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Liver Lead Concentrations in Raptors in New Jersey, USA, 2008—2010

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Abstract Lead exposure in New Jersey raptors was assessed by analyzing liver samples from carcasses obtained from wildlife rehabilitators. Samples were collected from 221 individuals representing 13 species. Concentrations were within the range of normal background exposure in 12 species. One red-tailed hawk had a liver lead concentration consistent with clinical poisoning (7.4 µg/g wet weight), which represents an incidence of 1% (1/104) in that species and 0.5% (1/221) in the overall sample. A second red-tailed hawk had a liver lead concentration consistent with subclinical exposure (2.1 µg/g wet weight). The combined incidence of elevated exposure (subclinical exposure + clinical poisoning) was 2% (2/104) in red-tailed hawks and 1% (2/221) in the overall sample.

Keywords Lead · Raptors · Liver lead concentration · New Jersey

Lead, a toxic metal with no essential biological functions, has been known to cause poisoning in humans for at least 2,500 years (Eisler 1988). Lead poisoning of wildlife was first recognized in the latter half of the nineteenth century, when waterfowl were poisoned by ingesting lead shot at hunting sites (Bellrose 1959). The magnitude of the problem became apparent when Bellrose (1959) estimated that 2%–3% of North American waterfowl populations were lost annually due to lead poisoning. A nationwide ban on the use of lead shot for waterfowl hunting was instituted in the US in 1991, and Canada followed suit in 1997 (Clark and Scheuhammer 2003). In 2005 the state of New Jersey extended the ban to include hunting for snipe (*Gallinago delicate*), rails (*Rallus sp.*) and moorhens (*Gallinula chloropus*). There are currently no restrictions on the use of lead shot for upland hunting in New Jersey (NJDFW 2005, 2010).

Raptors can be lead poisoned when they ingest prey that contains embedded lead shot. In fact, the US ban on lead shot for waterfowl hunting was intended not only to protect waterfowl from lead poisoning, but also to protect the then-endangered bald eagle (*Haliaeetus leucocephalus*) from secondary poisoning (Rattner et al. 2008). In addition to ingesting lead shot, raptors may be exposed to lead from a variety of other anthropogenic sources, such as mining and smelting activities, battery manufacturing, and the past use of leaded gasoline in automobiles (Eisler 1988). However, direct ingestion of lead ammunition or fragments presents a greater hazard to raptors and other birds than food chain uptake (Clark and Scheuhammer 2003; Fisher et al. 2006; Rattner et al. 2008). In areas where lead shot is no longer used to hunt waterfowl, an increasingly likely source of lead in clinically poisoned raptors is lead shot or bullets in upland game animals. Lead poisoning has been documented in a number of raptor species in the United States and Canada, including golden eagles (*Aquila chrysaetos*), great horned owls (*Bubo virginianus*), and red-tailed hawks (*Buteo jamaicensis*), species that feed primarily on upland prey (Clark and Scheuhammer 2003; Fisher et al. 2006).

The extent of lead exposure in many raptorial species in the US is not well defined at present. In this paper we

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report the results of a survey of liver lead concentrations in raptors in New Jersey. The concentrations are compared to established criteria for lead exposure and lead poisoning in wild birds.

Materials and Methods

Frozen raptor carcasses were obtained from six wildlife rehabilitators in New Jersey and neighboring Delaware. The birds were submitted from locations throughout New Jersey from February 2008 through November 2010. Most died while at the facilities, although some were dead upon arrival. Liver samples were excised with stainless steel implements, placed in polyethylene bags and frozen at -18°C prior to analysis. The birds were not necropsied by a pathologist. However, during dissection, the carcasses were carefully examined for any evidence of gunshot wounds.

Liver samples were analyzed at the University of Pennsylvania, School of Veterinary Medicine. Samples were digested overnight in 70% nitric acid at 70°C. Digested samples were diluted with deionized water after the addition of ^{159}Tb as an internal standard. Samples were analyzed by inductively coupled plasma mass spectrometry. Prior to analyzing each sample batch, the instrument was calibrated with a blank and a minimum of four standards to obtain a calibration curve with $r^2 > 0.995$. Standard Reference Materials (DOLT-2 dogfish liver from the National Research Council Canada and/or SRM 1577b bovine liver from the National Institute of Standards and Technology) were analyzed with each batch of samples. Data were considered acceptable only if the SRM recoveries were within 20% of the certified value. Mean recoveries for DOLT-2 and SRM 1577b were 97% and 94%, respectively. Bovine liver SRM 1577c was also analyzed as a negative control, given that the certified lead value of 0.063 µg/g is below the method detection limit of 0.1 µg/g. All results were <0.1 µg/g. Duplicate samples were also analyzed with each batch. The mean relative percent difference, excluding duplicates that were below the detection limit, was 6.6%.

Liver lead concentrations were compared to established criteria for background exposure (<2 µg/g wet weight), subclinical exposure (2 to <6 µg/g wet weight), and clinical poisoning (≥6 µg/g wet weight; Kendall et al. 1996; Rattner et al. 2008).

Results and Discussion

A total of 221 liver samples from 13 species were analyzed for lead (Table 1). One of the 104 red-tailed hawks (1%) had a liver lead concentration of 7.4 µg/g wet weight, which is consistent with clinical poisoning. This represents an overall incidence of 0.5% (1/221) in the entire sample. It should be noted that a definitive diagnosis of lead poisoning requires pathological findings in addition to lead residue data (Franson 1996). Because the raptors in this study were not examined by a pathologist, a definitive diagnosis is not possible. However, prior to its death this hawk was being treated for lead poisoning by chelation therapy after a blood lead concentration of 68 µg/dL was reported in a sample sent to a diagnostic laboratory (*Antech Diagnostics, Lake Success, New York; personal communication, Diane Nickerson, Director, Mercer County Wildlife Center*). Blood lead concentrations of 50—100 µg/dL are associated with clinical poisoning (Rattner et al. 2008). The hawk also had blood in the nares when it was admitted. Lead-induced neurological effects may have led to a collision-related injury. A second red-tailed hawk had a liver lead concentration of 2.1 µg/g wet weight, which is consistent with subclinical exposure. The total incidence of above-background exposure (subclinical exposure + clinical poisoning) was 2% in red-tailed hawks (2/104) and 1% overall (2/221). Neither of the hawks with elevated liver lead concentrations had gunshot wounds that might have contaminated tissues with lead fragments. All other samples had concentrations representative of background exposure (<2 µg/g wet weight). Two Cooper's hawks (*Accipiter cooperii*) had concentrations of 1.7 and 1.3 µg/g wet weight, and all other concentrations were <1 µg/g wet weight.

Although there are a number of anthropogenic sources of lead in the environment, the ingestion of embedded lead ammunition or fragments in prey animals is the most likely cause of lethal poisoning in raptors. A study of hawks, falcons and owls in the Coeur d'Alene River basin in the western US supports this contention (Henny et al. 1994). Portions of the basin were contaminated by mining and smelting operations to such an extent that waterfowl were lethally poisoned by ingesting lead-contaminated sediments. Effects on raptors, however, were notably less severe. Relative to birds from reference sites, there was evidence of lead exposure in American kestrels (*Falco sparverius*) and northern harriers (*Circus cyaneus*), but only modest effects were reported (i.e. slightly reduced hemoglobin and hematocrit in American Kestrels). Despite high lead levels in prey animals, no lead-related deaths were observed. The reason for the relatively mild effects in raptors is that most lead concentrates in the bones of prey animals, which are not digested at all by owls and are only partially digested by hawks, falcons and eagles. This trait reduces the potential for raptors to accumulate toxic amounts of lead through the food chain. It is telling that even in such a highly contaminated area lead poisoning did not occur. It therefore appears unlikely that environmental sources other than lead ammunition are concentrated

Table 1 Liver Pb concentrations (μg/g wet weight) in raptors in New Jersey, and the number of birds with concentrations consistent with subclinical exposure (2 to <6 μg/g) or clinical poisoning (≥6 μg/g)

Species	Number of Samples	Number of non-detects (<0.1 μg/g)	Range of Detectable Concentrations (*n*)	Number of birds with liver Pb consistent with subclinical exposure (Pb Conc.)	Number of birds with liver Pb consistent with clinical poisoning (Pb Conc.)
Barn Owl (*Tyto alba*)	1	1	Not applicable	0	0
Barred Owl (*Strix varia*)	2	1	0.35 (1)	0	0
Black Vulture (*Coragyps atratus*)	1	0	0.17 (1)	0	0
Broad-Winged Hawk (*Buteo platypterus*)	2	0	0.12–0.13 (2)	0	0
Cooper's Hawk (*Accipiter cooperii*)	63	38	0.10–1.7 (25)	0	0
Great Horned Owl (*Bubo virginianus*)	26	17	0.10–0.32 (9)	0	0
Osprey (*Pandion haliaetus*)	6	6	Not applicable	0	0
Red-Tailed Hawk (*Buteo jamaicensis*)	104	54	0.10–7.4 (50)	1 (2.1)	1 (7.4)
Red-Shouldered Hawk (*Buteo lineatus*)	2	0	0.18 – 0.70 (2)	0	0
Peregrine Falcon (*Falco peregrinus*)	1	1	Not applicable	0	0
Screech Owl (*Otus asio*)	2	2	Not applicable	0	0
Sharp-Shinned Hawk (*Accipiter striatus*)	4	3	0.31 (1)	0	0
Turkey Vulture (*Cathartes aura*)	7	2	0.11–0.60 (5)	0	0

enough to be a common cause of clinical poisoning in raptors. Subclinical exposure, on the other hand, may result from other environmental sources of lead (Clark and Scheuhammer 2003; Rattner et al. 2008).

Red-tailed hawks are highly adaptable predators with the potential to ingest embedded shot in their prey. Mammals typically account for most of the prey biomass in their diet, although birds are also consumed. In Wisconsin, for example, winter prey included cottontail rabbits and pheasants (Johnsgard 1990), both of which are popular game animals. The hawk with the highest lead concentration in the present study was submitted for treatment on January 22, which coincides with the hunting season for several small game species in New Jersey. Other studies have reported a higher incidence of lead exposure in raptors sampled during or immediately after hunting seasons (Pain et al. 1997; Mateo et al. 1999; Cade 2007).

Lead poisoning has been reported in other studies of North American raptors. Clark and Scheuhammer (2003) reported lead poisoning in 3% of red-tailed hawks (2/58) and 3% (6/179) of their overall sample, which consisted of 16 species of upland-foraging raptors found dead across Canada. Lead poisoning was reported in a great-horned owl, two golden eagles and a bald eagle, in addition to the red-tailed hawks. The authors arbitrarily chose the 90th percentile of the bone lead concentrations (6.75 μg/g dry weight) as the upper threshold of background exposure. Based on this criterion, 10% (14/134) of the raptors had above-background exposure. In a survey of 19 species of terrestrial raptors in southern Ontario, Canada, Martin et al. (2008) reported lead poisoning in 2% of red-tailed hawks (1/64) and 0.4% (1/225) of the overall sample. The total incidence of above-background exposure was 2% (4/225). Lead poisoning was diagnosed in 0.2%–0.9% of raptors in retrospective studies of records from veterinary medical schools in the US (Deem et al. 1998; Morishita et al. 1998; Wendell et al. 2002). Sample sizes in these studies ranged from 340 to 409. Another study by Fix and Barrows (1990) reported no cases of lead poisoning, but the sample size was smaller (n = 60). By way of comparison, traumatic injury was by far the most common cause of raptor deaths in these studies, accounting for 58%–82% of total mortality (Fix and Barrows 1990; Deem et al. 1998; Morishita et al. 1998; Wendell et al. 2002).

At the population level, lead poses the greatest risk to long-lived, slow breeding species with small initial populations (Fisher et al. 2006), such as the endangered California condor (*Gymnogyps californianus*). This species is one of the most sensitive birds in the US to changes in survival rates, and lead poisoning is the most frequently diagnosed cause of death in parts of their range (Hunt et al. 2009). In contrast, red-tailed hawks are one of the most common breeding hawks in North America (Johnsgard 1990). As such, red-tail populations are not likely to be at risk from lead poisoning. As far as the number of individual birds that are poisoned, it should be noted that the incidence of lead poisoning reported in this and similar studies may underestimate the true incidence in free-ranging populations. As with waterfowl, lead poisoning is typically not an acute event with highly visible losses, and many poisoning cases may go unnoticed. Lead-poisoned birds may seek dense cover for safety, lessening the likelihood of discovery, and carcasses quickly disappear due to predation and other causes (USFWS 1976). Also, sample collection is biased towards more populated areas with higher human activity (Deem et al. 1998). This may result in over-reporting of readily observable causes of mortality such as collisions with vehicles, but under-reporting of less noticeable and more widely dispersed causes of mortality like lead poisoning.

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