, and much of the population may not be experiencing negative Hg impacts. Therefore, proportional assessments to population exposure may be the best means of evaluating what proportion of the population is most likely impacted. 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.

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 8). 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 literature comparisons.

Table 8. 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).

Nestlings (blood)

Between 13-29% of eaglets in lacustrine habitats contain blood mercury levels designated as elevated or higher (>0.70 ppm) (Figure 9); while 2 – 8% exhibit concentrations designated as highly elevated (>1.0 ppm). Between 3-13% of eaglets sampled in riverine habitats were designated as elevated or higher; 1% of sampled riverine eaglets were considered highly elevated (Figure 10).

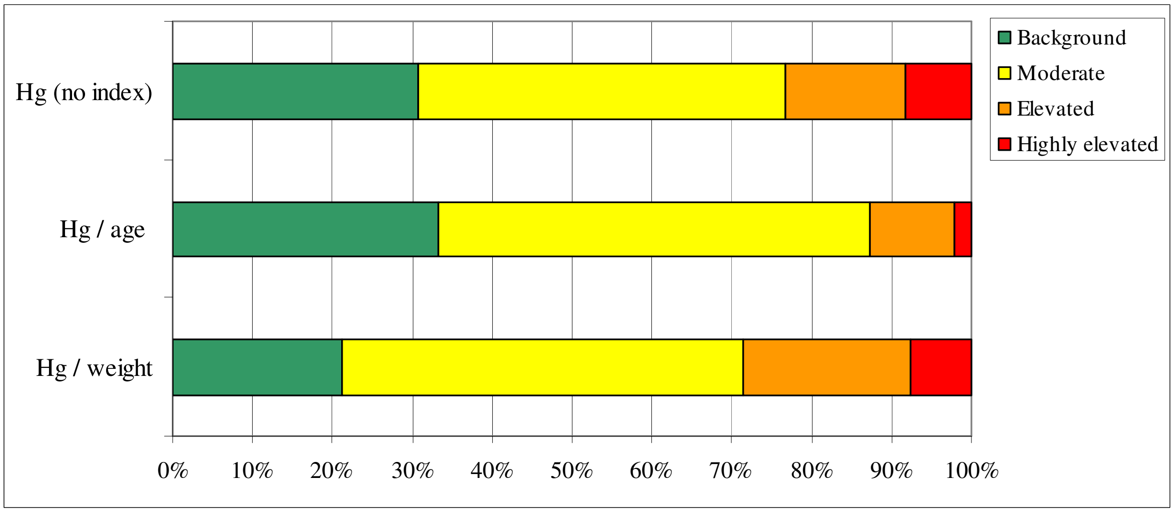


Figure 9. Proportion of lacustrine eaglets sampled 2001-2006 falling into different dietary mercury exposure groups.

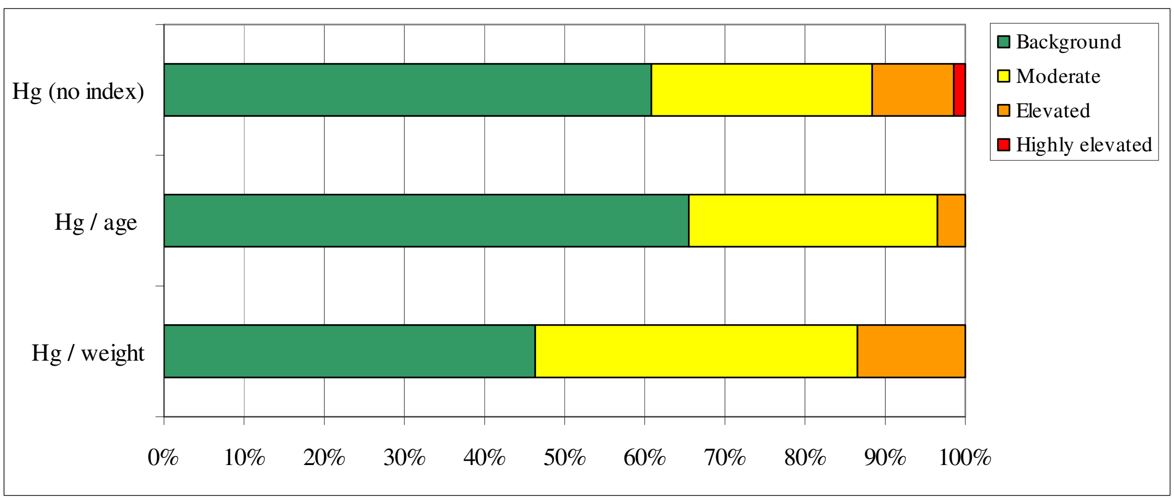


Figure 10. Proportion of riverine eaglets sampled 2001-2006 falling into different dietary mercury exposure groups.

Adults (feathers)

We analyzed 89 feathers from 69 Maine Bald Eagle territories in Maine (8 feathers from 5 territories in NH included) for Hg. In lacustrine habitats, 84% were at a level at which toxic effects should be considered[6] (≥20 ppm; Scheuhammer 1991) or higher (Figure 11). Forty-six percent of feathers were at or above the level designated as highly elevated (>40 ppm), based on findings by Spaulding et al. (2000), and 16% were at or above the level we designate as very highly elevated (>60 ppm). In riverine habitats, 72% of feathers contained concentrations considered elevated or greater. No feathers in riverine habitats can be considered very highly elevated.

Concentrations ≥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

[6] Feathers averaged/site.

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 et al. 2006).

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) may be similarly occurring in Maine's population. In addition to impacts observed on productivity observed in this study, Hg impacts on adults may result in more subtle impacts, such as incrased mate displacement rates, which can impact productivity. Such impacts would be difficult to detect in populations without monitoring marked adults.

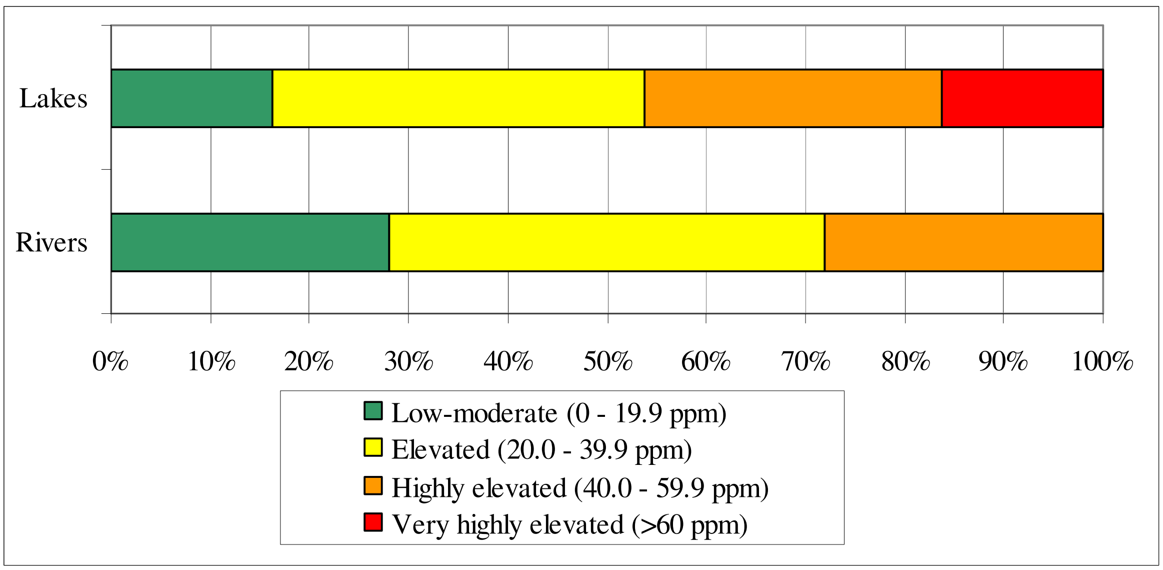


Figure 11. Proportion of shed adult eagle feathers collected 2004-2006 within four mercury exposure groups.

Feathers averaged at sites from multiple years, n = 105 territories (80 Lakes, 25 rivers).

Adults (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 4). 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. Egg collections are a very limited, skewed sample and are inadequate for speculations on population impacts. 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.

5.9 Proportional Evaluations of Eagelt Hg Exposure within Selected Maine River Basins.

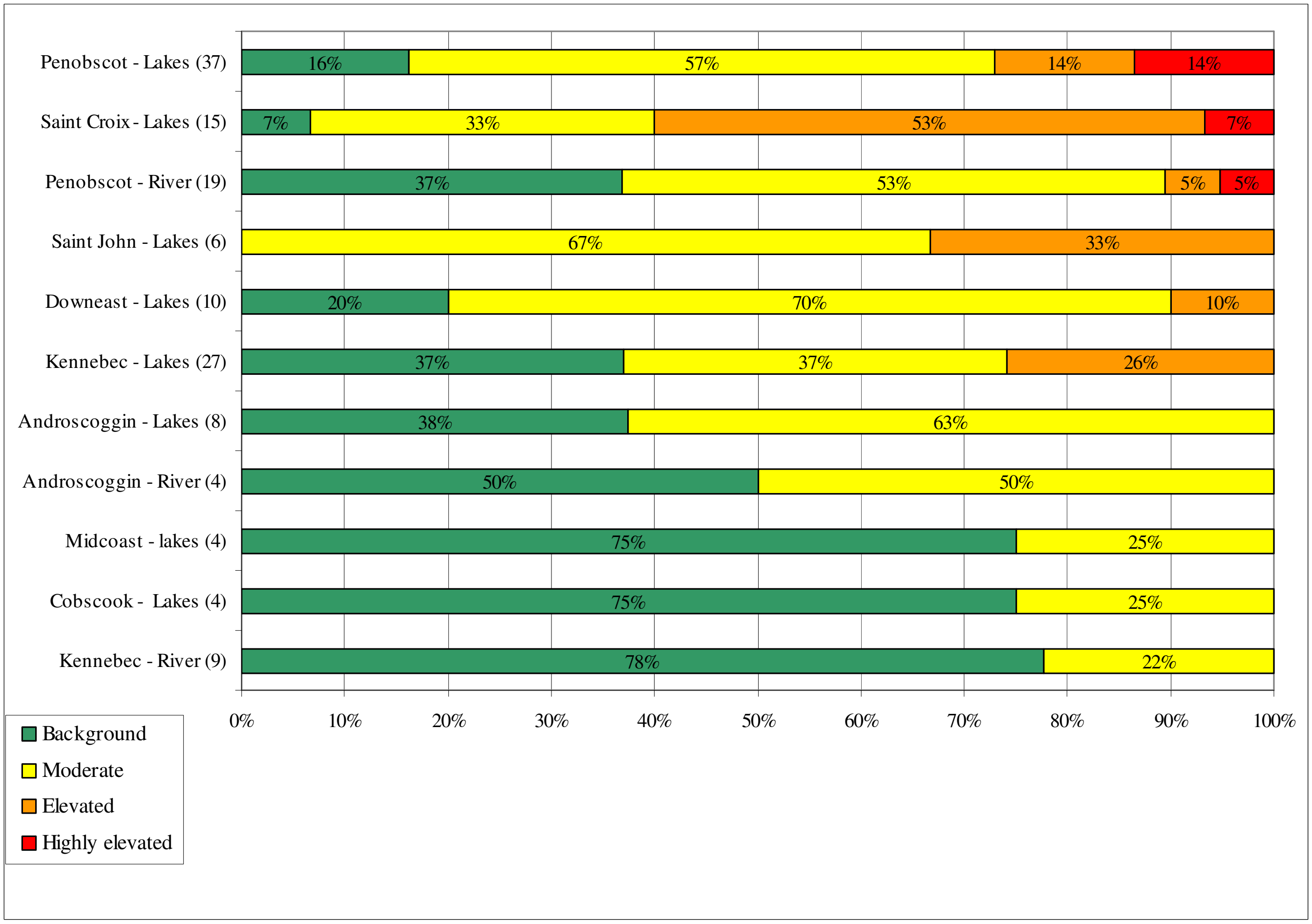


Figure 12. Proportion of sampled eagle territories in which mean territory blood Hg concentration fell into four dietary Hg exposure groups.

Watershed-focused analyses of Hg exposure in eagle populations in this study (Figure 12, Figures 7-9) emphasize that Maine watersheds vary in terms of the Hg exposure exhibited in wildlife, and habitat must be considered. Proportional approaches to evaluating Hg exposure in eagle populations within individual watersheds provide insights into the extent of Hg exposure and persistence within subregions of Maine[7]. Some watersheds in this study, particularly the Saint Croix (lakes), and lakes and rivers within the Penobscot River Basin, consistently indicate elevated Hg exposure in fish and wildlife. The Saint John River Basin (limited by sample size/sampling opportunities), and lakes within the Kennebec River watershed exhibit a notable proportion of nesting territories with Hg concentrations considered elevated in Maine. Given that Hg concentrations in this range have been associated with reproductive impacts in this study, eagle populations within these watersheds are likely at the highest risk of negative impacts from Hg exposure compared to other regions.

While Hg exposure patterns observed in Figure 12 (see also Figure 7) may indicate lesser concern for fish eating wildlife in the Androscoggin River Basin (i.e., no territories exhibiting mean

[7] Siblings averaged / nest; nest sampled in multiple years averaged/site; Watersheds containing ≥4 sampled territories / habitat type selected for figure.

Hg levels considered elevated) the fact that lacustrine and riverine eaglets in this watershed as well as the Downeast River Basin suggest additional Hg issues in these watersheds outside the norm in Maine and elsewhere. These patterns may reflect current or historical (or likely a combination) anthropogenic Hg inputs into rivers in both of these watershed basins.

5.10 Improving Spatial Resolution: Hg comparisons at the subdrainage level

Some larger Maine watersheds contain a sufficient number of eagle nests within watersheds that subdrainage level resolution of Hg exposure is possible. We analyze Hg exposure as indicated by mean eaglet blood within the Penobscot and Kennebec River Basins. Combined, these watersheds are responsible for draining over half of the state.

Penobscot River Basin

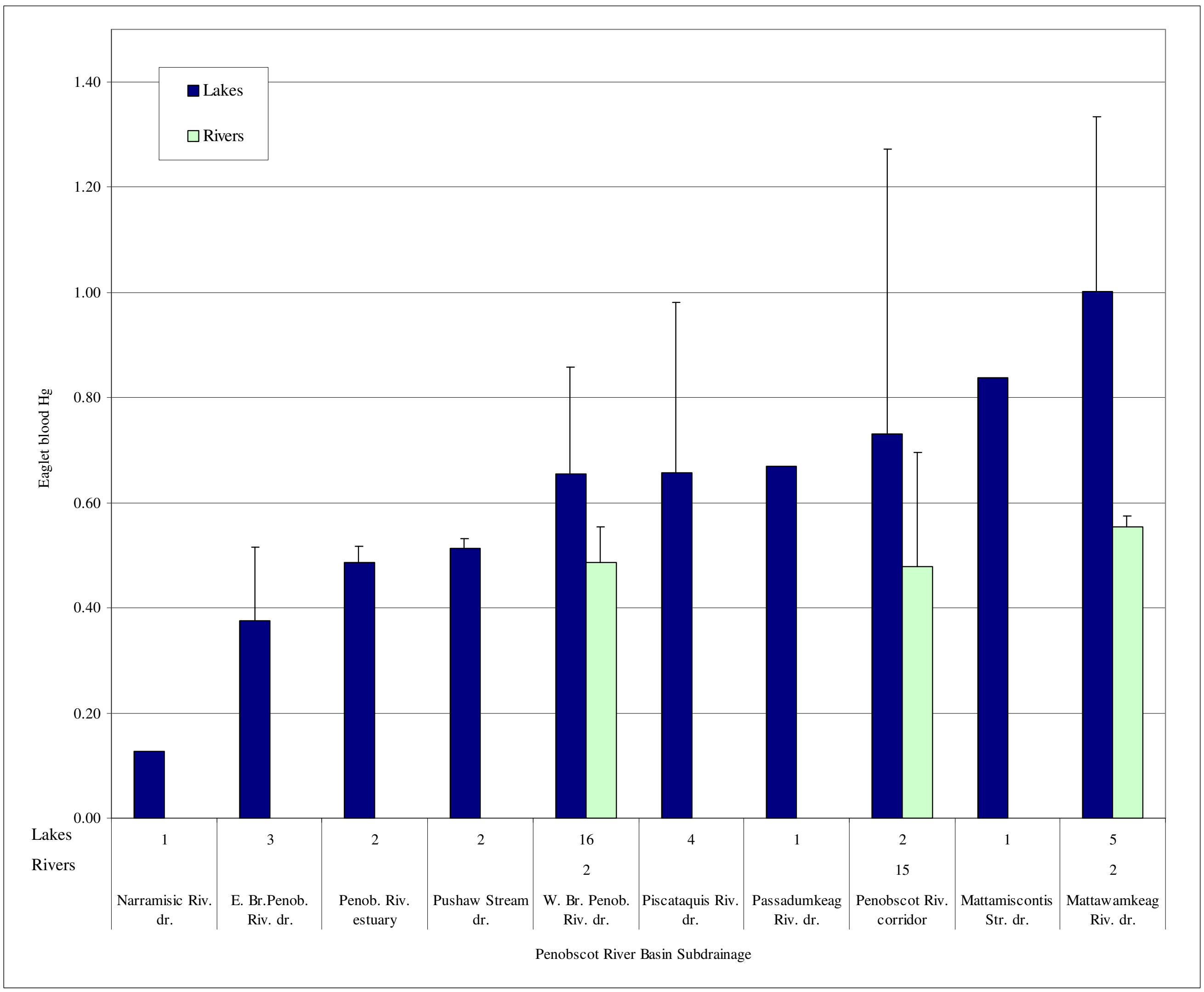


Figure 13. Mean eaglet blood Hg exposure among subdrainages within the Penobscot River Basin.

For lake habitats, mean eaglet blood Hg concentrations ranged from 0.13 ppm Hg concentration in eaglet blood in the Naramissic River subdrainage to 1.0 ppm in the Mattawamkeag River subdrainage in Penobscot River Basin lakes (Figure 13). Eaglet blood Hg concentrations appear to be most variable in the Penobscot River corridor subdrainage. Patterns of elevated lake Hg compared to rivers appears to be consistent within 3 subdrainages in which both habitat types were sampled. Mean eaglet blood Hg concentrations were significantly different among subdrainages within the Penobscot River Basin among lacustrine sites ($p< 0.05$, Wilcoxon test), but not among riverine sites ($p>0.05$, Wilcoxon test). Sample sizes limit comparisons in some subdrainages, particularly within riverine habitats.

Kennebec River Basin

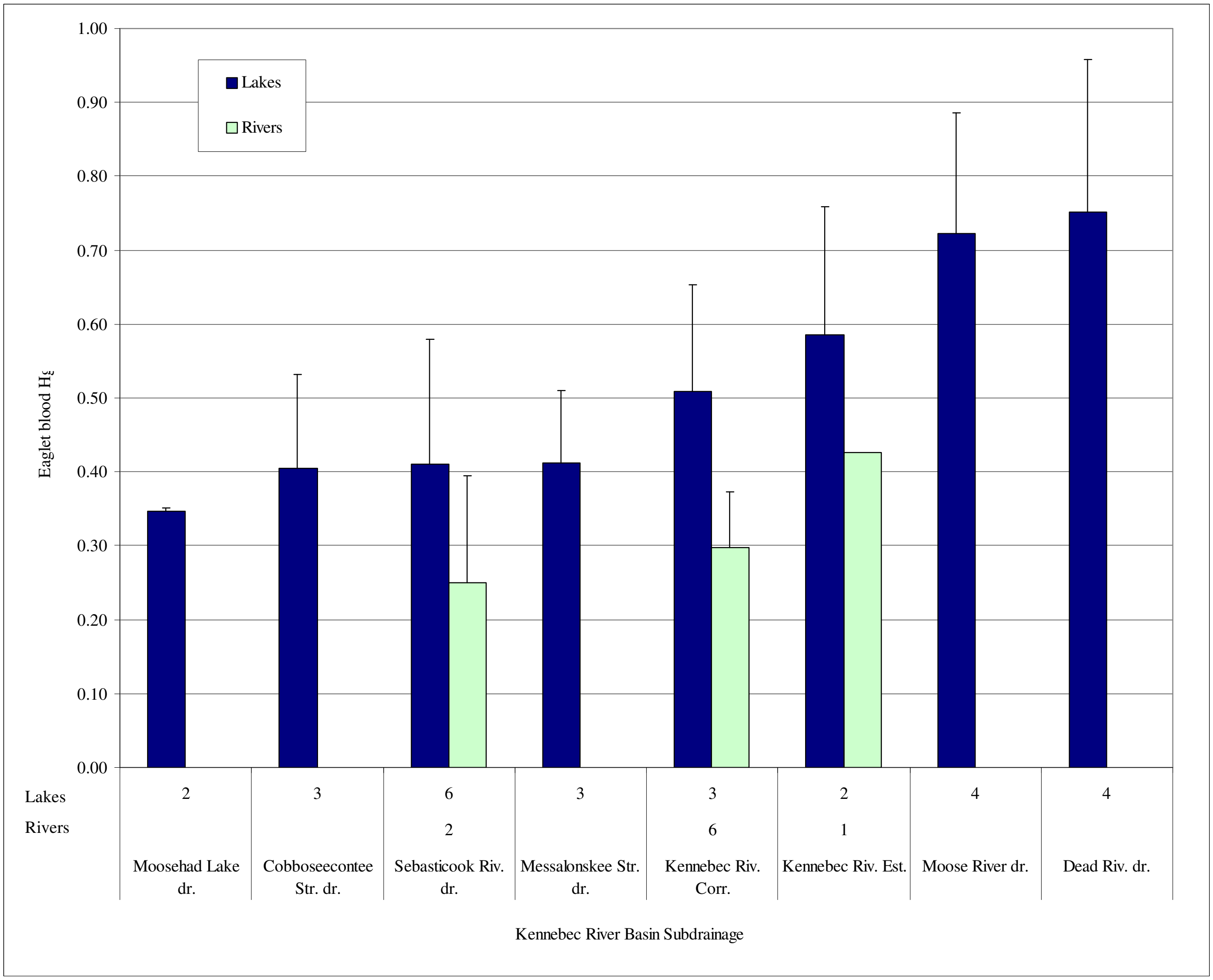


Figure 14. Mean eaglet blood Hg exposure among subdrainages within the Kennebec River Basin.

Subdrainages within the Kennebec River Basin exhibited mean eaglet blood Hg concentrations ranging from 0.35 ppm – 0.75 ppm in lacustrine habitats, and 0.25 ppm – 0.43 ppm in riverine habitats (Figure 14). Similar to the Penobscot River Basin, subdrainages differed significantly in mean eaglet blood Hg concentrations in lacustrine habitats ($p< 0.05$, Wilcoxon test), but not in riverine habitats ($p>0.05$, Wilcoxon test). Sample sizes limit comparisons in some subdrainages, particularly within riverine habitats.

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 in this study as well as numerous others indicate significant Hg problems in Maine's freshwater habitats that meet or exceed Hg exposure in many or all comparison regions in North America. Given the persistent nature of Hg (see point 3 below), and the abundance of habitats that enhance Hg methylation in Maine, policymakers should take proactive steps to control Hg inputs onto/into the landscape at a local, regional, national, and global level.

3. 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 the Midwestern U.S. (i.e., Bowerman et al. 2002) in order to evaluate temporal Hg trends observed during this study.

4. Sampling opportunities in Maine vary annually due to seasonal weather influences on nest success and chick survival, thus some target nests may not become available for sampling more once per 6 years. Therefore, scaled-back eaglet sampling at a moderate level to reach a minimum of six riverine and six lacustrine samples per Watershed Basin whenever available (see sample sizes in Figure 7), is recommended to allow for more comprehensive Hg evaluations at the statewide level and within / among watershed basins. Such sampling will provide valuable baseline comparisons for these regions presently and in the future as sampling in 1991-1992 (Welch 1994) has provided for this study.

5. Adult feathers are a valuable indicator of Hg exposure in Maine's adult eagle population. We recommend continued feather collections for archives and analysis to allow for improved spatial assessments of Hg exposure risk in adult Maine eagles, which are among some of the most elevated eagle feather Hg levels reported in North America.

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 transferred to the Maine Department of Inland Fisheries and Wildlife office 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.

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