Articles

Bald Eagle Lead Exposure in the Upper Midwest

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Abstract

In 2012, we examined lead exposure in 58 bald eagles *Haliaeetus leucocephalus* found dead in Iowa, Minnesota, and Wisconsin. We determined lead concentrations in livers, examined differences in exposure among ages and between sexes, and recorded clinical signs consistent with lead poisoning. Most (60%) of the bald eagles had detectable lead concentrations, and 38% of the 58 had concentrations within the lethal range for lead poisoning. We found no differences in exposure based on sex or age, but we did find an inverse relationship between body and liver mass and liver lead concentration. The high percentage of lead-exposed bald eagles encouraged us to further examine potential sources of lead in our local environment. We initiated a study on the Fish and Wildlife Service's Upper Mississippi River National Wildlife and Fish Refuge to investigate if discarded offal piles from hunter-killed deer were a potential source of lead exposure to scavenging wildlife such as the bald eagle. Radiographs showed that 36% of offal piles in our sample area contained lead fragments ranging from 1 to 107 particles per pile. Our study indicated that 1) lead exposure rates for bald eagles found dead in our Upper Midwest study area were high, 2) more than one-third of the bald eagles found dead in Iowa, Minnesota, and Wisconsin had liver lead concentrations consistent with lead poisoning, and 3) discarded offal piles from deer shot with lead ammunition can be a potential source of lead exposure for bald eagles.

Keywords: bald eagles; lead poisoning; Upper Midwest

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Introduction

During the winter, bald eagles *Haliaeetus leucocephalus* congregate in high numbers along the Upper Mississippi River and other large Midwest waterways in the states of Illinois, Iowa, Minnesota, and Wisconsin (Millsap 1986; Steenhof et al. 2002). Bald eagles in the Midwest typically forage on fish and birds (Southern 1963; Ewins and Andress 1995), though in the winter they become more dependent on carrion such as white-tailed deer *Odocoileus virginianus* (Harper et al. 1988; Ewins and Andress 1995; Lang et al. 2001). White-tailed deer hunting is popular in the Midwest, and hunters commonly use lead ammunition to harvest deer, due to its low cost, ballistic qualities, and capacity for producing humane kills (Oltrogge 2009). However, lead bullets fragment upon impact and can spread throughout tissues (Hunt et al. 2006; Knot et al. 2009; Craighead and Bedrosian 2008; Grund et al. 2010). If carcasses or offal piles with lead fragments are available on the landscape, they may be a source of lead exposure to scavenging wildlife (Hunt et al. 2006; Grund et al. 2010; Cruz-Martinez et al. 2012; Figure 1).

Figure 1. Bald eagles *Haliaeetus leucocephalus* feeding on white-tailed deer *Odocoileus virginianus* remains. Upper picture shows juvenile bald eagle feeding on a white-tailed deer carcass with an adult bald eagle and an American crow *Corvus brachyrhynchos* taken on March 13, 2013, at the Upper Mississippi River National Wildlife and Fish Refuge. Lower picture shows bald eagles feeding on the offal pile from a white-tailed deer killed in Monroe County, Iowa, in January 2013.

The quantity of deer remains discarded on the landscape during a hunting season can be substantial. For example, the total deer harvest reported during the 2012–2013 firearm hunting seasons in Illinois, Iowa, Minnesota, and Wisconsin was 645,317 deer (Iowa Department of Natural Resources 2013; Illinois Department of Natural Resources 2013; Minnesota Department of Natural Resources 2013; Wisconsin Department of Natural Resources 2013), resulting in hundreds of thousands of offal piles on the landscape. In addition to offal, whole carcasses (e.g., from fatally wounded, but unretrieved deer) can also be available on the landscape. Upwards of 32% of deer shot have been estimated to go unretrieved (17–32% in Indiana, 21–24% in Illinois; Stormer et al. 1979; Nixon et al. 2001). Where lead ammunition is used, offal, carcasses, and associated parts discarded during deer hunting seasons may present a substantial exposure pathway for scavenging wildlife (Hunt et al. 2006; Grund et al. 2010; Cruz-Martinez et al. 2012).

Lead is toxic to birds and can cause mortality with the consumption of even a small number of particles (Hoffman et al. 1981; Pattee et al. 1981; Beyer et al. 1988; Kramer and Redig 1997; Wayland and Bollinger 1999; Fisher et al. 2006; Helander et al. 2009). Lead bioaccumulates in tissues, leading to decreased survival, poor body condition, behavioral changes, and impaired reproduction (Hoffman et al. 1985a, 1985b; Wayland et al. 1999; Clark and Scheuhammer 2003; Franson and Pain 2011). Sublethal exposure to lead can affect normal health and responsiveness, thereby increasing the odds of mortality via causes such as collision or predation (Kelly and Kelly 2005; Hunt 2012). Overt signs of lead poisoning in birds can include lethargy, loss of muscle control (head and wing droop), inability to fly, and bile-stained diarrhea and vent (Franson and Pain 2011), while internal signs can include catastrophic gross lesions such as atrophied internal organs, loss of fat reserves and muscle wasting, distended gallbladder, and discolored gizzard lining (Franson and Pain 2011).

Research has amply documented lead exposure in raptors associated with eating offal and carcasses contaminated with lead ammunition (Church et al. 2006; Hunt et al. 2006; Cade 2007; Grund et al. 2010; Cruz-Martinez et al. 2012; Finkelstein et al. 2012). This exposure may have limited the recovery of the California condor *Gymnogyps californianus* (Church et al. 2006; Cade 2007; Finkelstein et al. 2012) and appears concurrent with late fall and winter deer hunting seasons for bald and golden eagles *Aquila chrysaetos* (California [Bloom et al. 1989], Wisconsin [Strom et al. 2009], Pacific Northwest [Stauber et al. 2010], Minnesota [Cruz-Martinez et al. 2012]). In the Midwest, numerous wildlife diagnostic laboratories and rehabilitation centers have reported lead poisoning as a cause of illness or death for bald eagles (Kramer and Redig 1997; Neumann 2009; Cruz-Martinez et al. 2012), with one facility in Minnesota reporting 344 out of 1,277 (27%) bald eagles from 1996 and 2009 having elevated blood and liver lead concentrations (Cruz-Martinez et al. 2012).

Midwest states provide important habitat for bald eagles, as well as excellent deer hunting opportunities for the public (U.S. Fish and Wildlife Service [USFWS] 2006). Given the overlap between the high densities of bald eagles and numerous deer hunting activities, Midwest states provide an ideal study area to investigate the potential exposure of bald eagles to lead in hunter-killed deer remains. The objectives of our study were 1) to quantify the extent of lead exposure in bald eagles incidentally found dead in the Midwest states of Iowa, Minnesota, and Wisconsin; and 2) to examine if deer offal piles are a potential source of lead exposure to scavenging wildlife such as the bald eagle.

Methods

During the winter of 2011–2012, we requested dead bald eagles that Midwest state and federal natural resource offices had salvaged in the states of Iowa, Minnesota, and Wisconsin (Figure 2). Typically, these offices collect bald eagles found dead on the landscape and send the carcasses to the USFWS's National Eagle Repository (http://www.fws.gov/le/national-eagle-repository.html) for

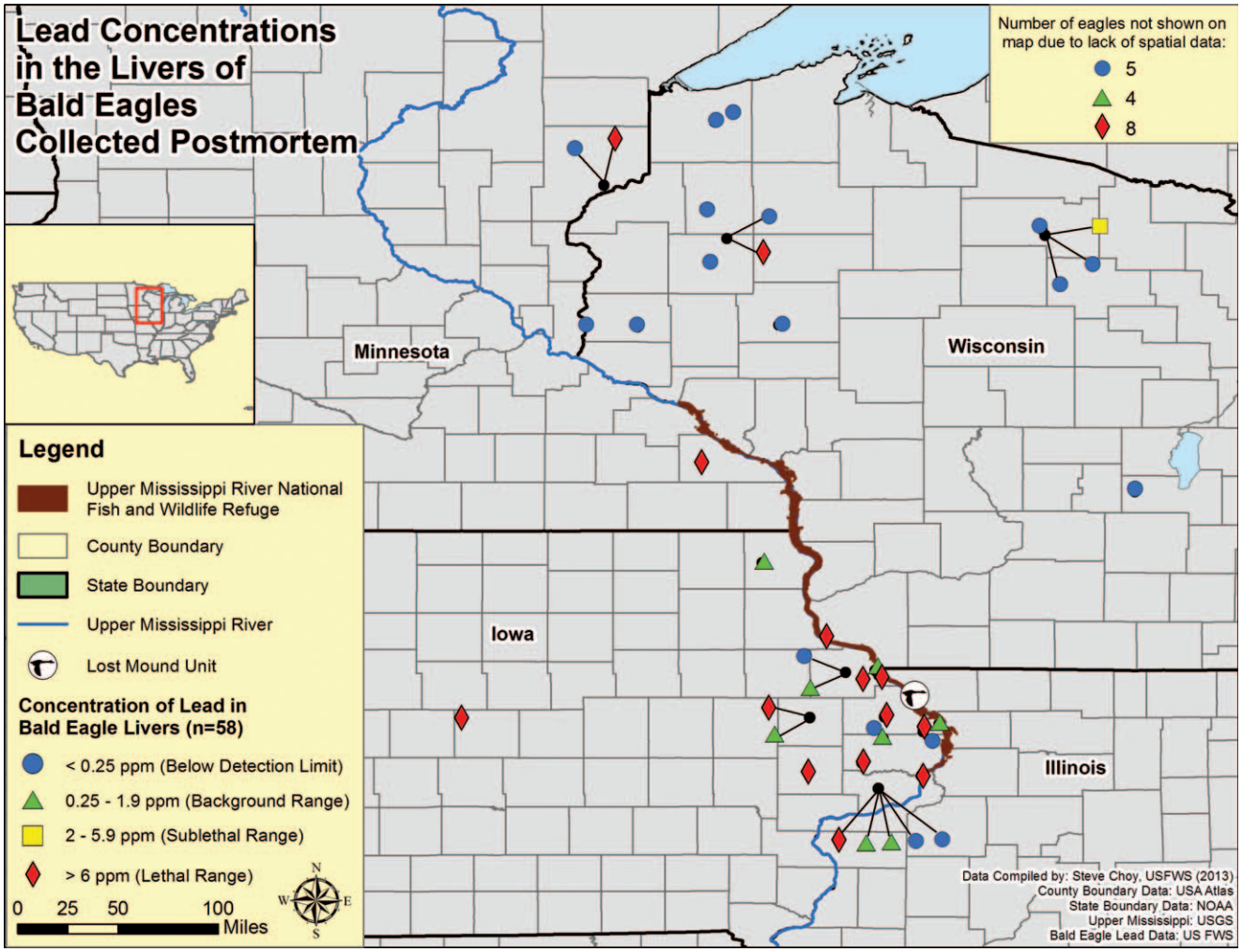

Figure 2. Liver lead concentrations and approximate collection sites for bald eagles *Haliaeetus leucocephalus* within the Midwest states. Study sites include Iowa, Minnesota, and Wisconsin and the Upper Mississippi River National Wildlife and Fish Refuge in Illinois. Bald eagles are marked either in their exact location, in the center of the county if they only had county and state data, or in the middle of the state if they only had state data.

storage and distribution to Native Americans for use in religious ceremonies.

We collected morphometric measurements, conducted postmortem examinations, and harvested the liver from each of the salvaged eagles in our study. Because some of the bald eagles had incomplete date and location information, we were unable to create complete collection histories for all samples. Also, due to the condition of some carcasses, we did not rely on examination of gonads to determine sex. Instead, we used the hallux claw size and bill depth on the cere (Bortolotti 1984), and we used plumage classification (McCollough 1989) to determine age. The maximum age that can be determined using McCollough's method is 5.5 y old. We ranked body condition based on the amount of fat deposits (e.g., pectoral muscle mass, coronary fat, mesentery fat, subcutaneous fat; Weech et al. 2003). This ranking system used a score between 0 and 5 to subjectively assess body condition (0 = poor, 1 = thin, 2 = fair, 3 = good, 4 = very good, 5 = excellent). We recorded other external and internal measurements and observations including body weight (0.1 kg), liver weight (0.1 g), and gross lesions characteristic of chronic lead exposure (e.g., distended and bile-engorged gallbladders, and green bile staining around the vent). We stored liver tissues in clean Whirl-Pac® bags (Nasco Company, Fort Atkinson, Wisconsin) in a standard freezer (−20°C) until shipment to the U.S. Geological Survey's National Wildlife Health Center in Madison, Wisconsin, for lead analysis. We shipped remains of dissected carcasses to the USFWS's National Eagle Repository.

Liver samples underwent nitric acid digestion and flame atomic spectrophotometry for total lead at the National Wildlife Health Center (Franson and Smith 1999). We report all results in milligrams per kilogram (mg/kg) on a wet weight (ww) basis, with lower limits of analytical detection at 0.25 mg/kg ww. Recoveries from spiked samples averaged 99.4%. We used the lead concentrations in the liver tissue to classify bald eagle

exposure as lethal (≥6 mg/kg ww), sublethal (2–5.9 mg/kg ww), or background (≤0.25–1.9 mg/kg ww; Franson and Pain 2011). Concentrations greater than 6 mg/kg ww are consistent with lead poisoning and typically occur in concert with characteristic necropsy observations (such as distended gallbladder, bile-stained vent, loss of fat reserves; Franson and Pain 2011). We used JMP Version 10 (JMP Discovery, SAS Software, Cary, North Carolina) for statistical analysis. We assigned a value of 0.125 mg/kg (one-half of the lower detection limit) to samples in which lead was not detected. We used a nonparametric test (Kruskal-Wallis) to determine whether there were differences in the lead concentrations between sexes and among ages, and we used Pearson's correlations to investigate associations between liver lead concentrations and body mass, liver mass, and body condition (a measure of fat deposits). Significance for all statistical analyses was based on a $P \leq 0.05$.

To meet our second objective of examining offal piles as a potential source of lead to scavenging wildlife, we collected offal piles from deer killed as part of managed public hunts on the USFWS's Upper Mississippi River National Wildlife and Fish Refuge (UMR Refuge; 2012–2013). As part of a concurrent study, we were able to select offal piles from deer we knew had been killed with lead ammunition. In addition, we also had information on the type of firearm used. We collected the offal piles soon after the deer were shot, placed them in plastic bags, and kept them frozen until delivery to veterinary clinics for radiography. We were able to examine lead particles visually on radiographs because they appear as high-density white specks, making them easy to detect (Grund et al. 2010). We performed visual counts of lead fragments in radiographs and calculated the percentage of offal piles with lead fragments present.

Results

We examined a total of 58 bald eagles from Iowa (n = 23), Wisconsin (n = 17), Minnesota (n = 1), and unknown locations (n = 17). The bald eagles from unknown locations came from Iowa, Wisconsin, and/or Minnesota. However, we were not able to assign a state for these birds due to lack of geographic information during processing. Most bald eagles (35 of 58; 60%) had liver lead concentrations indicating background exposure or greater. Twenty-two of the 58 eagles (38%), including two collected on or adjacent to the UMR Refuge, had liver lead concentrations consistent with poisoning (≥6.0 mg/kg ww); the greatest liver lead concentration was 56.9 mg/kg ww (Figure 2). One eagle (2% of our sample) had sublethal liver lead concentrations (3.6 mg/kg ww), 12 (21%) had liver lead concentrations indicative of background exposure (0.25–1.9 mg/kg ww), and 23 (40%) had liver lead concentrations below the detection limit (Figure 2). Sixteen of the 22 (73%) bald eagles that had concentrations consistent with lead poisoning also had distended and bile-engorged gallbladders, and one of these also had green bile staining around the vent (see Supplemental Material, Data S1). Six bald eagles with liver lead concentrations below the detection limit and one in the background category also had distended gallbladders with bile (see Supplemental Material, Data S1).

Of the bald eagles we sampled, 32 were male, 22 female, and 4 were of undetermined sex (see Supplemental Material, Data S1). We found no significant difference in liver lead concentrations between genders (H = 2.25, df = 2, P = 0.33) or among ages (H = 4.34, df = 4, P = 0.36). However, our sample was biased towards adult eagles, with most (37/58; 64%) in Definitive plumage and thereby classified as adults ≥ 5.5 y old. Younger age classes were less well represented in our sample; six in Basic IV plumage and classified as 4.5 y old, five were in Basic II plumage and classified as 2.5 y old, four were in Basic I or Juvenile plumage and classified as 1.5 y old, and two did not have plumage scoring to identify age (see Supplemental Material, Data S1). There were significant negative correlations between liver lead and body mass (Pearson's $r = -0.56$, $P < 0.01$), and liver lead and liver mass (Pearson's $r = -0.40$, $P < 0.01$). Although there was some evidence for a negative correlation between liver lead and body condition (Pearson's $r = -0.25$, $P = 0.06$), it was not significant at the 0.05 level.

We collected offal piles from 25 deer shot on the UMR Refuge and examined them at three different locations. The Mt. Carroll Veterinary Clinic in Mt. Carroll, Illinois, took standard radiographs of four deer offal piles. The clinic found that one contained lead, with a total of 10 high-density fragments of different sizes and shapes. This veterinary clinic used older cassette film that produced white background discoloration, which made it difficult to distinguish small lead fragments. The Dickinson County Veterinary Clinic in Spirit Lake, Iowa, and the Veterinary Associates of Manning in Manning, Iowa, digitally radiographed and scanned 21 offal piles, 9 and 12 piles, respectively. Their digital equipment produced high-quality images that allowed a more accurate identification of small lead fragments. Eight of the 21 digitally radiographed offal piles (38%) contained from 1 to 107 high-density fragments of different sizes and shapes. In total, the radiographs of offal piles from deer shot with lead ammunition showed that 9 of 25 piles (36%) contained fragments of different sizes and shapes ranging from 1 to 107 particles. Hunters used three firearm types during the managed hunts that produced these piles, including 12 and 20 gauge shotguns and muzzleloader rifles. All three firearms produced lead fragments in the deer tissues. The highest number of lead fragments from a shotgun and a muzzleloader was 36 and 107, respectively. The ammunition used in this muzzleloader was a copper-jacketed lead core bullet that mushroomed upon penetration, exposing the lead core, which fragmented in the tissues (Figure 3).

Discussion

In our study, we found that 35 of 58 (60%) of the bald eagles had lead exposure at or above concentrations considered to be background, with 22 of 58 (38%) falling

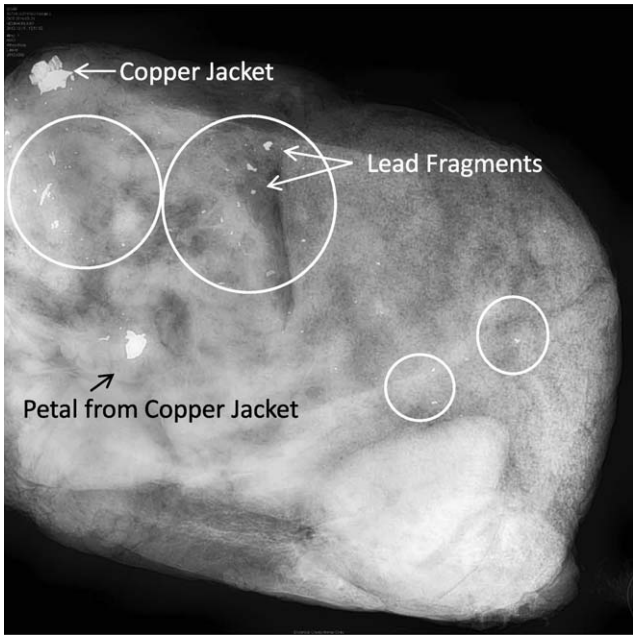

Figure 3. Radiograph shows lead fragments as white specks in the offal pile from a white-tailed deer *Odocoileus virginianus* shot with a copper-jacketed lead core bullet from a .50 caliber muzzleloader in 2012 on the Upper Mississippi River National Wildlife and Fish Refuge. The bullet's copper jacket (shown in the upper left corner) mushroomed, exposing the lead core, which fragmented into 107 pieces that were spread throughout the offal pile (some fragments are circled). The large fragment in the midcenter left is a petal from the copper jacket.

in a range consistent with lead poisoning. This proportion is greater than those in other Midwest studies (e.g., 27% in Minnesota [Cruz-Martinez et al. 2012], 15% in Wisconsin [Strom et al. 2009]). Our results also demonstrate that deer offal can contain lead particles, and therefore it is a potential source of lead exposure to bald eagles in the Upper Midwest.

A number of factors influence the toxicity of lead, including the concentration ingested, duration of exposure, time between exposure events, health of the bird prior to exposure, individual variability, and species sensitivity (Franson and Pain 2011). Once birds ingest lead, the fragments can be passed, regurgitated in pellets, or dissolved by acids in the gastrointestinal tract. Moreover, the length of time for absorption varies (24 h or days, weeks, or months) based on the ingested concentrations and exposure duration (Beyer et al. 1998; Pattee et al. 2006; Rodrígues et al. 2010; Franson and Pain 2011). Following ingestion, lead enters the blood stream and is stored in the soft tissues (e.g., liver and kidneys) and is eventually deposited in the bone. Lead concentrations in the bone can represent lifetime exposure, whereas concentrations in soft tissues usually indicate recent exposure. The amount of time that lead remains elevated in tissues can vary depending on the initial quantity and potential re-exposure. For example, blood lead can remain elevated for extended periods (e.g., 120 d) where re-exposure prolongs the exposure duration (Rodrígues et al. 2010). In one study, mallards *Anas platyrhynchos* that received a dose of one single No. 4 lead shot pellet exhibited elevated blood lead concentrations 3 d later, with values peaking around day 20, then decreasing to the initial concentration between days 120 and 150. Multiple exposure events resulted in the second dose showing a peak blood concentration 50% higher than the first dose (Rodrígues et al. 2010). Although lead retention time in tissues varies, the health effects of chronic exposure from small amounts of lead can cause blood and endocrine system dysfunction, reproductive impairment, and neurotoxicity (Sanborn et al. 2002).

Combining tissue concentrations with characteristic clinical signs and gross lesions consistent with lead poisoning can further substantiate a diagnosis of lead poisoning (Franson and Pain 2011). The signs and lesions can include emaciation, green diarrhea staining the vent, distended gallbladders, discolored gizzard linings, atrophied internal organs, and loss of fat reserves. In our study, most (73%) bald eagles with liver lead concentrations $\geq$ 6.0 mg/kg also had characteristics of chronic lead poisoning (e.g., distended and bile-engorged gallbladder). A distended and bile-engorged gallbladder is likely attributable to inappetance and gut stasis resulting from anemia and emaciation; indirect effects of lead poisoning. Bald eagles with acute exposure most likely die rapidly and have elevated liver levels prior to exhibiting the typical clinical signs or lesions (Pattee et al. 1981; Franson and Pain 2011). We found that 27% of the bald eagles with concentrations $\geq$ 6.0 mg/kg in our study did not show typical signs of lead poisoning, suggesting that acute lead exposure caused a quick death in these eagles. A distended and bile-engorged gallbladder can result from other conditions that cause inappetance or gut stasis in birds, especially when tissue lead concentrations are below thresholds. Seven of the bald eagles in our study with low lead concentrations had distended and bile-engorged gallbladders, lesions that were likely due to other health conditions. Loss of fat reserves and muscle degradation are some of the most consistent signs associated with lead poisoning (Franson and Pain 2011). As expected, we found that as the concentration of lead in the liver increased, body mass and liver mass decreased. Although we did not detect a similar significant statistical correlation at the 0.05 level between lead concentrations and body condition, our P value of 0.06 for this test suggests that at least a weak association existed between lead exposure and loss of fat reserves in the bald eagles.

Animal offal piles and carcasses with embedded lead ammunition are a potential exposure pathway of lead to scavenging birds (Church et al. 2006; Hunt et al. 2006; Cade 2007; Grund et al. 2010; Cruz-Martinez et al. 2012; Finkelstein et al. 2012). In our study, 36% of the offal piles we collected and radiographed from hunters who used either a shotgun or a muzzle loading firearm, contained lead fragments. There are potentially other sources of lead in the landscape in our Upper Midwest study area, such as historic mines, Army Depots, and discarded or lost lead fishing weights. Mining operations can deposit lead tailings on the landscape, and Army Depots typically use lead ammunition for military

purposes. These sources of lead can contaminate soils and also nearby waterways if surface runoff and leaching occurs. Lead exposure directly from soil contamination has been documented in ground feeding birds near a mining site in Coeur d'Alene, Idaho, in waterfowl (Chupp and Dalke 1964; Blus et al. 1991; Sileo et al. 2001) and passerine species that consume soil via foraging habits (Hansen et al. 2011). Henny et al. (1991) documented lead exposure in osprey *Pandion haliaetus* that forage on fish from a river near the Couer d'Alene, Idaho, lead mine. Although the study found lead concentrations in fish to parallel concentrations in adult and nestling osprey, the lead-exposed osprey did not show detectable increased death, behavioral abnormalities, or reduced productivity (Henny et al. 1991). Biologically incorporated lead in an animal may be less bioavailable to consumers because, as suggested by Custer et al. (1984), much of it may be incorporated in bone. Custer et al. (1984) fed American kestrels *Falco sparverius* with cockerels that were raised on a lead diet of varying concentrations. Although kestrels accumulated lead, there were no effects on survivorship, body mass, or on hematological endpoints. The study concluded that lead poisoning in raptors is probably due to the ingestion of lead shot, not the ingestion of biologically incorporated lead (Custer et al. 1984). Lead poisoning and the ingestion of lead fishing weights are common occurrences for diving waterbirds such as the common loon *Gavia immer* (Scheuhammer and Norris 1995; Sidor et al. 2003); it is less common in bald eagles as Scheuhammer et al. (2003) documented. Other potential sources of lead, such as lead in landfills, leaded-paint chips, atmospheric lead from industrial sites, and the combustion of gasoline are unlikely to present an exposure route or risk to bald eagles.

Although other sources of lead are potentially available in the landscape, it is unlikely that bald eagles would have frequent exposure to these sources, and the literature does not document examples of this occurring, except for the finding of an ingested lead fishing weight in a bald eagle in Canada (Scheuhammer et al. 2003). Other sources of lead would probably not explain the widespread lead poisoning we detected in bald eagles in our Upper Midwest study area. Moreover, lead exposure from many of these alternate sources is unlikely given that the diet of bald eagles is almost exclusively animal matter. Bald eagles, especially in the winter months, are known to rely heavily on deer remains (Ewins and Andress 1995; Stocek 2000; Lang et al. 2001). Stocek (2000) found that white-tailed deer and deer offal accounted for 30–40% of the diet, respectively, in the 949 feeding observations on bald eagles in New Brunswick. Similarly, dietary studies of bald eagles wintering in the lower Great Lakes basin found that 47% of the 339 feeding observations were on white-tailed deer carcasses (Ewins and Andress 1995). The contents of eagle castings support this dietary preference for deer in the winter. Analysis of regurgitated castings from bald eagles wintering along the St. Lawrence River found white-tailed deer remains in 67–72% of the castings, representing the most frequently detected dietary item (Lang et al. 2001).

Management Considerations

The Upper Midwest states provide important habitats to thousands of bald eagles, as well as other avian scavengers. Our study demonstrates that a high percentage (38%) of the bald eagles found dead in our Upper Midwest study area had exposure to lead at lethal levels. We also found lead ammunition fragments in discarded offal piles from hunter-killed deer on the USFWS's UMR Refuge. Given the quantity of deer shot in the Upper Midwest, remains from deer shot with lead can be a pathway for lead exposure to bald eagles and other scavenging wildlife that forage on deer remains. Nationwide, waterfowl hunting requires non-toxic shot (http://www.fws.gov/migratorybirds/CurrentBirdIssues/nontoxic.htm). However, lead slugs and bullets remain the most widely used form of ammunition by deer hunters. There are alternative types of ammunition that are considered non-toxic to wildlife. Several of these are preferred because they remain intact upon impact, are ballistically similar to lead and are approved by the Federal Government for hunting use (Knot et al. 2009; Risebrough 2001; Batha and Lehman 2011; Franson et al. 2012; Trinogga et al. 2012; http://www.fws.gov/migratorybirds/CurrentBirdIssues/nontoxic.htm). The use of non-toxic ammunition for deer hunting would eliminate lead particles in discarded deer remains and thereby reduce a potential source of lead exposure to bald eagles and other scavenging wildlife.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Data S1. Data used for the analysis of bald eagle *Haliaeetus leucocephalus* carcass morphological observations, measurements, liver lead concentrations, and collection information.

Found at DOI: http://dx.doi.org/10.3996/032013-JFWM-029.S1 (88 KB PDF)

Reference S1. Batha C, Lehman P. 2011. How good are copper bullets, really??? Wisconsin Department of Natural Resources.

Found at DOI: http://dx.doi.org/10.3996/032013-JFWM-029.S2 (8.3 MB PDF)

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Found at DOI: http://dx.doi.org/10.3996/032013-JFWM-029.S3 (3.2 MB PDF)

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Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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