EVIDENCE OF LEAD SHOT PROBLEMS FOR WILDLIFE, THE ENVIRONMENT, AND HUMAN HEALTH – IMPLICATIONS FOR MINNESOTA

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SUMMARY OF FINDINGS

There is considerable evidence published in professional scientific journals demonstrating that lead shot negatively impacts the health of wildlife, humans, and the environment. More than 100 species of birds (including upland birds, raptors, and waterfowl) have been weakened or killed by ingesting lead shot. The impacts of lead shot on wildlife include decreased survival, poor body condition, behavioral changes, and impaired reproduction. Studies in Canada, Greenland, and Russia have linked lead shot found in game animals to higher levels of lead in people who eat those game animals. Recent evidence shows that meat far from entry wounds may contain lead fragments. Effective nontoxic alternatives to lead shot are available at a similar cost. Countries, such as Denmark and The Netherlands, as well as some states in Australia have banned the use of lead shot. In North America, federal regulations prohibit the use of lead shot for waterfowl hunting and 26 states and provinces have additional nontoxic shot regulations for hunting doves, pheasants, and other species.

INTRODUCTION

Our nation has taken great strides to reduce environmental and human exposure to lead through restricting use of lead in gasoline and paints and restricting imported goods containing lead. However, lead continues to enter the environment and the diet of people through lead shot used by hunters.

Multiple reports published in professional scientific journals document that more than 100 species of birds (both waterfowl and upland birds) ingest lead ammunition that both weakens and kills them (Table 1). Some wildlife species, such as raptors (e.g., hawks, eagles, and condors), are "secondarily poisoned" by consuming animals that either ate or were shot with lead ammunition.

Thomas (1997) wrote that despite an awareness of the problems of lead shot to wildlife, regulatory action has been slow, "…due to hunters and international sport shooting organizations opposing the use of nontoxic substitutes and overt emphasis by government agencies on the burden of scientific proof for every situation, rather than taking preventative action according to the Precautionary Principle." (The precautionary principle supports decision-making processes involving serious or irreversible damage that are reasonable, rational, and responsible responses (Gilbert 2005)).

Wildlife mortality from ingestion of lead shot was first reported more than 100 years ago. In 1876, H. S. Calvert published "Pheasants Poisoned by Swallowing Shot" in *The Field* (Calvert 1876). In 1882, a second article about pheasants poisoned by lead shot appeared in the same publication (Holland 1882). In 1894, G. B. Grinnell published an article entitled, "Lead Poisoning," in *Forest and Stream* (Grinnell 1894). Since that time, professional journals have carried many manuscripts documenting wildlife being negatively impacted by hunters' use of lead shot: including die-offs from ingestion of lead shot, scientific studies regarding the toxicity of lead shot to wildlife, and lead accumulation in wildlife and human tissues resulting from lead shot. The impacts of lead shot on wildlife, the environment, and human health are of concern to many hunters and other people (Nontoxic Shot Advisory Committee 2006).

This report summarizes studies regarding ingestion of lead shot by wildlife species and the impacts of lead poisoning. Table 1 lists more than 100 species that have ingested and been poisoned by lead shot. Table 2 lists 15 recent examples of lead shot impacts on human health.

A companion to this document is a Literature Review (Tranel and Kimmel 2007) containing more than 500 references related to wildlife ingesting lead, wildlife being poisoned by lead ammunition, and lead impacts on the environment and human health.

Impacts of Lead Shot on Wildlife

There are hundreds of manuscripts published in the professional literature that provide scientific evidence of lead ingestion by wildlife, toxicity to wildlife, and lead accumulation in wildlife tissues from ingesting lead shot (Tranel and Kimmel 2007). Impacts of lead shot on wildlife include decreased survival, poor body condition, behavioral changes, and impaired reproduction. Tavecchia et al. (2001) reported decreased survival of mallards from lead ingestion in France. Spahn and Sherry (1999) noted increased nestling mortality was related to exposure of lead in little blue heron chicks in a wetland contaminated by heavy metals in Louisiana. Sileo et al. (1973) reported 25-45% reduction in body weight followed by death for Canada geese dosed with lead shot. Death as a result of poisoning from lead shot has been demonstrated for species including doves (Schulz et al 2006a, Schulz et al. 2007), mallards (Finley and Dieter 1978, Anderson and Havera 1985), and Canada geese (Cook and Trainer 1966). Fisher et al. (2006) suggested that behavioral changes resulting from lead poisoning can influence susceptibility to predation, disease, and starvation, which increases the probability of death. Experimental evidence has demonstrated impaired reproduction from lead shot ingestion for captive doves (Buerger et al. 1986) and domestic mallards (Elder 1954).

Lead shot impacts on wildlife were most obvious in heavily hunted areas, such as wetlands that were popular waterfowl hunting areas. Because grit is essential for the digestive systems of waterfowl (and most upland game birds) and birds do not differentiate between lead shot and grit of a similar size, wildlife feeding and gathering grit in these wetlands also pick up lead shot (Osmer 1940). Wilson (1937) reported lead poisoning in ducks, geese, and swans discovered in Back Bay, Virginia, and Currituck Sound, North Carolina. He analyzed gizzards; some of which contained more than 100 full-sized No. 4 lead shot and partly ground remains. Osmer (1940) noted that “ingestion of 6 No. 5 shot by a duck is fatal. Even 2 or 3 shot are often fatal.” Massive waterfowl die-offs were reported during the 20th century (Bellrose 1959).

Studies in Minnesota documented lead shot problems for bald eagles and Canada geese (Minnesota Department of Natural Resources 1981, Bengston 1984, Hennes 1985). Problems were considered severe enough at that time for a Steel Shot Zone to be established for Canada goose hunting at Lac Qui Parle Wildlife Management Area (Bengston 1984). Hennes (1985) noted that lead shot poisoning of bald eagles decreased, but wasn’t eliminated. A Trumpeter swan die-off in 2007 at Grass Lake in Wright County, Minnesota was attributed to poisoning from lead shot (Minnesota Department of Natural Resources 2007).

Impacts of lead shot at a population level are variable. Butler et al. (2005) noted that 3% of pheasants on shooting estates in Great Britain had lead in their gizzards. Kreager et al. (2007) examined gizzards from upland game birds harvested in Ontario, Canada and found lead pellets ingested by 8% of the chukars and 34% of the pheasants. They found that 13% of the livers (from chukars, pheasants, wild turkey, and Hungarian partridge) had elevated lead concentrations. Schulz et al. (2007) found that birds may expel lead shot after ingesting it, indicating incidence of lead exposure in wildlife may be lower than reported. Conversely, birds that expelled lead quickly suffered no obvious symptoms of lead poisoning (Schulz et al. 2007).

Fisher et al. (2006) suggested that a lack of evidence of poisoned species does not suggest a lack of poisoning. Die-offs and evidence of lead poisoning may not be apparent, because wildlife affected by lead poisoning may seek isolation and protective cover (Friend and Franson 1999). Furthermore, mortality due to non-lethal effects such as reproductive problems, lowered immunity, anemia, and weakened muscles could be higher than losses from direct lead poisoning (Michigan Department of Natural Resources 2002).

Wildlife Species Ingesting Lead Shot

In the "World Symposium on Lead in Ammunition," held in Rome, Italy in 2004, John Harradine from the United Kingdom, reported, "The issue of lead poisoning in wildlife as a consequence of shooting activities has long been debated as to its occurrence, its impact and how it should be managed. On the basis of evidence to date, and in general terms, waterfowl, some non-waterfowl species, and birds of prey are the groups of wildlife most at risk of poisoning by virtue of being most exposed to spent lead shot and vulnerable to its effects" (Harradine 2004). Table 1 documents lead ingestion or secondary lead poisoning for more than 100 wildlife species, including waterfowl, upland game birds, raptors, songbirds, mammals, and reptiles.

Bellrose (1959) summarized historic information on duck die-offs from lead poisoning. Die-offs ranged from hundreds of ducks in Indiana (1922) and in Louisiana (1930) to as many as 16,000 birds in Missouri (1945-1957) and Arkansas (1953-1954). Current use of lead shot for small game hunting (not waterfowl) potentially continues to deposit lead in wetlands continuing to impact waterfowl.

There is evidence that the problem extends to upland birds and raptors. Butler et al. (2005) reported lead exposure over a number of years (1996-2002) for ring-necked pheasants in Great Britain. Fisher et al. (2006) provides a review of 59 terrestrial bird species that have been documented to have ingested lead or suffered lead poisoning from ammunition sources. Nine were threatened species. Impacts of lead shot on doves and pheasants are considered by some scientists to rival the problem in waterfowl (Kendall et al. 1996, Harradine 2004). Ingestion of lead by wildlife, other than waterfowl and birds of prey, "appears to be extensive" and "some species, such as mourning dove and pheasant, however, which are subject to substantial hunting and which feed in those hunted areas, are exposed to relatively high levels of ingestion and its predictable consequences" (Harradine 2004).

Lead shot ingestion and toxicity problems for wildlife have been documented throughout the world where bird hunting exists. Tavecchia et al. (2001) found lead pellets in the muscles and gizzards of 11% of the mallards captured in France. In Spain, Mateo et al. (2003) reported lead poisoning from exposure to lead shot from prey species in 8 upland raptor species. Mörner and Petersson (1999) found lead poisoning in 2 woodpecker species in forested areas in Sweden suggesting that the woodpeckers searching for food removed lead pellets shot into trees.

Lead shot may secondarily poison wildlife that feed on hunted species. Studies have linked the likelihood of a species ingesting lead shot to feeding habits, with scavengers and predators that take game species the most susceptible (Pain and Amiard-Triquet 1993). Clark and Scheuhammer (2003) examined lead exposure in 184 dead raptors (16 species) found across Canada. They determined that, of the 3 most commonly encountered species, 3-4% died as a result of lead poisoning. They concluded that upland birds of prey and scavengers that eat game birds and mammals are at risk for lead poisoning from ingestion of lead ammunition used in upland hunting. They suggested that use of nontoxic ammunition for hunting upland game would effectively remove the only serious source of high lead exposure and lead poisoning for upland-foraging raptors.

Knopper et al. (2006) reported that carcasses from squirrel populations managed by shooting had lead levels lethal to raptors and suggested either collection of carcasses shot with lead or the use of nontoxic shot. Similar to the lead shot problems described by Clark and Scheuhammer (2003), deer carcasses containing lead fragments from bullets impact California condors (Cade 2007) and bald eagles (Franson 2007). Hunt et al. (2006) examined the remains of 38 deer killed with rifles and found that all deer killed with lead-based bullets contained bullet fragments. Mateo et al. (2003) analyzed bones from 229 birds of prey in Spain (11 species) and diagnosed lead poisoning in 8 raptor species that feed on wildlife targeted by hunters in upland habitats.

Lead Shot Problems for Humans

Lead poisoning in humans has occurred for at least 2,500 years (Eisler 1988). Today, it is widely known that lead is toxic to humans and can cause permanent developmental problems and death. Haldimann et al. (2002) concluded that frequent consumption of wild game meat had no effect on blood lead levels. However, studies in Canada, Greenland, and Russia have linked lead shot found in game animals to higher levels of lead in people who eat those game animals (Table 2). Levesque et al. (2003) stated, "lead shots may be a major source of lead exposure to humans that consume hunted game animals." This study found that lead shot was a source of lead exposure in the Inuit population; lead blood concentrations in 7% of Inuit newborns were higher than government-recommended levels. Studies linking game meat containing lead shot and elevated lead blood levels in children (Odland et al. 1999, Smith and Rea 1995) and newborns (Dewailly et al 2000, Hanning et al. 2003) are of particular interest.

Breurec et al. (1998) diagnosed lead poisoning in an adult patient who had frequently eaten game birds containing lead shot. Professional medical literature contains many references of humans carrying lead shot in their digestive tracts (Engstad 1932, Horton 1933, Hillman 1967, Madsen et al. 1988, Spitale and D'Olivo 1989, Moore 1994, Tsuji and Nieboer 1999, and Larsen and Blanton 2000). In animals shot for human consumption, meat far from the entry wound may contain lead. Scheuhammer et al. (1998) found fragments of lead far from wounds from shotgun pellets. Hunt et al. (2006) found lead fragments in meat away from rifle bullet wounds in game animals. Lead fragments, likely from bullets, were found in ground venison in North Dakota. This prompted North Dakota Health, Game and Fish, and Agriculture Departments to advise food pantries not to distribute or use donated ground venison because of the potential for lead contamination (North Dakota Department of Health 2008). Also, lead from shot may accumulate in tissues of game animals. In upland game birds and waterfowl killed by hunters using lead shot, 40% of 123 livers (Kreager et al. 2007) and 9% of 371 gizzard tissue samples (Tsuji et al. 1999) showed lead levels greater than Health Canada's guidelines for fish. Currently, no lead level guidelines exist for meat.

Tsuji et al. (1999) reported that, "People who consume *any* game species harvested with lead shot risk exposure to this metal by way of ingestion of tissue-embedded lead pellets and fragments." With alternatives to lead shot readily available (Sanborn n.d.), human exposure to lead through game meat is unnecessary (Rodrigue et al. 2005). Levesque et al. (2003) showed significant decreases in lead concentrations in umbilical cord blood after a public health intervention to reduce the use of lead shot by the Inuit population. Tsuji et al. (1999) suggested banning lead shot for all game hunting because of potential human health concerns.

Lead Shot Impacts in the Environment

The Minnesota Pollution Control Agency (1999) estimated that 2,610,720 pounds (1,184 metric tons) of lead shot were used annually in Minnesota in hunting and shooting ranges. In their legislative report on sources and effects of lead, they state, "The fact that lead ammunition is estimated to be the single largest source of lead released to the environment qualifies it as a concern that should be examined more closely."

De Francisco et al. (2003) estimated that lead shot can take 100 to 300 years to disappear from a site, allowing for concentration of large amounts of lead in areas of heavy hunting pressure. Although the breakdown is slow, lead shot pellets accumulating in the environment are not inert and ultimately the lead will be deposited as particles in soil and water (Scheuhammer and Norris 1995). Uptake of this lead by terrestrial and aquatic plants and animals can occur, leading to elevated lead concentrations.

Guitart et al. (2002) reported that a single lead shot could raise 12,000 liters of water to the European Union threshold guideline for lead in drinking water. Surface water contamination by lead shot from shooting ranges has been well documented (Stansley et al. 1992, Dames and Moore Canada 1993, Emerson 1994, USEPA 1994). Strait et al. (2007) found that shooting ranges contained areas where lead occurred at "concentrations significantly in excess of the

Michigan Department of Environmental Quality criteria and therefore pose a potential risk to the human users of the land as well as to the native wildlife." While shooting ranges contain far more spent shot than typical hunting areas, these studies demonstrate the ability of lead to accumulate over time and contaminate the surrounding environment and wildlife. Areas with acidic waters or soils are at particularly high risk for contamination from lead shot, as lead is more easily mobilized at a lower pH (Stansley et al. 1992).

Contamination of human food sources due to lead shot deposition has also been documented. Guitart et al. (2002) suggested that the high lead content of rice produced in Spain was a result of hunting with lead shot near rice fields. Rice et al. (1987) reported lead poisoning of cattle from ingestion of silage contaminated with lead shot. In addition, milk production decreased and stillbirths increased in cattle ingesting lead contaminated hay cut from a field used for clay pigeon shooting (Frape and Pringle 1984).

Alternatives to Lead Shot

Substituting nontoxic shot for lead shot could reduce lead shot impacts on the health of wildlife, humans, and the environment. Friend and Franson (1999) noted, "The use of nontoxic shot is the only long-term solution for significantly reducing migratory bird losses from lead poisoning." Migratory birds that have been shown to be impacted by lead shot include doves, waterfowl, and other species. Upland birds, such as ring-necked pheasants, are also impacted by lead shot.

Alternatives to lead shot were not readily available in the past, especially prior to the federal ban on lead shot for waterfowl hunting in the United States (US). However, other types of shot, particularly steel shot, are now available at a cost comparable to lead shot ammunition (Sanborn n.d.). Nontoxic shot is now also available for safe use in vintage and older shotguns (Cabela's 2008). Scheuhammer and Norris (1995) found that, while nontoxic alternatives to lead shot are more expensive than lead, they represent only a 1-2% increase in the average hunter's yearly expenses. There are currently 11 types of shot approved as nontoxic by the US Fish and Wildlife Service (US Fish and Wildlife Service 2006). Recent studies have demonstrated the effectiveness of steel shot. For example, Schulz et al. (2006b) evaluated crippling rates in waterfowl prior to and following implementation of nontoxic-shot regulations in the US. They found that, after a 5-year phase-in period, crippling rates for ducks and geese were lower after nontoxic shot restrictions were implemented.

Small game hunters have already begun to switch to nontoxic shot. In Minnesota, a recent survey, conducted by the University of Minnesota, Schroeder et al. (2008) found that 40% of pheasant hunters reported they are currently voluntarily using nontoxic shot.

Nontoxic Shot Regulations

Despite numerous reports of negative impacts of lead shot on wildlife worldwide, restrictions on the use of lead shot have been minimal (Thomas 1997). Interest in nontoxic shot regulations has resulted in discussions on restricting lead ammunition and some legislation on different continents.

Thomas and Twiss (1995) felt that lead contamination of Canadian lakes, a problem for waterfowl and other birds, could be reduced by regulating production and commerce in lead shot and sinkers. They suggested regulations from Canada, the US, and Mexico on a continental scale. In Europe, Denmark and The Netherlands have banned all uses of lead shot (Thomas 1997). Broad regulatory action to restrict lead shot across Europe has been discussed by various cross-continental groups, such as the European Council, the Bonn and Bern Conservations, and by the European Union (Thomas and Owen 1996). In Australia, lead shot restrictions vary by state from a total ban on lead shot to lead shot restrictions for waterfowl hunting similar to the US or suggesting nontoxic alternatives and leaving the choice of shot up to the hunters (Green 2004).

The most significant nontoxic shot regulation in the US was the federal ban on the use of lead shot for hunting waterfowl in 1991. This ban has been demonstrated to have a positive impact on wildlife. For example, Stevenson et al. (2005) found that lead concentrations in the bones of 2 species of ducks decreased after the federal ban on lead shot for waterfowl hunting. In comparison, they noted that bone lead concentrations showed no change for woodcock, a migratory upland species not impacted by the lead shot ban for waterfowl hunting.

Case et al. (2006) surveyed US states and Canadian provinces regarding nontoxic shot regulations and found that 45% (26) of surveyed states and provinces have nontoxic shot regulations beyond federal waterfowl regulations. Nine states and provinces that have nontoxic shot regulations were discussing additional regulations. Regulations for species other than waterfowl include 15 states and provinces with regulations for dove hunting, 22 for snipe, 13 for grouse, 12 for quail, and 12 for pheasants. Currently, Minnesota's nontoxic shot regulations beyond federal waterfowl regulations are for managed dove fields, which included 4 Wildlife Management Areas for 2007.

CONCLUSIONS

There is considerable evidence that lead shot negatively impacts the health of wildlife, humans, and the environment. This manuscript includes more than 175 citations related to this problem. More than 100 species of birds (including upland birds, raptors, and waterfowl) have been weakened or killed by ingesting lead shot (Table 1). The impacts of lead shot on wildlife include decreased survival, poor body condition, behavioral changes, and impaired reproduction. Humans can be exposed to lead in game meat, even when the shot is no longer present. Meat far from the entry wound may contain high levels of lead. Children and pregnant women are especially sensitive to lead exposure. Studies in Canada, Greenland, and Russia have linked lead shot found in game animals to higher levels of lead in people who eat those game animals (Table 2).

Effective nontoxic alternatives are available at a cost comparable to lead. Some countries (Denmark, The Netherlands, and some states in Australia) have banned the use of lead shot. In the US, federal legislation prohibits use of lead shot for waterfowl hunting and many states have additional nontoxic shot regulations for hunting doves, pheasants, and other species.

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Table 1. Species documented as ingesting or poisoned by lead shot. Due to the large amount of literature for many species, only selected references are listed.

SPECIES	SCIENTIFIC NAME	REFERENCE	LOCATION
Birds			
American black duck	*Anas rubripes*	White & Stendell (1977); Zwank et al. (1985)	North America
American coot	*Fulica americana*	Jones (1939); Anderson (1975)	North America; Illinois, USA
[C]American crow	*Corvus brachyrhynchos*	NYDEC (2000) as read in Golden & Rattner (2002)	New York, USA
[B]Andean condor	*Vultur gryphus*	Locke et al. (1969)	Captive
[B]Bald eagle	*Haliaeetus leucocephalus*	Jacobson et al. (1977); Clark & Scheuhammer (2003)	North America
Black-bellied whistling duck	*Dendrocygna autumnalis*	Estabrooks (1987)	Sinaloa, Mexico
Black-necked stilt	*Himantopus mexicanus*	Hall & Fisher (1985)	Texas, USA
Black scoter	*Melanitta nigra*	Lemay et al. (1989) as translated in Brown et al. (2006)	Quebec, Canada
Black swan	*Cygnus atratus*	Koh & Harper (1988)	Australia
Black-tailed godwit	*Limosa limosa*	Pain (1990)	France
Blue-headed vireo	*Vireo solitarius*	Lewis et al. (2001)	Georgia, USA
Blue-winged teal	*Anas discors*	Bellrose (1959); Zwank et al. (1985)	North America
Brant goose	*Branta bernicla*	National Wildlife Health Laboratory (1985)	North America
Brown thrasher	*Toxostoma rufum*	Lewis et al. (2001)	Georgia, USA
Brown-headed cowbird	*Molothrus atar*	Vyas et al. (2000)	North America
Bufflehead	*Bucephala albeola*	Scanlon et al. (1980); Sandersen and Belrose (1986)	North America
[A]California condor	*Gymnogyps californianus*	Church et al. (2006); Cade (2007)	North America
California gull	*Larus californicus*	Quortrup & Shillinger (1941)	North America
Canada goose	*Branta canadensis & B. hutchinsii*	Bellrose (1959); Szymczak & Adrian (1978)	North America
Canvasback	*Aythya valisineria*	Bellrose (1959); Havera et al. (1992)	North America
Chukar	*Alectoris chukar*	Walter & Reese (2003); Larsen et al. (2006)	Oregon, USA
Cinnamon teal	*Anas cyanoptera*	Bellrose (1959)	North America
Clapper rail	*Rallus longirostris*	Jones (1939)	North America
[B]Common buzzard	*Buteo buteo*	MacDonald et al. (1983); Battaglia et al. (2005)	France; Italy
Common coot	*Fulica atra*	Mateo et al. (2000)	Spain
Common eider	*Somateria mollissima*	Franson et al. (1995); Flint et al. (1997)	Alaska, USA
Common goldeneye	*Bucephala clangula*	Bellrose (1959); Anderson (1975)	North America
Common moorhen	*Gallinula chloropus*	Jones (1939); Locke & Friend (1992)	North America
Common pochard	*Aythya ferina*	Mateo et al. (2000)	Spain
[B, A]Common raven	*Corvus corax*	Scheuhammer & Norris (1995); Craighead & Bedrosian (2008)	Canada; Wyoming, USA
Common snipe	*Gallinago gallinago*	Pain (1990); Olivier (2006)	France
Common teal	*Anas crecca*	Mateo et al. (2000)	Spain
Common wood-pigeon	*Columba palumbus*	Clausen & Wolstrop (1979)	Denmark

SPECIES	SCIENTIFIC NAME	REFERENCE	LOCATION
[C]Cooper's hawk	*Accipiter cooperii*	Martin & Barrett (2001)	Canada
Dark-eyed junco	*Junco hyemalis*	Vyas et al. (2000)	North America
Dunlin	*Calidris alpina*	Kaiser et al. (1980)	British Columbia, Canada
[B]Egyptian vulture	*Neophron percnopterus*	Donazar et al. (2002)	Canary Islands
[B]Eurasian eagle owl	*Bubo bubo*	Mateo et al. (2003)	Spain
[B]Eurasian griffon	*Gyps fulvus*	Mateo et al. (2003); Garcia-Fernandez et al. (2005)	Spain
[B]Eurasian sparrowhawk	*Accipiter nisus*	MacDonald et al. (1983)	France
[C,B]European honey-buzzard	*Pernis apivorus*	Lumeij (1985)	The Netherlands
Gadwall	*Anas strepera*	Bellrose (1959); Mateo et al. (2000)	North America; Spain
Glaucous-winged gull	*Larus glaucescens*	National Wildlife Health Laboratory (1985)	North America
[A, B]Golden eagle	*Aquila chrysaetos*	Craig et al.(1990); Kenntner et al. (2007)	Idaho, USA; Switzerland
[C]Gray-headed woodpecker	*Picus canus*	Mörner and Petersson 1999	Sweden
Greylag goose	*Anser anser*	Mudge (1983); DeFrancisco (2003)	England; Spain
[B]Great horned owl	*Bubo virginianus*	Clark & Scheuhammer (2003)	Canada
Greater & Carribean flamingo	*Pheonicopterus ruber*	Schmitz et al. (1990); Mateo et al. (1997)	Yucatan, Mexico; Spain
Greater scaup	*Aythya marila*	Bellrose (1959)	North America
Greater white-fronted goose	*Anser albifrons*	Zwank et al. (1985)	Louisiana, USA
Green-winged teal	*Anas carolinensis*	Bellrose (1959); Zwank et al. (1985)	North America
Hardhead (duck)	*Aythya australis*	Baxter et al. (1998)	Australia
Herring gull	*Larus argentatus*	National Wildlife Health Laboratory (1985)	North America
Hungarian partridge	*Perdix perdix*	Keymer & Stebbings (1987); Kreager et al. (2007)	England; Canada
Jack Snipe	*Lymnocryptes minimus*	Olivier (2006)	France
Japanese quail	*Coturnix coturnix*	Yamamoto et al. (1993)	Japan
King rail	*Rallus elegans*	Jones (1939)	North America
[B]King vulture	*Sarcorhampus papa*	Decker et al. (1979)	Captive
[B]Laggar falcon	*Falco jugger*	MacDonald et al. (1983)	Captive
Lesser scaup	*Aythya affinis*	Bellrose (1959); Havera et al. (1992)	North America
Long billed dowitcher	*Limnodromus scolopaceus*	Hall & Fisher (1985)	Texas, USA
[B]Long-eared owl	*Asio otus*	Brinzal (1996)	Spain
Long-tailed duck	*Clangula hyemalis*	Flint et al. (1997); Skerratt et al. (2005)	Alaska, USA; North America
Magpie goose	*Anseranas semipalmata*	Harper & Hindmarsh (1990); Whitehead & Tschirner (1991)	Australia
Mallard	*Anas platrhynchos*	Bellrose (1959), Mateo et al. (2000)	North America; Spain
Maned duck	*Chenonetta jubata*	Kingsford et al. (1994)	Australia
Marbled godwit	*Limosa fedoa*	Hall & Fisher (1985); Locke et al. (1991)	Texas, USA; North America
Marbled teal	*Marmaronetta angustirostris*	Mateo et al. (2001); Svanberg et al. (2006)	Spain
Merganser	*Mergus spp.*	Bellrose (1959); Skerratt et al. (2005)	North America

SPECIES	SCIENTIFIC NAME	REFERENCE	LOCATION
Middendorff's bean goose	*Anser fabalis middendorffii*	Chiba et al. (1999)	Japan
Mottled duck	*Anas fulvigula*	Merendino et al. (2005)	Texas, USA
Mourning dove	*Zenaida macroura*	Lewis & Legler (1968); Schulz et al. (2006a)	North America
Mute swan	*Cygnus olor*	Bowen & Petrie (2007)	Great Lakes, Canada
Northern bobwhite quail	*Colinus virginianus*	Westemeier (1966); Keel et al. (2002)	Illinois, USA
[A, B]Northern goshawk	*Accipiter gentillis*	Martin & Barrett (2001); Pain & Amiard-Triquet (1993)	Canada; France
Northern pintail	*Anas acuta*	Bellrose (1959); Mateo et al. (2000)	North America; Spain
Northern shoveler	*Anas clypeata*	Bellrose (1959); Mateo et al. (2000)	North America; Spain
[C]Oriental white-backed vulture	*Gyps bengalensis*	Oaks et al. (2004)	Pakistan
Pacific black duck	*Anas superciliosa*	Baxter et al. (1998)	Australia
Pacific loon	*Gavia pacifica*	Wilson et al. (2004)	Alaska, USA
[B]Peregrine falcon	*Falco peregrinus*	MacDonald et al. (1983); Pain et al. (1994)	Captive; England
Pink-footed goose	*Anser brachyrhynchus*	Mudge (1983)	England
[B]Prairie falcon	*Falco mexicanus*	Redig (1980); MacDonald et al. (1983)	Captive
[B]Red kite	*Milvus milvus*	Mateo et al. (2003); Pain et al. (2007)	England
Red tailed hawk	*Buteo jamaicensis*	Sikarskie (1977); Clark & Scheuhammer (2003)	Canada
Red-crested pochard	*Netta rufina*	Mateo et al. (2000)	Spain
Red-legged partridge	*Alectoris rufa*	Butler (2005)	England
Redhead	*Aythya americana*	Bellrose (1959); Zwank et al. (1985)	North America
Ring-necked duck	*Aythya collaris*	Anderson (1975); Havera et al. (1992)	North America
Ring-necked pheasant	*Phasianus colchicus*	Hunter & Rosen (1965); Butler et al. (2005)	North America; England
Rock dove	*Columba livia*	DeMent et al. (1987)	New York, USA
Rough-legged hawk	*Buteo lagopus*	Locke & Friend (1992)	North America
Ruddy duck	*Oxyura jamaicensis*	Perry & Artmann (1979); Sanderson & Bellrose (1986)	North America
Ruffed grouse	*Bonasa umbellus*	Rodrigue et al. (2005); Kendall et al. (1984)	Virginia, USA; Canada
Sandhill crane	*Grus canadensis*	Windingstad et al. (1984); Franson & Hereford (1994)	North America
Scaled quail	*Callipepla squamata*	Campbell (1950); Best et al. (1992)	New Mexico, USA
Snow goose	*Anser caerulescens*	Bellrose (1959); Zwank et al. (1985)	North America
[A]Snowy owl	*Nyctea scandiaca*	MacDonald et al. (1983)	Captive
Sora rail	*Porzana carolina*	Artmann & Martin (1975); Stendell et al. (1980)	Maryland, USA
Spanish Imperial eagle	*Aquila adalberti*	Mateo et al. (2000); Pain et al. (2005)	Spain
Spectacled eider	*Somateria fischeri*	Franson et al. (1995); Grand et al. (1998)	Alaska, USA
[A]Steller's sea eagle	*Haliaeetus pelagicus*	Kurosawa (2000)	Japan
Trumpeter swan	*Cygnus buccinator*	Bellrose (1959); Blus (1994)	North America
Tufted duck	*Aytha fuligula*	Mudge (1983); DeFrancisco et al. (2003)	England; Spain
Tundra swan	*Cygnus columbianus*	Trainer & Hunt (1965); Blus (1994)	Wisconsin, USA; North America

SPECIES	SCIENTIFIC NAME	REFERENCE	LOCATION
[B]Turkey vulture	*Cathartes aura*	Clark & Scheuhammer (2003); Martin et al. (2008)	North America
Virginia rail	*Rallus limicola*	Jones (1939)	North America
[B]Western marsh-harrier	*Circus aeruginosus*	Pain & Amiard-Triquet (1993); Mateo et al. (1999)	France; Spain
[C]White-backed woodpecker	*Dendrocopus leucotos*	Mörner and Petersson (1999)	Sweden
White-faced ibis	*Plegadis chihi*	Hall & Fisher (1985)	Texas, USA
White-fronted goose	*Anser albifrons*	Bellrose (1959); Ochiai et al. (1993)	North America; Japan
White-headed duck	*Oxyura leucocephala*	Mateo et al. (2001); Svanberg et al. (2006)	Spain
White pekin (wild)	*Anas platyrhychos*	Schwab & Padgett (1988)	Virginia, USA
[A]White-tailed eagle	*Haliaeetus albicilla*	Kurosawa (2000); Krone et al. (2004)	Japan; Greenland
White-throated sparrow	*Zonotrichia albicollis*	Vyas et al. (2000)	North America
Whooper swan	*Cygnus cygnus*	Ochiai et al. (1992); Honda et al. (2007)	Japan
Whooping crane	*Grus americana*	Hall & Fisher (1985)	North America
Wigeon	*Anas americana*	Zwank et al. (1985); Mateo et al. (2000)	Louisiana, USA; Spain
Wild turkey	*Meleagris gallopavo*	Stone & Butkas (1972); Kreager et al. (2007)	New York, USA; Canada
Wood duck	*Aix sponsa*	Bellrose (1959); Sanderson & Bellrose (1986)	North America
[B]Woodcock	*Scolopax minor*	Scheuhammer et al. (2003)	Canada
Yellow-rumped warbler	*Dendroica coronata*	Lewis et al. (2001)	Georgia, USA
Mammals			
Gray squirrel	*Sciurus carolinensis*	Lewis et al. (2001)	Georgia, USA
[B]Domestic cattle		Rice et al. (1987)	
White tailed deer	*Odocoileus virginianus*	Lewis et al. (2001)	Georgia, USA
Reptiles			
[A, B]American alligator	*Alligator mississippiensis*	Camus et al. (1998); Lance et al. (2006)	North America; Captive
[B]Crocodile	*Crocodylus porosus*	Hammerton et al. (2003); Orlic et al. (2003)	North America; Australia

[A] Evidence of secondary poisoning from lead bullets.
[B] Evidence of secondary poisoning from lead shot.
[C] Source of lead unknown, lead shot suspected.

Table 2. Selected literature regarding elevated lead levels in humans consuming game meat harvested with lead shot.

Author	Country	Findings
Bjerregaard et al. 2004	Greenland	Blood lead adjusted for age and sex was found to be associated with the reported consumption of sea birds.
Breurec et al. 1998	Not reported	Patient diagnosed with adult lead poisoning by ingestion of game birds with small lead shots.
Dewaily et al. 2000	Canada, Artic	Ingestion of lead shot/fragments in game meat may be responsible for higher lead levels found in Inuit new-borns. Lead isotopes of shotgun cartridges were similar to those of Inuit new-borns.
Dewailly et al. 2001	Quebec, Canada	Evaluated 492 blood levels of lead and mercury in Inuit adults, revealed that smoking, age, and consumption of waterfowl were associated with lead concentrations ($r^2 = .30$, $p < .001$).
Guitart et al. 2002	Spain	Approximately 30,000 waterfowl hunters and their families, especially children, are at risk of secondary lead poisoning from lead poisoned birds in Spain.
Hanning et al. 2003	Canada	Traditional animal food intake, especially wild fowl, correlated significantly with umbilical cord blood lead, and reflected the legacy of using lead-containing ammunition.
Johansen et al. 2001	Ontario, Canada	Breast meat lead values in birds killed with lead shot were 10 times higher than birds not killed with lead shot. Shot is a significant source of lead in many people in Greenland.
Johansen et al. 2004	Greenland	Lead intake of Greenland bird eaters can largely exceed the tolerable lead intake guidelines, and the shot is a more important source of lead than previously estimated.
Johansen et al. 2006	Greenland	Found clear relationship pointing to lead shot as the dominating lead source to people in Greenland.
Levesque et al. 2003	Quebec, Canada	Lead from game hunting was a major source of human exposure to lead. Calls for international ban on lead shotgun ammunition.
Mateo et al. 2007	Spain	Consumption of half a pickled quail/week with embedded shot may cause the provisional tolerable weekly intake of lead by the Spanish consumer to be exceeded.
Odland et al. 1999	Russia	Suggests lead shot as the main source of lead in population in the Kola Peninsula, Russia.
Smith and Rea 1995	Canada	Elevated lead blood levels in children probably due to consumption of birds containing lead shot, suggest use of alternative shot.
Trebel and Thompson 2002	Canada	Young child exhibited elevated blood lead levels after ingesting spent air rifle pellets.
Tsuji et al. 1999	Ontario, Canada	Consumption of any game species harvested with lead shot risks exposure by way of ingestion of tissue-embedded lead pellets and fragments.