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MERCURY IN BALD EAGLE NESTLINGS FROM SOUTH CAROLINA, USA

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ABSTRACT: Bald eagles (*Haliaeetus leucocephalus*) may be at risk from contaminants in their diet and young birds may be particularly sensitive to contaminant exposure. To evaluate potential risks from dietary mercury exposure to eagle nestlings in South Carolina (USA), we surveyed mercury concentrations in 34 nestlings over two breeding seasons (1998 and 1999). Samples were also obtained from several post-fledging eagles in the region. Nestling feather mercury ranged from 0.61–6.67 μg Hg/g dry weight, nestling down mercury from 0.50–5.05 μg Hg/g dry weight, and nestling blood mercury from 0.02–0.25 μg Hg/g wet weight. We did not detect significant differences in tissue mercury between nestlings from coastal and inland regions in contrast to some other studies of piscivorous birds. Mercury concentrations were much higher in the post fledging birds we sampled. Our data show that nestling eagles in South Carolina are accumulating mercury, and that concentrations in older birds may exceed regulatory guidelines.

Key Words: Bald eagle, Haliaeetus leucocephalus, mercury, nestlings.

INTRODUCTION

The decline of bald eagle *(Haliaeetus leucocephalus*) populations throughout the United States in the mid-twentieth century was associated with exposure to environmental contaminants, especially pesticides such as DDT (Stickel et al., 1966; Buehler, 2000). Because eagles occupy high trophic positions they are particularly susceptible to contaminants that biomagnify through food webs and can pass these contaminants on to their young (Anthony et al., 1993; Bowerman et al., 1994). Methyl mercury, the major form of mercury found in fish (Bloom, 1992), is known to biomagnify and has emerged as a major contaminant of concern in the southeastern United States (Facemire et al., 1995). Mercury can cause neuropathologies resulting in changes in behavior (Wolfe et al., 1998). Such behavioral changes may be especially important to populations of threatened species if they disrupt foraging and reproduction and result in poor breeding success.

Young, developing organisms are thought to be most susceptible to chronic dietary mercury exposure (Wolfe et al., 1998). When nesting, parent bald eagles forage and return to the nest with prey items to feed their young. Fish are a major component of their diet, creating a risk for mercury exposure in areas where fish mercury concentrations are high. Previous work has demonstrated that mercury concentrations in pre-flight eagle nestlings reflect mercury concentrations in prey within the foraging range of their nests (Welch, 1994; Wood et al., 1996).

The number of breeding bald eagles in South Carolina (USA) has steadily increased from 15 nesting pairs in 1978 to nearly 170 pairs in 2000 (T. Murphy, unpubl. data.). Recovery of the South Carolina eagle population was enhanced by construction of inland reservoirs for flood control and electric power generation, which created additional eagle foraging habitat (Bryan et al., 1996). However, mercury concentrations in prey fish are often higher in inland waters than coastal waters (Welch, 1994; Gariboldi et al., 1998). Recently-constructed reservoirs may also have elevated mercury levels due to flooding of dry soils (Morrison and Therien, 1995). These considerations suggest that some of the newly-available nesting habitat may also confer new risks due to increased

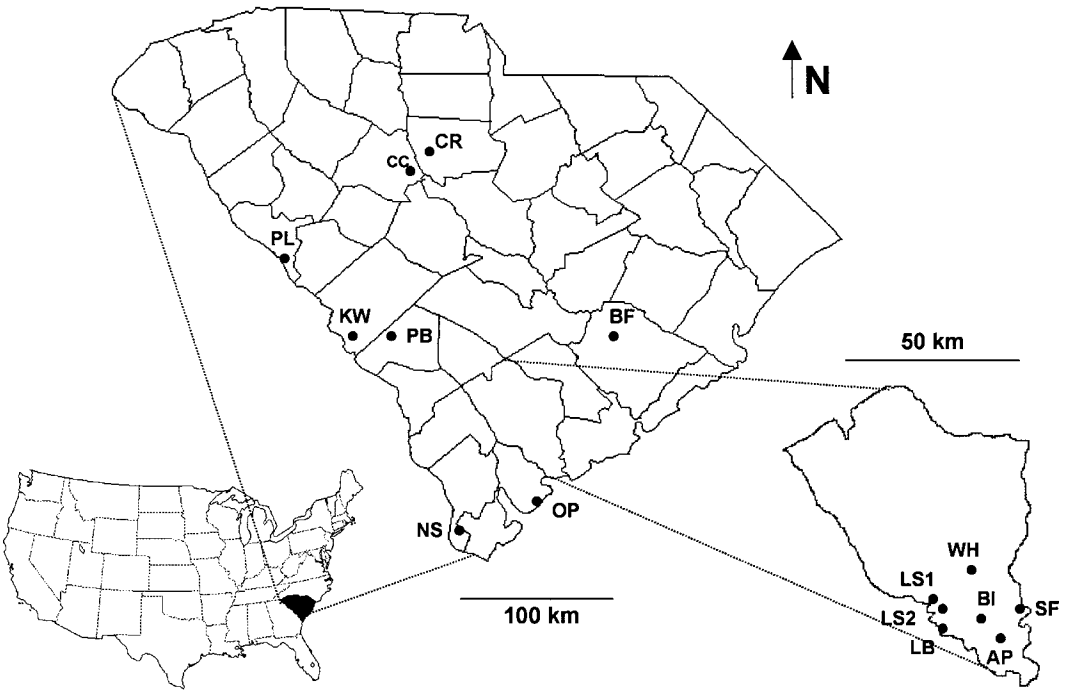

FIGURE 1. Map of South Carolina, with enlargement of Colleton County, showing the locations of the bald eagle nests sampled. Two-letter location codes for each nest correspond to codes in Table 1 and Fig. 2, 3.

potential for mercury exposure. Potential mercury threats to bald eagles have been documented in Maine (USA; Welch, 1994), the Great Lakes region (Bowerman et al., 1994), the Columbia River estuary (Anthony et al., 1993), and Florida (USA; Wood et al., 1996). However, no data are available for the southeastern Atlantic coastal plain. To address this, we measured mercury concentrations in blood and feathers of eagle nestlings sampled during banding in South Carolina in 1998 and 1999. We also analyzed tissues from several post-fledging eagles that were found dead in the state during this period.

MATERIALS AND METHODS

All samples were collected under appropriate state and federal permits. Bald eagle nests (Fig. 1) were visited when nestlings were approximately 5–6 wk of age as part of ongoing survey and banding projects of the South Carolina Department of Natural Resources. A climber ascended to each nest and lowered the young to a sampling crew on the ground. Body measurements, including weight (kg), body length (cm), wing cord (cm), wingspan (cm), bill depth (mm), hind foot length (mm), and length of the hallux (mm) were taken. Blood samples (1.0–1.5 ml) were collected from the brachial vein in the wing with sterile syringes. Samples were immediately placed in lithium heparin tubes on ice and later frozen. A "pinch" of down and feathers (<10) were collected from the breast area of each nestling, placed in plastic bags (Whirl-Pak, Fisher Scientific, Suwanee, Georgia, USA) and stored on ice until frozen. Feathers and down were manually separated and analyzed separately for this study. Visible debris was manually removed prior to analyses, and the feather and down samples washed with dilute, mercury-free detergent, rinsed with 18 megaohm deionized water, and freeze-dried to constant weight.

In addition to nestlings, samples were obtained from a post-fledging eagle found dead at the Kathwood Ponds near Jackson, Aiken County, South Carolina in June 1999 and from two older eagles that were also found dead in South Carolina. The post-fledging bird found at Kathwood had been sampled as a nestling about 2 mo earlier. One adult was found on the US Department of Energy's Savannah River Site (SRS) in Aiken County, South Carolina in December 1998. The other was found in Mc-

Cormick County, South Carolina in December 1999; this bird had been sampled as a nestling at the Plum Branch nest (Fig. 1) in March 1998. Tissues from the adult birds were digested and analyzed using the same methods as nestling blood and feathers.

Blood mercury concentrations are expressed on a wet-weight basis. Digestion protocols followed EPA method 3051 (USEPA, 1994). Aliquots of whole blood and dried and feathers were digested in quartz-distilled nitric acid in sealed Teflon vessels in a microwave oven (CEM, Inc. Matthews, North Carolina, USA), followed by a second microwave digestion in 30% hydrogen peroxide. After cooling, samples were diluted to volume with deionized water containing BrCl to a final concentration of 1% BrCl and analyzed within 72 hr.

Mercury was measured by cold-vapor atomic fluorescence spectroscopy (CVAF) using a modification of EPA method 1631 (USEPA, 2001). In this modified method, samples were reduced with $SnCl_2$, and the mercury released as cold vapor was directly determined without preconcentration (Louchouarn et al., 1993) using Brooks-Rand (Seattle, Washington, USA) Model II and III analyzers. Instruments were calibrated daily with standards traceable to the National Institute of Standards and Technology. For quality assurance, over 20% of all analyses were replicates, spikes, or standards. Samples were digested in batches containing a blank and a standard reference material of known mercury concentration (purchased from the National Research Council of Canada, Ottawa, Ontario, Canada). If mercury was detected in a blank, or standards fell outside the certified range or spike recovery fell outside ±10% of the expected value, the sample set was repeated. Statistical analyses were done with SAS version 8.1 (SAS Inc., Cary, North Carolina, USA). Locations and years were compared by analysis of variance; potential relationships between variables were examined using Pearson's correlation. Because small sample sizes often prevented robust testing of the assumptions of parametric statistics (normality, heteroscadicity), all data were also analyzed using non-parametric analogs of the above procedures (Wilcoxon and Kruskal-Wallis tests, Spearman's rank correlation). The parametric and non-parametric methods led to identical conclusions, and we report only the former here for brevity.

RESULTS

Samples were collected from nestlings in eight nests in 1998 and 10 nests in 1999 (Fig. 1, Table 1). In many cases, multiple individuals were sampled from a single nest. Mercury was detectable in all blood, down, and feather samples we collected (Figs. 2, 3). In 1998 (Fig. 2), feather mercury was (mean±standard deviation; range) 2.49±1.17; 0.61–4.38 μg Hg/g dry weight, down mercury 2.50±1.22; 1.17–5.05 μg Hg/g dry weight, and blood mercury 0.115±0.089; 0.03–0.25 μg Hg/g wet weight. In 1999 (Fig. 3), feather mercury was 3.67±1.91; 1.06–6.67 μg Hg/g dry weight, down mercury was 2.43±1.22; 0.50–3.70 μg Hg/g dry weight, and blood mercury was 0.085±0.057; 0.02–0.17 μg Hg/g wet weight.

For all of the nests sampled, mean mercury concentrations in blood, feather, and down did not differ between years. There was also no clear trend of increase or decrease over time in individual nests sampled in both years. Three of the same nests were sampled in both 1998 and 1999. In two, mercury concentrations in nestling blood and down decreased slightly from 1998 to 1999. In two, mercury concentrations in feathers increased slightly. Thus, there was no clear evidence of an increase or decrease in mercury in nestlings over the 2 yr period of our data.

The post-fledging eagle found dead at the Kathwood Ponds in June 1999 had mercury concentrations of 1.22 and 1.71 μg Hg/g dry weight in feathers and down, respectively, and so fell within the range we measured in live nestlings. However, concentrations were somewhat higher in this individual when it had been sampled as a nestling in April 1999 (2.71 and 2.77 μg Hg/g dry weight in feathers and down, respectively).

The older eagles that were found dead contained much higher mercury concentrations than the nestlings we sampled. The individual found on the SRS had mercury concentrations of 45.88 and 36.15 μg Hg/g dry weight in feathers and down, respectively. Muscle and liver mercury concentrations were 9.37 and 36.58 μg Hg/g dry weight, respectively. Examination at the Southeastern Cooperative Wildlife

TABLE 1. Sampling dates, counties where nests were located, sex, and habitat classifications of nestling bald eagles sampled in 1998 and 1999. Two-letter location codes correspond to the two letter code used in Figs. 1, 2, 3. Habitat indicates whether parent eagles were restricted to foraging in inland waters, or had access to both fresh and salt water habitats in a coastal area. ND indicates sex was not determined.

Date	Nest name	Code	County	Sex	Habitat
2/10/98	Pen Branch	PB	Barnwell	F	Inland
2/10/98	Pen Branch	PB	Barnwell	F	Inland
3/11/98	Ashepoo pond	AP	Colleton	F	Coastal
3/11/98	Springfield pond	SF	Colleton	F	Coastal
3/12/98	Oak point nest	OP	Beaufort	M	Coastal
3/12/98	Oak point nest	OP	Beaufort	ND	Coastal
3/12/98	Laurel springs 1	LS1	Colleton	F	Coastal
3/12/98	Laurel springs 2	LS1	Colleton	ND	Coastal
3/30/98	Black's fish camp	BF	Berkeley	ND	Inland
3/30/98	Black's fish camp	BF	Berkeley	ND	Inland
3/30/98	Black's fish camp	BF	Berkeley	ND	Inland
3/31/98	Plum Branch	PL	McCormick	ND	Inland
3/31/98	Plum Branch	PL	McCormick	ND	Inland
4/20/98	Kathwood	KW	Aiken	ND	Inland
4/20/98	Kathwood	KW	Aiken	ND	Inland
2/26/99	New Savannah	NS	Jasper	F	Coastal
3/11/99	Bear Island E	BI	Colleton	F	Coastal
3/11/99	Bear Island E	BI	Colleton	M	Coastal
3/11/99	Oak Point	OP	Beaufort	F	Coastal
3/25/99	White House	WH	Colleton	M	Coastal
3/25/99	White House	WH	Colleton	F	Coastal
3/25/99	Laurel Springs 2	LS2	Colleton	M	Coastal
3/25/99	Laurel Springs 2	LS2	Colleton	F	Coastal
3/25/99	Long Brow	LB	Colleton	M	Coastal
3/25/99	Long Brow	LB	Colleton	ND	Coastal
4/14/99	Kathwood	KW	Aiken	F	Inland
4/14/99	Kathwood	KW	Aiken	M	Inland
4/14/99	Kathwood	KW	Aiken	F	Inland
4/21/99	Crumpton	CR	Fairfield	M	Inland
4/21/99	Crumpton	CR	Fairfield	M	Inland
4/21/99	Cannon Creek	CC	Newberry	F	Inland
4/21/99	Cannon Creek	CC	Newberry	F	Inland
5/5/99	Pen Branch	PB	Barnwell	F	Inland
5/5/99	Pen Branch	PB	Barnwell	M	Inland

Disease Study, College of Veterinary Medicine, University of Georgia, also showed that this individual had avian vacuolar myelinopathy (Fischer, pers. comm.).

The individual found dead in McCormick County in December 1999 had been banded and sampled as a nestling on 31 March 1998. As a nestling, mercury concentrations in feathers and down were 2.35 and 2.04 μg Hg/g dry weight, respectively. After 20 mo, mercury concentrations were 16.11 and 10.50 μg Hg/g dry weight in feathers and down, respectively.

Nestlings tended to be heavier in 1998 than in 1999 (Figs. 2, 3; $F=4.24$, $P<0.05$). Other body size measurements did not differ between the 2 yr. Pooled measurements for 1998 and 1999 (mean±standard error) were: wing cord 29.8±0.3 cm, wing span 142.6±6.2 cm, total length 64.7±1.6 cm, bill depth 30±1 mm, hallux length 33±1 mm, and foot length 123±2 mm.

Blood, feather, and down mercury concentrations within individuals were correlated in both sampling years. In 1998, blood mercury was correlated with down mercury ($r=0.89$; $P<0.01$) and with feather mercury ($r=0.92$; $P<0.01$), and down

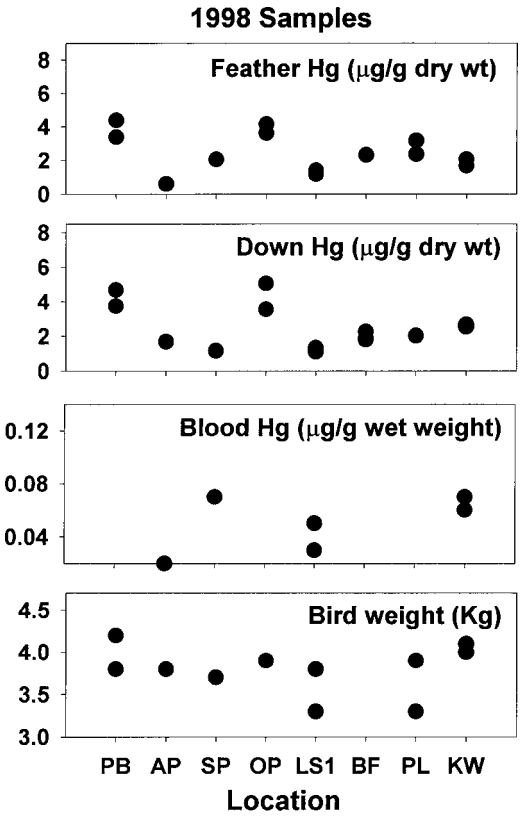

FIGURE 2. Mercury concentrations and body weights of nestling bald eagles sampled in South Carolina in 1998. Two-letter location codes correspond to those in Fig. 1 and Table 1. Nests are plotted in chronological order of sampling from left to right.

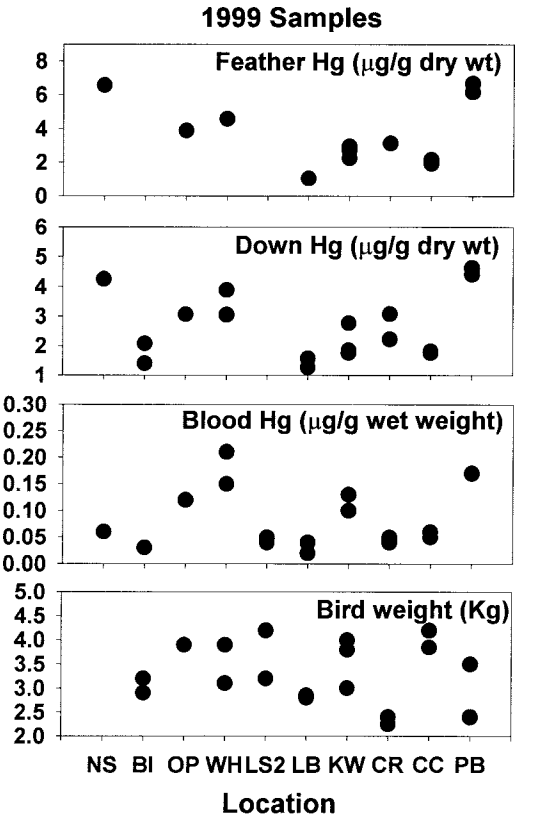

FIGURE 3. Mercury concentrations and body weights of nestling bald eagles sampled in South Carolina in 1999. Two-letter location codes correspond to those in Fig. 1 and Table 1. Nests are plotted in chronological order of sampling from left to right.

was correlated with feather mercury (r=0.93, P<0.01). In 1999, blood mercury was correlated with down mercury (r=0.70, P<0.05) and feather mercury (r=0.59 P<0.05). Down and feather mercury were also correlated (0.96, P<0.01). Body weight, wing cord, wind span, total length, hallux length, and foot length were unrelated to mercury in blood, down, or feathers in both years, suggesting that factors other than size were important to the differences in Hg among nests. When multiple nestlings were present, we tested to see whether larger siblings tended to have higher mercury concentrations than smaller siblings. There was no relationship between tissue mercury concentration and size within a nest.

DISCUSSION

Eisler (1987) proposed a concentration of 5 μg Hg/g fresh weight in bird feathers as a level of concern. Concentrations above this level are believed to be associated with adverse effects (Eisler, 1987). Based on the moisture content of the feathers we analyzed, this would correspond to a dry weight concentration of about 7.5 μg Hg/g dry weight. By this criterion, all samples we analyzed were below the level of concern, although some individuals in 1999 approached this limit.

It is worth noting that most eagles we sampled were very young and still under parental care in the nest. Mercury accumulates over time because it is difficult to excrete and feather growth is believed to

act as a sink for mercury that is consumed during the feather growth period (Braune and Gaskin, 1987). Nestlings are able to sequester most of the mercury they consume into their growing down and feathers (Furness et al., 1990), but post-fledging birds must store mercury in soft tissues until molt, when mercury can again be excreted into growing feathers. Concentrations in feathers of adult birds are typically higher than in those of nestlings (Furness et al., 1990; Beyer et al., 1997). This is well illustrated by the post fledging bird found dead in McCormick County in 1999; mercury in feathers had increased from 2.35 μg Hg/g when it was banded in 1998 to 16.11 μg Hg/g when found in 1999, an increase of 685 %.

In comparison with other regions where fledgling eagles have been sampled, mercury concentrations in the birds we sampled were relatively low. Bowerman et al. (1994) reported feather concentrations of 20 μg Hg/g dry weight in nestlings from Voyageurs National Park, Minnesota (USA), 8.0–8.8 μg Hg/g dry weight in nestlings from the upper and lower Michigan peninsulas and Lakes Michigan, Superior, and Huron, and 3.7 μg Hg/g dry weight in nestlings from Lake Erie. Anthony et al. (1993) found a mean blood concentration of 0.47 μg Hg/g wet weight in nestlings from the Columbia River estuary. However, the concentrations we found were similar to those reported by Wood et al. (1996) for eagle nestlings in central Florida. They reported concentrations of 0.16 μg Hg/g wet weight in blood and 3.23 μg Hg/g wet weight in feathers. Averaging all locations for both 1998 and 1999, we found 0.10 μg Hg / g wet weight in blood and 3.06 μg Hg/g dry weight in feathers in South Carolina eagles.

Welch (1994) surveyed nestling bald eagles in Maine and found that nestlings sampled along the coast had lower blood and feather mercury concentrations than nestlings sampled at inland sites. This reflects differences in mercury concentrations of prey; fresh water fish in the diet of piscivorous birds tend to have higher mercury concentrations than salt water fish (Welch, 1994; Gariboldi et al., 1998). We classified our nests as either inland or coastal (Table 1), based on the likely foraging range of the parents. There were no significant differences in bird size or tissue Hg concentration between the two regions, although blood Hg concentrations tended to be higher in inland than coastal nestlings (0.11 versus 0.08 μg Hg/g wet weight, respectively; $P=0.08$). The inland birds that Welch (1994) sampled, which should be comparable to nestlings from our inland sites, based on their exclusive use of freshwater resources, had blood concentrations of 0.07–1.46 μg Hg/g wet weight and feather concentrations of 8.0–36.7 μg Hg/g dry weight, higher than the concentrations we measured.

A recent study reported mercury concentrations in nestling wood storks (*Mycteria americana*) in the same geographic region as the present study. Gariboldi et al. (2001) found that nestling wood storks from inland colonies had higher mercury concentrations in blood and feathers than nestlings from coastal colonies. Wood stork nestlings are highly dependant on fish and differences in nestling Hg reflects coastal versus inland differences in prey Hg (Gariboldi et al., 1998, 2001). In contrast, nesting eagles in this region forage on a variety of items including waterfowl, as well as fish. The percentage of these other items in the diet of eagle nestlings may vary both spatially and temporally. We speculate that variations in prey composition may obscure differences in dietary Hg exposure from consumption of coastal versus inland fish in the nests we examined.

Our data demonstrate that nestling eagles in South Carolina are exposed to dietary mercury and that older birds may accumulate substantial mercury concentrations. It is not presently known whether the concentrations we measured are impacting growth, reproduction or development in this species. Given that bald eagles are a protected species with a history

of population effects associated with environmental contaminants, some caution appears warranted. Further studies are clearly needed to determine effects of mercury exposure on populations and individuals, and to further define exposure levels in wild populations.

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