The Wildlife Society

Sources and Implications of Lead Ammunition and Fishing Tackle on Natural Resources

Technical Review 08-01
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The Wildlife Society
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Technical Review Committee on Lead in the Environment

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Foreword

Presidents of The Wildlife Society and the American Fisheries Society occasionally appoint ad hoc committees to study and report on select conservation issues. These reports ordinarily appear as either a Technical Review or a Position Statement. Review papers present technical information, and position statements are based on these reviews. Preliminary versions of position statements are published for review and comment by Society members. Following the comment period, revision, and leadership approval, the statements are published as official positions of The Wildlife Society and the American Fisheries Society.

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Charge to the Committee

Conduct an overview of the technical literature addressing (1) sources of lead that originate from hunting, shooting sports, and fishing activities, (2) the hazard and risk that lead from these activities pose to natural resources, and (3) the management implications for fish and wildlife professionals and policy makers. This document may be used to prepare policy statements by the American Fisheries Society and The Wildlife Society on the hazards of lead-based ammunition and fishing tackle.

Disclaimer

The opinions and views communicated in this document are not necessarily those of the government agencies (U.S. Geological Survey, Great Lakes Fishery Commission, New York State Department of Environmental Conservation, Minnesota Department of Natural Resources) with which some of the authors are affiliated.

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SYNOPSIS

A technical review of lead sources that originate from hunting, shooting sports, and fishing activities was undertaken by the American Fisheries Society and The Wildlife Society.

Lead is a naturally occurring metal in the environment. In biological systems, it is a nonessential metal with no functional or beneficial role at the molecular and cellular levels of organization. Its use in ammunition and fishing tackle dates back hundreds to thousands of years, respectively. Realization of the hazards of lead shot to waterfowl can be traced to the late 1870s, while the hazards of lead fishing sinkers to birds became well recognized in the 1970s with lead poisoning of swans in Britain. By the 1980s, Britain and some jurisdictions within the United States and Canada began placing restrictions on the use of lead shot and fishing sinkers.

Large quantities of lead ammunition and fishing tackle are produced annually. Estimates of lost fishing tackle are much less than the quantity of spent ammunition at waterfowl hunting areas and target ranges. Nonetheless, lost fishing tackle poses a toxicological threat to some waterbird species.

Lead from spent ammunition and lost fishing tackle is not readily released into aquatic and terrestrial systems. Lead artifacts can be relatively stable and intact for decades to centuries. Nevertheless, under some environmental conditions (e.g., soft acidic water, acidic soil), lead can weather and be mobilized from such artifacts, yielding free dissolved lead, precipitates, and complex species with inorganic and organic matter. Dissolved, complex species and particulate lead can be adsorbed onto or incorporated into the surface of plants. In soil and sediment, various forms of lead can become adsorbed, taken up by tissues, and entrained in the digestive tract of invertebrates. Lead that is released from artifacts can evoke a range of biochemical, physiological, and behavioral effects in some species and life stages of invertebrates, fish, amphibians, and terrestrial vertebrates and can exceed criteria for protecting some biota (e.g., water quality criteria for invertebrates). Lead in soil, adsorbed or incorporated into food items, and fragments emanating from shooting ranges can ultimately result in elevated tissue concentrations in birds and small mammals and cause hematological changes and pathological lesions. For anthropogenic activities such as mining and smelting, lead concentrated in sediments (lead in silt, fine particulates, and pore water) can also be lethal to aquatic invertebrates, fish and waterbirds.

There is evidence documenting ingestion of spent shot and bullets, lost fishing sinkers and tackle, and related fragments by reptiles, birds, and mammals. Ingestion of some of these elemental lead artifacts can be accompanied by a range of effects (molecular to behavioral) in individuals and potentially even population-level consequences in some species (e.g., waterfowl, eagles, condors). Fish can ingest sinkers, jigs, and hooks, but unlike higher vertebrates, mortality seems to be related to injury, blood loss, exposure to air, and exhaustion rather than lead toxicosis. There are no data demonstrating the ingestion of spent shot or bullets by invertebrates, fish, or amphibians. Numerous reports in the medical literature describe accidental or purposeful ingestion of lead fragments in humans. Lead shot and sinkers can be retained in the appendix and digestive tract, and in some instances (particularly in children) lead artifacts are surgically removed to minimize exposure and adverse effects.

Lead poisoning related to spent ammunition and lost fishing tackle has been most studied in avian species, and at least two studies indicate that the ban on the use of lead shot for hunting waterfowl and coots in North America has been successful in reducing lead exposure in waterfowl. Nonetheless, other species including upland game (e.g., doves, quail) and scavengers (e.g., vultures, eagles) continue to be exposed, and in some instances populations (e.g., California condor) may be at risk. Accordingly, many states have instituted restrictions on the use of lead ammunition to minimize effects on upland game birds and scavengers. The hazard of ingested lead sinkers and fishing tackle is well-documented in swans and loons, and restrictions on the sale and use of lead weights have been instituted in the United Kingdom, Canada, numerous other countries, and several states in the United States to minimize effects on these and other species. There are only limited data on lead ingestion at shooting ranges by terrestrial vertebrates, and reproductive rates and estimation of population parameters of wildlife at these sites have not been adequately investigated. The hazards of spent ammunition and lost fishing gear to fish populations are unknown but suspected to be minimal.

There has been an extensive effort in the development, efficacy testing, and regulation of alternatives to lead shot for hunting waterfowl and coots. Environmentally safe alternatives have been approved and currently are available in North America and elsewhere. Environmentally safe (non-lead) alternatives for some other types of hunting (e.g., shot for some upland birds, bullets for large game) and for target shooting are more recent developments, and use of these alternatives is not widespread. Many substitutes for lead fishing tackle have entered the marketplace in recent years. Some, but not all, lead-substitute metals in fishing tackle have been previously deemed safe if ingested by waterfowl and some other birds and mammals. Less is known about the potential hazard of these alternatives to lower vertebrates.

The overall understanding of the hazards of lead used in shot, bullets, and fishing tackle would benefit from research generating toxicological and environmental chemistry data, and monitoring and modeling of exposure and effects. Those of highest priority include (1) broad scale monitoring on the incidence of lead poisoning in wildlife in countries where the extent of the problem is poorly documented or unknown, (2) data on the prevalence of lead poisoning related to fishing tackle in reptiles and aquatic birds, (3) information on the weathering, dissolution, and long-term fate of lead fragments, and bioavailability of lead in various aquatic and terrestrial ecosystems, (4) the hazards of spent ammunition and mobilized lead to wildlife at or near shooting ranges, and (5) evaluation of the results of regulations restricting the use of lead ammunition and fishing tackle on exposure and health of biota in various ecosystems.

If the American Fisheries Society or The Wildlife Society seek to prepare position statements on the continued use of lead in ammunition and fishing tackle, there are at least three position options. Namely, the introduction of lead into the environment from hunting, shooting sports, and fishing activities (1) is adequately regulated and the toxicological consequences of ingestion of lead are currently considered acceptable, (2) could be restricted in locations where lead poses an unacceptable hazard to biota and their supporting habitat, or (3) could be phased out with a goal of complete elimination. The leadership of both the American Fisheries Society and The Wildlife Society could interact with various entities to disseminate information about hazards and toxic effects of lead ammunition and tackle, as well as the availability and ecological benefits of safe alternatives.

INTRODUCTION

Lead (Pb) is a nonessential heavy metal with no known functional or beneficial role in biological systems at the molecular and cellular levels of organization. It had numerous uses in ancient Egypt, and its biocidal properties were well known at that time (Eisler 2000, Hernberg 2000). The presence of lead in water pipes, cosmetics, and pottery, and its use in wine preparation, has been hypothesized as contributing factors to the fall of the Roman Empire (Eisler 2000, Hernberg 2000, Pattee and Pain 2003, Needleman 2004). The use of lead fishing net sinkers dates back to the Bronze age (Pulak 1988, Galili et al 2002), and the appearance of lead shot and bullets parallels the development of gunpowder and firearms in the 14th century (Tunis 1954).

Lead is one of the easiest metals to mine and smelt (Pattee and Pain 2003). Use of lead increased dramatically during the Industrial Revolution, and was widely used during the 1900s as a gasoline additive. Anthropogenic emissions of lead in urban centers have resulted in its global distribution. In remote polar regions, lead concentrations in ice layers are two orders of magnitude greater than in prehistoric times (Pattee and Pain 2003). On a worldwide basis, approximately 3.6 million metric tons of lead are refined annually and major uses currently include storage batteries, cable sheathing, pigments, and chemicals, as well as alloys and ammunition (Eisler 2000).

The adverse health effects evoked by lead exposure have been long recognized. Lead-induced encephalopathy and behavioral changes have been described in lead trades-workers and miners for centuries (Eisler 2000). In colonial times, the correspondence of Benjamin Franklin mentions adverse effects of lead on human health, and during the 20th century it was one of the most highly studied metals from a toxicological standpoint (Pattee and Pain 2003). The neurological, behavioral, and developmental effects of lead are well documented in children (Goyer 1996). Monitoring of lead exposure in children is commonplace in many cities in North America and elsewhere, due to the higher sensitivity of infants and juveniles to lead poisoning. Lead evokes its toxicity in multiple organ systems. Perhaps best known are its hematological effects including lead-induced anemia due to reduced erythrocyte lifespan and impairment of heme synthesis caused by the inhibition of delta-aminolevulinc acid dehydratase (ALAD) and other enzymes (heme oxidase, ferrochelatase, coproporphyrinogen oxidase, aminolevulinic acid synthetase) (Goyer 1996). Neurological effects include impairment of cell-to-cell connections, neuronal circuitry, and synaptic transmission, as well as central and peripheral neuropathy (Goyer 1996). Lead exposure can result in acute (reversible) and chronic (irreversible) nephrotoxicity, characterized by structural (e.g., inclusion bodies in tubular cells, swelling of mitochondria) and functional (e.g., glycosuria, impaired ion transport) changes (Goyer 1996). Lead exposure can result in immunosuppression, with effects in mammals including increased susceptibility (reduced resistance) to various bacterial and viral diseases, and altered host resistance (Franson 1986, Luster and Rosenthal 1993, Fabri and De Lorenzo 1995). Lead may cause hypertension, reproductive and endocrine system toxicity, and is known to be a carcinogen in rodents (Goyer 1996).

In comparison to the lengthy history of lead toxicity in humans, recognition of the hazard of ingested lead shot and fishing sinkers to wildlife is a relatively recent occurrence. Incidents of lead poisoning of waterfowl at hunting sites in Texas and North Carolina made their way into the popular press and scientific literature in the late 1800s (Sanderson and Bellrose 1986). However, it was not until the publication of the classic monograph by Bellrose (1959), *Lead Poisoning as a Mortality Factor in Waterfowl Populations*, that the widespread hazard of spent lead shot was fully appreciated. (Figure 1)

Figure 1. Frank Bellrose and James S. Jordan conducting fluoroscopic examination of a duck to detect the presence of lead shot. (courtesy of the Illinois Natural History Survey)

In 1986, new federal regulations in the United States resulted in a five-year phase-out of the use of lead shot in hunting waterfowl and American coots (*Fulica americana*) after intoxicated or crippled waterfowl were found to be a secondary poisoning source of the then-endangered bald eagle (*Haliaeetus leucocephalus*) (Griffin et al. 1980, Pattee and Hennes 1983). In Canada, a similar federal regulation prohibiting the use of lead shot for the purpose of hunting all migratory game birds (exempting a few upland species) came into effect in 1999. Lead poisoning of hunted upland birds by spent shot, and accidental poisoning of raptors by shot and bullet fragments has also received considerable attention (Kendall et al. 1996, Fisher et al. 2006). Concern about lead toxicity from fishing weights emerged as an important issue in the 1970s as mute swan (*Cygnus olor*) populations declined in Britain (Sears 1988). This eventually resulted in the banning of most lead fishing sinkers in Britain in 1986 (Pattee and Pain 2003). The hazard of fishing sinkers and tackle to common loons (*Gavia immer*) was subsequently reported in North America (Pokras and Chaffel 1992, Scheuhammer and Norris 1995, Stone and Okoniewski 2001, Sidor et al. 2003).

This technical review focuses primarily on the hazards to fish and wildlife of visible lead particulates, fragments, spent shot and ammunition, and fishing tackle introduced into the environment. Some discussion of the impacts of dissolved lead, inorganic and organic lead compounds, complexes and particulates, as well as effects of lead on humans will be included to provide a more comprehensive overview.

SOURCES AND ESTIMATED QUANTITIES OF LEAD FROM HUNTING, SHOOTING SPORTS, AND FISHING ACTIVITIES

Hunting and Shooting Sports

It generally is accepted that the density of spent shot in a field or wetland is related to hunting intensity. In waterfowl hunting areas, shot/hectare has been reported to range from 125,970 (Bellrose 1959) to 5,000,000 (Pain 1992). Historically, certain scenarios (waterfowl hunting from fixed position blinds or pits) resulted in the accumulation of shot in the same location year after year, which can pose a serious localized hazard. Prior to the banning of lead shot for hunting waterfowl and coots, an estimated 2,721 metric tons of shot were deposited in United States wetlands annually (Pain 1992). Others have demonstrated that annual shot deposition in upland fields may be as much as one million shot/hectare (Schulz et al. 2002). Despite the lead shot ban for hunting waterfowl, large quantities of spent lead ammunition currently are deposited in the environment through a variety of other hunting (e.g., upland species, big game, furbearers) and predator control activities (Scheuhammer and Norris 1995, Schulz et al. 2002). Furthermore, shot, bullets, and bullet fragments in tissue or entrails of wounded or moribund animals recently has been recognized as a serious hazard to many avian species (Janssen et al. 1986, Hunt et al. 2006, Knopper et al. 2006). A global estimate of lead ammunition production in 2000 was 194,820 metric tons, accounting for 3% of the lead with consumer end uses (Nordic Council of Ministers 2003).

Sources of spent lead also include shooting sports (i.e., target shooting, trap, and skeet), which are popular recreational activities in the United States and elsewhere, as well as firearms training for home/national defense and law enforcement activities. According to estimates of the National Shooting Sports Foundation (NSSF), millions of Americans participate annually at roughly 9,000 outdoor non-military shooting ranges in the United States (United States Environmental Protection Agency 2001, NSSF 2007). The number of sport shooting ranges in Canada is not accurately known (Scheuhammer and Norris 1995), although a survey in Ontario documented 211 ranges (Darling and Thomas 2003). Because of the frequency of use and the age of some shooting ranges, substantial amounts of lead from shells and cartridges have accumulated at and near many of these sites. The United States Environmental Protection Agency (U.S. EPA) estimates that roughly 72,600 metric tons of lead shot and bullets are deposited in the U.S. environment each year at outdoor shooting ranges (U.S. EPA 2001). Reported lead accumulation rates on individual shooting ranges are between 1.4 metric tons/year (Craig et al. 2002) to greater than 15 metric tons/year (Tanskanen 1991). (Figures 2 and 3) Craig et al. (2002) found that lead is irregularly distributed at shooting ranges because of the use of stationary targets, the general trajectory of

Figure 2. Drifts of spent lead shot in the fall zone of a shooting. (courtesy of Daniel J. Soeder, U.S. Geological Survey).

Figure 3. Lead shot with white oxide or carbonate coatings on surface in the fall zone at the Broadkiln Sportsman's Club (24 mm coin for scale). (courtesy of Daniel J. Soeder, U.S. Geological Survey).

launched clay targets and the congregation of shooters. This results in large concentrations of spent lead shot and bullets on relatively small parcels of land. Clustering of lead shot occurred at distances of approximately 28, 80, and 180 m, and reached maximum concentrations of more than 5,000 g/m^2. Other reports have documented up to 17,000 g/m^2 (reviewed in Darling and Thomas 2003). Significant amounts of fine particulate lead occur close to the shooting stations. Soil lead concentrations of greater than 1,000 mg/kg were reported for shooting ranges in Denmark, England, Finland, New Zealand, Sweden, Switzerland, and the United States (Jorgensen and Willems 1987, Tanskanen et al. 1991, Mellor and McCartney 1994, Lin et al. 1995, Rooney et al. 1999, Craig et al. 2002, Knechtenhofer et al. 2003).

The availability of spent lead shot in a terrestrial setting is a function of the depth of fragments in the soil. The depth of lead fragments in soil is also influenced by land management practices, most notably cultivation (Fredrickson et al. 1977, Kendall et al. 1996). Environmental persistence of shot and bullet fragments can be quite protracted, ranging from many decades to hundreds of years (Jorgensen and Willems 1987).

In aquatic settings, spent lead availability is affected by water depth and the depth of buried shot within the sediment. Several investigations have demonstrated that shot accumulates near the surface of sediments, and thus the total number of lead shot available to waterfowl increases over time (Pain 1992).

Fishing

Lead has been associated with fishing activities for millennia (Nriagu 1983). Lead in the form of fishing lures, sinkers, lead core fishing line, downrigger weights, and weights on a wide variety of fishing traps and nets can be introduced accidentally or intentionally into the aquatic environment when commercial fishers or recreational anglers lose fishing gear. Accurate quantitative information about the amount of lead fishing weights, jigs, and downriggers produced, purchased, and subsequently lost in the aquatic environment through recreational and commercial activities is not available. An approximation can be made from the amount of lead used by fishing tackle manufacturers and the reported quantity of lead fishing tackle sold by wholesalers. Estimates of the amount of lead sold annually in Europe as fishing tackle are between 2,000 and 4,000 metric tons (European Commission Enterprise Directorate-General 2004). Using the annual expenditure estimate provided by the U.S. EPA, Scheuhammer et al. (2003b) approximated that 3,977 metric tons of lead fishing sinkers are sold in the United States annually. Scheuhammer et al. (2003b) also estimated that approximately 559 metric tons of lead sinkers are sold annually in Canada. This estimate was an extrapolation from the average amount of money spent annually by the average angler (CAD$3.25 or US$2.32, dollar conversion based on average 2003 monthly exchange rate) to purchase sinkers. Furthermore, Scheuhammer et al. (2003b) assumed that most sinkers are purchased to replace those lost while fishing, suggesting that the estimated mass of sinkers purchased each year was also a reasonable estimate of the mass of lead lost to the environment through recreational angling. However, Radomski et al. (2006) stated that many anglers continue to acquire additional tackle, including sinkers, even when they have a surplus of tackle. Thus, estimates of the total amount of lead sold annually within each nation provide at best a very rough approximation of the potential maximum amount of lead lost in the aquatic environment that may be available for uptake by aquatic species.

Only a few studies attempted to obtain a more direct representation of the amount of lead fishing sinkers introduced into the aquatic environment. In two studies summarized by the European Commission-Enterprise Directorate-General (2004), it was estimated that approximately 1,000 to 1,500 metric tons of lead sinkers were lost annually in Poland; whereas Annema et al. (1995 cited in European Commission-Enterprise Directorate-General 2004) estimated that approximately 28 metric tons of lead from fishing sinkers were introduced into surface waters in the Netherlands.

A study in the United Kingdom reported that anglers lose or discard two to three lead sinkers/angling day (Bell et al. 1985). Duerr (1999) interviewed 850 anglers (mostly shore anglers) during 1996 and 1997 from 14 sites throughout the United States known to have elevated loon mortality related to lead fishing weight ingestion. Duerr (1999) found that anglers on average reported losing 0.18 sinkers/hour, 0.23 hooks and lures/hour, and 2% reported releasing or losing a fish with fishing tackle still attached. Radomski et al. (2006) conducted interviews with more than 6,000 anglers on five Minnesota lakes during 2004 (98% of whom were boat anglers) and found that angler-reported loss rates were low. Among the 3% to 13% of anglers that reported losing terminal fishing tackle, the mean loss rates were 0.0127 lures/hour, 0.0081 large sinkers/hour, 0.0057 split shot sinkers/hour, 0.0247 jigs/hour, and 0.0257 hooks/hour, constituting approximately one metric ton of lead (Radomski et al. 2006).

A number of studies assessed the amount of lead fishing tackle found along shorelines in the United States and the United Kingdom. Duerr (1999) used visual observation, as well as a metal detector and a logistic regression model (Duerr and DeStefano 1999) to estimate that there were up to 0.01 sinkers/m^2 in areas of low angling pressure but up to 0.47 sinkers/m^2 in areas of high angling pressure along United States shorelines. In the United Kingdom, Sears (1988) estimated 0.84 to 16.3 sinkers/m^2 in the Thames River and along its shoreline, and Cryer et al. (1987) estimated 24 to 190 sinkers/m^2 along the shoreline in South Wales. These estimates reveal that the amount of lead fishing sinkers introduced into aquatic ecosystems varies greatly depending on the intensity of fishing pressure, the type of aquatic habitat (e.g., rocky or heavily vegetated that may increase gear breakage and loss) and angler skill. Nevertheless, estimates of lead fishing weights produced and estimates of lost or discarded fishing weights in some geographic areas indicate that fishing activities can introduce substantial amounts of lead into the aquatic environment.

BIOGEOCHEMISTRY AND PHYSICOCHEMICAL PROPERTIES OF LEAD

The properties of lead are well known and will only be briefly addressed. Elemental lead is an ubiquitous bluish-gray soft metal (molecular weight 207.19, atomic number 82) with a melting point of 327.5°C and a density of 11.34 g/cm^3. Lead exists in four valance states (0, +1, +2 and +4), and in the environment it occurs principally in the +2 and +4 states. Lead has four stable isotopes and 24 radioisotopes. In natural systems lead can exist in free ionic forms, in numerous compounds, and as complex species with other inorganic or organic substances (ATSDR 2007). Metallic lead has low solubility in hard basic water (30 µg/L) and has greater solubility in soft acidic water (up to 500 µg/L), and some salts are far more soluble (lead nitrate, 565 g/L).

Atmospheric deposition is the major input of lead in the biogeochemical cycle. The greatest inputs are onto the forest floor with turnover times as great as 5,000 years, and release of lead to mineral soil and surface water has been documented (Johnson et al. 1995). Most lead entering natural waters is precipitated to the sediment bed (Eisler 2000).

The dissolution of lead objects and fragments in environmental media is affected by geochemical processes including oxidation/reduction, precipitation/dissolution, absorption/desorption, and complexation/chelation (SAAMI 1996). All of the elemental lead in a bullet, shot pellet, sinker, or other fragment eventually will be transformed into particulates, ionic species, compounds, or complexes that are dispersed in the environment. The ratio of surface area to mass is a significant factor affecting dissolution. Annual dissolution rates of lead fragments, however, generally are low.

Atmospheric conditions can weather fragments of metallic lead into more soluble and mobile forms (SAAMI 1996). Oxidation rates and product formation is highly variable among environmental media. Once oxidized, lead can be precipitated as hydroxides, sulfates and sulfides, carbonates, and phosphates. Small fragments that result from weathering are the most mobile.

Lead in soil is most often present as galena (PbS), cerrusite ($PbCO3$), and anglesite ($PbSO4$) (Scheuhammer et al. in press). Lead in sediment (silt, finer-sized particles, pore water) is associated with organic matter, mineral sulfides, carbonates, and oxide coating. Lead mobility in soils and sediment is enhanced as pH decreases. Lead mobility is also affected by soil redox state potential, available anions (e.g., carbonate, phosphate, sulfate) and cation exchange capacity (SAAMI 1996). High annual precipitation rates and the absence of organic material in soil enhance lead mobility (Scheuhammer and Norris 1995). Solid phase organic carbon can enhance lead adsorption, while dissolved organic carbon can increase lead mobility. With increasing acidity, soil organic matter can dissolve and enlarge the pool of organic ligands in soil solution that mobilize lead. In general, neutral or slightly alkaline conditions result in low mobility. Complexation and chelation may increase physical movement over time but have little effect on bioavailability.

In aquatic systems, very limited quantities of free lead (Pb^{+2}) are dissolved in water (Scheuhammer et al. in press). Most of the lead in aquatic systems is associated with or adsorbed onto particulates. In solution, lead salts dissociate and free lead can form stable complexes with carbonates, hydrides, and chlorides. In general, most lead entering aquatic systems precipitates (phosphates, sulfides, carbonates, hydroxides), thereby reducing bioavailability in sediment and water. Surface water runoff can result in transport of small lead particles to adjacent water bodies (SAAMI 1996). Concentrations of dissolved lead in surface and ground water are effectively controlled by adsorption to organic iron, manganese oxyhydroxides, clays, carbonates, and sulfides.

Fate of Elemental Lead in Terrestrial Environments

The concentration and mobility of lead in soils and sediment at shooting ranges has received considerable attention during the past 20 years. When shot or a bullet impacts its target or soil berm, it may penetrate, agglomerate, fragment, smear, or ricochet (SAAMI 1996). Most of the mass consists of the intact projectile or large fragments of the bullet or shot. At one time, it was assumed that spent ammunition was environmentally stable and inert. Spent pellets or fragments of elemental lead at outdoor shooting ranges weather over time and have visible white, gray, or brown crusts composed of cerussite, hydrocerussite [Pb(CO3)2(OH)2], and anglesite (Jorgensen and Willems 1987, Lin 1996, Chen et al. 2002). Aerobic and acidic conditions enhance pellet breakdown, while anaerobic and alkaline conditions retard dissolution (Scheuhammer and Norris 1995). Notably, soil pH for 17 of 67 shooting ranges in Ontario were reported to be slightly acidic (pH <6), and several of these had soils with poor buffering capacity (Darling and Thomas 2003).

Jorgensen and Willems (1987) examined the dissolution of lead from shot in several different soil types at three shooting ranges in Denmark. Their data suggest that one-half of a metallic lead pellet would be transformed to other lead compounds and released into the soil within 40 to 70 years, and that the entire lead shot would be completely transformed in 100 to 300 years. Mechanical disturbance of the soil (e.g., cultivation) can enhance the transformation rate as can abrasion of the projectile by berm soil (Hardison et al. 2004). Similar breakdown rates of lead shot have been reported from studies in Finland and the United States (Scheuhammer and Norris 1995). At shooting ranges in Sweden, the amount of lead bound to mineral or organic components in the soil ranged from 0% to 92%, depending upon a combination of factors including soil pH, organic matter, cation exchange capacity, and leaching rate (Lin et al. 1995). This is important because soils or sediments containing little or no ionic binding capacity, such as clean sands, can be quite efficient at transporting dissolved lead, especially in areas with acidic rain and low pH ground water (Soeder and Miller 2003).

Lead concentrations in soil at shooting ranges are as great as 55,000 mg/kg (>10,000 times background levels), and elevated lead concentrations may be present in subsurface soil due to its mobility (Scheuhammer and Norris 1995, Murray et al. 1997, Rooney et al. 1999). Leachable lead in soil or sediment near ranges can exceed lead criteria for hazardous waste (e.g., Rooney et al. 1999, Chen et al. 2002, Cao et al. 2003a, 2003b). There are numerous reports that document dissolved lead from shooting ranges entering surface water and/or ground water and exceeding water quality criteria (e.g., Bruell et al. 1999, Craig et al. 1999, Soeder and Miller 2003, Sovari et al. 2006). Thus, lead from spent shot becomes bioavailable to terrestrial and aquatic plants, invertebrates, and vertebrates (Scheuhammer and Norris 1995).

Fate of Elemental Lead in Aquatic Environments

The fate of lead lost from recreational and commercial fishing gear and spent lead ammunition in the aquatic environment depends on whether it remains exposed in water, is buried in sediments, or is ingested in its solid form (Jacks et al. 2001). Weathering and dissolution of elemental lead in spent ammunition and lost fishing tackle is influenced by water chemistry and the extent of the mechanical disturbance (e.g., water flow rate), grain size of soils and sediments, gaseous aerobic conditions, and acidity and alkalinity (Eisler 1988, IPCS 1989, Scheuhammer and Norris 1995, Jacks et al. 2001, European Commission Enterprise Directorate-General 2004). The dissolution rate of lead in aquatic environments increases with acidity, water softness (< 25 mg/L $CaCO_3$), and water velocity (Nriagu 1983, Eisler 1988, Scheuhammer and Norris 1995, Jacks et al. 2001, European Commission Enterprise Directorate-General 2004).

A 1% corrosion rate of lead sinkers was documented in high velocity rivers in Sweden with pH ranging from 6.3 to 6.7, but the amount of dissolved lead contributed to the total lead concentration in the river was not described (Jacks and Byström 1995). In aquatic environments with lower water velocities (e.g., lakes), lead particles and artifacts would become buried in bottom sediments, where they would move into the anoxic sediment layer and may be strongly adsorbed onto sediment and soil particles (European Commission Enterprise Directorate-General 2004). Once buried in the sediments, the dissolution of an elemental lead artifact, as well as its direct availability to organisms, would be more limited (Jacks et al. 2001).

A short-term study (<1 year) conducted to quantify the fate of lead from lead sinkers did not find any significant uptake of lead by aquatic moss downriver (Jacks et al. 2001). Nevertheless, there was an increase in the water concentration of the lead isotope released from the sinkers compared to the lead isotope signature upriver from the lead sinkers. Thus, there is evidence that lead sinkers dissolve in aquatic environments, but direct evidence that dissolved lead from sinkers (e.g., stable isotopic studies) is absorbed or adsorbed by organisms was not found.

In a study of eight shooting ranges over water, shot density ranged from 1.32×10^6 to 3.7×10^9/hectare in the upper 7.5 cm of the soil/sediment fall zone (Stansley et al. 1992). In this study, lead concentration in water samples reached 581 µg/L and was up to two orders of magnitude greater than the reference site; values exceeded U.S. EPA water quality criteria for aquatic life (chronic exposure freshwater 2.5 µg/L; U.S. EPA 2007) and safe drinking water criteria for household tap water (<0.015 µg/L; U.S. EPA 2006). There was no measurable off-site movement of lead contamination from trap and skeet ranges at alkaline pH. In a slightly acidic marsh, however, greater lead concentrations were found, suggesting enhanced mobilization at lower pH. High levels of lead were found in sediments at a gun club at Lake Michigan that operated for 73 years, but lead concentration in water overlying the sediments was below the State of Michigan water quality criteria (i.e., <50 µg/L; Pott et al. 1993).

The bioavailability of lead is affected by its form and the presence of organic matter, sediment, or mineral particles such as clay (IPCS 1989). Generally, lead in spent shot and lost fishing tackle is thought to be less bioavailable to aquatic organisms compared to the lead introduced into the aquatic environment from atmospheric deposition or wastewater (European Commission Enterprise Directorate-General 2004).

PATHWAYS OF EXPOSURE TO LEAD FROM HUNTING, SHOOTING SPORTS, AND FISHING ACTIVITIES

As a result of anthropogenic activities (e.g., mining, smelting, manufacturing, and combustion), lead is widely dispersed throughout the environment (ATSDR 2007). The manufacturing of leaded gasoline, lead-based paints and pesticides, and the use of lead solder in food cans have nearly been eliminated. The use of lead ammunition and fishing tackle are but a small fraction of total environmental releases (3% of consumer end uses; Nordic Council of Ministers 2003). On a global scale, environmental distribution of lead from hunting, shooting sports, and fishing activities is relatively small and more geographically restricted compared to that emanating from mining, manufacturing, and other activities. Depending upon environmental conditions, elemental lead in the form of shot, bullets, fragments, and fishing tackle may undergo dissolution, be bound to sediment or a filterable particulate, or remain intact for extended periods of time. Thus, biota can be exposed to several different forms of lead that arise from these activities. Lead accumulates in plants and animals, but its concentration is not biomagnified up the food chain. A brief discussion of lead exposure routes principally related to hunting, shooting sports, and fishing activities is presented as a prelude to more in-depth information in sections to follow.

Aquatic Environments

Invertebrates and fish are exposed to waterborne lead by adsorption to the exoskeleton or integument, absorption by gills, and through ingestion of sediment, particulates, and food items. Elevated concentrations of lead and biological effects are well documented in aquatic biota near mining sites, smelting sites, and metal finishing industries (Eisler 2000). At such locations, ingestion of lead-contaminated sediments can also be a significant exposure route in waterbirds (Blus et al. 1991, Beyer et al. 1998). Lead released from spent shot in aquatic habitats could be taken up by invertebrates and fish, but very little empirical data exists to document this exposure pathway (Stansley et al. 1992, Hui 2002). Consumption of waterborne lead and ingestion of lead-contaminated sediment and food items likely are exposure pathways for amphibians and reptiles residing near shooting ranges and heavily hunted wetlands (Stansley and Roscoe 1996, Hammerton et al. 2003, Pattee and Pain 2003).

There are no reports of direct ingestion of spent ammunition and fragments by aquatic invertebrates, fish, and amphibians, and such exposures seem unlikely. Numerous studies have described the physical damage and trauma incurred by tackle (often containing lead) to fish (Ferguson and Tufts 1992, Mitton and McDonald 1994, Muoneke and Childress 1994, Cooke et al. 2001). Embedded hooks and jigs can work their way loose or be retained in place. Small fragments could potentially pass through the digestive tract and release lead. There are no data documenting lead uptake or poisoning from such exposures in fish, although there are a few case reports of turtles with lead toxicosis following ingestion of lead fishing tackle (Borkowski 1997, Scheuhammer et al. 2003b).

In contrast, there is extensive literature on the direct ingestion of shot, bullet fragments, sinkers, and jigs and lead toxicosis in dabbling and diving ducks, swans, loons, and other waterbirds, as well as raptorial species that prey on game birds and mammals shot with lead ammunition. For these species groups, lead is released from metallic lead artifacts by the grinding action of the gizzard or stomach that greatly enhances the surface area of the fragments. (Figures 4 and 5) Shot retention, and thus exposure, is influenced by the amount and characteristics of the ingested food and grit (Pattee and Pain 2003). Softer foods with low fiber have been suggested to increase the passage and release of lead shot and

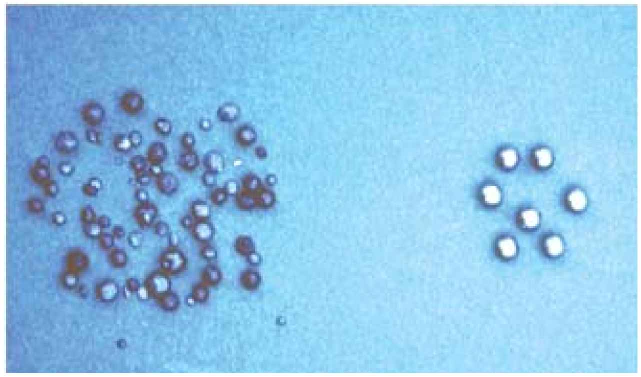

Figure 4. Ground lead shot (left) recovered from gizzard of waterfowl. (courtesy of U.S. Fish and Wildlife Service)

Figure 5. Ingested lead weights found in a redhead duck *(Aythya americana)* (left), trumpeter swan *(Cygnus buccinators)* (center), and a common loon *(Gavia immer)* (right). (courtesy of James Runningen, U.S. Geological Survey)

fragments (Pattee and Pain 2003), although there are exceptions (Marn et al. 1988). Dissolution and uptake of lead is enhanced by low pH and nutritional factors (e.g., low calcium) in portions of the digestive tract. In other species, including mammals, lead fragments usually pass through the digestive system nearly intact, thus minimizing exposure, although there are exceptions (e.g., fragments trapped in the appendix of humans). In aquatic systems, it is probable that secondary poisoning occurs in loons and other species of fish-eating birds that ingest prey items containing lead fishing tackle or other lead artifacts (e.g., Ensor et al. 1992, Pokras and Chafel 1992, Stone and Okoniewski 2001, Franson et al. 2003, Sidor et al. 2003). (Figures 6 and 7)

Terrestrial Environments

In upland habitats, a variety of plants, terrestrial invertebrate and vertebrate species may be exposed to lead released and mobilized from shot and bullet fragments, and lead from these sources can move

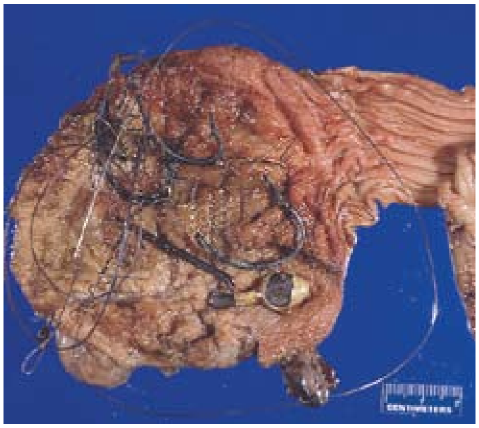

Figure 6. Stomach of brown pelican *(Pelecanus occidentalis)* containing ingested jig head, hooks and line. (courtesy of Scott Hansen, U.S. Geological Survey).

Figure 7. Lead sinker and stones in the stomach of a common loon *(Gavia immer)*. (courtesy of Sheila Schmeling, U.S. Fish and Wildlife Service)

Figure 8. Ingested lead shot in stomach of bald eagle *(Haliaeetus leucocephalus)*. (courtesy of J. Christian Franson, U.S. Geological Survey)

Figure 9. Radiograph of immature bald eagle *(Haliaeetus leucocephalus)* containing numerous lead shot in its digestive tract (Jacobson et al. 1977). (courtesy of Journal of the American Veterinary Medical Association)

through the food chain. There are reports of elevated lead concentrations and adverse effects in plants, invertebrates, amphibians, reptiles, and small mammals in proximity to shooting ranges and heavily hunted sites. Exposure can be attributed to adsorption and ingestion of soil, food items, and water containing elevated concentrations of lead (discussed in sections to follow). Lead from preening, grooming, and inhalation seem to be minor exposure routes in wild birds and mammals. The most pronounced exposures and effects are related to the direct ingestion of spent lead shot and fragments by waterfowl (Sanderson and Bellrose 1986) and certain upland game bird species (Kendall et al. 1996). For granivorous species, retention and dissolution of metallic lead artifacts is facilitated by specializations of the avian digestive tract and influenced by diet. Secondary poisoning by consumption of wounded or dead prey (waterfowl, large game, predators shot with lead ammunition) and scavenging of gut piles containing spent lead ammunition or fragments (Hunt et al. 2006, Pauli and Buskirk 2007) is a significant source of toxicosis in predatory and scavenging birds, with significant effects on bald eagles (Pattee and Hennes 1983) and the California condor (*Gymnogyps californianus*) (Kramer and Redig 1997, Meretsky et al. 2000, Church et al. 2006). (Figures 8 and 9) Notably, poisoning from lead bullet fragments in scavenged carcasses has been identified as the most prominent mortality factor for the California condor (Meretsky et al. 2000).

EXPOSURE TO AND EFFECTS OF LEAD FROM VARIOUS SOURCES IN PLANTS, ANIMALS, AND HUMANS

Although there are extensive data on lead exposure and toxicological effects, the exact exposure pathway and the fraction of total exposure attributable to lead released from spent ammunition or fishing tackle is difficult to assess. This is especially true for animals experiencing sublethal exposure. Recently, the use of stable lead isotope ratios have been employed to help discriminate among potential sources of lead exposure in wild birds (e.g., lead from ammunition versus lead from Precambrian mining wastes and gasoline) (Scheuhammer and Templeton 1998, Scheuhammer et al. 2003a, Church et al. 2006).

The greatest burdens in terrestrial organisms are often near areas with dense vehicular traffic, mines, smelting sites, petrochemical refineries, and facilities that reclaim storage batteries (Eisler 2000). Lead found in contaminated fields tends to adsorb strongly to soil and sediments, and is less bioavailable than more soluble forms (Freeman et al. 1992, Freeman et al. 1994, Schoof et al. 1995). Because of low solubility, lead exposure of biota often occurs through ingestion (soil, sediment, food items). Uptake of lead by plants is more limited (Manninen and Tanskanen 1993). Relatively few studies have examined exposure and effects of lead released into the environment from spent ammunition. For this source to have significant effects on biota, the quantity of lead ammunition lost within a given area has to be substantial. Nonetheless, lead from shot, bullets and fragments in heavily hunted fields, wetlands, and shooting ranges can be directly ingested, and can also be solubilized, biologically incorporated into food items, and then ingested (Ma 1989, Stansley and Roscoe 1996, Hui 2002).

For aquatic organisms, greatest lead burdens are found near mining, smelting, and industrial sites. Uptake and effects of lead on aquatic organisms depends on its chemical (e.g., elemental, inorganic or organic compounds, complexed) and physical form (e.g., dissolved in liquid, associated/adsorbed to inorganic or organic material, solid), as well as the quantity adsorbed or ingested, duration of exposure, environmental conditions, and the life-stage of the organism (Christensen et al. 1977, Weis and Weis 1977, Hodson et al. 1978a, Sastry and Gupta 1978, Johansson-Sjobeck and Larsson 1979, Ozoh 1979, Shaffi 1979, Hodson et al. 1980, Ellgaard and Rudner 1982, Giattina and Garton 1983, IPCS 1989, Eisler 2000, Pattee and Pain 2003, Darling and Thomas 2005). The availability of lead to aquatic organisms also depends on environmental factors such as water temperature, salinity, and pH (IPCS 1989). Additionally, organic lead is more toxic than inorganic lead and is more readily taken up by organisms (IPCS 1989).

Exposure, accumulation, and toxicity of dissolved lead and various lead compounds in plants, invertebrates, and vertebrates including humans have been documented in numerous studies. Exposure and toxicological effects of ingested lead fragments, shot, bullets, and fishing tackle will be presented in detail later in this document.

Plants

Migration of lead from soil to roots and other parts of plants generally is considered to be minimal (Sorvari et al. 2006), although some studies have documented elevated lead levels in plants in the vicinity of shooting ranges (Peterson et al. 1993, Mellor and McCartney 1994, Rooney et al. 1999, Hui 2002). Lead is strongly adsorbed onto soil particles and is not readily translocated to above-ground portions of plants, thus limiting exposure to grazing animals (McLaughlin 2002). In general, concentrations in below-ground plant tissues are approximately three times greater than in above-ground tissues (Linder et al. 1999).

Lead from shot pellets was mobilized into humus and apparently incorporated into several plants (birch, *Betula pendula*; coltsfoot, *Tussilago farfara*; woodland horsetail, *Equisetum sylvaticum*) near a shooting range in Finland, although lead concentrations in leaves were only slightly elevated (1.5- to 5-fold) compared to the reference area (Manninen and Tanskanen 1993). Lingonberries (*Vaccinium vitis-idaea*) and berries of the European mountain ash (*Sorbus aucuparia*) near the range averaged 0.1 to 0.3 mg/kg and approached Finnish food safety regulations. In another study, concentrations of lead in oilseed rape plants (*Brassica* sp.) at a clay pigeon-shooting site were greatest in the area of intense lead shot deposition; in root samples the lead concentration exceeded 450 mg/kg while seeds contained nearly 150 mg/kg (Mellor and McCartney 1994). A study examining lead uptake by barley (*Hordeum vulgare*), lettuce (*Lactuva sativa*), ryegrass (*Lolium perenne*), radish (*Raphanus sativus*) and clover (*Trifolium repens*) grown on soils contaminated with lead shot (11 to 5,998 mg lead/kg) found that concentrations in leaves of some plants were proportionately greater at lower lead concentrations (Rooney et al. 1999). The proportional lead concentrations in roots appeared to be more species-specific, with root/soil lead ratios ranging from 0.032 to 3.43, and with lettuce and clover having the highest root/soil ratios (11 mg/kg soil lead (3.28) and 103 mg/kg soil lead (3.43), respectively)(Rooney et al. 1999).

Few studies have examined lead in aquatic plants near shooting ranges. Lead concentrations in tule seedheads (*Scirpus* sp.) and coontail (*Ceratophyllum* sp.) were about five times greater at a skeet range in Merced, California compared to the reference site (Peterson et al. 1993). At another skeet range in California, lead concentrations in saltwort (*Batis maritima*) and cordgrass (*Spartina foliosa*) in tidal sites near the fall zone were tenfold greater than at sites just a few hundred meters away (Hui 2002).

High concentrations of lead in soil (>1 mg/g) are toxic to plants (Scheuhammer et al. 2007). Although there are limited published data on phytotoxicity of lead at shooting ranges, Mellor and McCartney (1994) noted reduced density of plants within the shot-fall zone where soil lead concentrations ranged from 1,500 to 10,500 mg/kg. A recent report described reduced pine litter production (perhaps tree performance) at an abandoned shooting range, but no effect on pine growth was noted (Rantalainen et al. 2006).

Invertebrates

Numerous studies have assessed lead toxicity for aquatic and terrestrial invertebrates and water quality criteria for their protection (reviewed by Eisler 2000). For aquatic invertebrates, both dissolved lead in water and ingestion of lead incorporated into food items prove significant exposure routes that can contribute to toxicity (Besser et al. 2005). Bioaccumulation of lead from sediments in coastal waters is influenced by salinity with bioaccumulation rates increasing with higher salinity (Boesch et al. 1999).

Uptake of lead by earthworms (Order Haplotaxida) varies with site characteristics. Bioaccumulation of lead in earthworms is higher in areas with high soil calcium concentrations and low pH (Peijnenburg 2002). Concentrations of lead in uncontaminated areas generally are well below 20 mg/kg dry weight for most species, with notable exceptions including whole earthworms (common food source for many species of birds) of the genera *Lumbricus* and *Eisenia* (Eisler 2000). As a general rule, lead concentrations in earthworm "tissues" (excluding digestive tract) are well below lead concentrations in soils. At contaminated sites, lead concentrations for invertebrates can exceed 1,000 mg/kg dry weight. Lead burdens in invertebrates are greatest at sampling locations close to anthropogenic activities. Limited work has examined uptake of lead by invertebrates collected near hunting sites and shooting ranges. A recent study documented lead concentrations in the horn snail (*Cerithidea californica*) collected near a skeet range that were two orders of magnitude greater than at distant sites (Hui 2002). Similarly, lead concentrations in earthworms collected at a small arms firing range at West Point, New York were reported to be up to 90 times greater than observed at a reference site (Labare et al. 2004). Lead-contaminated prey can contribute to lead burdens in wildlife and may evoke a variety of sublethal effects. It is not clear whether contaminated prey species at such sites can cause death in higher vertebrates.

Fish

The availability of dissolved lead to fish depends on the presence of other cations, water hardness, pH, salinity, and oxygen content in the aquatic environment (Jones 1938, Lloyd 1961, Merlini and Pozzi 1977, Somero et al. 1977, Hodson et al. 1978b, Nordic Council of Ministers 2003). An early study by Jones (1938) found that the addition of calcium chloride decreased the toxicity of lead, thereby lengthening the survival time of three-spined stickleback (*Gasterosteus aculeatus*). Lead salts were shown to precipitate out of harder water, thus decreasing the availability of lead to fish (Pickering and Henderson 1966, Davies et al. 1976). Merlini and Pozzi (1977) found that pumpkinseed (*Lepomis gibbosus*) accumulated up to three times as much lead nitrate when maintained in water at pH 6.0 compared to pH 7.0. Fish were observed to accumulate more lead at higher water temperature and lower salinity (Somero et al. 1977), and at lower pH (Merlini and Pozzi 1977, Hodson et al. 1978b). Fish exposed to lowered dissolved oxygen concentrations in water (decreased from 65% to 45%) are slightly more sensitive to lead exposure (1.2 to 1.4 times) (Lloyd 1961).

Lead absorbed by fish accumulates mainly in the gills, liver, kidney, and bone (Holcombe et al. 1976, Merlini and Pozzi 1977, Somero et al. 1977, Hodson et al. 1978b, Muramoto 1980, Vighi 1981, Wong et al. 1981). There is evidence that lead levels in fish eggs increase with concentrations in water, although lead does not appear to be taken up by the embryo, but rather resides on the egg membrane (Holcombe et al. 1976, IPCS 1989). Additionally, accumulated lead in fish was observed to be rapidly eliminated after exposure ceased (Vighi 1981, Wong et al. 1981).

Lead exposure also has been associated with behavioral effects in fish. For instance, goldfish (*Crassius auratus*) were observed to lose pre-trained avoidance behavior when exposed to dissolved lead nitrate (Weir and Hine 1970). Giattina and Garton (1983) observed behavioral avoidance of inorganic lead salts by rainbow trout (*Oncorhynchus mykiss*) at levels of 0.026 mg/L. A similar behavioral avoidance was observed in the Eurasian minnow (*Phoxinus phoxinus*) and the three-spined stickleback exposed to 0.6 mg/L of total lead (Jones 1948). Avoidance behavior was not observed, however, in green sunfish (*Lepomis cyanellus*) exposed to 10, 20, or 40 mg/L of total lead (Summerfelt and Lewis 1967). Following a four-week exposure to lead acetate (0.5 and 1 mg/L), Weber et al. (1991) documented an increased incidence of failed feeding attempts by fathead minnows (*Pimephales promelas*) on *Daphnia magna* compared to controls. In addition, increased brain serotonin and norepinephrine concentrations were found in lead-treated minnows, although no causal relation between behavioral changes and neurotransmitters levels was suggested.

Chronic exposure of adult fish to various doses of inorganic lead can affect their morphology and physiology (summarized in IPCS 1989). Juvenile fish are more sensitive to lead than adults or egg-stage larvae (IPCS 1989). The morphological effects most frequently observed in fish exposed to inorganic lead include blackening of the caudal region and tail (Davies et al. 1976, Hodson et al. 1978a), curvature and other deformities of the spine (Davies et al. 1976, Holcombe et al. 1976, Weis and Weis 1977, Bengtsson 1979, Ozoh 1979), and erosion of the caudal tail (Davies et al. 1976). Morphological alterations in the intestinal brush border, increased mucous cell activity and decreased sodium and chloride flux have been documented in rainbow trout (*Salmo gairdneri R.)*, although lead doses were substantial (10 mg/kg/day for 30 days) (Crespo et al. 1986). Other effects in various species of fish include increases in red blood cell count and decreases in red blood cell volume (Hodson et al. 1978a), inhibition ALAD activity (Jackim 1973, Hodson et al. 1978a, Johansson-Sjobeck and Larsson 1979), anemia and basophilic stippling of erythrocytes (Johansson-Sjobeck and Larsson 1979), possible alterations in bone phosphorus metabolism (Dwyer et al. 1988), decreases in hatching success (Ozoh 1979), decreases in survival (Jones 1938), and effects on the properties of epidermal mucus, which affect swimming efficiency (Varanasi et al. 1975). Elevated lead concentrations in blood and carcass, as well as reduced ALAD activity and total protein, were detected in field-caught fish (primarily catastomids) from sites contaminated by historic mining activities (Schmitt et al. 1993). Several field studies have demonstrated that lead exposure and substantial inhibition of blood ALAD activity are not always accompanied by depressed hemoglobin concentrations (Schmitt et al. 1993, 2002, 2005). Wildhaber et al. (2000) ventured that the presence of toxic contaminants, including lead, may be limiting the population of threatened Neosho madtoms (*Noturus placidus*) in the Spring River flowing through Kansas, Oklahoma, and Missouri. Wildhaber et al. (2000) found that the presence and abundance of Neosho madtoms appeared to be directly limited by water contaminated with lead, cadmium, and zinc, and natural factors including physical habitat, water chemistry, and nutrients. In addition, Neosho madtoms may be affected by contaminated invertebrate prey as well as by reduced prey abundance caused by exposure to these metals. Notably, metals were introduced into the system from historic lead and zinc mining activities, and zinc is known to be far more toxic to fish than lead. At other mining sites, reductions in fish community diversity and density have been observed, however, influences of other stressors cannot be discounted (Moraes et al. 2003).

Other studies have investigated the effects of lead ingestion by fish. An investigation in rainbow trout fed lead at concentrations of 0, 7, 77, or 520 μg/g dry weight until satiated found accumulation (in decreasing order) in the intestine, carcass (includes gut tissues), kidney, liver, and gills, although there were no effects on growth or survival (Alves et al. 2006). The higher concentrations in the intestine may be due to the lead attaching to mucus secreted in response to the presence of heavy metal (Glover and Hogstrand 2002). Glover and Hogstrand (2002) reported that the adsorption to mucus may help isolate the metal, thereby reducing epithelial tissue exposure, and may also result in the excretion of mucus-isolated metal with food items. Lead that accumulates in gills (Alves et al. 2006) may have been absorbed from the combination of lead in the diet and lead leached from fish feces into the water; this is evidenced by greater lead concentrations in water of tanks holding the rainbow trout than of the highest dietary level. Within 14 days of exposure to lead, calcium and magnesium ion regulation was affected, although this stabilized by day 21 (Alves et al. 2006). Additionally, the concentration of lead in red blood cells also increased with dietary concentration and exposure duration, but only at the highest exposure level. This study (Alves et al. 2006) demonstrated that ingested lead can bioaccumulate in soft tissues of fish, yet fish health, feeding, growth, and food conversion efficiency were not significantly altered during the 21-day period (a moderate exposure duration).

Similarly, Woodward et al. (1995) found that the survival of brown trout (*Salmo trutta*) and rainbow trout were not significantly affected by diets of benthic invertebrates containing heavy metals, including arsenic, cadmium, copper, zinc, and lead. Weight reduction of 40% in brown trout and 40% to 50% in rainbow trout were observed, although it was not determined whether all five heavy metals equally affected the fish. Lead accumulated in tissues of brown trout in response to dietary exposure, although a similar increase was not demonstrated for rainbow trout (Woodward et al. 1995). Histological examination of the tissues revealed adverse effects on zymogen granules (precursors of digestive enzymes), vacuolation and sloughing of intestinal mucosal epithelial cells, and increased lipid peroxidation in brown trout, but again not in rainbow trout (Woodward et al. 1995). Additionally, brown trout had swollen abdomens with some occurrence of gut impaction, as food was not being passed, but this did not occur in rainbow trout. Furthermore, both the brown and rainbow trout receiving the heavy metal contaminated diet had long ribbon-like feces compared to the shorter and narrower feces of control fish (Woodward et al. 1995). A study on cutthroat trout (*Oncorhynchus clarki*) found decreased survival following exposure to a heavy metal-contaminated diet (Farag et al. 1999) and a similar effect was observed by Woodward et al. (1994) in rainbow trout fry. Reduced feeding and histological effects were also reported by Farag et al. (1999) for cutthroat trout. Although Woodward et al. (1995) suggest that the ingestion of the heavy metal contaminated diet (rather than waterborne lead) may affect the sustainability of the fishery in the contaminated Clark Fork River, the role of lead in this possible population-level effect is uncertain. Thus, other than the suggestions made by Woodward et al. (1995) and Wildhaber et al. (2000) that non-solid lead might exert population-level effects on fish, no additional or more conclusive studies supporting this hypothesis were found.

Amphibians and Reptiles

Data exist on the effects of lead on amphibians and reptiles, although relatively few studies focus on shooting ranges. Elevated concentrations of lead have been found in tissues of amphibians and reptiles near shooting ranges and in heavily hunted areas (Stansley and Roscoe 1996, Stansley et al. 1997, Hammerton et al. 2003, Pattee and Pain 2003). Exposure in such circumstances generally is thought to result from lead contained in food items or dissolved in water, although it is certainly possible that small lead fragments might be directly ingested.

Information about the toxic effects of lead on amphibians is insufficient to make comparisons among species and families (Linder and Grillitsch 2000). A study examining the effect of various concentrations of lead nitrate on the development of frog embryos found that at 0.7 mg/L most spawned eggs did not develop, but the few that did had a delayed hatch (Dilling and Healey 1926). Stunted growth of tadpoles occurred in eggs surviving exposure to 16.5 mg/L. Those exposed to 33 mg/L did not develop past the late gastrula stage, at 165 mg/L spawned eggs did not develop, and at 330 mg/L all adult frogs died (Dilling and Healey 1926). Exposure of Indian green frog (*Rana hexadactyla*) tadpoles to lead yielded a 96-hour median lethal concentration estimate of 33.2 mg/L (Khangarot et al. 1985). Lead concentrations of 250 µg/L slowed the rate of development in toad tadpoles (*Bufo arenarum*) and median lethal concentrations (470-950 µg/L) were age-dependent (Perez-Coll et al. 1988). Among studies of adult amphibians, Kaplan et al. (1967) observed that exposure of northern leopard frogs (*Rana pipi-*

ens) to lead nitrate (25 and 300 mg/L) for 30 days resulted in diminished postural tone, decreased red and white blood cell counts, and erosion of the gastric mucosa. In a summary prepared by the International Programme on Chemical Safety (IPCS 1989), frog and toad eggs exhibited arrested development and delayed hatching when exposed to lead concentrations as low as 0.04 mg/L, whereas adults were not affected by concentrations lower than 5 mg/L. Lead has been documented to cause hypoxia-like responses in bullfrog (*Rana catesbeiana*) larvae and decreased body mass (Rice et al. 1999).

The toxicity of lead-contaminated sediments recently was investigated in tadpoles of the southern leopard frog (*Rana sphenocephala*) (Sparling et al. 2006). The median lethal concentration of lead in sediment was estimated to be 3,728 mg/kg, which corresponded to 12,539 µg/L in sediment pore water. Depressed growth and development, as well as numerous skeletal abnormalities, were apparent at much lower concentrations (2,360 mg/kg in sediment and 8,100 µg/L in pore water).

A study of captive pickerel frogs (*Rana palustris*) exposed to lead-contaminated water collected near a trap and skeet range found nearly complete mortality of tadpoles following a 10-day exposure period (Stansley et al. 1997). In a study investigating the effects of ingesting lead-contaminated earthworms (10 mg lead/kg, 308, or 816 mg lead/kg), Ireland (1977) found that neither growth nor survival were affected in the African clawed toad (*Xenopus laevis*). Lead-exposed individuals, however, exhibited decreased ALAD activity.

Data on lead toxicity in reptiles are scarce. Studies in western fence lizards (*Sceloporus occidentalis*) suggest that lethality occurs at doses greater than 100 mg/kg body weight, and possibly as great as 2,000 mg/kg (Salice et al. 2003, Holem et al. 2006). No studies were found examining the effects of dissolved lead in the environment emanating from lead fishing weights or tackle on amphibians or other reptiles.

Birds

Several studies on the ingestion and toxicity of lead in non-metallic forms have focused on incidental ingestion of lead-contaminated sediments. Many studies focus on a U.S. EPA Superfund site (Coeur d'Alene River Basin) that is highly contaminated with lead after a century of mining activities (BEST 2005). Low pH at this site enhances lead dissolution. This type of mining-related wildlife mortality is much less common than instances involving ingestion of lead artifacts (Beyer et al. 1997).

Within the Coeur d'Alene River Basin in Idaho, lead concentrations in sediment are as high as 5,000 µg/g (Henny et al. 2000, Henny 2003). This site is also contaminated with many other heavy metals that were released during mining and smelting activities (Day et al. 2003). Waterbird die-offs in the Coeur d'Alene floodplain were reported in the early 1900s and continue to this day (Henny 2003). (Figure 10) Initially, it was thought that waterfowl were ingesting lead-contaminated sediment and plant material (Chupp and Dalke 1964, Benson et al. 1974, Blus et al. 1991, Henny et al. 1991, Beyer et al. 1997, Beyer et al. 1998, Blus et al. 1999, Day et al. 2003). The ingestion of lead from plant materials was subsequently determined to be unlikely given the low concentration of lead accumulated by aquatic plants preferred by waterfowl (Beyer et al. 1997). Thus, accidental ingestion of lead-contaminated sediments along with food items is believed to be the main pathway for waterfowl die-offs at this site (Blus et al. 1991, Beyer et al. 1998).

Accidental ingestion of molecular lead through contaminated prey or contaminated sediments ingested along with prey items produced adverse effects in ospreys (*Pandion haliaetus*), raptors, songbirds, and tundra swans (*Cygnus columbianus*) in the Coeur d'Alene floodplain. Elevated lead levels in the blood of osprey nestlings were attributed to the higher lead concentrations in fish from the Coeur d'Alene floodplain (Henny et al. 1991). Although ALAD activity was inhibited and increased concentrations of protoporphyrin were found, the concentration of lead in osprey blood did not appear to affect hemoglobin concentration or hematocrit (Henny et al. 1991). Furthermore, the concentration of lead did not appear to be sufficiently high to affect osprey reproduction, recruitment, and behavior, and there was no evidence that lead resulted in death of adult ospreys (Henny et al. 1991).

Henny et al. (1994) found that American kestrels (*Falco sparverius*) and northern harriers (*Circus cyaneus*) nesting in the Coeur d'Alene floodplain also were affected by lead. Nestling American kestrels had significantly greater lead concentrations in blood compared to birds from the reference area (0.24 µg/g wet weight versus 0.087 µg/g, respectively). Additionally, blood ALAD activity was inhibited by 35% in northern harrier nestlings and by 55% in American kestrel nestlings, with activity inversely related to blood lead levels. Blood ALAD activity was inhibited by 81% in adult American kestrels, and both nestlings and adults had slightly lower hemoglobin concentrations (reduction of 8.2% and 7.5%, respectively) compared to birds from the reference area. Although American kestrels and northern harriers exhibited signs of lead exposure and modest effects, Henny et al. (1994) did not observe any mortality or reproductive impairment. These investigators concluded that raptors might be less prone to accumulating lead from contaminated prey due to the formation and regurgitation of pellets. This was based on observations of high lead concentrations in small mammal prey species (deer mice, *Peromyscus maniculatus* and voles, *Microtus* sp.) as well as the finding that most of the lead was concentrated in bone (Mierau and Favara 1975, Chmiel and Harrison 1981). Lead within bone of small mammal prey species may evoke minimal effects on raptors (e.g., hawks, falcons, and eagles), as they only partially digest bones before expelling them along with hair when they regurgitate pellets, and owls do not digest any of the bones of their prey (Duke et al. 1975).

Johnson et al. (1999) found that American robins (*Turdus migratorius*) and song sparrows (*Melospiza melodia*) in the Coeur d'Alene floodplain had elevated liver lead concentrations, with nearly one-half of the individuals having levels great enough to inhibit ALAD by >50%. Although hematocrit values tended to be lower compared to birds from the reference area, apparent differences were not statistically significant. Johnson et al. (1999) determined that American robin and song sparrow diets of insects, other soil-associated invertebrates, and some soil were probably the source of exposure. Overall, the detected effect of lead poisoning in songbirds found in the Coeur d'Alene floodplain was similar to that observed in raptors (Henny et al. 1991, 1994).

Lead contamination in the Coeur d'Alene floodplain had greater effects on tundra swans and wood ducks than on raptors and songbirds (Blus et al. 1991, Henny et al. 1991). Day et al. (2003) studied the effects of ingesting lead-contaminated sediments in mute swans and found that the severity of lead poisoning depended on the amount of lead ingested and the quality of their diet. Mute swans fed lead-contaminated sediments along with their rice diet had elevated tissue lead concentrations and exhibited signs of lead poisoning and weight loss when compared to controls. Wood ducks from contaminated sites were found to have high levels of lead in blood and tissues (maximum levels of 8 µg/g wet weight in blood and 14 µg/g in liver) and decreased ALAD activity. Activity of ALAD, hemoglobin concentration, and body mass were inversely related to blood lead concentration, while protoporphyrin values were in the range associated with lead toxicosis in birds (Blus et al. 1993). Nevertheless, elevated lead concentrations did not significantly affect nesting success. Lead levels in wood ducks from the contaminated sites were attributed to accidental ingestion of lead-contaminated sediments (Beyer et al. 1997).

Elevated lead concentrations in tissues, increased protophorphyrin levels in blood, and pathological lesions associated with lead poisoning in birds collected near shooting, trap, and skeet ranges have been reported. In a study of northern pintails (*Anas acuta*) collected from a tidal marsh adjacent to a trap and skeet range (Roscoe et al. 1989), elevated blood lead and protophorphyrin concentrations were clearly attributable to direct ingestion of spent shot. Two recent studies with passerines at firing ranges indicate ingestion of soil and prey items as additional exposure routes, although overall effects appear to be more modest than those evoked by ingestion of spent lead ammunition and fragments (Vyas et al. 2000, Johnson et al. 2007).

Mammals

There are extensive data on exposure and toxicological effects of lead in domestic livestock, laboratory rodents, and humans (Eisler 2000). Nevertheless, for wild terrestrial and aquatic mammals there are principally only lead exposure data, and most are focused on sites contaminated by mining and industrial activities (Eisler 2000, Shore and Rattner 2001). Ma (1989), however, reported markedly elevated concentrations of lead in kidney, liver, and bone of small carnivorous mammals (shrews, *Sorex araneus*), herbivores (wood mice, *Apodemus sylvaticus*), and bank voles (*Clethrionomys glareolus*) trapped within the shot fall zone of a shooting range compared to subjects collected at least 300m away from the range. Kidney lead concentrations in shrews and bank voles collected from the range exceeded 25 µg/g dry weight (diagnostic threshold of lead poisoning in mammals), and increased kidney to body weight ratios were also apparent in these species. In another study, white-footed mice (*Peromyscus leucopus*) and short-tailed shrews (*Blarina brevicauda*) were live-trapped in the fall zone of a shooting range and from a nearby reference area (Stansley and Roscoe 1996). A five- to 64-fold elevation in lead concentration in liver, kidney, and femur was found in mice trapped from the fall zone, and lead was greatly elevated in tissues from the single shrew that was collected from the range compared to shrews from the control area. Compared to mice from the control area, mean blood ALAD activity was inhibited by 48% and hemoglobin concentration was depressed by 6.7% in mice trapped on the range. There was some evidence of renal lesions (intranuclear inclusion bodies) in a few individuals collected from the range. A monitoring study involving mammalian species was initiated following diagnosis of lead poisoning in a gray squirrel (*Sciurus carolinensis*) and a yellow-rumped warbler (*Dendroica coronata*) at a shooting range in Georgia (Lewis et al. 2001). Of the 37 mammals collected, five gray squirrels, two Virginia opossums (*Didelphis virginiana*), three raccoons (*Procyon lotor*), one white-footed mouse and one white-tailed deer (*Odocoileus virginianus*) had kidney and/or liver lead concentrations exceeding 1 µg/g wet weight. Radiographs revealed the presence of metal fragments (unspecified composition) in the abomasum of two deer (deer collected by spot lighting and head shot with a high-powered rifle), and it was suggested that metal fragments (rather than other physical forms of lead) were the principal source of exposure. Johnson et al. (2004) compared lead bioaccumulation in woodchucks (*Marmota monax*) inhabiting small arms and skeet shooting ranges at a U.S. Army facility in Maryland to that from two nearby reference sites. Lead concentrations in blood were below values known to cause toxicity, and concentrations of lead in bone, blood, and feces of woodchucks did not differ between suspect sites and reference areas, possibly because of the large home range of woodchucks.

Elevated concentrations of free environmental lead (presumably only a small fraction of total lead compounds) can affect terrestrial vertebrates by altering prey abundance and plant communities (Burger 1995, DeShields et al. 1998) and can evoke a wide range of biochemical, hematological, immunological, histopathological, and behavioral effects. Reproductive rates and population parameters have not been adequately investigated at shooting ranges. No studies documenting effects in mammals related to lead released from fishing tackle were found.

Humans

The adverse effect of lead on human health has been known since Roman times (Nriagu 1983, Needleman 1999, Hernberg 2000, Tong et al. 2000). The Romans were exposed to lead by drinking water flowing through lead pipes and wine stored in lead wine urns, and by eating food cooked using lead utensils and pots (Waldron 1973, Nriagu 1983, Needleman 1999, Hernberg 2000, Tong et al. 2000, Needleman 2004). Today humans continue to be exposed through drinking water and food consumption, and inhalation and occupational exposure can also be a significant source of lead for some individuals (IPCS 1977, Hernberg 2000, Needleman 2004). Children are also exposed by ingestion of non-food items such as lead paint chips and soil (IPCS 1977, Needleman 2004, ATSDR 2006) and are more susceptible to adverse neurological, metabolic, and behavioral effects (Nordic Council of Ministers 2003, Khan 2005). Lead exposure through food has decreased over time, as lead solder is no longer used in tin cans used to store food (Tukker et al. 2001). Organic lead is known to be more toxic to humans than inorganic lead (Nordic Council of Ministers 2003). Exposure to organic lead has been primarily through leaded gasoline, which largely has been phased out in most countries.

As detailed in the report of the International Programme on Chemical Safety (IPCS 1977), lead absorbed by humans depends on the degree of lead exposure, the physical and chemical state of the lead, nutritional factors, temperature, and age. The provisional tolerable weekly intake of lead is 25 µg /kg body weight (IPCS 1977), which takes into account the more sensitive groups, infants, and children (Nordic Council of Ministers 2003). Humans' lead absorption through diet is estimated at 10% for adults but as high as 50% in children; the actual quantity depends on the bioavailability of the forms ingested (Kehoe 1976, Hammond 1977, IPCS 1995). Additionally, the amount of lead retained within the body and its storage sites are dependent on blood flow, and the site of deposition within the body can change over time (IPCS 1977). Studies have found that in humans lead accumulates mainly in bones, with concentrations increasing over time, whereas levels in other tissues and blood reflect more recent exposure (IPCS 1977, IPCS 1995, Khan 2005). Some researchers believe that lead stored in bones may serve as an endogenous source that is slowly released over years (Nordic Council of Ministers 2003, Khan 2005). In humans, lead can be eliminated through urine and feces, and to a lesser degree in hair, nails, and sweat (IPCS 1977).

Lead exposure in humans can result in adverse effects on the hematopoietic system (inhibition of blood ALAD, heme synthesis, mild anemia, stippled and blue erythrocytes, and reduced erythrocyte survival), central nervous system (encephalopathy and neurological manifestations including clumsiness and impaired cognition), peripheral nervous system (lead palsy, reduced motor conduction velocity), renal system (renal tubular damage, generalized aminoaciduria, renal failure, and chronic nephropathy), and cardiovascular system (increased capillary permeability) (IPCS 1977, Nordic Council of Ministers 2003, Needleman 2004, Khan 2005). Lead may cause brain dysfunction, developmental defects, chronic encephalopathy, neuropathy, impaired amino acid transport, anemia, and death (IPCS 1977, Goyer 1996, Nordic Council of Ministers 2003, Needleman 2004, Khan 2005). Historically, occupational lead exposure in adults resulted in serious health effects; there are still concerns in some industrial settings (Nordic Council of Ministers 2003, ATSDR 2007). Furthermore, some studies have associated bone or blood lead levels with aggression and delinquent behavior (Nevin 2000, Needleman et al. 2002, Needleman 2004), as well as attention deficit hyperactivity disorder (Braun et al. 2006). There is, however, no evidence of deleterious effects of lead on skin, muscle, and the immune system, and effects on human reproduction seem to be minimal (IPCS 1977, Nordic Council of Ministers 2003, Khan 2005).

Several international conventions and treaties have been signed to reduce human exposure and environmental releases of lead (Nordic Council of Ministers 2003, ATSDR 2007). These include the Long Range Transport of Airborne Pollutants Convention and its 1998 Aarhus Protocol on Heavy Metals, covering Central and Eastern Europe, Canada, and the United States; the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR convention), which covers the North-East Atlantic including the North Sea and the internal waters and territorial seas of several European countries; the Helsinki Convention, which applies to the Baltic Sea region; and the globally applied Basel Convention, which address the release of lead and lead compounds in waste and other products. Legislation that restricts lead in paint and in gasoline is relevant to North American countries, as Canada and the United States both have limits on lead emission in water and air and have remediation criteria for lead in soil at contaminated sites. Canada restricts the use of lead solder in food containers and has a program to support the collection and recycling of lead-acid batteries. Mexico has legislation that bans the use of lead in pottery, and the United States places limits on lead in ceramics and has legislation that bans the use of lead solder on food containers and household plumbing, lead in house paints, and lead foil capsules on wine bottles.

Increased blood lead concentrations resulting in biochemical effects and clinical disease, including neurotoxicity, have been reported in individuals who frequent indoor and outdoor firing ranges, both as customers and employees (Fischbein et al 1979, Novotny et al 1987, Chisholm 1988, Valway et al. 1989, Peddicord and LaKind 2000). In one report, it was suggested that exposure may be from handling lead materials during reloading of lead ammunition, as well as inhalation of lead during shooting activities at the range. In one case, the blood lead concentration doubled over a period of about three months in a person who loaded his own 9 mm and .22 caliber ammunition, and shot often at both indoor and outdoor ranges (Gulson et al. 2002).

The U.S. EPA (1994) estimated that approximately 800,000 to 1,600,000 people manufacture lead fishing weights in their homes for either personal use or for sale, representing approximately 30% to 35% of lead sinkers produced in the United States. Scheuhammer and Norris (1995) speculated that a similar "cottage industry" exists in Canada. Melting lead and producing lead fishing tackle, such as lead sinkers and jigs, are also sources of lead poisoning in humans through inhalation of the resulting lead dust and fumes (U.S. EPA 2004). For example, an adult male who had been making fishing sinkers from salvaged lead suffered from lead toxicity symptoms including fatigue, stomach pain, and fever following the inhalation of particles emitted during melting (State of Alaska Epidemiology 2001). Melting occurred in a poorly ventilated area with no filters in the ventilation system. The individual used only a paper mask, which did not prevent the passage of the minute lead particles, and was not aware of the health hazards of melting and casting lead nor safe handling procedures. Ultimately, the individual was admitted to a hospital, and following chelation therapy, blood lead levels declined from 133 to 48 µg/dL (State of Alaska Epidemiology 2001). Many anglers also cast their own sinkers and jigs in their garages and basements, which also poses a human health risk.

EXPOSURE TO AND EFFECTS OF INGESTED LEAD SHOT, BULLETS, AND FISHING TACKLE IN FISH, AMPHIBIANS, REPTILES, BIRDS, AND MAMMALS INCLUDING HUMANS

Fish, amphibians, reptiles, and higher vertebrates can ingest lead shot, bullets, fragments of shot and bullets, and fishing tackle. Fish most frequently ingest fishing tackle, partially or wholly, when hooked. Whether the fishing tackle remains in the fish depends on if the angler successfully lands the fish and if the hook is too deeply ingested to safely remove. There is limited evidence of amphibians and reptiles directly ingesting and being affected by spent lead ammunition and lost fishing tackle. Nevertheless, it is well documented that birds can ingest spent shot and bullets, or their fragments from various environmental matrices or prey items, and some species ingest fishing tackle that has been lost or abandoned by anglers. Other organisms, including humans, ingest lead from shot, bullets, and fishing tackle; examples of such occurrences are discussed below. Most of the concern related to ingestion of these lead artifacts arises from sub-lethal and lethal effects on birds, and to a lesser degree on humans.

Fish

There is no widely disseminated or published evidence documenting ingestion of spent lead shot, bullets, or bullet fragments by fish. Fish, however, are known to ingest hooks, jigs, and other tackle left attached to the mouth, esophagus, eyes, gills, or other body parts. Fish hooks and associated tackle may be abandoned when anglers break the line with a fish attached, or leave deeply set hooks in released fish to reduce injury (Weidlein 1989, Siewert and Cave 1990, Nuhfer and Alexander 1992, Carbines 1999, Cooke et al. 2001). Most mortality associated with fishing tackle is not related to the fish being exposed to the lead, but rather to the extent of injury, blood loss, exposure to air, and exhaustion during handling in order to remove hooks (Ferguson and Tufts 1992, Mitton and McDonald 1994, Muoneke and Childress 1994, Cooke et al. 2001). For instance, bluegills (*Lepomis macrochirus*) were reported to have 100% mortality when hooked in the esophagus, gills, tongue or eye, with only 40% mortality when hooked in the jaws and lips (Siewart and Cave 1990). The high mortality associated with deeply set hooks in bluegills most likely arises from injury incurred during the removal of the hook. Studies conducted on Atlantic salmon (*Salmo salar*) and rainbow trout found a 33% and 66% decrease in mortality if the deeply set hook is left in the fish (Mason and Hunt 1967; Warner and Johnson 1978; Warner 1979), whereas a 43% increase in mortality for smallmouth bass (*Micropterus dolomieu*) was observed when the deeply set hook was removed (Weidlein 1989). Additionally, a study by Ferguson and Tufts (1992) found that mortality increased within a 12-hour period following catch and release, which was related to fish exhaustion and the duration of air exposure during handling to remove the hook. The injury or stress from being caught and released may also render fish more susceptible to secondary infections by parasites, bacteria, or fungi, and may adversely affect foraging and survival of fish (Wright 1972, Chipeniuk 1997). Ingestion of fishing hooks, not necessarily associated with lead fishing tackle, is also of concern in sharks, as these hooks may contribute to mortality (e.g., obstructing the esophagus, perforating the stomach, lacerating the liver, and causing various lesions) of recreationally targeted sharks in catch-and-release fisheries (Borucinska et al. 2002).

No studies that related lead exposure from ingested lead sinkers and jigs or other tackle to the mortality of fish were found. It is commonly accepted, however, that embedded hooks and leaded jigs work their way loose, and thus the specific effects of lead from such embedded tackle would be minimal in comparison to the potentially sub-lethal and lethal injuries that may occur directly from the deeply embedded hooks. Although there are no data, it is certainly possible that a fish with an embedded lead jig and attached tackle could be consumed by a predatory fish, resulting in secondary poisoning.

Amphibians and Reptiles

There is no widely disseminated or published evidence that ingestion of lead shot, bullets, and fishing tackle by amphibians or reptiles is a widespread problem. There is limited information documenting the incidence of these lead objects in the digestive system of these vertebrates. Camus et al. (1998) described the ingestion of lead bullets by farmed American alligators (*Alligator mississippiensis*) consuming nutria (*Myocastor coypus*) that had been shot. Lead shot has also been documented to cause chronic health problems in a captive American alligator colony (Lance et al. 2006). Notably, reproductive failure in this captive population led to investigative necropsies and tissue analyses. High bone lead levels (mean of 252 µg/g wet weight) were found and high yolk lead concentrations were suggested as a probable cause for early embryonic death in alligator eggs. Elevated lead concentration in these alligators was attributed to long-term consumption of nutria meat contaminated with lead shot. Hammerton et al. (2003) alluded to the presence of lead shot, bullets, and fishing sinkers in the carcasses of crocodiles (*Crocodylus porosus*) in the vicinity of hunting sites in Australia. Amphibians and reptiles in close proximity to shooting ranges have been found to have elevated concentrations of lead in their tissues, which is thought to be due to accidental ingestion of lead in food items or in water (Stansley and Roscoe 1996, Hammerton et al. 2003, Pattee and Pain 2003).

A common snapping turtle (*Chelydra serpentina*) that had ingested a lead fishing sinker had a blood lead concentration of 3.6 µg/g and was suffering from toxicosis (Borkowski 1997). The turtle recovered following the removal of the fishing sinker and treatment. A few unpublished reports (Scheuhammer et al. 2003b) have also indicated that turtles may suffer from lead toxicosis following the ingestion of lead fishing weights. These include a report from Canada of a common snapping turtle ingesting a fishing sinker or jig (M. Ouellett, Redpath Museum, McGill University, Montreal, Quebec, unpublished observation) and a report from the United States of snapping turtles and a painted turtle (*Chrysemys picta*) ingesting a fishing sinker or jig (M. Pokras, Tufts University, School of Veterinary Medicine, North Grafton, Massachusetts, unpublished necropsy reports 1999). The reports did not state whether ingested lead fishing sinkers and jigs resulted in death in these three turtles. Although there are no data, it is plausible that secondary poisoning of reptiles could result from ingestion of a fish with an embedded jig or attached tackle. No studies or reports describing ingestion of lead fishing tackle by amphibians were found.

Birds

Extensive research has examined exposure and effects of lead in birds, as they are known to ingest lead shot, bullets, sinkers, and jigs, possibly by mistaking the item for food or grit material (Sanderson and Bellrose 1986, Kendall et al. 1996, Scheuhammer and Norris 1995, Scheuhammer et al. 2003, Fisher et al. 2006). Birds' dietary exposure to shot, bullets, bullet fragments, and fishing tackle depends upon specific feeding and grit ingestion habits. Waterfowl's exposure to lead varies with species and diet, with greater risks for birds that forage in areas where lead objects accumulate (Nordic Council of Ministers 2003). Tissue concentrations of lead associated with toxicity are relatively well established for wild birds (Table 1) (Friend 1985, Franson 1996, Pain 1996, Pattee and Pain 2003). Lead shot or bullet fragments embedded in muscle or skin of birds generally does not result in poisoning, as there is little absorption of lead into the blood from these tissues (De Francisco et al. 2003).

Ingestion of spent ammunition. Shot density affects ingestion rate. For example, a study by Rocke et al. (1997) estimated a 45% ingestion rate of lead pellets by sentinel mallards (*Anas platyrhynchos*) in a wetland enclosure containing more than 2 million shot/hectare in the upper 10 cm of sediment. In enclosures with 15,750 and 173,200 pellets/hectare, mallards exhibited ingestion rates of 4% and 34%, respectively (Rocke et al. 1997).

Highly cited reviews addressing the effects of ingested shot on waterfowl include Bellrose (1959) and Sanderson and Bellrose (1986). Waterfowl ingesting as few as one or two shot can waste away

Table 1. General criteria for lead poisoning in wild birds.

	Blood		Liver		Bone
	wet weight µg/dL	wet weight µg/g or ppm	wet weight µg/g or ppm	dry weight µg/g or ppm	dry weight µg/g or ppm
Background	<20	<0.2	<2	<8	<10
Subclinical Poisoning	20 to <50	0.2 to <0.5	2 to <6	>20	10 to 20
Clinical Poisoning	50 to 100	0.5 to 1	6 to 15		
Severe Clinical Poisoning	>100	>1	>15	>50	>20

Derived from Friend 1985, 1999, Franson 1996, Pain 1996 and Pattee and Pain 2003.

over a period of several weeks (30% to 50% loss of body weight) and die. Furthermore, mallards dosed with two or more pellets were recaptured in greater numbers than controls, suggesting that in a debilitated state ducks are more vulnerable to hunting and that migratory behavior may be impaired (Bellrose 1951). Less frequently, when many shot are ingested, an acute form of lead poisoning ensues, and birds quickly succumb while in good physical condition. A diagnosis of lead toxicosis is based on clinical signs (e.g, wing droop, weakness, anemia), necropsy observations (e.g., emaciation, esophageal impaction, bile staining of gizzard and vent, presence of ingested lead), and concentrations of lead in tissues (e.g., blood, liver, and bone) (Pain 1996, Friend 1999). Lead levels greater than 6 µg/g wet weight in liver are considered to be toxic in waterfowl (Friend 1999, Pain 1996). (Figures 10 and 11) In addition, widely used biomarkers of exposure to lead in birds include blood ALAD activity and concentrations of free protoporphyrin and zinc protoporphyrin (reviewed in Pattee and Pain 2003). For example, when mallards were dosed with a single No. 4 pellet (195-215 mg, equivalent to approximately 150 mg/kg body weight), blood ALAD activity was inhibited within hours and remained depressed for three months (Dieter and Finley 1978, Pain and Rattner 1988; Rattner et al. 1989). Protoporphyrin concentration in blood of lead-dosed mallards and black ducks (*Anas rubripes*) was elevated in a matter of days (Roscoe et al. 1979, Pain and Rattner 1988, Rattner et al. 1989). High protoporphyrin levels also

Figure 10. Wing and tail droop in lead-intoxicated black duck *(Anas rubripes).* (courtesy Barnett A. Rattner, U.S. Geological Survey)

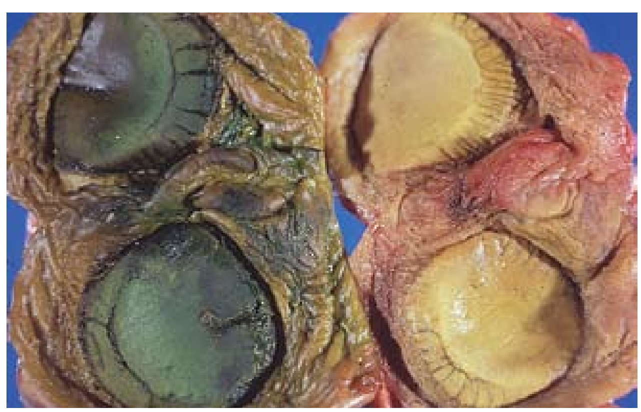

Figure 11. Gizzards of Canada geese *(Branta canadensis)* showing bile staining from lead poisoning (left) and normal yellow color (right). (courtesy of J. Christian Franson, U.S. Geological Survey)

were found in wild canvasbacks with elevated blood lead concentrations, presumably from lead shot exposure (Franson et al. 1996a).

One of the most striking examples of mass mortality of waterfowl from lead shot ingestion involves trumpeter swans (*Cygnus buccinator*) and tundra swans of northwestern Washington and southern British Columbia (Lagerquist et al. 1994, Degernes et al. 2006). This area provides wintering habitat for these swans, which are classified as "game" birds, although they are not hunted there. Although the use of lead shot in these wetland habitats was prohibited many years ago, swan mortalities from lead poisoning continue to occur regularly in this area. In recent decades, thousands of swans have died in this area and hundreds have been examined for cause of death. Following examination of 115 trumpeter and 21 tundra swan carcasses collected from 1986 to 1992, Lagerquist et al. (1994) found that 39 (35%) of 110 livers had lead concentrations diagnostic of poisoning and accounted for 29% of the mortality. In a more recent study, Degernes et al. (2006) examined 365 trumpeter and 35 tundra swan carcasses collected between 2000 and 2002, and found that 81% died from lead poisoning (302 trumpeters, 20 tundras). There was no apparent association between grit ingestion (total mass or mass categorized by size) and lead poisoning or number of lead shot consumed. Lead-poisoned swans were more likely to have one or more lead shot as well as nontoxic shot compared to swans that were not poisoned (Degernes et al. 2006). One suggested reason for this continued swan mortality is that swans are capable of foraging deeper into bottom sediments than other waterfowl, thereby allowing continued ingestion of shot deposited years earlier (Lagerquist et al. 1994).

Lead poisoning of a threatened sea duck, the spectacled eider (*Somateria fischeri*), was discovered in the early 1990s when spectacled eiders and a common eider (*S. mollissima*) were found dead with ingested lead shot in the remote Yukon-Kuskokwim Delta of Alaska (Franson et al. 1995). Subsequent studies using field radiography found that up to nearly 12% of spectacled eider adults and 2.5% of ducklings had ingested shot, and blood lead concentrations of ≥0.5 µg/g wet weight were found in 20% of adult females and 6% of ducklings (Flint et al. 1997, Franson et al. 1998). Radiotelemetry and other marking studies revealed that adult female spectacled eiders died of lead poisoning and predation, and that adult females exposed to lead prior to hatching their eggs survived at a much lower rate than females not exposed to lead before their eggs hatched (Flint and Grand 1997, Grand et al. 1998). It was suggested that mortality from lead exposure, leading to reduction in adult survival, may impede recovery of local spectacled eider populations (Grand et al. 1998).

Raptors and other avian predators and scavengers may be exposed to lead from the consumption of shot pellets and bullet fragments embedded in tissues of dead or wounded animals or from tissues discarded in gut (offal) piles. Ingestion of lead shot by both predatory and scavenging raptors feeding on hunter-killed carcasses is an international issue, and lethal effects are well-documented in many species. Examples of affected species include bald eagles, golden eagles (*Aquila chrysaetos*), white-tailed sea eagles (*Haliaeetus albicilla groenlandicus*), Spanish imperial eagles (*Aquila adalberti*), Steller's sea eagles (*Haliaeetus pelagicus*), red-tailed hawks (*Buteo jamaicensis*), common buzzards (*Buteo buteo*), Eurasian sparrowhawks (*Accipiter nisus*), northern goshawks (*A. gentilis*), marsh harriers (*Circus aeruginosus*), turkey vultures (*Cathartes aura*), black vultures (*Coragyps atratus*), and California condors (Janssen et al. 1986, Craig et al. 1990, Langelier et al. 1991, Pain and Amiard-Triquet 1993, Franson et al. 1996b, Pain et al. 1994, Kim et al. 1999, Wayland and Bollinger 1999, Iwata et al. 2000, Kurosawa 2000, Kenntner et al. 2001, Mateo et al. 2001, Clark and Scheuhammer 2003, Krone et al. 2004).

Much of what we know about secondary poisoning of raptors by lead shot and bullet fragments resulted from studies of bald eagles preying upon dead or dying waterfowl and other game (Figure 9). As opportunistic predators and scavengers, bald eagles congregate in waterfowl hunting areas and prey on crippled waterfowl (often carrying embedded lead shot) or scavenge on unretrieved waterfowl carcasses. In the earliest published studies in the United States, Coon et al. (1969) reported that 7% of 45 bald eagle carcasses had high enough lead levels to have caused mortality, and Kaiser et al. (1980) reported that 9% of 158 bald eagle carcasses contained elevated lead levels in the liver, ranging from 22.9 to 38.1 µg/g wet weight. Pattee and Hennes (1983) reviewed the relationship between lead shot in waterfowl and bald eagles, and found that lead toxicity in bald eagles occurs seasonally (late fall and winter), corresponding with the waterfowl hunting season. In response to these and other data, in 1986 the United States Fish and Wildlife Service (U.S. FWS) initiated a five-year phase-out of the use of lead shot for hunting waterfowl and coots in order to minimize lead exposure in both waterfowl and bald eagles.

Although lead shot exposure in waterfowl appears to have decreased substantially, eagles continue to be exposed to lead shot and bullet fragments in other prey items. Kramer and Redig (1997) conducted a 16-year epizootiological review of lead in bald and golden eagles and found a reduction in blood lead concentrations in both species following the ban on lead shot for waterfowl hunting in Minnesota and Wisconsin. There was no change in the prevalence of lead poisoning, however, which was attributed in part to availability of gut piles from hunter-killed white-tailed deer. Clark and Scheuhammer (2003b) found that upland game birds and mammals, the primary food of many raptors, are now more likely to contain lead shot than waterfowl since the prohibition of lead shot for hunting waterfowl. Birds of prey (e.g., red-tailed hawks, golden eagles, and great horned owls, *Bubo virginianus*) that feed on upland game birds and mammals sometimes succumb to lead poisoning from incidental ingestion of lead shot, bullets, and related fragments. Recent studies have begun to document the hazard to scavengers of bullet fragments in gut piles and carcasses of hunter-killed white-tailed deer and mule deer (*Odocoileus hemionus*) lost to wounding (Hunt et al. 2006), small game such as Richardson's ground squirrel (*Spermophilus richardsonii*) (Knopper et al. 2006), and recreational shooting of prairie dogs (*Cynomys* spp.) (Pauli and Buskirk 2007). There is some evidence that use of lead shot in upland game hunting and lead bullets in hunting small and large game species are an important cause of continued lead toxicity in bald and golden eagles (Harmata and Restani 1995, Fisher et al. 2006). Furthermore, following the decline of the coastal fishery in Japan, large numbers of Steller's and white-tailed sea eagles switched feeding strategies and subsequently died from consumption of a growing number of carcasses of hunter-killed sika deer (*Cervus nippon*) containing lead bullet fragments (Kurosawa 2000). It was even suggested that the level of adult mortality attributed to lead poisoning of Steller's sea eagles and white-tailed sea eagles feeding on sika deer carcasses could possibly be adversely affecting their populations (Kurosawa 2000).

Vultures and condors appear highly susceptible to toxicity from ingesting small quantities of lead shot or bullets due to their inability to regurgitate pellets from their gastrointestinal tracts (Eisler 1988). In fact, the presence of lead in California condor habitats in California and Arizona, coupled with the species' extreme sensitivity to lead, has been suggested as the primary threat to the continued existence of the California condor (Janssen et al. 1986, Wiemeyer et al. 1988, Pattee et al. 1990, Meretsky et al. 2000). Recent evidence pinpoints lead fragments from ammunition embedded in carcasses of hunted game and mammalian predators (coyotes, *Canis latrans*) or gut piles as the main source of the lead accumulated by California condors (Church et al. 2006).

The risk of spent shot to upland game species, including doves and quail, is well recognized (Kendall et al. 1996). Lead exposure and poisoning from the ingestion of spent lead ammunition has been reported in many species of upland game birds and hunted non-Anseriform waterbirds, including chukar (*Alectoris chukar*), grey partridge (*Perdix perdix*), ring-necked pheasant (*Phasianus colchicus*), wild turkey (*Meleagris gallopavo*), scaled quail (*Callipepla squamata*), northern bobwhite (*Colinus virginianus*), American woodcock (*Scolopax minor*), ruffed grouse (*Bonasa umbellus*), sandhill crane (*Grus canadensis*), American coot, clapper rail (*Rallus longirostris*), king rail (*R. elegans*), Virginia rail (*R. limicola*), and sora (*Porzana carolina*) (Fisher et al. 2006). The authors of a risk assessment of lead shot exposure in non-waterfowl species concluded that, of upland game birds, the mourning dove (*Zenaida macroura*) is particularly at risk for lead poisoning mortality. This is because of cold susceptibility of lead-dosed birds, increased shot ingestion as hunting seasons progress, and because they frequent high-risk habitats (Kendall et al. 1996). Indeed, on managed dove fields, post-hunt shot availability has been reported to be as high as 860,185 pellets/hectare (Best et al. 1992). Furthermore, evidence exists that doves may ingest large numbers of lead shot and die rather quickly, thus being unavailable for harvest, the usual source of samples for estimating lead shot ingestion in doves (Schulz et al. 2002, 2006).

Limited work has been conducted on the hazard of spent ammunition to passerines. Lead exposure and toxicity was assessed in ground foraging white-throated sparrows (*Zonotrichia albicollis*) and brown-headed cowbirds (*Molothrus ater*) housed for 28 days in an outdoor aviary within a site that had been used as a trap and skeet range (Vyas et al. 2000). Supplemental feed was available for these birds. Free-ranging passerines were also mist-netted at the shooting range. Passerines housed in the aviary and free-ranging dark-eyed juncos (*Junco hyemalis*) exhibited elevated blood protoporphyrin levels, and sparrow and cowbird carcasses collected within the aviary had elevated concentrations of lead. Additional monitoring and establishment of diagnostic thresholds for lead toxicity in passerines were recommended. Using both deterministic and spatially explicit exposure models to examine risk from two small arms ranges, Johnson et al. (2007) found that songbird species (wood thrush, *Hylocichla mustelina*, northern cardinal, *Cardinalis cardinalis*, and eastern phoebe, *Sayornis phoebe*) had slightly elevated blood lead concentrations, although most values were below clinical effect levels.

Ingestion of fishing tackle. Lead fishing sinkers and jigs have contributed to lead poisoning mortalities in aquatic birds, particularly mute swans, whooper swans (*Cygnus cygnus)*, Canada geese (*Branta canadensis*), mallards, brown pelicans (*Pelecanus occidentalis*), and common loons (Locke et al. 1982, Blus et al. 1989, Pain 1992, Pokras and Chafel 1992, U.S. EPA 1994, Scheuhammer and Norris 1995, 1996; Daoust et al. 1998, Friend 1999, Stone and Okoniewski 2001, Franson et al. 2003, Sidor et al. 2003). Other species reported to ingest lead sinkers include trumpeter swans, tundra swans, redhead ducks (*Aythya Americana*), wood ducks (*Aix sponsa*), black ducks, red-breasted mergansers (*Mergus serrator*), double-crested cormorants (*Phalacrocorax auritus*), great blue herons (*Ardea herodias*), white pelicans (*Pelecanus erythrorhynchos*), royal terns (*Sterna maxima*), laughing gulls (*Larus atricilla*), herring gulls (*L. argentatus*), white ibis (*Eudocimus albus*), snowy egrets (*Egretta thula*), great egrets (*Ardea alba*), pochard (*Aythya ferina*), greater scaup (*Aythya marila*), white-winged scoters (*Melanitta fusca*), black-crowned night-herons (*Nycticorax nycticorax*), and bald eagles (Mudge 1983, U.S. EPA 1994, Scheuhammer and Norris 1995, Friend 1999, Franson et al. 2003, Scheuhammer et al. 2003b).

In their reviews, Scheuhammer and Norris (1995, 1996) stated that birds generally do not ingest lead fishing weights larger than 57 g (2 ounces). Thus, the hazard from fishing weights to waterbirds appear to involve mainly the smaller lead fishing weights used by sport anglers (Scheuhammer and Norris 1995) and not larger weights or downriggers. Franson et al. (2003), however, found one pyramid sinker in a common loon that weighed 78.2 g, and was 22 x 39 mm in size, and also found five sinkers in other waterbirds that were larger than 25 mm in one dimension, weighing <57 g. It has also been suggested, based on the recovery of fishing weights associated with other fishing tackle (i.e., swivels and hooks), that some birds such as the common loon may be ingesting lead fishing weight as a byproduct of ingesting the bait attached to the fishing tackle (Franson and Cliplef 1992, Stone and Okoniewski 2001). Once ingested, the lead object, if retained within the ventriculus, will be ground down and, combined with the effect of the acidic conditions in the digestive tract, lead will be released, absorbed into the blood, and, depending on the absorbed dose, potentially evoke toxic effects (IPCS 1989, Scheuhammer and Norris 1995, 1996, Nordic Council of Ministers 2003, Scheuhammer et al. 2003b).

A brief summary of some of the studies investigating lead poisoning associated with lead fishing sinkers in birds follows. In Britain, lead poisoning from the ingestion of fishing weights was shown to be the largest single cause of death (up to 90% of the mortality) in the mute swan population that had been declining since the 1960s (Simpson et al. 1979, Birkhead 1982, Birkhead and Perrins 1985, Kirby et al. 1994). This population trend was reversed following a ban on the sale of small lead fishing weights in Britain in 1987 (Delaney et al. 1992 cited in Kelly and Kelly 2004, Owen 1992, Kirby et al. 1994, Perrins et al. 2003). Nevertheless, mute swans in the region continue to die from lead poisoning. This is believed to be caused from the ingestion of lead fishing weights that were either lost prior to the 1987 ban or lost during illegal use after the ban, although other sources of lead cannot be ruled out (Perrins et al. 2003). Locke and Young (1973) reported the death of a tundra swan (previously called whistling swan) as being related to lead poisoning following the ingestion of a 2.97 g lead sinker lodged in its gizzard along with two copper swivels and assorted fish hooks. Among 18 trumpeter swans examined from Idaho, Montana, and Wyoming during 1976 to 1987, Blus et al. (1989) diagnosed lead poisoning as the cause of death for one male and three females that were found to have lead fishing sinkers in their gizzards.

Locke et al. (1982) reported that two common loons from New Hampshire and Wisconsin died of lead poisoning and contained lead fishing sinkers in their gizzards. In the northeastern United States, lead poisoning from ingestion of lead fishing sinkers or jigs has been reported as a frequent cause of death in adult common loons, accounting for about one-half of the mortality of examined dead adult loons. Pokras et al. (1992) examined 60 dead adults collected from 1989 to 1992, and 27 adults had ingested lead sinkers. Pokras and Chafel (1992) examined 75 dead loons of various ages from 1989 to 1990 and determined that 16 of 31 dead adult loons had ingested lead sinkers. Sidor et al. (2003) examined 254 dead or moribund breeding common loons and determined that 44% of loons died of lead toxicosis. Pokras et al. (1992) listed lead sinker and jig-related mortality in loons within New England as the single most important mortality source when compared to tumors, trauma, fractures, gunshot wounds, and infections. In a study examining common loon mortality in New York between 1972 and 1999, lead poisoning associated with the ingestion of fishing weights was deemed as the cause of death in 21% of 105 individuals, second only to infection as the leading cause of mortality (Stone and Okoniewski 2001). Lead fishing weights were recovered mainly from the stomach, but also from the colon and cloaca. In eight of these cases, other fishing tackle were found along with weights, such as swivels, snap-swivels, hooks and line. In the upper Midwest, Ensor et al. (1992) indicated that lead exposure appears to be a threat to loons in Minnesota, as 17% of those necropsied in their study died of lead poisoning, and Franson and Cliplef (1992) reported lead poisoning in 7 of 77 common loons from Minnesota and 2 of 17 from Wisconsin.

Franson et al. (2003) reported that common loons and brown pelicans ingested lead objects more frequently when compared to 26 other species of waterbirds sampled across the United States. They noted that 11 of 313 common loons found dead, brought sick to rehabilitation centers, or live-trapped when apparently healthy had ingested lead fishing weights including split shot, jig heads, and a pyramid sinker. In an earlier study of U.S. Geological Survey National Wildlife Health Center diagnostic records, Franson and Cliplef (1992) reviewed the records of 222 dead loons (69% adults) examined between 1976 and 1991. Of these, 14 were diagnosed as dying from lead poisoning. Lead fishing weights were found in the stomach of 11 loons, one loon had ingested fishing line, and the other two had no lead objects in their stomachs. All 14 loons diagnosed with lead poisoning were reported to be emaciated with elevated concentrations of lead in their livers, ranging between 4.7 to 46.1 μg/g wet weight. Notably, waterbirds trapped when apparently healthy rarely show evidence of lead sinker ingestion.

In eastern Canada, lead poisoning from lead fishing weight ingestion accounted for the largest percentage (22%) of deaths diagnosed in common loons from 1983 to 1995 in environments where loon breeding habitats and sports fishing activity overlapped (Scheuhammer et al. 2003b). Daoust et al. (1998) reported that five of the 31 common loons with lead fishing weights collected between 1992 and 1995 from the Maritime Provinces in Canada died from lead poisoning.

Loon mortality attributed to lead poisoning from the ingestion of fishing tackle is substantial in some geographical areas. This source of mortality has the potential to adversely affect local adult loon populations with a high level of exposure to fishing tackle due to intense fishing activity, especially if the population size is already depressed (Sidor et al. 2003). Nevertheless, in areas where loon populations are healthy and intense fishing activity does not overlap with loon populations, the ingestion of lost fishing tackle is less likely to be an important source of mortality compared to other sources (e.g., disease, trauma).

There are several reports of species less frequently affected by lead fishing gear. An adult female little penguin (*Eudyptula minor*) from Australia died from lead poisoning with ingested pieces of rock, glass, plastic, and metal, including a 1.0 gram (0.35 ounces) fragment of a lead fishing sinker (Harrigan 1992). Windingstad et al. (1984) reported lead fishing weights in two moribund sandhill cranes (*Grus canadensis*) diagnosed with lead poisoning. An endangered Mississippi sandhill crane (*G. c. pulla*), found dead with an unidentified triangular (8 x 8 x 10 mm) lead object in its gizzard, had a liver lead concentration of 69 µg/g wet weight (Franson and Hereford 1994). Additionally, a double-crested cormorant was found to have ingested a bell sinker, and a black-crowned night-heron had ingested a lead jig head; both birds were found dead (Franson et al. 2003). It should be noted that Anderson et al. (2003) examined the gizzards of 16,651 ducks in hunting areas in the Mississippi flyway and observed the presence of only one lead sinker.

There is also the risk of secondary poisoning linked to ingestion of lead fishing weights by predators and scavengers of waterbirds. For instance, if a predatory bird consumes lead fishing weights that were ingested by a prey animal, the predatory bird may be poisoned, because lead is easily dissolved by the low pH (pH 1-2) found in the ventriculus of the predator (Benson et al. 1974). Nevertheless, studies linking lead poisoning of predators to ingestion of lead fishing weights contained in their prey were not found in the literature.

Mammals

In an unusual case reported by Shlosberg et al. (1997), a captive bottlenose dolphin (*Tursiops truncatus*) died following accidental ingestion of lead air gun pellets at a public dolphinarium. Necropsy revealed 55 pellets in the second stomach, liver enlargement, acid-fast intranuclear inclusion bodies in the kidneys, and hepatic and renal lead concentrations of 3.6 and 4.2 µg/g wet weight, respectively.

During a 10-year period (1977 to 1986), 347 cases of lead poisoning in small companion animals were diagnosed at Angell Memorial Animal Hospital in Boston, Massachusetts (Morgan et al. 1991a, 1991b). The origin of lead exposure in these companion animals was most commonly paint chips, although lead-containing foreign bodies were found in the digestive tracts of 12 dogs.

Ingestion of lead shot and bullets by humans or dust associated with casting of lead ammunition has received considerable attention (Consumer Product Safety Bureau 2002). There are numerous case reports of accidental or purposeful ingestion (i.e., pica) of lead shot and lead sinkers by humans in the medical literature (Durlach et al. 1986, Madsen et al. 1988, Mowad et al. 1998, Gustavsson and Gerhardsson 2005). While consuming wild game killed with lead shot or bullets, humans may inadvertently ingest lead fragments or dust in the meat (Tsuji et al. 1999, Johansen et al. 2004). In one study of subsistence hunters in Canada, 15% of 132 radiographs showed ingested lead pellets, with 8% located in the lumen of the digestive tract and 7% in the appendix (Tsuji and Nieboer 1997). Ingestion of lead shot and bullets, or having these lodged in certain tissues, can result in lead intoxication (Khan 2005). Large numbers of shot or sinkers have been reported to be retained in the appendix, and in some instances they are surgically removed, particularly when accompanied by elevated blood lead concentrations. Removal of lead objects from the digestive tract seems to be most appropriate in children, due to their greater lead absorption rates compared to adults and the concern for developmental neurological effects (Gustavsson and Gerhardsson 2005).

Accidental ingestion of lead objects by children has been documented (Roberts et al. 1998, Durback et al. 1989), including the ingestion of a lead muzzle ball by a nine-year-old girl who successfully passed it in her stool 11 days after ingestion and showed no signs of lead toxicity (Durback et al. 1989). Previous studies have reported lead toxicity and lead-related mortality following ingestion of lead objects (i.e., key chain, block) that were retained in the gastrointestinal tract for extended periods of time (Durback et al. 1989).

After surgical removal of larger fragments from leadshot and bullets, lead intoxication arising from small retained fragments has been documented in several reports (e.g., Dillman et al. 1979, Linden et al. 1982, Beazley and Rosenthal 1984, Selbst et al. 1986, Stromberg 1990, Kikano and Stange 1992). Kikano and Stange (1992) indicate that the location of the bullet or shot fragments is important in determining whether lead intoxication will occur. Lead fragments in contact with the acidic synovial fluids may dissolve and enter the blood, whereas fragments embedded in soft tissue may be covered by avascular fibrotic tissue, inhibiting lead dissolution and absorption into the blood (Kikano and Stange 1992). Additionally, the number of fragments is more important than their size, as the combined surface area of multiple fragments can be more than a single fragment, as evidenced by lead intoxication occurring earlier when multiple fragments are involved rather than a single bullet (Kikano and Stange 1992).

Many sportsmen who reload rifle and pistol ammunition cast their own lead bullets, an activity particularly popular with black powder shooters. Molds to cast lead bullets are commercially available. Bullet molds and catalogs generally carry the warning, "Melting lead and casting lead objects will expose you and others in the area to lead, which is known to cause birth defects, other reproductive harm and cancer," and also provide guidelines for reducing exposure (Anonymous 2006).

Ingestion of lead sinkers or inhalation of the fumes and dust associated with manufacturing sinkers can be harmful to humans. When sinkers are ingested, the occurrence of lead toxicity depends on the length of time that the object is retained in the stomach (Fergusson et al. 1997). If the lead object is retained in the stomach long enough to be dissolved by gastric acid, then the dissolved lead will be absorbed by the small intestine. Once the lead object is out of the stomach and in the small intestine, there is less risk of lead toxicity. In one case report, a four-year-old girl who had ingested a 1.0 cm lead sinker did not suffer any harm as the object was removed soon after ingestion (Fergusson et al. 1997). In another case, an eight-year-old boy ingested 20 to 25 lead sinkers and a nail (Mowad et al. 1998). After hospitalization and removal of most of the sinkers, and eventual passing of the remaining sinkers, the lead concentration in the blood of the boy dropped from 53 µg/dL to 45 µg/dL after six days, and to 3 µg/dL after one month.

Population level effects

Lead poisoning from ingested shot is a well-documented cause of mortality in waterfowl, and may impact populations at the local level but has not been definitively linked to large-scale effects on waterfowl populations. Bellrose (1959) estimated that 2% to 3% of the annual losses of North American waterfowl between 1938 and 1954 could be attributed to poisoning from ingested lead shot. Species with low recruitment rates, depressed populations, and those in recovery (e.g., the bald eagle during the 1950s to 1980s, the spectacled eider in the 1990s, and the California condor currently in North America) are particularly vulnerable (Pattee and Hennes 1983, Grand et al. 1998, Church et al. 2006). Lead exposure or poisoning from ingested lead shot or bullet fragments has been described in more than 50 avian species other than waterfowl (Fisher et al. 2006), although demographic effects are incompletely known. It is clear that waterfowl and waterbirds, particularly common loons, can suffer lead toxicosis and mortality from ingestion of lead sinkers. Ingestion of lead shot by waterfowl is widespread, while ingestion of lead sinkers by waterbirds seems to be more geographically restricted. However, ingestion of lead fishing weights by common loons is of concern, particularly where populations are declining. The direct effect that ingestion of lead from spent ammunition, fishing weights, and smaller jigs may have on populations of amphibians, reptiles, and wild mammals is unclear. Nevertheless, the potential hazard of lead on aquatic and terrestrial ecosystem fauna and humans lends support to an ongoing comprehensive effort to reduce lead introduced in the environment by human activities.

REGULATIONS AND BANS ON LEAD AMMUNITION AND FISHING TACKLE

The desire to limit lead exposure in humans has resulted in several international conventions and treaties, as well as national restrictions to minimize environmental release of lead from anthropogenic activities (Nordic Council of Ministers 2003). In a survey summarized in the 2000 International Update Report on Lead Poisoning in Waterbirds, 54% of responding nations (i.e., 74 of 137) indicated that they had regulations on the use of lead shot, and 27% of the remaining countries indicated that lead shot legislation was being prepared (Beintema 2001). Several papers provide an overview of national restrictions that are specific to the use of lead shot (Scheuhammer and Norris 1995, Beintema 2001, Nordic Council of Ministers 2003). These restrictions range from voluntary, partial statutory bans applied to certain species and areas, to total statutory bans for all waterbird hunting. Examples of voluntary use of non-toxic shot by nations include Germany's voluntary ban (i.e., recommendation) on use of lead shot (Beintema 2001) and the 1999 implementation of the four-year voluntary use of non-toxic shot for all wetland bird hunting in the United Kingdom (DEFRA 2001). Partial statutory bans on the use of lead shot for hunting select species, or use of lead shot in specific areas, have been instituted in many countries (e.g., Australia, Belgium, Cyprus, Ghana, Israel, Japan, Malaysia, Mexico, Russian Federation, South Africa, Spain, Sweden, United Kingdom) (Beintema 2001). Total statutory bans on using lead shot to hunt any waterbird species exist in countries such as Canada, Denmark, Finland, Netherlands, Norway, and Switzerland, and specifically waterfowl and coots in the United States (Beintema 2001, Nordic Council of Ministers 2003).

The potential adverse impacts of ingested lead fishing weights on aquatic fauna and humans have also resulted in societal pressure to have restrictions placed on the sale and use of lead fishing weights. For instance, nations applying at least some restrictions on the sale and use of lead fishing sinkers and jigs include Denmark, Canada, Great Britain, and the United States (partially summarized by Nordic Council of Ministers 2003). As pointed out by Thomas and Guitart (2005), there has been limited transfer of the rationale for phasing out lead in hunting to restricting its use in fishing activities.

In 2006, D.J. Case & Associates was engaged by the Ad Hoc Mourning Dove and Lead Toxicosis Working Group (Fish and Wildlife Health Committee of the Association of Fish and Wildlife Agencies) to conduct a survey on the current status of nontoxic shot regulations for hunting waterfowl, game birds, and upland birds. The survey was distributed to 50 states, 10 Canadian provinces, and two Canadian territories (D.J. Case & Associates 2006). Data were obtained from 56 (90%) of these entities that addressed nontoxic shot regulations for dove, crane, rail, snipe, quail, and pheasant hunting. Forty-five percent of the states and provinces that responded have nontoxic shot regulations for some or all of these species that extend beyond those required by U.S. federal law for waterfowl hunting (note: Canadian regulations include migratory birds such as snipe and rail not addressed by U.S. federal non-toxic shot regulations). These states and provinces include Alaska, California, Illinois, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Missouri, Nebraska, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Ontario, Oregon, South Dakota, Utah, Washington, and Wyoming. In some instances, the restrictions apply to public land but not private land. The nontoxic shot regulations were more widespread for species with habitats that coincide with waterfowl (e.g., crane, snipe, rail) and, to a lesser extent, doves. The use of nontoxic shot presently is less restrictive for upland game birds (e.g., grouse, quail, pheasant).

There have been several efforts to restrict the use of lead ammunition in the range of species of concern (e.g., California condor, spectacled eider and other waterbirds). The Arizona Game and Fish Department website provides a list of distributors of non-lead ammunition in a range of calibers, and in 2005 free redeemable coupons were issued to deer hunters for non-lead ammunition (Arizona Game and Fish Department 2007). In California, the Condor Preservation Act was recently approved; it requires the use of non-lead ammunition for hunting big game and coyotes in the range of the California condor in central and southern California (Center for Biological Diversity 2007). The risk of lead exposure to waterbirds, including the threatened spectacled eider, was an important factor considered by the Alaska Board of Game in the adoption of a proposal in November 2007 to prohibit the use of lead shot T size and smaller for small game, furbearers, and unclassified game on the entire Yukon-Kuskokwim Delta. This new action, in conjunction with nontoxic shot regulations already in place for waterfowl hunting, effectively bans the use of all lead shot in this area, except for buckshot used for predators.

In 1994, the U.S. EPA proposed a nationwide ban on the manufacture, importation, processing, and distribution of fishing sinkers containing lead or zinc that are <25.4 mm in any dimension (U.S. EPA 1994). These regulations were not ratified. Nonetheless, Maine, Massachusetts, New Hampshire, Vermont, and New York have instituted restrictions on the use or sale of certain lead sinkers and jig heads, and lead sinkers are prohibited at certain reservoirs used by loons in Massachusetts (see Appendix 1A and 1B) (Michael 2006). Lead tackle is also banned on some federal lands that have loon and swan populations, including Red Rock Lakes National Wildlife Refuge (NWR) in Montana, the National Elk Refuge in Wyoming, Yellowstone National Park in Wyoming, Bear Lake NWR in Idaho, Seney NWR in Michigan, Union Slough NWR in Iowa, Rachel Carson NWR in Maine, Assabet River NWR in Massachusetts, and Rappahannock River Valley NWR in Virginia (see Appendix 1A) (Franson et al. 2003, Michael 2006).

In 1999, the U.S. FWS announced its intention to establish additional lead-free fishing areas by expanding the prohibition of certain fishing sinkers and jigs to more national wildlife reserves used by loons (U.S. FWS 1999). In addition to national wildlife reserves, proposed lead-free fishing areas included refuges, wilderness areas, and waterfowl production areas in Alaska, Florida, Maine, Minnesota, and Wisconsin (U.S. EPA 1999, U.S. FWS 1999). A nationwide decision on the use of lead fishing sinkers and jigs on refuges has yet to be made by the U.S. FWS.

Canada amended its Wildlife Area Regulations and its National Parks Fishing Regulations (Ottawa RiverKeeper 2005) to prohibit the use of lead sinkers or jigs weighing <50 g (1.76 ounces) in national parks and national wildlife areas in 1997 (Appendix 2A and 2B) (Canadian Wildlife Service 1997, Canadian Wildlife Service National Site 2005, Department of Justice Canada 2006a and 2006b, Michael 2006). The Canadian House of Commons discussed the proposal to expand the existing but limited ban on lead fishing tackle during 2002 (Canada House of Commons Debates 2002). In 2004, the Minister of Environment announced intentions to develop regulations to prohibit the importation, manufacture, and sale of lead fishing sinkers and fishing jigs <2.5 cm, and Environment Canada released a discussion paper entitled "Fishing lead-free: a regulatory proposal," which discussed and sought public comment on a proposed regulatory initiative (Environment Canada 2004a, Canadian Wildlife Service National Site 2005, Environment Canada 2005). The Government of Canada has yet to finalize its national lead sinker risk management strategy. To date, beyond the restrictions on national parks and wildlife areas, there are no general provincial or territorial regulations restricting the use of lead fishing tackle in Canada.

RESULTS OF CURRENT LEAD BANS FOR HUNTING, SHOOTING SPORTS, AND FISHING ACTIVITIES

Prior to restrictions on the use of lead shot for hunting waterfowl and coots, estimates of annual waterfowl mortality in North America related to lead poisoning ranged from 1.6 to 3.9 million birds (Bellrose 1959, Feierabend 1983). Within five to six years following the ban on use of lead shot for hunting waterfowl, a large-scale study conducted in the Mississippi flyway demonstrated dramatic reductions in the ingestion of lead shot (Anderson et al. 2000). Of the gizzards containing ingested pellets, 68% of mallards, 45% of ring-necked ducks *(Aythya collaris),* 44% of scaup, and 71% of canvasbacks contained only nontoxic shot. Anderson et al. (2000) estimated that lead poisoning of mallards was reduced by 64% in the Mississippi flyway and projected that 1.4 million ducks of the North American fall continental flight were spared from fatal lead poisoning. Another approach to assessing exposure to lead shot involves a threshold concentration of 0.2 ppm in blood (Friend 1985). Using this criterion, Samuel and Bowers (2000) demonstrated a 44% reduction in lead exposure of black ducks from Tennessee by comparing exposure prevalence in 1986 through 1988 to that in 1997 through 1999 after the ban in lead shot for hunting waterfowl. Samuel and Bowers (2000) suggest that conversion to nontoxic shot conservatively reduced lead exposure in waterfowl by 50%. Similarly, in Canada, substantial decreases (52% to 90%, depending on species and location) in mean bone lead concentrations in hatch-year ducklings have occurred since nontoxic shot regulations were established (Stevenson et al. 2005).

No information about compliance in the use of lead-free fishing weights in Canada and the United States was found. Officials from Maine, New Hampshire, Vermont, and New York stated that their regulations to restrict the sale and use of lead sinkers were too recent for compliance data to be obtained. It was reported, however, that the number of lead-poisoned swans from the River Thames and adjacent waters dropped from a peak of 107 in 1984 to 25 in 1988, a year after the ban on the sale of lead fishing weights (Sears and Hunt 1991). Perrins et al. (2002) examined lead poisoning of swans in the United Kingdom following the 1987 ban. In this study, 13.7% of fishing tackle with weights that were removed from rescued swans (34/249 swans) included illegal lead weights, suggesting that some anglers may be violating the ban, unless the swans had ingested lead weights that were lost prior to the ban. An unpublished study using surveys to assess compliance of anglers to the 1987 United Kingdom ban found that only 7% of anglers were using banned lead fishing weighs (A. Taylor personal communication cited in Perrins et al. 2003).

ALTERNATIVES TO LEAD AND THEIR CURRENT USE IN HUNTING, SHOOTING SPORTS, AND FISHING ACTIVITIES

Ammunition

There has been an extensive effort by the U.S. FWS to develop testing guidelines for registration of shot that does not contain lead. Initially, test guidelines for candidate shot were focused exclusively on toxicity tests related to waterfowl (erosion rate tests, and acute, chronic, and reproductive trials) (U.S. FWS 1986). Subsequently, concern was expressed by staff of the U.S. FWS (Rattner and Morehouse 1994) that, from an ecosystem management perspective, there was a need to evaluate the potential toxicity of candidate nontoxic shot in other species such as invertebrates and fish. Rattner and Morehouse (1994) developed a tiered-testing protocol to evaluate candidate material as potential nontoxic shot. In tier 1, the applicant was required to compile existing acute and chronic toxicity data for biota (invertebrates, fish, amphibians, reptiles, birds, and mammals) as well as information on erosion and absorption of the candidate shot, and to estimate environmental concentrations upon use and conduct a risk assessment using the quotient method. Pending results of the tier 1, erosion rate testing, short-term toxicity testing in waterfowl, acute and chronic testing in *Daphnia* spp., and fish early life stage toxicity tests might be required. Pending results of tier 2, the candidate material might be further evaluated in long-term toxicity tests under depressed environmental temperature and reproductive trials in mallards. This tiered tested scheme was formalized in 1997 (U.S. FWS 1997).

Based upon results in the aforementioned testing scheme, there are now many shot types and shot coatings that are approved and commercially available for hunting waterfowl and coots (e.g., steel, bismuth-tin, tungsten-bronze, tungsten-iron, tungsten-matrix, tungsten-nickel-iron, tungsten-polymer, tungsten-tin-bismuth, tungsten-tin-iron, tungsten-tin-iron-nickel) (U.S. FWS 2004, 2007). At least one candidate material, zinc, was found to be highly toxic when administered to waterfowl (Levengood et al. 1999), and was not approved. Alternative shot types have come into widespread use in North America. Notably, the U.S. military embraced the use of "environmentally green ammunition" in 2000. However, testing of heavy metal tungsten alloys (used in large caliber ammunition by the military) in cell culture systems has revealed effects on gene expression involved in toxicity and tumorigenesis (Miller et al. 2004). Furthermore, studies of tungsten alloys in male F344 laboratory rats (*Rattus norvegicus*) demonstrated the development of tumors (rhabdomyosarcomas) within several months of implanting the material (Kalinich et al. 2005).

The voluntary use of lead-free ammunition is gaining popularity with public and private shooting range facilities as a strategy for minimizing lead release and the potential for adverse environmental effects. There are a wide variety of lead-free ammunition products available, including those manufactured from tin, zinc, copper, steel, polymers, and various composite materials. Ammunition can be manufactured with a lead-free detonating mixture (primer) and a lead-free bullet (projectile), and thus both components can be made without lead. Rifle and handgun bullets composed of 100% copper and rifle bullets composed of a tungsten-core are available for hunting, and are also available as reloading components or as factory-loaded ammunition (California Department of Fish and Game 2007). For target shooting, there are both frangible and non-frangible lead-free ammunition made of copper and tin that are available from a variety of manufacturers (Ventana Wildlife Society 2007).

In general, the cost of lead-free ammunition is about twice that of lead ammunition (INFORM, Inc. 2007). However, the cost to purchase lead-free ammunition likely would more than offset the cost involved in regular cleanup and management of lead debris as hazardous waste. The price of lead-free ammunition has continued to drop over time as demand has risen. Both Arizona and California have published a list of non-lead ammunition for hunting, which includes rifle, shotgun, muzzleloader, and pistol ammunition (Arizona Game and Fish Department 2007, California Department of Fish and Game 2007).

There are a variety of minimization practices for continued lead uses at shooting sports facilities. The U.S. EPA (2005) recently issued a revised set of best management practices for lead at outdoor shooting ranges. Among the best management practice recommendations are the use of lime to increase soil pH, the planting of vegetation, the use of bullet traps, recycling spent lead, and containment of lead to prevent migration off-site. The Department of the Interior maintains a website on sustainable practices that includes guidance and resources on environmental management of outdoor shooting ranges (U.S. DOI 2007). This website includes links to state websites (Florida, Massachusetts, Michigan) with active stewardship programs for their outdoor shooting ranges. The Interstate Technology and Regulatory Council (ITRC) has also published a document on environmental management of outdoor small arms firing ranges (ITRC 2005).

Fishing Tackle

The fishing tackle manufacturing industry was initially reluctant to seek and manufacture alternatives to lead fishing tackle. This reluctance partially stemmed from the associated high cost of re-tooling equipment to manufacture tackle using different materials, particularly since lead is quite malleable in comparison to alternative materials (Geoffrey Ratte, Water Gremlin Company, personal communication). Additionally, the industry requested scientific information on the safety (i.e., low toxicity) of the alternative materials. Nevertheless, today most fishing tackle retail stores in Canada and the United States carry alternatives to lead sinkers. The fishing tackle industry might benefit if any rules or regulations concerning the sale and use of lead-free tackle are consistent among jurisdictions in order to allow industry to re-tool, manufacture, and package tackle that can be sold in all markets. This latter request has yet to be met as evidenced by the disparity in lead tackle regulations within Canada and the United States (see Appendices 1 and 2).

Substitutes for lead fishing tackle have been available in retail stores for several years (Scheuhammer and Norris 1995, 1996, Simpson 2001, Nordic Council of Ministers 2003, Scheuhammer et al. 2003b, Michael 2006). The Nordic Council of Ministers (2003) estimated that the lead in most sinkers and jigs used for angling could be substituted with iron, tin, or zinc, with tin being appropriate for split shot and iron for sinkers. All alternatives are more expensive than lead and some, such as bismuth and tungsten, are considerably more expensive, and some are made of materials known to be toxic to birds and other biota (e.g., zinc: Grandy et al. 1968, Zdziarski et al. 1994, Levengood et al. 1999). (Figure 12)

Sinkers made from alternative materials have been accepted in varying degrees depending on their cost and effectiveness in fishing. Several of these alternatives, including ceramics and tin, are not as dense as lead and, hence, need to be larger to produce the same weight. Many anglers believe this increase in size is detrimental when inducing fish to take the offered bait. Other alternatives such as steel, while somewhat larger in size, have been advertised as making more noise as they bump over the bottom, which is claimed to serve as an attraction to fish and to increase the tendency for fish to strike.

At least 10 substitutes for lead fishing tackle seem to have found some acceptance in the marketplace (MOEA 2006). These include tungsten (both plastic composites and putty), stainless steel, carbon steel, tin, tin/bismuth, brass, ceramics, glass, pewter, and zinc (Scheuhammer and Norris 1995, Nordic Council of Ministers 2003, Scheuhammer et al. 2003b, European Commission Enterprise Directorate-General 2004, MOEA 2006).

Tungsten, in its various forms, appears to be one of the more widely accepted substitutes for lead in fishing tackle (European Commission Enterprise Directorate-General 2004, MOEA 2006). Tungsten is sold as a tungsten-plastic composite and as tungsten putty. Tungsten putty, which is a specialty product marketed to fly fishers, can be molded into different shapes of varying sizes and affixed to fishing line, which enables anglers to vary the sink rate of their fly presentation. Tungsten is comparable to

Figure 12. Relative sizes of sinkers manufactured from different materials. Top row: 0.1 oz lead and tin split shot. 2nd row: 0.2 oz lead and tin split shot. 3rd row: 0.8 oz lead, bismuth, and plastic/iron composite egg sinkers. (courtesy of Water Gremlin. Photograph by T. Lawrence, Great Lakes Fishery Commission)

lead in density and in some circumstances may be smaller than lead with the same weight. It seems to have some noise-making attributes that may serve to attract fish in certain situations. The expense of tungsten tackle is significantly greater than lead tackle, due to the much higher cost of the tungsten itself and the requisite need for plastic sleeves to cover the sharp edges on tungsten products. Its future availability to anglers and its cost is questionable, due to its increasing demand for shotgun shell pellets and military uses. Nevertheless, tungsten-plastic composites are becoming one of the more popular alternative products because they can be manufactured to be more or less dense than lead (European Commission Enterprise Directorate-General 2004, MOEA 2006) and because some of the tungsten-plastic products have scent attractants added during the manufacturing process. Tungsten products currently are available in the larger retail sporting good stores, via catalogues and the Internet (MOEA 2006).

Stainless steel substitutes are advertised (but not scientifically verified) as having a competitive edge over lead for fishing because of the fish-attracting noise it makes as it bounces, but stainless steel tackle is larger than the lead tackle it is meant to replace (European Commission Enterprise Directorate-General 2004, MOEA 2006). At least one major manufacturer is producing this product as an alternative to lead and it is becoming more widely available in retail sporting goods stores.

Carbon steel has been used to create products that have no lead counterpart. Some manufacturers are using recovered steel from solid waste and mixing it with resins. This product uses steel balls within a cotton sleeve. By adding or subtracting steel balls on a three-way swivel, anglers can adjust the sink rate to hold the bait on the bottom. The popularity of this gear is increasing in river fisheries. Steel is also being used to replace lead in a wide variety of commercial traps. It is primarily available through the Internet.

Iron is among the cheaper alternatives to lead, although still more expensive than lead (European Commission Enterprise Directorate-General 2004). Unfortunately, iron is a more difficult material to use in the manufacturing of fishing weights and tends to corrode after exposure to water.

Tin alternatives have a superior malleability that allows anglers to reuse the split shot many times before it is lost or discarded. Some anglers like the lower density as they feel the slower sink rate allows the bait to stay in the "strike zone" longer. However, tin alternatives tend to be larger in size and are more costly than lead (European Commission Enterprise Directorate-General 2004, MOEA 2006). Tin alternatives are available in many sporting goods stores.

Bismuth is brittle and can be used in non-split fishing weights, including egg, worm, swivel, bullet slips, and jig heads (Scheuhammer and Norris 1995). The use of bismuth/tin compounds is becoming popular for anglers who make their own jigs. The advent of better paint quality on jig heads using bismuth/tin makes this alternative more attractive. The use of bismuth, however, is becoming economically nonviable because of the high cost of the raw material.

Brass alternatives are advertised as producing sound with fish-attracting qualities. Brass alternatives, however, often include lead mixed with the brass and are not considered to be lead-free tackle, even though the lead is in a bound state that is not thought to be toxic (MOEA 2006). Brass is less dense than lead, hence the larger size for the same weight, and brass costs more than lead. More importantly, brass is an alloy of copper and zinc, and metallic zinc is known to be highly toxic to birds when ingested (Grandy et al. 1968, Zdziarski et al 1994, Levengood et al. 1999). At this time, brass sinkers have had limited use, even though they are available on the shelves of many retail outlets.

Glass fishing tackle tends to be larger and more expensive than lead. A selling point for one type of glass is that it can be made to "glow" after it has been stimulated by light, which many anglers believe improves fish biting frequency. Nevertheless, the large size for a one-ounce glass sinker has reduced acceptance by most anglers. It is currently available through the Internet and some small stores in the midwestern United States.

Ceramic, pewter, and zinc fishing tackle currently are not favored alternatives. Ceramic fishing tackle is considerably larger in size than lead tackle. Lead-free pewter has not been widely explored as an alternative to lead, but it is expected that the size of pewter tackle will be larger and more costly than lead. Pewter tackle currently is not available to consumers. Zinc was used initially as a replacement for lead sinkers, until it became widely known that the industrial grade zinc used in the tackle actually was more toxic in the aquatic environment than lead (Grandy et al. 1968, Zdziarski et al. 1994, Levengood et al. 1999).

Although several substitutes for lead sinkers currently are available, lead fishing sinkers remain very popular with anglers as they are economical and perform well. None of the lead-free alternatives offer the overall performance of lead fishing tackle with respect to specific gravity, malleability, ease of production, and cost. If anglers were unable to purchase lead products and had to purchase lead alternatives, it is estimated that their annual increase in cost would be $5.00 to $25.00 (MOEA 2006). The accuracy of this estimate depends on the cost of the raw material used in the production of lead-free fishing tackle. Currently, it is unknown whether the difference in performance and estimated increase in cost will be significant enough to deter anglers from switching to tackle manufactured from alternative materials or reduce participation in fishing. Angler acceptability of the various substitutes for lead sinkers has not been formally investigated beyond the fact that alternatives to lead sinkers are being purchased and used.

Some states in the U.S. and Environment Canada, as well as nongovernmental organizations, are offering programs that exchange non-lead tackle for angler-owned lead tackle (Rondeau Bay Watershed Rehabilitation Program 2000, Environment Canada 2004b, MOEA 2006, Severn Sound Environmental Association 2007). This educational campaign is to show anglers that non-lead substitutes exist, as well as to educate them on the toxicity of lead in the aquatic environment. It should be noted that these programs exist on a small scale and generally rely on the industry to supply the alternative tackle at no cost or at greatly reduced cost. Programs such as this are targeting younger anglers and should increase anglers' use of lead-free alternatives.

RESEARCH AND MONITORING NEEDS ON EXPOSURE AND EFFECTS OF SHOT, BULLETS, AND FISHING TACKLE ON ORGANISMS AND THEIR HABITATS

There are ample data on the effects of various forms of lead on invertebrates, fish, birds, and mammals, although data for amphibians and reptiles are lacking. Furthermore, a great deal is known about the hazards of ingested spent lead ammunition or fragments in many species of birds and mammals. Because the mechanism and adverse effects of lead are well documented, it is likely that the effects of lead shot, bullets, and fishing tackle at and below the organismal level could be extrapolated to adequately predict effects for birds and mammals.

Exposure and effects data for ingested lead shot, bullet fragments, and fishing tackle are lacking for aquatic fauna, amphibians, and reptiles. For some species and situations, our understanding of lead and alternative materials used in shot, bullets, and fishing tackle would be improved through monitoring, experimental and empirical studies, and modeling efforts. A broad range of topics worthy of investigation follows.

Basic Toxicological Data

Toxic reference values (effect thresholds) are needed for alternative (non-lead) shot, ammunition and fishing tackle in fish, amphibians, reptiles, and some species of birds (e.g., passerines). Ideally, comparative information on the relative toxicity of alternative materials to lead should be generated. Some additional lead toxicity data on amphibians and reptiles would assist interpretation of tissue concentrations in animals collected in proximity to shooting ranges and waterbodies with low pH and significant angling pressure.

Environmental Chemistry

Although a great deal is known, additional data are needed on the weathering, dissolution, and long-term fate of solid lead materials used in ammunition and fishing tackle in aquatic and terrestrial ecosystems. Modeled and empirical data are needed on the half-life of lead fragments, rate of release of lead from fragments, and bioavailability of released lead under differing types of conditions (pH, anaerobic and aerobic, soil and sediment, freshwater, estuarine, and marine systems).

Exposure Assessment

The application of newer technologies to discriminate source (anthropogenic versus naturally occurring) of lead in environmental and biological samples would assist in exposure assessments. For example, measurement of stable lead isotope ratios to identify the source of lead in environmental samples (ammunition versus mining wastes) has recently been used to document exposure of California condors to lead ammunition (Church et al. 2006).

Monitoring Exposure and Effects

Data are needed on the extent to which spent lead ammunition from hunting and lost tackle from fishing are directly ingested by reptiles and piscivorous birds, and the incidence of lead poisoning in these groups. Information about ingestion of spent lead ammunition and lead fishing tackle in fish, amphibians, swans, rails, and mammalian predators would be a secondary priority. More efficient interaction and development of an infrastructure between various entities (e.g., federal and state governmental agencies, academia, and conservation agencies) in identifying incidents of lead and other contaminant-related poisoning in wildlife would be beneficial. The compilation of data from such efforts would be appropriate. Broad scale investigations of lead poisoning in wildlife should be implemented in countries where the extent of this problem in wildlife is poorly documented or unknown.

The fate of spent ammunition and mobilized lead at and near shooting ranges in a variety of climates and habitat types is needed to more completely assess the extent of this issue. Data on lead movement, concentrations, and effects in environmental matrices and biota (plants and animals) in proximity to such sites would help resolve this issue. Monitoring the success of remedial activities is also appropriate.

Assessment and evaluation of the results of currently implemented prohibitions on the use of lead ammunition and fishing tackle on exposure, health, and survival of biota (particularly birds) in aquatic and terrestrial ecosystems are warranted.

SUMMARY

Lead is a metal with no beneficial role at the molecular or cellular levels of biological organization, and its hazards have been recognized for millennia. Its use in gasoline, paint, pesticides, and solder in food cans has nearly been eliminated. Nonetheless, its use in ammunition for hunting and shooting sports and in fishing tackle remains widespread, despite well-documented adverse effects to wildlife (waterbirds, raptors, and scavenging species) (Table 2).

Elemental lead from spent ammunition and lost fishing tackle is not readily released into aquatic and terrestrial systems, although under some environmental conditions such fragments can weather to yield forms of lead that are more mobile and bioavailable to plants and animals. In some circumstances, environmental contaminant problems from mobilized lead can arise in proximity to shooting ranges, and, potentially, at heavily hunted sites. The most significant hazard to wildlife, however, is through the direct ingestion of spent lead shot and bullets, lost fishing sinkers and tackle, and related fragments, or through consumption of wounded or dead prey or their remains containing lead shot, bullets, and/or fragments. (Figure 13)

The scientific literature is replete with evidence that ingestion of spent ammunition and fishing tackle can be lethal to birds, and the magnitude of poisonings in some species (e.g., waterfowl, eagles, California condors, swans and loons) is daunting. By the late 1980s, various regulations on the use of nontoxic shot for hunting waterfowl and coots were being implemented in the United States and Canada, and a ban on the use of lead fishing sinkers was instituted in Britain to protect swans. Safe alternatives to lead shot and fishing sinkers have become commercially available.

Many countries, and several U.S. states, now restrict the use of lead in ammunition and fishing tackle and have expanded the scope of species to be protected. For example, in the United States, investigations assessing effects of lead shot ingestion are being conducted in more species (e.g., chukars, mourning doves; Walter and Reese 2003, Schulz et al. 2006), and discussions regarding the implications of lead toxicosis are an ongoing issue among managers and policy-makers (e.g., Non-toxic Ammunition Task Force and its Ad Hoc Mourning Dove and Lead Toxicosis Working Group of the Association of Fish and Wildlife Agencies). Most recently, restrictions have been placed upon the use of lead ammunition in parts of the range of the endangered California condor.

The understanding of the hazards of lead used in shot, bullets, and fishing tackle would benefit from broad-scale monitoring of the incidence of lead poisoning in wildlife in countries where the extent of the problem is poorly documented. Additional data about the incidence of lead poisoning related to fishing tackle in aquatic birds and reptiles is needed to better understand the magnitude of this problem. More complete information on the weathering, dissolution, and long-term fate of lead fragments and the bioavailability of lead in various aquatic and terrestrial ecosystems is also warranted.

Figure 13. Radiograph of fishing tackle in the digestive tract of a common loon *(Gavia immer).* (courtesy of Minnesota Department of Natural Resources).

SOME MANAGEMENT IMPLICATIONS

As stewards of terrestrial and aquatic ecosystems, natural resource management agencies, conservation organizations, manufacturers and retailers

Table 2. Evidence and Magnitude of Lead Exposure. Adverse Effects and Poisoning Directly Related to Ingestion of Spent Ammunition, Fishing Tackle, and Fragments in Fish, Wildlife, and Man.

Endpoint	Fish	Amphibians	Reptiles	Birds			Mammals	Man
				Waterbirds	Upland	Scavenging		
EXPOSURE								
Ingestion	+	+	+	+++	++	++	+	+
Lead detected in tissues		+	+	+++	++	++	+	+
ADVERSE EFFECTS								
Molecular				+++	++	++	+	
Cellular and histopathology				++	++	+		
Organ System			+	+++	++	+		
Organismal (including death)			+	+++	++	++	+	+
Population-level				+++	+	++		

of ammunition and fishing tackle, and the public at large work actively and often collectively to protect natural resources. Minimizing the introduction or release of any toxic substance that can evoke serious and unintended adverse effects into the environment is a tenet of such stewardship. Stated in ecological risk assessment and regulatory terminology, attempts should be made to limit exposure (i.e., hazard), and thereby minimize the probability of toxicity (i.e., risk). In many settings, minimizing or restricting the use of lead ammunition and fishing tackle would be beneficial to waterbirds, scavenging birds, upland birds, and possibly other species.

Decisions and strategies for lead ammunition and fishing tackle

The leadership of both the American Fisheries Society and The Wildlife Society seek to address the scientific data on the hazard and risk of lead in hunting, shooting sports, and fishing activities to fulfill their conservation missions. Brief position statements defining the issues, factual background data, the probable biological, social, and economic results of alternatives, and the recommended course(s) of action may be drafted. There are at least three options for the recommended course of action on continued use of lead in hunting, shooting sports, and fishing activities.

(1) The introduction of lead into the environment from hunting, shooting sports, and fishing activities is adequately regulated, and its toxicological consequences to natural resources are currently considered acceptable.

(2) The introduction of lead into the environment from hunting, shooting sports, and fishing activities could be restricted in locations where lead poses an unacceptable hazard to biota and their supporting habitat.

(3) The introduction of lead into the environment from hunting, shooting sports, and fishing activities could be phased out with a goal of complete elimination.

Option 1 (status quo) embraces the notion that the most serious effects of lead from hunting, shooting sports, and fishing activities have already been addressed by regulations in many countries. In time, other countries will probably follow suit. Some might argue that there are inadequate scientific data to reach a sound management decision, and the economic burden of further restricting the use of lead in hunting, shooting, and fishing activities outweighs the conservation benefits.

Option 2 (proposal of restricted use) embraces the notion that lead does not have any beneficial effects and in certain forms (e.g., lead fragment) and exposure pathways (e.g., ingestion) can evoke toxic effects in some species (e.g., waterbirds, scavenging, and upland birds). This alternative is moderate in character. Actions to prevent or minimize the ingestion of lead from spent ammunition and lost fishing tackle would be provided to those species of concern and their supporting habitat. For example, the smaller-sized fishing sinkers that tend to be ingested by some waterbird species and the use of lead fishing sinkers and ammunition in habitats that result in increased lead-poisoning mortality of wildlife would ultimately be regulated. Based on current knowledge, large lead objects used in fishing (e.g., downrigger weights; weights used in commercial traps and nets; lead core fishing line; lead sinkers >25.4 mm in length and >57 g in weight, Scheuhammer and Norris 1995, 1996) do not seem to pose a hazard to biota in most aquatic settings, and would, therefore, not require changes in their use. Nevertheless, if new and significant data that identified a previous unrecognized hazard of a particular size or use of lead ammunition or fishing tackle, restrictions on their use might be subsequently imposed. Such decisions could employ the precautionary principle and a weight-of-evidence approach driven by the realization of unacceptable levels of adverse effects. The adverse effects could be focused on hazard (e.g., subclinical lead exposure) and possibly even more substantial responses (e.g., mortality), but need not be focused on the demonstration of a population-level consequence. Notably, migratory birds and other species are protected by broad legislative provisions (e.g., Migratory Bird Treaty Act, Endangered Species Act) and various international conventions and conservation agreements (Beintema 2001). The precedent to render protection to biota without demonstrating a population-level effect is also supported by the U.S. EPA ruling restricting the use of the pesticide diazinon. The ruling was in part based upon "an expectation of future harm" (i.e., risk of injury) and inferences that waterfowl could be exposed to acutely toxic levels of this pesticide (Bascietto 1998).

Option 3 (proposal of elimination) embraces the notion that lead does not have any beneficial role in biological systems, and in certain forms and exposure pathways can have profound toxicological consequences. With the acquisition of contemporary data describing molecular, cellular, immunological, behavioral, and cognitive effects, lead concentration thresholds that evoke adverse responses have been found to be lower than initially suspected. Furthermore, new sources of significant environmental exposure related to hunting, shooting sports, and fishing activities will likely be realized. For example, initial observations of lead poisoning in animals focused on ingestion of spent shot by waterfowl. Subsequently, the hazards of spent ammunition to upland birds and lead fishing sinkers to swans were realized. This was followed by observations of loon poisoning resulting from ingestion of lead fishing sinkers and the mortality of scavenging raptors from ingesting bullet fragments embedded in their prey. In all likelihood, these trends of identifying new exposure scenarios, effects, and affected species will continue for the foreseeable future. Eliminating the further introduction of lead fragments from ammunition and fishing activities will reduce the likelihood of exposure over time (e.g., Anderson et al. 2000, Samuel and Bowers 2000, Stevenson et al. 2005).

Alternative materials

Many candidate shot materials have been evaluated using a tiered testing scheme that considers potential adverse effects not only to waterfowl, but to other biota and their supporting habitats (U.S. FWS 1997, 2004, 2007). As safe alternative materials have been approved and are commercially available, their increased use in other types of ammunition and in fishing tackle might be encouraged. It is important to evaluate new candidate materials for potential environmental effects, including toxicity, before they enter the marketplace.

Education and outreach

The leadership of the American Fisheries Society and The Wildlife Society interacts with many fish and wildlife management agencies, conservation organizations, hunting, sport shooting, and fishing organizations, ammunition and tackle manufacturers, and retailers and could continue to foster the education of their members, their constituency, and the general public on (1) the hazards and toxic effects of lead ammunition and tackle to fish, wildlife, and the environment, and (2) the availability and ecological benefits of using safe alternatives. Both the American Fisheries Society and The Wildlife Society could develop education and outreach projects on lead-free alternatives. These societies might consider interacting with human health entities to communicate potential hazards of lead to hunters, sport shooters, and anglers, particularly those casting their own shot, bullets, and fishing tackle.

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APPENDICES

Appendix 1A: Federal Regulations at National Parks and National Wildlife Refuges on Lead Fishing Weights.

Location	Sportfishing regulation	Reference
Bear Lake National Wildlife Refuge, Idaho	Use and possession of lead weights or sinkers prohibited.	50 CFR Part 32. 31 (file updated Feb 21, 2006)
Union Slough National Wildlife Refuge, Iowa	Use or possession of lead terminal tackle prohibited.	50 CFR Part 32. 34 (file updated Feb 21, 2006)
Rachel Carson National Wildlife Refuge, Maine	Lead jigs and sinkers prohibited.	50 CFR Part 32. 38 (file updated Feb 21, 2006)
Assabet River National Wildlife Refuge, Massachusetts	Lead sinkers prohibited.	50 CFR Part 32. 40 (file updated Feb 21, 2006)
Seney National Wildlife Refuge, Michigan	Use of fishing weights or lures containing lead prohibited.	50 CFR Part 32. 41 (file updated Feb 21, 2006)
Red Rock Lakes National Wildlife Refuge, Montana	Use or possession of lead sinkers or any lead fishing product while fishing prohibited.	50 CFR Part 32. 45 (file updated Feb 21, 2006)
Rappahannock River Valley National Wildlife Refuge, Virginia	Use of lead sinkers prohibited.	50 CFR Part 32. 66 (file updated Feb 21, 2006)
Yellowstone National Park	Leaded fishing tackle such as leaded split-shot sinkers, weighted jigs (lead molded to a hook), and soft lead-weighted ribbon for nymph fishing are not allowed. Lead core line and heavy (> 4 lb.) downrigger weights used to fish for deep-dwelling lake trout are permissible because they are too large to be ingested by wildlife.	Fishing Regulations, Yellowstone National Park. February 2006 revision.

Appendix 1B: United States of America's State Regulations of Lead Fishing Weights.

State	Sportfishing regulation	Reference
Alabama	No lead fishing regulations.	Alabama regulations relating to game, fish and fur-bearing animals 2005-2006. Alabama Department of Conservation and Natural Resources
Alaska	No lead fishing regulations.	Alaska Department of Fish and Game 2005 Sport Fishing Regulations. 2005 Sport Fishing Regulations for Bristol Bay; Southcentral Alaska; Interior-AYK; Kodiak; and Southeast Alaska
Arizona	No lead fishing regulations.	Arizona Game and Fish Department 2005 & 2006 Fishing Regulations
Arkansas	No lead fishing regulations.	Arkansas Game and Fish Commission's Arkansas Fishing Guide Book 2006
California	No lead fishing regulations.	California Fish and Game Commission 2006 Freshwater Sport Fishing Regulation Booklet
Colorado	No lead fishing regulations.	Colorado Division of Wildlife's Colorado Fishing 2006 booklet
Connecticut	No lead fishing regulations.	2006 Connecticut Angler's Guide
Delaware	No lead fishing regulations.	Delaware Division of Fish & Wildlife – Recreational Fish Regulations in Delaware for 2005
Florida	No lead fishing regulations.	2005-2006 Florida Freshwater Fishing Regulations
Georgia	No lead fishing regulations.	Georgia 2005-2006 Sport Fishing Regulations
Hawaii	No lead fishing regulations.	Hawaii Department of Land and Natural Resources Division of Aquatic Resources 2005 Hawaii Fishing regulations, Regulated Species- Freshwater; Gear restrictions.
Idaho	No lead fishing regulations.	Idaho Fish and Game 2006-2007 Fishing Seasons and Rules Including Steelhead
Iowa	No lead fishing regulations.	Iowa Department of Natural Resources, 2006 Iowa Fishing Regulations

State	Sportfishing regulation	Reference
Kansas	No lead fishing regulations.	Kansas Department Wildlife & Parks; 2006 Kansas Fishing Regulations Summary
Kentucky	No lead fishing regulations.	Kentucky Fish and Wildlife. Kentucky Sport Fishing and Boating Guide
Louisiana	No lead fishing regulations.	Louisiana Department of Natural Resources
Maine	1. Sale of lead sinker. A person may not sell a lead sinker for fishing that contains any lead and weighs 1/2 ounce or less. 2. Offer lead sinker for sale. A person may not offer for sale a lead sinker for fishing that contains any lead and weighs 1/2 ounce or less.	Maine Legislature: Chapter 923 Fish: Fishing Seasons and Restrictions. Title 12: Conservation Part 13: Inland Fisheries and Wildlife Subpart 4: Fish and Wildlife Section 12663-A
Maryland	No lead fishing regulations.	Maryland Freshwater Sport fishing Guide
Massachusetts	Prohibitions: Except as otherwise provided for in M. G. L. c. 131 and 321 CMR, it shall be unlawful: (i) to use lead sinkers for fishing in the Quabbin and Wachusett Reservoirs. " (1) Definitions: For the purposes of 321 CMR 4. 01, the following words or phrases shall have the following meanings: "… Lead Sinker means fishing devices including, but not limited to, split shot, bullet weights, egg sinkers, slip sinkers, bell sinkers, pinch sinkers, rubber grip sinkers, bank sinkers, pyramid sinkers, or twist, strap, or wrap-around sinkers. The term lead sinker does not include other lead-composition fishing-related objects such as artificial lures, jigs, lead-core fishing line, down-rigger weights, keel sinkers, torpedo casting and trolling sinkers, and weighted flies.	Massachusetts 321 CMR 4. 01
Michigan	No lead fishing regulations.	Michigan Department of Natural Resources 2005 Fishing Guide
Minnesota	No lead fishing regulations.	Minnesota Fishing Regulations 2006
Mississippi	No lead fishing regulations.	Mississippi Wildlife Fisheries & Parks Freshwater Fishing in Mississippi Fishing Regulations
Missouri	No lead fishing regulations.	Missouri Department of Conservation. A Summary of Missouri Fishing Regulations 2006

Appendix 1B: United States of America's State Regulations of Lead Fishing Weights. (continued)

State	Sportfishing regulation	Reference
Montana	No lead fishing regulations.	Montana Fish, Wildlife, & Parks 2005 Montana Fishing regulations
Nebraska	No lead fishing regulations.	Nebraska Game and Park Commission. 2006 Nebraska Fishing Guide Regulations and Public Waters
Nevada	No lead fishing regulations.	Nevada Department of Wildlife 2005 Fishing Regulations
New Hampshire	Lead Fishing Sinkers and Jigs; Use Prohibited. – I. No person shall use any lead sinker or lead jig for the taking of fish in any fresh water, except as otherwise specifically permitted in this title. IV. For purposes of this section, "lead sinker" means any sinker made from lead, the lead portion of which has a mass of one ounce or less, and "lead jig" means a lead weighted hook that measures less than one inch along its longest axis. Lead sinkers and lead jigs shall not include lead fishing related items including but not limited to fishing line, flies, lures, or spoons.	New Hampshire State Legislature Title XVIII Fish and Game Chapter 211 Fish, Shellfish, Lobsters and Crabs - Methods and Manner of Taking Fish Section 211:13-b
New Jersey	No lead fishing regulations.	New Jersey Division of Fish & Wildlife, 2006 Freshwater Fishing Issue of the Fish and Wildlife Digest
New Mexico	No lead fishing regulations.	2005-2006 New Mexico Fishing Rules & Information
New York State	Sale of small lead fishing sinkers prohibited. 1. No person shall sell at retail or offer for retail sale lead fishing sinkers weighing one-half ounce or less.	Laws of New York, Environmental Conservation Title 3 General Powers and Duties of the Department Section 11-0308
North Carolina	No lead fishing regulations.	North Carolina Wildlife Resource Commission, North Carolina Inland Fishing, Hunting and Trapping regulations Digest 2005-2006
North Dakota	No lead fishing regulations.	North Dakota Game and Fish Department. North Dakota Fishing Guide 2004-2006
Ohio	No lead fishing regulations.	Ohio Department of Natural Resources Division of Wildlife 2006-2007 Ohio Fishing Regulations
Oklahoma	No lead fishing regulations.	Oklahoma 2006 Fishing Guide

State	Sportfishing regulation	Reference
Oregon	No lead fishing regulations.	Oregon Department of Fish and Wildlife. 2006 Oregon Sport Fishing Regulations
Pennsylvania	No lead fishing regulations.	2006 Pennsylvania Fishing Summary
Rhode Island	No lead fishing regulations.	State of Rhode Island and Providence Plantation Department of Environmental Management Fish and Wildlife, Freshwater and Anadromous Fishing Regulations for the 2005-2006 Season
South Carolina	No lead fishing regulations.	South Carolina Department of Natural Resources. South Carolina Rules and Regulations 2005-2006
South Dakota	No lead fishing regulations.	South Dakota Game, Fish and Parks. 2006 South Dakota Fishing Handbook
Tennessee	No lead fishing regulations.	Tennessee Wildlife Resources Agency. 2006 Tennessee Fishing Regulations
Texas	No lead fishing regulations.	Texas Parks and Wildlife. Legal Freshwater and Saltwater Devices & Restrictions
Utah	No lead fishing regulations.	Utah Division of Wildlife Resources. 2006 Fishing Proclamation & Information
Vermont	A person shall not use a lead sinker for taking of fish in any state waters. In this section, “sinker” means any device which weighs one-half ounce or less and is attached to a fishing line for the purpose of sinking the line, and does not include other lead fishing-related items such as weighted fly line, lead-core fishing line, downrigger cannon balls, weighted flies, lures, spoons, or jig heads. It is unlawful to sell or offer for sale a lead sinker in the state of Vermont. In this section “sinker” means any device which weighs one-half ounce or less and is attached to a fishing line for the purpose of sinking the line, and does not include other lead fishing-related items such as weighted fly line, lead-core fishing line, downrigger cannon balls, weighted flies, lures, spoons, or jig heads.	General Assembly of the State of Vermont: H. 516, Sec. 1. 10 VSA subsection 4606(g); Sec 2. 10 VSA Subsection 4614; Section 3
Virginia	No lead fishing regulations.	Virginia Department of Game & Inland Fisheries. Freshwater Fishing in Virginia 2005-2006

State	Sportfishing regulation	Reference
Washington	No lead fishing regulations.	Washington Department of Fish and Wildlife. 2005/2006 Fishing in Washington Rule Pamphlet
West Virginia	No lead fishing regulations.	West Virginia Department of Natural Resources Wildlife Resources. 2006 West Virginia Fishing regulations Summary
Wyoming	No lead fishing regulations.	Wyoming Game and Fish Commission, Fish Division. 2006 through 2007 Wyoming Fishing Regulations

Appendix 2A: Canada Protected Wildlife Areas' Federal Regulations for Lead Fishing Weights.

Protected Wildlife	Sport fishing regulation	Reference
Alberta: Blue Quills, Meanook, Spiers Lake, and Canadian Forces Base Suffield National Wildlife Area.	Same as above	Same as above
British Columbia: Alaksen, Widgeon Valley, Columbia, Qualicum, and Vaseux-Bighorn National Wildlife Area.	Same as above	Same as above
Manitoba: Pope, and Rockwood National Wildlife Area.	Same as above	Same as above
New Brunswick: Tintamarre, Portage Island, Shepody, Cape Jourimain, Portobello Creek National Wildlife Area.	Same as above	Same as above
Newfoundland and Labrador: none	Not applicable	Not applicable
Northwest Territories: Polar Bear Pass, and Nirjutiqavvik National Wildlife Area.	Same as above	Same as above
Nova Scotia: John Lusby Marsh, Sand Pond, Boot, Wallace Bay, Sea Wolf Island, and Chignecto National Wildlife Area	Wildlife Area Regulations, General Prohibitions: 3.(1) Subject to subsection (2), no person shall, in any wildlife area, (b.1) be in possession of, while fishing, any lead sinkers or lead jigs that weigh less than 50 grams.	Wildlife Area Regulations, C.R.C., c. 1609, Schedule 1 (C.R.C., c. 1609, Section 3.(1)(b.1)), (Department of Justice 2006a)
Nunavit: none	Not applicable	Not applicable
Ontario: Big Creek, Eleanor Island, Mohawk Island, Mississippi Lake, St. Clair, Wellers Bay, Wye Marsh, Prince Edward Point, Scotch Bonnet Island National Wildlife Area.	Same as above	Same as above
Prince Edward Island: none	Not applicable	Not applicable
Quebec: Cap Tourmente, Îles de Contrecoeur, Îles de la Paix, Lac Saint-François, Pointe de l'Est, Baie de l'Isle-Verte, Îles de l'Estuaire, and Pointe-au-Père National Wildlife Area.	Same as above	Same as above
Saskatchewan: Bradwell, Prairie, Stalwart, St. Denis, Tway, Webb, Raven Island, and Last Mountain Lake National Wildlife Area.	Same as above	Same as above
Yukon Territory: Nisutlin River Delta National Wildlife Area	Same as above	Same as above

Appendix 2B: Canada Federal Regulations of Lead Fishing Weights in National Parks.

Note: National Parks fishing regulation for each park on lead fishing tackle is available from each National Parks' website through the National Parks of Canada website www.pc.gc.ca/progs/np-pn/list_e.asp

National Park	Sport fishing regulation	Reference
Alberta: Banff, Elk Island, Jasper. Waterton Lakes, Wood Buffalo	Same as above	Same as above
British Columbia: Glacier, Gulf Islands, Gwaii Haanas, Kootenay, Mount Revelstoke, Pacific Rim, Yoho	Same as above	Same as above
Manitoba: Riding Mountain, Wapusk	Same as above	Same as above
New Brunswick: Fundy, Kouchibouguac	Same as above	Same as above
Newfoundland and Labrador: Gros Morne, Terra Nova, Torngat Mountains	No person shall, when fishing in park waters, use….. (h) a lead sinker or lead jig that weighs less than 50 gram.	National Parks of Canada Fishing Regulations C.R.C., c. 1120, section 17.(h) – (Department of Justice Canada 2006b)
Northwest Territory: Aulavik, Nahanni, Tuktut Nogait, Wood Buffalo	Same as above	Same as above
Nova Scotia: Cape Breton Highlands, Kejimkujik	Same as above	Same as above
Nunavit: Auyuittuq, Quttinirpaaq, Sirmilik, Ukkusiksalik	Same as above	Same as above
Ontario: Bruce Peninsula, Georgian Bay Islands, Point Pelee, Pukaskwa, St. Lawrence Islands,	Same as above	Same as above
Prince Edward Island: Prince Edward Island	Same as above	Same as above
Quebec: Forillon, La Mauricie, Mingan Archipelago	Same as above	Same as above
Saskatchewan: Grasslands, Prince Albert	Same as above	Same as above
Yukon Territory: Ivvavik, Kluane, Vuntut	Same as above	Same as above

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