LEAD EXPOSURE IN WISCONSIN BIRDS

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ABSTRACT.—The Wildlife Health Program of the Wisconsin Department of Natural Resources has monitored lead (Pb) exposure in numerous avian species including Bald Eagles (*Haliaeetus leucocephalus*), Trumpeter Swans (*Cygnus buccinator*), Common Loons (*Gavia immer*), and American Woodcock (*Scolopax minor*). A comprehensive review of Trumpeter Swan health data indicated approximately 25% of Trumpeter Swan fatalities were attributed to lead toxicity. Similarly, approximately 15% of live-sampled Trumpeter Swans had blood lead levels above background concentrations (20 µg/dL). A similar review of necropsy data for Bald Eagles revealed approximately 15% of all Bald Eagle deaths in Wisconsin were attributed to lead toxicity. A noticeable increase in the percent of fatalities attributed to lead toxicity began in October and peaked in December. This pattern overlapped with the hunting seasons in Wisconsin suggesting lead ammunition could be a major source of lead exposure in eagles. A surveillance program examining lead toxicity as a factor in mortality of Common Loons was initiated in 2006. To date, approximately 30% of the dead loons submitted for necropsy were found to be lead poisoned. Lead fishing gear was recovered from the GI tracts of loons in all cases where lead toxicity was a major contributor to the cause of death. A comprehensive study investigating lead levels in woodcock from Wisconsin was completed in 2002. The results of the study indicated American Woodcock were exposed to lead on their breeding grounds in Wisconsin, resulting in high accumulations of lead in bone tissue. Bone lead concentrations considered to be toxic in waterfowl were observed in all age classes of woodcock. Stable isotope analysis was conducted on a subset of bone samples from young-of-year birds in order to identify the source of the lead. The results were inconclusive but did not rule out anthropogenic sources, and although the pathway of lead exposure was not identified, the data suggest a local and dietary source. It is clear that numerous species of Wisconsin wildlife are being exposed to potentially harmful levels of lead, and lead poisoning remains a significant mortality factor for many of these species. The prevalence of lead poisoning cases in Wisconsin is unlikely to decrease until the amount of lead discharged into the Wisconsin environment is reduced. *Received 9 July 2008, accepted 3 September 2008.*

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THE DELETERIOUS IMPACTS on waterbirds of ingesting spent lead (Pb) shot have been recognized for over 100 years (Grinnell 1894). Ingestion of spent shot has been implicated in substantial die-offs of numerous waterfowl species (Bellrose 1959, Sanderson and Bellrose 1986) and as a result, non-toxic shot has been required to hunt waterfowl in the United States since 1991 (Anderson 1992). Even though the federal ban on lead shot for waterfowl hunting has been in effect for nearly 20 years, lead poisoning continues to be a significant mortality factor for several species of birds in Wisconsin. Lead is still regularly deposited in the environment as a result of lead shot used for upland game hunting, lead in rifle bullets, and lead fishing weights.

Lead is one of the most toxic metals known, with adverse impacts ranging from slight alterations of biochemical and physiological systems to serious damage in organs leading to death of the individual. Lead modifies the function and structure of the kidney, bone, the central nervous system, and the hematopoietic system and also has adverse biochemical, histopathological, fetotoxic, teratogenic and reproductive effects (Eisler 1988). Mortality associated with exposure of birds to lead has been shown to result from direct consumption of spent lead shot, consumption of lead shot or bullet fragments embedded in food items, and from the ingestion of lead fishing weights (Franson 1996).

In Wisconsin, lead exposure has been monitored in numerous avian species including Bald Eagles (*Haliaeetus leucocephalus*), Trumpeter Swans (*Cygnus buccinator*), Common Loons (*Gavia immer*), and American Woodcock (*Scolopax minor*). In this paper, we report on lead as a mortality factor for Bald Eagles, Trumpeter Swans, and Common Loons. In addition, we report on concentrations of lead in bone of American Woodcock of different ages.

METHODS

American Woodcock.—Detailed methods of woodcock sample collection and analysis can be found in Strom et al. (2005). Briefly, woodcock were harvested between 1999 and 2001 at selected locations in Wisconsin using steel shot (Figure 1). Birds were collected a minimum of two weeks prior to the regular hunting season (late September through early November) to increase the probability that only locally exposed birds (young of year) would be collected. Woodcock age and sex were determined via plumage characteristics as described by Sepik (1994). Pointing dogs were used to assist in finding woodcock nests and broods. When a brood was found, one chick was randomly selected and euthanized via cervical dislocation for tissue analysis.

Figure 1: American Woodcock collection sites 1999–2001.

For sample collection, the humerus and radius/ulna were excised and excess tissue and cartilage removed. This process was followed for all woodcock collected, regardless of age or year collected. The GI tracts of all woodcock were radiographed and the radiographs were evaluated for any objects of comparable radiodensity with metal. The GI tracts were also dissected and visually inspected for lead pellets or metallic particles. The sex of the animal was confirmed at the time of dissection. All lead analyses were conducted at the Wisconsin Veterinary Diagnostic Laboratory, Madison, Wisconsin.

Bone samples were forced-air dried overnight at 100ºC to remove water, finely crushed in a mortar, and extracted with diethyl ether to remove fat prior to weighing for lead analysis. All tissue samples (bone, liver and blood) were digested in Teflon microwave vessels, under pressure with nitric acid in a microwave. After the samples cooled to room temperature, the contents were transferred to a volumetric flask and brought to volume with purified water. Samples were analyzed on a Perkin-Elmer

Table 1: Bone lead concentrations (μg/g dry weight) in Wisconsin American Woodcock.

Collection Site	n	Mean	Median	SD	Range
Navarino					
Chick	7	30.1	27.9A	22.5	9.6 – 72.0
Young of Year (YOY)	12	18.4A	11.25	18.0	<3.0–48.0
Adult	14	22.0A	15.9	12.8	8.1–48.0
Mead					
Chick	3	76.0	87.0B	24.4	48.0–93.0
YOY	13	39.2A	29.1	50.0	4.5–198.0
Adult	10	63.8B	33.3	56.0	18.9–171.0
Peshtigo					
YOY	6	67.5A	40.5	80.7	6.9–222.0
Adult	9	25.7AB	18.0	23.7	5.1–81.0
Pembine					
YOY	6	18.45A	19.7	11.3	<3.0–33.0
Adult	11	18.4A	15.6	12.0	5.1–45.0
Danbury					
YOY	5	12.5A	5.7	14.8	4.8–39.0
Adult	5	32.6AB	22.8	22.2	8.7–63.0
Douglas					
YOY	4	10.5A	7.4	8.9	3.9–23.4
Adult	3	6.4AB	6.6	0.62	5.7–6.9

For each age class, means or medians sharing the same letter are not significantly different.

Table 2: Mortality factors of Trumpeter Swans, Bald Eagles and Common Loons submitted to the Wisconsin Department of Natural Resources for necropsy.

		Diagnosis (%)						
Species	N	Lead Poisoning	Trauma	Undetermined	Gunshot	Electrocution	Drowning	Other
Trumpeter Swan	143	25	25	19	12	10	1	7
Bald Eagle	583	16	48	16	0	12	0	9
Common Loon	26	29	31	4	7	0	4	25

5100ZL graphite furnace atomic absorption spectrometer. A tissue and/or blood control sample was tested with each analytical run to ensure accuracy.

Trumpeter Swan, Bald Eagle and Common Loon.—Trumpeter Swans, Bald eagles, and Common Loons were submitted to the Wisconsin Department of Natural Resource's Wildlife Health Program for necropsy, as part of statewide mortality monitoring programs for these species. At the time of necropsy, all carcasses were evaluated for metal foreign bodies using radiography. If radio-dense objects were observed, attempts were made to recover the object from the carcass. Liver samples were collected from all individuals and submitted for laboratory lead analysis as described above. For Trumpeter Swans, data accumulated between the years 1991–2007 were reviewed and causes of mortality were summarized. A similar review was performed for Bald Eagle data collected between the years 2000–2007. A program investigating causes of Common Loon mortality was initiated in 2006.

Data Analysis.—For statistical analyses, samples with metal concentrations below the detection limit were assigned a value equal to one-half the detection limit. All statistical analyses were carried out using Excel and SYSTAT software packages. Non-parametric methods (Kruskal-Wallis tests) were utilized to determine differences between tissue

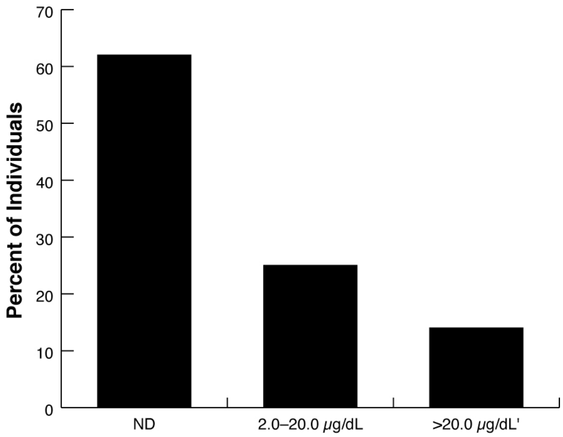

Figure 2: Blood lead concentrations (µg/dL) of Trumpeter Swans from Wisconsin (n = 1172 individuals). ND = below the limit of detection (detection limit range 2.0–5.0 µg/dL).

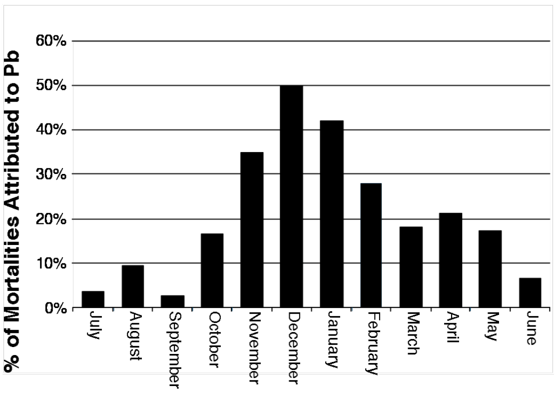

Figure 3: Percent of Bald Eagle fatalities attributed to lead toxicity according to month.

lead concentrations from woodcock collected at various sites across the state. The level of statistical significance was set at $\alpha = 0.05$.

RESULTS

American Woodcock.—The mean bone lead concentrations from chicks, young-of-year, and adult woodcock collected at various sites throughout Wisconsin are listed in Table 1. No significant differences were observed between bone lead concentrations in young-of-year woodcock from any of the areas sampled ($p = 0.174$). However, a significant difference was observed with the adult data ($p = 0.006$), with bone lead concentrations of Navarino adults being significantly different than those of Mead adults. Furthermore, bone lead concentrations of Pembine adults were significantly different than those of Mead adults. The concentration of lead in the wing bones from Mead chicks was significantly different than those from Navarino ($p = 0.03$). Radiography of the GI tracts of the woodcock did not reveal any lead pellets or metallic particles. Furthermore, no lead pellets or metallic objects were observed during the visual inspection of the GI tracts.

Trumpeter Swans.—Between 1991 and 2007, 143 swan fatalities were investigated. Approximately 25% of the fatalities were attributed to lead toxicity. The diagnosis of lead toxicity as a cause of mortality was often based only on tissue lead concentrations, as clinical history and histologic assessment of tissues were not available. Collisions with power lines as well as shootings also appear to be significant mortality factors.

During this same period, 1,172 blood samples were collected from swans and analyzed for lead (Figure 2). Lead was detected in 38% of the blood samples, with a geometric mean of 16 µg/dL. Approximately 15% of all sampled swans had blood lead concentrations above 20µg/dL. The overwhelming majority (80%) of the blood samples were collected from juvenile swans. Therefore, due to the age bias in sampling, age-specific differences in lead accumulation could not be not examined.

Bald Eagles.—Between 2000 and 2007, nearly 600 Bald Eagles were submitted to Wildlife Health for necropsy. Lead toxicity was diagnosed as the cause of death for 16% of the eagles during this period. A unique temporal pattern in eagle mortality was observed, with a dramatic increase in the percent of fatalities attributed to lead toxicity beginning in October, peaking in December, and then decreasing through the winter months (Figure 3). This pattern overlaps with the hunting seasons in Wisconsin which suggests lead ammunition could be a major source of lead exposure in eagles.

Common Loons.—Between 2006 and 2008, 26 Common Loons were submitted for necropsy. Approximately 30% of the dead loons submitted for necropsy were judged to have died from lead poisoning. Remnants of lead fishing tackle were recovered from the GI tracts of loons in all cases where lead toxicity was a major contributor to the cause of death.

DISCUSSION

Our data indicate lead exposure is a significant health problem for several bird species in Wisconsin, accounting for 15–30% of fatalities in Trumpeter Swans, Bald Eagles, and Common Loons. For our study, liver lead levels of >6.0 µg/g (wet weight) were considered indicative of lead toxicosis and bone lead levels >20 µg/g dry weight were considered significantly elevated (Franson 1996, Pain 1996). Blood lead levels >20 µg/dL were considered above background (Pain 1996).

Scheuhammer et al. (1999) documented a high incidence of elevated lead levels (>20 µg/g dry weight) in wing bones from adult (52%) and young-of-year woodcock (29%) from eastern Canada. Strom et al. (2005) found elevated lead levels in wing bones of woodcock from Wisconsin in 43% of young-of-year woodcock and 64% of woodcock chicks sampled.

Although the prevalence of lead exposure in waterfowl has declined following implementation of non-toxic shot for waterfowl hunting (Samuel and Bowers 2000), exposure to lead continues to be a significant factor in Trumpeter Swan mortality. The incidence of lead related mortality in Trumpeter Swans in Wisconsin (26%) is slightly higher than the 20% lead-related mortality observed in Trumpeter Swans from the tri-state area of Idaho, Montana, and Wyoming (Blus et al. 1989), but much lower than that observed in Trumpeter and Tundra Swans (81%) in Washington State (Degernes et al. 2006).

The geometric mean of blood lead levels observed in Trumpeter Swans from Wisconsin (16 µg/dL) was greater than the geometric mean reported in blood from Trumpeter Swans in the western U.S. (Blus et al. 1989). A blood lead concentration below 20 µg/dL has been suggested as a background level in waterfowl (Pain 1996, Beyer et al. 2000). Considering over 60% of the blood samples analyzed in the present study were below the detection limit (detection limit range 2.0–5.0 µg/dL) it is plausible the true background blood lead concentration for apparently healthy Trumpeter Swans is below the 20 µg/dL threshold.

The occurrence of lead poisoning in Bald Eagles from Wisconsin (15%) is higher than that reported in other studies where prevalence ranged from 0% to 5% (Coon et al. 1970, Deem 2003, Harris and Sleeman 2007, Morishita et al. 1998, Wendell et al. 2002). However, our findings are consistent with those of Elliot et al. (1992) who observed that 14% of Bald Eagles found dead in British Columbia, Canada, between 1988 and 1991 died as a result of lead poisoning and Wayland et al. (2003) who observed 14% of 546 Bald Eagle deaths in western Canada were attributable to lead toxicosis.

The proportion of lead poisoning among loon fatalities in Wisconsin is comparable to that observed in Canada (26%–30%) (Daoust et al. 1998, Scheuhammer and Norris 1996) but lower than that of breeding loons in the New England states (44%–52%) (Pokras and Chafel 1992, Sidor et al. 2003). The contrast of our results to the New England studies may be due to the much smaller sample size in the present study (n = 26), and may also reflect differences in regional landscape, human population, or land and wetland usage (Sidor et al. 2003). It nevertheless appears that lead exposure is a major mortality factor for loons in Wisconsin.

The percentages of lead poisoning cases in Wisconsin birds from this study are likely underestimated because, in many cases where cause of death was undetermined, liver lead analysis was not performed. Moreover, human-related mortality agents tend to occur in areas frequented by humans, whereas lead-poisoned fatalities are more randomly distributed and thus less likely to be discovered.

Sources of Lead.—Scheuhammer et al. (2003) found no evidence of lead shot ingestion in woodcock from Canada with elevated bone-lead concentrations. Likewise, we did not detect any ingested lead shot in any of the woodcock radiographed for the present study. However, ingestion of lead shot has been observed in other species related to woodcock, such as godwits, dowitchers, and snipe (Hall and Fisher 1985, Pain 1990). Scheuhammer et al. (2003) suggest that because woodcock do not have a large muscular gizzard, it is possible that lead pellets ingested by woodcock are quickly voided, and thus not observed in studies of woodcock gizzard and stomach contents.

Stable lead isotope analysis on a small number of bone samples from Wisconsin young-of-year woodcock produced inconclusive results. The observed lead isotope ratios in Wisconsin woodcock overlapped with ratios of both lead shotgun pellets and Precambrian lead, i.e. soil-associated lead (Strom et al. unpub. data). Similarly, Scheuhammer et al. (2003) observed lead isotope ratios in wing bones of woodcock that were consistent with, though not proof of, lead shot ingestion because the range of ratios for wing bones overlapped with ratios of lead shot pellets. In any case, ingestion of lead shot used for upland game bird hunting cannot be ruled out as a primary source of high bone-lead accumulation in woodcock from Wisconsin.

The feeding habits of Trumpeter Swans and Bald Eagles may predispose these species to lead exposure. Trumpeter Swans typically forage by digging up large amounts of sediments in lakes and streams (Banko 1960). Ingestion of these large volumes of sediments increases the likelihood of birds ingesting lead shot or sinkers (Blus et al. 1989). Of the lead poisoning cases observed in Trumpeter Swans in this study, 39% had lead artifacts in their ventriculus at the time of necropsy.

The increased prevalence of lead poisoning cases in Bald Eagles during October to January overlaps with the hunting seasons in Wisconsin, suggesting lead ammunition is likely the primary source of exposure in Bald Eagles. In addition to lead shot, lead bullet fragments may be a significant source of lead exposure in eagles. This pattern of increased lead exposure during hunting seasons has also been observed in Golden Eagles (*Aquila chrysaetos*) (Bloom et al. 1989), California Condors (*Gymnogyps californianus*) (Cade 2007, Hall et al. 2007, Hunt et al. 2007, Sorenson and Burnett 2007), and Common Ravens (*Corvus corax*) (Craighead and Bedrosian 2008). Hunt et al. (2006) observed that as lead bullets pass through deer, the bullets often fragment, leaving numerous lead fragments which are distributed throughout the carcass or the gut pile left on the landscape after the animal is field dressed. It is likely eagles feed on either unretrieved animals or scavenge the gut piles, thus exposing themselves to harmful levels of lead.

Conclusions.—Multiple species of Wisconsin wildlife are being exposed to potentially harmful levels of lead, and lead poisoning remains a significant mortality factor for some of these species. The association of lead-related mortality in Bald Eagles with the major hunting seasons in Wisconsin implies that exposure to spent lead ammunition should be considered as a potentially significant mortality factor in species which feed upon hunter-killed animals. It is unlikely the prevalence of lead poisoning cases will decrease until the amount of lead discharged into the Wisconsin environment is reduced.

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