

Using Feathers To Assess Risk of Mercury and Selenium to Bald Eagle Reproduction in the Great Lakes Region

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Abstract. Mercury (Hg) and selenium (Se) concentrations were determined in feathers of nestling and adult bald eagles (*Haliaeetus leucocephalus*) in the Great Lakes region, 1985-1989. Relationships between concentrations and two measures of reproduction, productivity and nesting success, were examined. Hg and Se were detected in all feathers analyzed. A maximum concentration of 66 mg/kg Hg was found in adult feathers in the upper peninsula of Michigan. The geometric means of Hg in adult feathers for sample areas were: interior lower peninsula of Michigan, 21 mg/kg; interior upper peninsula of Michigan, 21 mg/kg; Lake Superior, 22 mg/kg; Lakes Michigan and Huron, 20 mg/kg; and Lake Erie, 13 mg/kg. The geometric means of Hg in nestling feathers for sample areas were: interior lower peninsula of Michigan, 8.8 mg/kg; interior upper peninsula of Michigan, 8.1 mg/kg; Lake Superior, 8.7 mg/kg; Lakes Michigan and Huron, 8.0 mg/kg; Lake Erie, 3.7 mg/kg; and Voyageurs National Park, 20 mg/kg. Se concentrations were not significantly different across regions or between adult and nestling feathers, and Se concentrations ranged from 0.8 to 3.2 mg/kg.

No significant relationships between adult or nestling feather concentrations and either measure of reproduction, productivity or nesting success, was found for either Hg or Se. It was concluded that neither Hg nor Se concentrations are currently affecting bald eagle reproduction in the Great Lakes region.

Some species of birds are sensitive to the adverse effects of mercury (Hg) and selenium (Se). For Hg, reproductive failure and altered nesting behavior have been documented in common loons (*Gavia immer*, Barr 1986), and laboratory feeding studies have shown acute lethality, neurotoxicity, and altered nesting behavior related to Hg concentrations in food for the goshawk (*Accipiter gentilis*, Borg *et al.* 1970) and red-tailed hawk (*Bu-*

teo jamaicensis, Fimreite and Karstad 1971). Selenium produces embryoletality and teratogenicity in waterfowl (Ohlendorf *et al.* 1986; Hoffman *et al.* 1988).

Concentrations of Hg have increased in the aquatic environment throughout eastern North America primarily due to atmospheric deposition (Norton *et al.* 1981; Nriagu 1990; Wong *et al.* 1984; Johnson 1987). Hg concentrations in fish of inland lakes in Michigan have also been increasing (Evans *et al.* 1991). The bald eagle (*Haliaeetus leucocephalus*) is a tertiary avian predator in the Great Lakes region aquatic food web, and because of its position in the food web, it is susceptible to bioaccumulation of xenobiotics. It is, therefore, a good sentinel species in which to measure tissue concentrations of xenobiotics. The use of feathers to monitor environmental exposure of birds to heavy metals is a common method (Westermarck *et al.* 1975; Bühler and Norheim 1982; Bruane and Gaskin 1987; see review by Burger 1993). Concentrations of Hg and Se in the feathers of nestling and adult bald eagles in the Great Lakes Basin are reported here. The relations between Hg, Se, and mean 5-year reproductive measures in breeding areas in Michigan, Minnesota, Wisconsin, Ohio, and Ontario were investigated.

Methods

Molted adult feathers were collected in the vicinity of nests, and two to three breast feathers were plucked from nestlings during normal population monitoring of the bald eagle populations within the Great Lakes region, during 1985-89. In Michigan, adult and/or nestling feathers were collected from 132 of 196 breeding areas occupied at least 1 year during this time period. Feathers from six Minnesota, three Ohio, five Ontario, and eight Wisconsin breeding areas were obtained as part of studies conducted to determine organochlorine pesticide and PCB concentrations in the blood of nestlings throughout the Basin (Bowerman 1993). The study area was subdivided into six regions for statistical comparison: Voyageurs National Park, Minnesota; within 8.0 km of the shoreline of Lake Superior; within 8.0 km of the shoreline of Lakes Michigan and Huron; interior upper peninsula of Michigan; interior

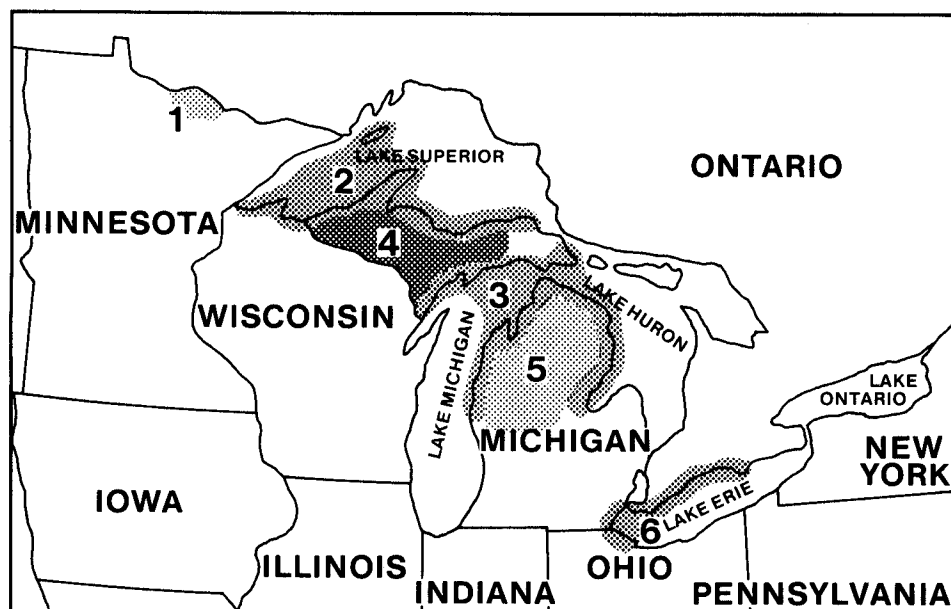


Fig. 1. Six geographic regions where feather samples of bald eagles were collected for Hg and Se analysis in the Great Lakes region, 1985–1989. Geographical regions are: (1) Voyageurs National Park, Minnesota; within 8.0 km of (2) Lake Superior and (3) Lakes Michigan and Huron; interior areas in the (4) upper and (5) northern lower peninsulas of Michigan; and (6) within 8.0 km of Lake Erie.

lower peninsula of Michigan; and within 8.0 km of the shoreline of Lake Erie (Figure 1).

Feathers from adult bald eagles were classified as either primaries, secondaries, retrices, or body. Feathers of nestlings were primarily breast feathers and were not further subdivided. Feathers were cleaned of any obvious debris and air-dried. The apical portion of the feather was removed for analysis for large feathers while smaller feathers were completely digested. Concentrations of Hg and Se are expressed on an air dried basis. Sample preparation and analysis followed USEPA approval methodologies, as outlined in detail in the Michigan Department of Natural Resources (MDNR) laboratory Analytical Methods Manual (MDNR 1981) and Quality Assurance Manual (MDNR 1987). Analysis for Hg was completed by the Cold Vapor Atomic Absorption method with a reportable detection limit of 0.1 mg/kg. Five-gram samples of feathers were digested in a solution of sulfuric and nitric acids and potassium persulfate at 100°C. Quantification was accomplished with a Perkin Elmer 5000 atomic absorption spectrophotometer, equipped with a Perkin Elmer MHS-20 mercury hydride system, a Perkin Elmer 056 recorder, and fitted with a hollow, mercury, cathode lamp, and a Perkin Elmer quartz absorption cell. Four ml of sodium chloride hydroxylamine-hydrochloride was added to each feather aliquot. Samples were then diluted to 50 ml with deionized water with 25 ml of the solution utilized for analysis. Elemental mercury was purged from the solution using a stream of argon delivered at 200 ml/min into an absorption cell which was placed in the light path of the cathode lamp. Quantification was accomplished using linear least squares analysis.

Analysis for Se was completed by the Hydride Atomic Absorption method with a reportable detection limit of 0.5 mg/kg. Samples were digested in a solution of nitric and phosphoric acids, and hydrogen peroxide at 100°C. Quantification was accomplished with a Perkin Elmer 4000 atomic absorption spectrophotometer, equipped with a Perkin Elmer MHS-20 mercury hydride system, a Perkin Elmer 056 recorder, and fitted with a Perkin Elmer electrodeless discharge lamp and EDL power supply and a Perkin Elmer quartz absorption cell. One ml of the feather aliquot was combined with 8 ml of deionized water, 2 ml of hydrochloric acid, and 2 ml of potassium iodide solution (10% potassium iodide and 1% ascorbic acid in 5% hydrochloric acid). Samples were allowed to stand for 30 min prior to analysis. Elemental selenium was purged from the solution using a stream of argon gas delivered at 200 ml/min into a quartz cell heated to 900°C, which was

placed in the light path of the discharge lamp. Quantification was accomplished using linear least squares analysis.

Statistical analyses were made by SAS NPARIWAY (SAS Institute Inc. 1991) procedure for the Kruskal-Wallis one-way analysis of variance test to determine difference between feather types, adults, nestlings, and geographical regions for either Hg or Se. The Kruskal-Wallis simultaneous rank procedure was applied to differentiate between mean ranks (Miller 1981). Differences were considered to be significant if $P \leq 0.05$. Geometric mean concentrations of Hg and Se were used for statistical comparison between breeding areas if more than one value for each feather type (*i.e.*, adult primary, secondary, retrices, body, or nestling) had been obtained for that breeding area. Multiple feathers from one breeding area were from either one or both adults utilizing the same or multiple nests within that breeding area and were assumed to be from the same individuals for the entire 5-year period reproductive measures were determined.

The relationship between logarithmic geometric mean concentrations of Hg in adult feathers among breeding areas and mean 5-year reproductive measures were compared using general linear methods for regression analysis (PROC GLM; SAS Institute Inc. 1991). Reproductive measures used were those developed by Postupalsky (1974). An *occupied breeding area* is an area consisting of one or more nests within the range of a mated pair that shows evidence that it was used during the current breeding season. *Productivity* is defined as the number of young per occupied nest for each breeding area. *Nesting success* is the proportion of occupied breeding areas successfully fledging at least one young, usually expressed as percent. Reproductive measures were analyzed on a 5-year time period using the method of Wiemeyer *et al.* (1984) by calculating the mean value for the period of 3 years prior to collection, the year of collection, and the year following collection. When Hg data spanned more than 1 year, the year of collection was defined as the year corresponding to the average year that feathers were collected within that breeding area.

Results

Adult Feathers

All feathers collected were analyzed for Hg and a subsample of these was also analyzed for Se. All feathers analyzed had mea-

Table 1. Mean and range for Hg and Se concentrations in feathers of adult and nestling bald eagles in the Great Lakes region, 1985–1989. Same letters within columns do not differ significantly

	Years	Concentrations in feathers		nSe/n ^a
		Hg (mg/kg)	Se (mg/kg)	
Adult primaries	1985–89	21 A (3.6–48)	1.9 A (1.6–3.2)	25/53
Adult secondaries	1985–89	23 A (5.3–66)	1.8 A (1.2–3.0)	8/39
Adult retrices	1985–89	19 A (5.1–46)	1.7 A (0.60–2.7)	14/57
Adult body	1985–89	21 A (0.20–48)	1.6 A (1.1–2.2)	11/71
Nestling ^b	1985–89	9.0 B (1.5–2.7)	1.9 A (0.80–2.9)	19/115

^anSe = number of breeding areas sampled for Se; n = number of breeding areas sampled for Hg

^bNestling includes all feathers collected; primarily breast feathers

Table 2. Geometric mean and range for Hg and Se concentrations in feathers of adult bald eagles in the Great Lakes region, 1985–1989. Same letters within columns do not differ significantly

	Years	Concentrations in feathers		nSe/n ^a
		Hg (mg/kg)	Se (mg/kg)	
Interior Lower Peninsula	1985–89	21 A (6.1–62)	1.9 A (1.1–3.2)	12/31
Interior Upper Peninsula	1985–89	21 A (0.2–66)	1.8 A (1.0–2.9)	18/51
Lake Superior	1985–89	22 A (5.9–38)	1.6 A (1.1–2.2)	3/14
Lakes Michigan and Huron	1985–89	20 A (7.2–40)	1.7 A (1.5–1.9)	4/13
Lake Erie	1989	13 B (9.0–19)		0/3

^anSe = number of breeding areas sampled for Se; n = number of breeding areas sampled for Hg

surable concentrations of Hg and Se. In adult feathers, no significant differences were found among feather groups for either Hg or Se ($X^2 = 1.276$, d.f. = 3, $p = 0.0735$ Hg; $X^2 = 1.406$, d.f. = 3, $p = 0.692$ Se; Table 1).

In comparing among geographic regions using geometric means of feather concentrations by breeding area, no significant differences were found for Hg ($X^2 = 3.640$, d.f. = 4, $p = 0.457$) or Se ($X^2 = 0.549$, d.f. = 3, $p = 0.908$; Table 2).

Nestling Feathers

All feathers collected were analyzed for Hg and a subsample of these were also analyzed for Se. All feathers analyzed had measurable concentrations of Hg and Se. Significant differences were found between adult feather groups and nestling feathers for Hg ($X^2 = 122.15$, d.f. = 4, $p = 0.0001$) but not for Se ($X^2 = 1.963$, d.f. = 4, $p = 0.743$; Table 1).

In comparing geometric means of feather concentrations among geographic regions, we found significant differences between Lake Erie, Voyageurs National Park, and all other

Table 3. Geometric mean and range for mercury and selenium concentrations in feathers of nestling bald eagles in the Great Lakes region, 1985–1989. Same letters within columns do not differ significantly

	Years	Concentrations in feathers		nSe/n ^a
		Hg (mg/kg)	Se (mg/kg)	
Interior Lower Peninsula	1985–89	8.8 A (4.6–14)		0/28
Interior Upper Peninsula	1985–89	8.1 A (3.5–16)	1.8 A (0.80–2.8)	15/44
Lake Superior	1985–89	8.7 A (2.7–18)	2.7 A (2.5–2.8)	2/19
Lakes Michigan and Huron	1985–89	8.0 A (4.1–14)	2.0 A (1.0–2.9)	2/10
Lake Erie	1989	3.7 B (1.5–7.4)		0/6
Voyageurs National Park	1989	20 C (5.2–27)		0/8

^anSe = number of breeding areas sampled for Se; n = number of breeding areas sampled for Hg

regions combined for Hg ($X^2 = 25.178$, d.f. = 5, $p = 0.0001$), but no significant regional differences were found for Se ($X^2 = 2.729$, d.f. = 2, $p = 0.256$; Table 3).

Effects on Reproduction

Reproductive parameters varied among geographic regions (Table 4). However, neither of the reproductive parameters, productivity nor nesting success, was significantly correlated with logarithmic concentrations of Hg. No significant correlations between productivity or success and logarithmic concentrations of Hg in either adult ($F = 0.66$, d.f. = 92, $p = 0.906$, productivity; $F = 0.73$, d.f. = 92, $p = 0.836$, success) or nestling feathers were observed ($F = 1.64$, d.f. = 94, $p = 0.070$, productivity; $F = 1.09$, d.f. = 94, $p = 0.299$, success) when individual breeding areas were analyzed using a 5-year time period.

Discussion

Mercury and selenium were detected in all feathers analyzed, and concentrations in feathers in the Great Lakes Basin were elevated above background concentrations previously determined for feathers of bald eagles in Alaska in 1988 and feathers collected from museum specimens of eagles from Michigan for the period 1953–1957 (Evans 1993). Concentrations in feathers may reflect either the blood concentration (Westermarck *et al.* 1975; Scanlon *et al.* 1980) and/or the tissue concentration (Braune and Gaskin 1987) at the time the feather developed. Birds deposit metals and other elements in feathers and this may comprise a significant route of metal detoxification. Feathers in some instances have contained 49–93% of the body burden of metals, most notable as methyl mercury (Tejning 1967; Hakkinen and Hasanen 1980; Bühler and Norheim 1982; Braune and Gaskin 1987).

Marine mammals possess enzyme systems capable of demethylating methyl mercury with the result that most of the Hg

Table 4. Arithmetic mean, standard deviation (s.d.) and range for reproductive measures of bald eagles at nests where feathers were collected for Hg and Se analysis within six areas within the Great Lakes region, 1985–1989

	Productivity (Young/occupied nest)		Success rate (%)	
	Mean (s.d.)	Range	Mean (s.d.)	Range
Interior Lower Peninsula	1.20 (0.53)	0–2.25	75 (23)	25–100
Interior Upper Peninsula	1.04 (0.58)	0–2.00	66 (32)	0–100
Lake Superior	0.69 (0.55)	0–1.75	44 (32)	0–100
Lakes Michigan and Huron	0.44 (0.54)	0–1.40	26 (31)	0–100
Lake Erie	1.19 (0.50)	0.25–2.00	77 (23)	25–100
Voyageurs National Park	1.17 (0.35)	0.60–1.67	80 (13)	60–100

(97–98%) stored in their liver and kidneys is in inorganic form. Fish-eating birds are comparable to marine mammals in respect to food and tissue distribution of methyl mercury and it seems reasonable to extend this capability to these birds (Fimreite 1979). Honda *et al.* (1990) suggested that coaccumulation of toxic metals and zinc in seabirds may be a detoxification and regulatory mechanism. Demethylation of methyl mercury seems to be a significant detoxification route for methyl mercury in birds of prey (Norheim and Froslic 1978).

The lack of association between bald eagle reproduction and Hg concentrations is not surprising in view of previous studies (Wiemeyer *et al.* 1984; Frenzel 1984; Anthony *et al.* 1993). A theoretical NOAEL for Hg concentration in the egg of bald eagles was given as 0.5 mg/kg ww (Wiemeyer *et al.* 1984) with this value derived from a mallard (*Anas platyrhynchos*) feeding study where dietary dose was 0.5 mg/kg ww (Heinz 1979). The concentration of *p, p'*-DDE in eggs of bald eagles from Wiemeyer's studies where Hg concentrations were above 0.5 mg/kg ww were greater than the *p, p'*-DDE concentration associated with greater than a 50% decline in productivity. In the white-tailed eagle (*Haliaeetus albicilla*) no indication of effects of Hg on reproduction was observed (Helander *et al.* 1982). A theoretical concentration in eggs related to lesser productivity, was given as 1.0 mg/kg ww in eggs, although no direct linkage to adverse effects were noted (Helander *et al.* 1982). Berg *et al.* (1966) observed that white-tailed eagles in the Baltic that had Hg concentrations in feathers from 40 to 65 mg/kg air-dried weight seldom produced eggs that hatched. However, no organochlorine pesticide analyses had been completed when these data were published. Subsequent research refutes the mercury/reproduction conclusions of Berg *et al.* (1966) and link white-tailed eagle reproductive problems primarily to *p, p'*-DDE and PCBs (Koivusaari *et al.* 1980; Helander *et al.* 1982).

It has been stated that effects of Hg on wild populations of nesting bald eagles are hard to assess since organochlorine contamination is nearly always present (Frenzel 1984). This is also true in the Great Lakes Basin where *p, p'*-DDE and PCBs have been found to cause reproductive effects in bald eagles (Best *et al.* 1994).

Another factor that may also decrease the effect of Hg on bald eagle productivity is the basic life history of the eagle. The greatest exposure to Hg in the eagle's yearly diet would come from walleye (*Stizostedion vitreum*) and northern pike (*Esox lucius*) based on Hg concentrations in these fishes in inland lakes in Michigan (Evans *et al.* 1991). Although walleye are rarely taken, northern pike are a major source of prey for nesting eagles in the Great Lakes Basin (Bowerman 1993) and their consumption is almost exclusively during the period of time corresponding with molting and replacement of feathers by the adults during the spring and summer. This may be a natural mechanism that lessens the adverse effects of Hg to nesting eagles. The effects of Hg may become more evident as organochlorine concentrations in the environment decrease (Frenzel 1984).

Data pertaining to concentrations of Se in feathers of birds dependent on freshwater ecosystems are sparse and none are cited for fish eating birds in the reviews of Jenkins (1980) and Eisler (1985). Johnson (1987) found Se concentrations in fish flesh in Ontario to be related to atmospheric loadings and increasing sediment concentration and suggested that it was in limited supply as a micronutrient. Relative to bald eagle prey in the region, Se in walleye, northern pike, yellow perch (*Perca flavescens*), white sucker (*Catostomus commersoni*), lake trout (*Salvelinus namaycush*), and lake whitefish (*Coregonus clupeaformis*), from Ontario lakes had mean concentrations ranging from 0.25 to 0.84 mg/kg ww (Johnson 1987). By comparison, mosquitofish (*Gambusia affinis*) from ponds at Kesterson Reservoir in California, contaminated with great levels of Se from irrigation underdrainage, had from 26 to 31 mg/kg ww Se, but fish from a nearby reference site had only 0.39 mg/kg ww (Ohlendorf *et al.* 1986). The similarity between Se concentrations in adult and eaglet feathers is in contrast with the marked differences in Hg concentrations. Selenium is apparently in adequate supply in bald eagle diets in the Great Lakes Basin and, as an essential nutrient, is within the regulatory capability of these birds at this time.

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