HISTORICAL PERSPECTIVE ON THE HAZARDS OF ENVIRONMENTAL LEAD FROM AMMUNITION AND FISHING WEIGHTS IN CANADA

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ABSTRACT.—In Canada, the environmental hazards of lead ammunition first gained prominence with waterfowl managers during the 1960s after publication of the seminal paper by Bellrose (1959); however, concerns regarding possible increased crippling of waterfowl from use of early steel shot ammunition, and a belief that lead shot ingestion and poisoning was primarily a USA problem, delayed the regulation of lead shot in Canada for many years. During the 1980s, increased national and regional research by the Canadian Wildlife Service and partners established the frequency and extent of shot ingestion and elevated lead accumulation in waterfowl, and led to the creation of the first non-toxic shot zones in Canada in 1990 and 1991. Gradual development of a wider array of non-toxic shot products, and increasingly broad bans on the use of lead shot, culminated in a national regulation in 1999 prohibiting the use of lead shot for the purpose of hunting all migratory game birds anywhere in Canada (exempting upland species—American Woodcock [*Scolopax minor*], Mourning Doves [*Zenaida macroura*], and Rock Doves [*Columbia livia*]). After non-toxic shot regulations were established in Canada, the incidence of elevated lead exposure in hatch year (HY) ducks declined dramatically, testifying to the effectiveness of the regulations and a generally high compliance by hunters. Compared with waterfowl, ingestion and accumulation of lead in upland birds has received relatively little attention in Canada, and elsewhere. However, the frequency of elevated lead accumulation in some HY upland game birds (e.g., Hungarian Partridge [*Perdix perdix*]) in Canada can be comparable to that experienced by HY ducks prior to non-toxic shot regulations. In addition, lead poisoning is a significant cause of death in some upland-foraging raptors (e.g., Golden Eagles [*Aquila chrysaetos*]) that may feed on dead or wounded upland prey with embedded lead shot or bullet fragments. Embedded fragments of metallic lead from ammunition projectiles are also a source of dietary lead exposure in humans who consume hunted game animals. The environmental impacts of small lead fishing sinkers and jigs in Canada have also been assessed. A major conclusion from a review of available data was that ingestion of small lead sinkers or jigs accounts for about 20–30% of recorded mortality of breeding adult Common Loons in habitats that experience high recreational angling activity. A common thread in these issues is the risk of elevated lead exposure and toxicity from ingestion of small metallic lead items deposited into the environment, largely through recreational activities. These risks can be avoided by replacing the use of lead in these activities by less toxic materials. *Received 29 May 2008, accepted 28 June 2008.*

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LEAD IS A TOXIC METAL with no known biological function. Lead's low melting point, malleability, ease of processing, and low cost have resulted in its use in a wide range of applications for over a thousand years. However, the recognition of adverse effects of lead at increasingly lower levels of exposure in humans and other animals has led to the gradual elimination of lead from many of its once common uses. A major continuing use of lead is in the manufacture of projectiles for ammunition used in hunting and target shooting; and for terminal tackle (sinkers and jigs) used in recreational angling. Here, the hazards resulting from the release of metallic lead into the environment from these activities are discussed from a Canadian perspective.

Lead in Canadian Wetland (Waterfowl) Hunting.— In Canada, significant concern over possible lead poisoning of waterfowl from lead shot ingestion first surfaced in the late 1960s and early 1970s, following publication of the comprehensive USA study by Bellrose (1959) and subsequent regulations by the US government to establish non-toxic shot zones for waterfowl hunting. During this time, Environment Canada (the federal environment department) contemplated banning the use of lead shot; and the Canadian Wildlife Service (CWS), in collaboration with the National Research Council, conducted studies to investigate the manufacture and ballistic properties of various alternative, non-lead shot. However, little research on shot ingestion rates in waterfowl beyond a few local or regional studies was conducted in Canada during this period. This was partly due to a belief by many waterfowl managers that, because waterfowl did not overwinter in Canada, lead shot ingestion was probably not a significant problem in Canadian wetlands; and that the use of steel shot might cripple far more waterfowl than would be saved by prohibiting the use of lead.

Concerted research and monitoring efforts to study the nature and extent of lead shot ingestion nationally were initiated in Canada when the USA announced, in the late 1980s, its intent to completely ban the use of lead shot for waterfowl hunting by 1991. Once research had been completed that demonstrated significant rates of shot ingestion by waterfowl in several locations across the country (collated in Kennedy and Nadeau 1993), the CWS, using its regulatory authority under the Migratory Birds Convention Act, and with Provincial agreement, established the first Canadian non-toxic shot zones in British Columbia, Manitoba, and Ontario in 1989 and 1990. At that time, the CWS judged that there was insufficient evidence to justify a national ban on the use of lead shot for waterfowl hunting, and it developed a set of criteria for assessing whether local lead exposure in waterfowl was sufficiently severe to require non-toxic shot regulations. This framework (Wendt and Kennedy 1992) and its subsequent modifications are typically referred to as the "hot spot" approach to regulating the use of lead shot. The CWS criteria were accepted in 1990 by federal and provincial wildlife Ministers as an interim policy for managing the problems associated with the use of lead shot for waterfowl hunting. However, a national wing bone survey to determine the pattern of elevated lead exposure in hatch-year (HY) ducks in Canada reported a widespread geographic association between elevated bone lead concentrations and waterfowl hunting, rather than a few, local sites of high lead exposure (Scheuhammer and Dickson 1996). In addition, lead poisoning of Bald Eagles (*Haliaeetus leucocephalus*), which in the USA had been linked to feeding on dead or wounded waterfowl containing embedded lead shot (Pattee and Hennes 1983), was also documented in Canada (Elliott et al. 1992). Scheuhammer and Norris (1995, 1996) reviewed the environmental impacts of lead from shotshell ammunition and lead fishing weights in Canada. Studies such as these, combined with the development of a wider variety of non-toxic shot products by the ammunition industry, and decisions by some Canadian provinces to completely phase out the use of lead shot for waterfowl hunting within their jurisdictions, resulted in a policy evolution away from the "hot spot" management approach in favour of broader controls on the use of lead shot. Beginning in 1997, a national regulation came into effect prohibiting the use of lead shot for the purpose of hunting migratory game birds within 200 meters of a watercourse anywhere in Canada (exempting upland migratory species—American Woodcock [*Scolopax minor*], Mourning Doves [*Zenaida macroura*], and Band-tailed Pigeons [*Columba fasciata*]); and in 1999, this regulation was expanded to include dry land as

well as wetland areas (although upland migratory species were still exempt).

The regulation prohibiting the use of lead for migratory bird hunting was expected to reduce the deposition of lead into the Canadian environment by approximately 1,000 metric tonnes per year. Stevenson et al. (2005) confirmed that bone lead concentrations in HY ducks in Canada declined by 50%–90% (depending on species and location) after non-toxic shot regulations were established. Declines in bone-lead concentration were consistent with the results of a large anonymous hunter survey, which indicated a high level of reported compliance (>80%) with the nontoxic shot regulation among Canadian waterfowl hunters (Stevenson et al. 2005). Conversely, American Woodcock, an important upland game species not affected by the nontoxic shot regulation, showed no decrease in mean bone-lead concentration in samples collected after the national regulation came into effect; and a majority (70%) of Canadian waterfowl hunters who also hunt upland game birds reported continued (legal) use of lead shot for upland game bird hunting (Stevenson et al. 2005). These findings are in agreement with those of USA studies that also reported a generally low rate of lead shot ingestion in waterfowl and a high compliance by hunters after non-toxic shot regulations were established (Anderson et al. 2000, Moore et al. 1998). However, lead shot ingestion and poisoning remains a significant problem in some aquatic environments; for example, for swans in southern British Columbia and northern Washington (Degernes et al. 2006, Wilson et al. 2004), in environments where the availability of "old" lead shot may still be high.

Lead in Canadian Upland Hunting.—The harvest of upland game birds in Canada was estimated to be roughly equal to that of waterfowl (Scheuhammer and Norris 1995), suggesting that shot deposition rates may be similar for each type of hunting. However, relatively little research has been undertaken to estimate rates of shot ingestion or elevated lead exposure in upland birds. In Canada, migratory upland species such as American Woodcock were exempted from the national regulation requiring nontoxic shot for migratory game bird hunting, based on a lack of data indicating lead shot ingestion or elevated lead accumulation in these species; and there are no provincial regulations prohibiting the use of lead for hunting non-migratory game species. However, Kendall et al. (1996) concluded that concern for lead shot impacts on upland game birds and raptors was warranted, and that the issue merited continued scrutiny to protect upland game bird and raptor resources. In this context, Scheuhammer et al. (1999) investigated the degree of lead exposure in American Woodcock in eastern Canada, reporting that HY woodcock had median bone-lead concentrations of 11 μg/g, almost twice as high as HY Mallard (*Anas platyrhyncos*) and American Black Ducks (*Anas rubripes*) prior to restrictions on the use of lead shot for waterfowl hunting. Similar findings of elevated lead were later reported in American Woodcock from Wisconsin (Strom et al. 2005). Although the finding of a high incidence of elevated lead exposure in young woodcock was surprising, the source of exposure was uncertain. In a follow-up study, Scheuhammer et al. (2003a) sampled American Woodcock, surface soil, and earthworms from a number of sites in eastern Canada, and reported that, although lead concentrations in soils were low in most sites—typical of uncontaminated rural soils—lead concentrations in earthworms could be many times that of soil, and might therefore be a significant source of elevated lead exposure in American Woodcock as this species feeds extensively on earthworms and other soil invertebrates (Keppie and Whiting 1994). However the stable lead isotopic signatures (Scheuhammer and Templeton 1998) for bones of American Woodcock with elevated lead accumulation were often significantly different from signatures for both worms and soils sampled from the same areas. The range of $^{206}Pb/^{207}Pb$ ratios in wing bones of American Woodcock with elevated lead exposure was not consistent with exposure to lead in earthworms, nor to environmental lead from past gasoline combustion or mining wastes related to Precambrian lead ores, but was consistent with ingestion of spent lead shotgun pellets sold in Canada (Scheuhammer et al. 2003a). Ingestion of lead shot used for upland game bird hunting is a likely source of high bone-lead accumulation for American Woodcock in eastern Canada.

Table 1. Percent of hatch year (HY) upland game birds and ducks from Saskatchewan, Canada, with elevated (>10 µg/g dry wt.) bone lead concentrations.

Species	Percent with >10 µg/g lead in bone	Year Sampled
Hungarian Partridge (*Perdix perdix*)	11 (19/169)	2001
Sharp-tailed Grouse (*Tympanuchus phasianellus*)	5 (4/79)	2001
Mallard (*Anas platyrhyncos*)	8 (17/214)	1989/90

In addition to American Woodcock, lead exposure has been studied in a few other upland game bird species in Canada. For example, 11% of HY Hungarian Partridge (*Perdix perdix*) from Saskatchewan had elevated (>10 µg/g) bone-lead concentrations (Table 1), higher than the percentage of dabbling ducks from the same province that had elevated bone-lead levels prior to the establishment of non-toxic shot regulations (~8%: Scheuhammer and Norris, 1995). Chukar (*Alectoris chukar*) and Ring-necked Pheasant (*Phasianus colchicus*) from a heavily hunted area in southern Ontario, Canada, had shot ingestion rates of 8% and 34%, respectively (Kreager et al. 2008). A lower ingestion rate (1.2%) was reported for Ruffed Grouse (*Bonasa umbellus*) in Quebec (Rodrigue et al. 2005). Studies such as these demonstrate that the ingestion of lead shot in upland game birds can be comparable to that documented for waterfowl prior to restrictions on the use of lead shot for waterfowl hunting.

In a study examining lead exposure in 184 individuals of 16 upland raptor species found dead across Canada, Clark and Scheuhammer (2003) reported that 3–4% of total mortality in the three most commonly encountered species (Red-tailed Hawk [*Buteo jamaicensis*], Great Horned Owl [*Bubo virginianus*], and Golden Eagles [*Aquila chrysaitos*]) was attributable to lead poisoning. Golden Eagles, which feed exclusively on terrestrial/upland prey, die of lead poisoning on the Canadian Prairies as frequently as Bald Eagles that typically feed on more aquatic prey (waterfowl, fish) (Wayland and Bollinger 1999), indicating that some upland environments can present a risk of lead exposure and poisoning for raptors. A major source of elevated lead exposure in upland predators and scavengers is lead fragments from ammunition used for upland hunting, and for varmint shooting (Cade 2007, Craighead and Bedrosian 2008, Fisher et al. 2006, Hunt et al. 2006, Knopper et al. 2006). Replacing lead shot and high velocity lead bullets used in upland shooting with non-toxic alternatives would eliminate the only significant source of high lead exposure and poisoning for large avian predators and scavengers.

Small fragments of metallic lead are often present in tissues of animals shot with lead ammunition, and can be detected using radiography. In Canada, approximately 11% of breast muscle samples from a large number of hunter-killed game birds had elevated (>2 µg/g dry wt.) lead concentrations, with some samples having >1,000 µg/g (Scheuhammer et al. 1998). All muscle samples were examined visually prior to analysis, and none contained detectable lead pellets; however, radiography confirmed the presence of numerous small (<1 mm diameter) metallic fragments (Scheu–hammer et al. 1998). Similar results have been reported by others (Frank 1986, Hunt et al. 2006, Johansen et al. 2004). Small pieces of metallic lead from shotgun pellet and bullet fragmentation embedded in the flesh of game animals are potential sources of dietary lead exposure for predators, and for human consumers of wild game, especially in communities that rely on subsistence hunting and for whom hunter-killed wild game represents a major food source (Hanning et al. 2003, Levesque et al. 2003, Tsuji et al. 1999). This risk can be eliminated by the use of non-toxic materials for manufacturing bullets and shotgun pellets.

Lead in Recreational Angling in Canada.—As reviewed in Scheuhammer et al. (2003b), more than 5 million Canadians take part in recreational angling each year, spending over 50 million days fishing on open water. Recreational anglers contribute to environmental lead deposition through the loss of lead fishing sinkers and jigs. Lost or discarded fishing sinkers and jigs amounting to an estimated 500 tonnes of lead, and representing up to 14% of all non-recoverable lead releases in Canada, are deposited in the Canadian environment

annually. Wildlife, primarily Common Loons (*Gavia immer*) and other water birds, ingest fishing sinkers and jigs during feeding, when they mistake the sinkers and jigs for food items or grit, or consume lost bait fish with the line and weight still attached. Lead sinkers and jigs weighing <50 g and smaller than 2 cm in any dimension are generally the size found to be ingested by wildlife. Ingestion of a single lead sinker or lead-headed jig, representing up to several grams of lead, is sufficient to expose a loon or other bird to a lethal dose of lead. Lead sinker and jig ingestion has been documented in 10 different wildlife species in Canada; and in 23 species of wildlife in the United States, including loons, swans, other waterfowl, cranes, pelicans, and cormorants. Lead sinker and jig ingestion is the only significant source of elevated lead exposure and lead toxicity for Common Loons, and the single most important cause of death reported for adult Common Loons in eastern Canada and the United States during the breeding season, frequently exceeding deaths associated with entanglement in fishing gear, trauma, disease, and other causes of mortality. In addition to lead poisoning of wildlife, there are also risks of lead exposure in humans during both the home manufacture and handling of lead sinkers and jigs.

There are numerous viable non-toxic materials for producing fishing sinkers and jigs, including tin, steel, bismuth, tungsten, rubber, ceramic, and clay. Tin, steel, and bismuth sinkers and bismuth jigs are the most common commercially available alternatives in Canada. Many of the available non-lead products are currently more expensive than lead; however, switching to these products is estimated to increase the average Canadian angler's total yearly expenses by only about $2.00.

Regulatory action has been taken by some nations to reduce the use of lead sinkers and jigs. In 1987, Britain banned the use of lead fishing sinkers weighing less than one ounce. The United States has banned the use of lead sinkers and jigs in some National Wildlife Refuges, and in Yellowstone National Park. New Hampshire, Maine, and New York have established statewide regulations prohibiting the use of lead sinkers. Environment Canada and Parks Canada prohibited the possession of lead fishing sinkers or lead jigs weighing less than 50 g by anglers fishing in National Wildlife Areas and National Parks under the *Canada Wildlife Act* and the *National Parks Act*, respectively, in 1997. Environment Canada is currently considering broader controls on the manufacture, import, and sale of small lead sinkers and jigs.

CONCLUDING REMARKS

Although lead has been mined, smelted, and used in western society for hundreds of years, over the last half century many of its once common uses have been phased out in favour of less toxic materials. Thus, lead in house paints, water pipes, solder, pottery glazes, and gasoline has been eliminated or greatly reduced. A major remaining source of continuing environmental deposition of lead is metallic lead used in ammunition for hunting and target shooting, and in sinkers and jigs for recreational angling. These uses of lead have both environmental and human health consequences. Given the availability and continued development of functional, affordable, non-toxic alternatives to lead, the development of policies aimed at phasing out the use of lead for these activities is highly probable. It is important in the crafting of such policies that all significant stakeholders be actively involved in a consultative approach, including federal and state/provincial environmental and human health agencies, ammunition and tackle industries, non-governmental environmental and wildlife organizations, and hunting and angling communities.

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