Population-level Impacts from Lead Fishing Tackle Ingestion by Fish and Wildlife Species in North America: A Literature Review

Summary
This white paper reviews publications in the peer-reviewed scientific literature for evidence of possible population-level impacts to fish and wildlife species in North America from ingestion of lead fishing tackle. In New Hampshire, a reduction in the population growth rate (λ) and a decrease in the overall statewide population of common loons (*Gavia immer*) have been attributed to lead toxicosis resulting primarily from ingestion of small lead fishing sinkers (≤ 28.4 g). Evidence for population-level impacts in other fish and wildlife species is lacking or inconclusive, although discussion in the peer-reviewed literature suggests that certain species including trumpeter swans (*Cygnus buccinator*), tundra swans (*Cygnus columbianus*), and mute swans (*Cygnus olor*), are probably not experiencing population-level impacts from lead fishing tackle ingestion in North America.

Introduction
Since the 1970s, the Association of Fish and Wildlife Agencies (AFWA) has worked collaboratively with the state, provincial, territorial, and federal wildlife and natural resource management agencies in North America to address issues related to lead and fish and wildlife health. This literature review has been prepared at the request of the current leadership and membership of the Lead and Fish and Wildlife Health Working Group of AFWA's Fish and Wildlife Health Committee.

Lead is toxic to vertebrate species and the adverse effects of lead have been known since antiquity (Rattner et al. 2008). There is a substantial body of peer-reviewed scientific literature documenting mortalities and sub-lethal poisoning of wildlife from lead from a broad range of sources (see Rattner et al. 2008 and citations therein). The purpose of this review is to identify known population-level impacts to fish and wildlife species in North America which have been attributed to lead toxicosis resulting from the ingestion of lead fishing tackle. The present review focuses primarily on publications which have appeared in the peer-reviewed scientific literature in the decade following the publication of a major literature review and synthesis on lead and fish and wildlife health, which was prepared jointly by the American Fisheries Society and The Wildlife Society (Rattner et al. 2008).

Why A Focus on Population-level Impacts?
The scientific literature contains numerous reports and case studies of individual lead poisoning events involving a wide range of fish and wildlife species (Rattner et al. 2008). For some wildlife species, such as common loons (*Gavia immer*), lead toxicosis is a commonly-reported source of individual animal mortality (see citations in Rattner et al. 2008 and more recent citations provided below). Understanding whether these poisoning incidents constitute a significant threat to the species generally requires additional information about the species' biology and population dynamics, the frequency and routes by which individuals are exposed to lead, and overall population trends within the species (Franson et al. 2003; Schuehammer et al. 2003). Quantitative modeling studies such as that of Grade et al. (2018) can be

helpful in estimating whether mortalities from lead poisoning are actually affecting species population dynamics.

In 2010, AFWA's Directors formally adopted a set of principles, described more fully in AFWA Resolution 2010-04-01 (Association of Fish and Wildlife Agencies 2010), regarding potential future regulation of lead ammunition and lead fishing tackle. This resolution states that:

> "State fish and wildlife agencies should proactively address issues associated with wildlife population health…"

and

> "Decisions related to future regulation of lead ammunition and lead fishing tackle should be based on the best available science related to wildlife population health."

and

> "State agencies should focus regulation efforts where population-level impacts to wildlife are substantiated."

Given continued interest by state and federal fish and wildlife agencies and the general public regarding potential effects of lead fishing tackle on populations of fish and wildlife species in North America, the AFWA Lead and Fish and Wildlife Health Working Group directed AFWA staff to provide an updated literature review on this topic.

History

Population-level impacts from ingestion of lead fishing tackle have been documented since at least the 1960s in mute swans (*Cygnus olor*) in England (Sears 1988; Blus 1994; Rattner et al. 2008). In North America, population-level effects from the ingestion of lead fishing tackle are much less well documented, with most research focusing on common loons (*Gavia immer*) (Scheuhammer et al. 2003; Trushenski and Radomski 2013; Haig et al. 2014). Mortalities from ingestion of lead fishing tackle have been reported in multiple North American waterfowl species, including mute swans (*Cygnus olor*), tundra swans (*Cygnus columbianus*), Canada geese (*Branta canadensis*), mallards (*Anas platyrhynchos*), brown pelicans (*Pelecanus occidentalis*), and common loons (*Gavia immer*) (Rattner et al. 2008). Ingestion of lead fishing tackle has been documented in additional avian species, including trumpeter swans (*Cygnus buccinator*), redhead ducks (*Aythya americana*), wood ducks (*Aix sponsa*), black ducks (*Anas rubripes*), long-tailed ducks (*Clangula hyemalis*), common mergansers (*Mergus merganser*), 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*), Mississippi sandhill crane (*Grus canadensis pulla*), greater scaup (*Aythya marila*), white-winged scoters (*Melanitta fusca*), black-crowned night-herons (*Nycticorax nycticorax*), and bald eagles (*Haliaeetus leucocephalus*) (Scheuhammer et al. 2003; Rattner et al. 2008; Schummer et al. 2011). Ingestion of lead fishing sinkers has also been reported in two North American reptile species, snapping turtle (*Chelydra serpentina*) and painted turtle (*Chrysemys picta*) (Scheuhammer et al. 2003; Rattner et al. 2008).

Publications Since 2008

Research since 2008 has focused primarily on avian species, particularly common loons. The following review is organized by species for avian taxa and by major taxonomic group for non-avian taxa.

Common Loons (*Gavia immer*)

Ingestion of lead fishing tackle is a commonly-reported cause of mortality of adult common loons submitted to agencies and laboratories for necropsy in the United States and Canada (Rattner et al. 2008; Pokras and Kneeland 2008; Pokras et al. 2009; Scheuhammer et al. 2009; Strom et al. 2009; Stoddart and Brooks 2012; Kornetsky et al. 2013; Vogel 2013; Haig et al. 2014; González-Astudillo et al. 2016; Grade et al. 2018). Range-wide, 10%-50% of reported loon mortalities are attributable to lead poisoning (Tischler 2011), and the ingestion of lead fishing weights is considered the primary route of lead exposure in loons (Pokras and Kneeland 2009). Scheuhammer et al. (2003) provided an extensive review of the difficulties in translating these mortality statistics into estimates of population-level effects and concluded that "substantially improved estimates of critical model parameters are needed before the population effects of lead-induced mortality in common loons can be assessed with any confidence." Grade et al. (2018) reviewed long-term loon mortality data (1989-2012) from New Hampshire and constructed a retrospective population model to test for population-level effects from lead mortality. These authors estimated that mortality from lead tackle ingestion reduced the loon population growth rate (λ) in New Hampshire by 1.4% and the statewide loon population by 43% during the course of the study. Grade et al. (2018) recommended replacing lead fishing sinkers and jigs weighing $\leq$ 28.4 g with non-toxic alternatives in New Hampshire.

Brown Pelicans (*Pelecanus occidentalis*)

There is at present no evidence of population-level effects to brown pelicans from ingestion of lead fishing tackle. Franson et al. (2003) reported that 10 of 365 brown pelicans necropsied between 1995 and 1999 had ingested lead fishing weights. These pelicans were all received from wildlife rehabilitation centers and had ingested lead fishing weights at higher frequencies (2.7% of 365 birds) than pelicans recovered in the field following acute mortality events (0.4% of 279 birds). These authors suggest that the prevalence of exposure to fishing tackle may be overestimated when data from rehabilitation centers are used (Franson et al. 2003).

Canada Geese (*Branta canadensis*)

There is at present no evidence of population-level effects to Canada geese from ingestion of lead fishing tackle. Franson et al. (2003) reported two incidents of lead sinker ingestion by Canada geese in 1978 and 1979, based on information contained in the files of the National Wildlife Health Center in Madison, Wisconsin. Tsipoura et al. (2011) reported elevated lead levels in eggs and feathers of Canada geese in the New Jersey Meadowlands, which these authors thought could potentially be attributable to ingestion of contaminated sediments and/or ingestion of lead ammunition or fishing tackle.

Sandhill Cranes (*Grus canadensis*)

There is at present no evidence of population-level effects to sandhill cranes from ingestion of lead fishing tackle. Windingstad et al. (1984) reported the presence of lead fishing weights in two sandhill cranes diagnosed with lead toxicosis, and an unidentified triangular lead object was found in the gizzard of a dead Mississippi sandhill crane (*G. c. pulla*) with elevated lead levels in its blood (Franson and Hereford 1994).

Mallards (*Anas platyrhynchos*)

There is at present no evidence of population-level effects to mallards from ingestion of lead fishing tackle in North America. Adverse population-level effects from lead shot ingestion have been reported in North American mallard populations (e.g., Anderson et al. 2000; Stevenson et al. 2005; Rattner et al. 2008). In a major study investigating the effects of lead shot restrictions on migratory waterfowl populations, Anderson et al. (2000) estimated that lead poisoning of mallards had been reduced by 64% in the Mississippi Flyway as a direct result of the implementation of the lead shot restrictions, with an estimated 1.4 million birds spared from fatal lead toxicosis in 1997 alone.

Trumpeter Swans (*Cygnus buccinator*)

There is at present no evidence of population-level effects to trumpeter swans from ingestion of lead fishing tackle in North America. Degemes et al. (2006) conducted epidemiological investigations of lead poisoning in trumpeter swans in Washington State, USA, between 2000-2002. Of the 365 trumpeter swans necropsied in this study, 302 (82.7%) were diagnosed as "lead poisoned" (Degemes et al. 2006). However, the majority of this poisoning was evidently due to ingestion of lead shot; according to these authors only "three lead-poisoned trumpeters had one or two lead fishing sinkers" while at least 256 individuals had ingested one or more lead shot (Degemes et al. 2006). Wilson et al. (2009) provided information on trumpeter swan mortalities associated with lead ingestion in northwestern Washington state and southwestern British Columbia during the period 1999-2008. Of 1,727 intact remains suitable for toxological testing which were examined during this period, the cause of mortality for 1,376 (80%) was attributed to lead shot ingestion (Wilson et al. 2009). These authors did not report finding any lead fishing tackle in the 1,727 swans they necropsied.

Tundra Swans (*Cygnus columbianus*)

There is at present no evidence of population-level effects to tundra swans from ingestion of lead fishing tackle in North America. Degemes et al. (2006) conducted epidemiological investigations of lead poisoning in tundra swans in Washington State, USA, between 2000-2002 and attributed all 20 cases of lead poisoning among the 35 birds that were necropsied to ingestion of lead shot. These authors did not find lead fishing tackle in any of the 35 tundra swans that were necropsied. Likewise, Bowen and Petrie (2007) did not find any fishing tackle in any of the 77 tundra swans that they necropsied. Bartonek et al. (1991) reported that lead poisoning was identified as the cause of death of 29% of 171 tundra swans necropsied by the National Wildlife Health Research Center in Madison, Wisconsin, between 1981 and 1988, but these authors did not differentiate between mortality from lead shot ingestion and lead fishing tackle ingestion. Bartonek et al. (1991) urged caution in the interpretation and application of these data, due to multiple known biases which can affect the submission of birds for necropsy:

> "(1) a particular specimen may represent an event involving just one bird or it may represent a sample of many birds involved in a major die-off;
>
> (2) mortalities in and around wildlife management areas and densely populated areas tend to be detected at a higher rate; and

(3) for similar reasons, most swan specimens are collected during winter or in migration but not in summer on remote nesting grounds." (Bartonek et al. 1991).

Mute Swans (*Cygnus olor*)

As noted above, there is a substantial literature documenting mortalities and population-level effects of lead poisoning resulting from fishing tackle ingestion by mute swans in England (Sears 1988; Blus 1994; Rattner et al. 2008). Bowen and Petrie (2007) provided information on artifacts ingested by 243 mute swans collected between 1999 and 2003 in the lower Great Lakes Region of Canada. Six percent of the swans examined had ingested lead shot and 1.6% contained fishing tackle. These authors concluded that "angling related injuries and mortalities are likely lower in the LGL [Lower Great Lakes] than has been reported for swans in Europe" (Bowen and Petrie 2007).

Other Avian Species

There is at present no evidence of population-level impacts to other avian species from ingestion of lead fishing tackle in North America. Available evidence reviewed by Rattner et al. (2008) suggests that ingestion of lead fishing tackle is, for most avian species, a rare event. For example, Anderson et al. (2000) examined the gizzards of 16,651 ducks from hunting areas along the Mississippi flyway and observed the presence of only one lead sinker. Although Rattner et al. (2008) also expressed concern about secondary poisoning of predators and scavengers ingesting waterbirds with lead poisoning, these authors note that actual cases of secondary poisoning have not been documented in the scientific literature. No cases of secondary poisoning were documented in the literature examined for this review.

Reptiles

There is at present no evidence of population-level impacts to reptilian species from ingestion of lead fishing tackle in North America. Rattner et al. (2008) found only four reports of ingestion of lead fishing sinkers by two species of turtles in North America: three reports of ingestion by common snapping turtles, *Chelydra serpentina*, and a single report of ingestion by a painted turtle, *Chrysemys picta*. No additional published reports were uncovered during this review.

Mammals

As noted by Rattner et al. (2008), there are numerous reports of ingestion of lead fishing tackle by humans in the medical literature. Rattner et al. (2008) did not report any accounts of ingestion of lead fishing tackle by non-human mammals. Zabka et al. (2006) present a detailed account of a single mortality event involving a single adult female harbor seal (*Phoca vitulina richardsi*) which had ingested a "112-g, 2.75-cm-long X 0.75-cm-diameter, torpedo-shaped, metallic-colored lead sinker attached to a ball of 50-cm-long monofilament line and braided stainless steel wire leader with multiple attachment sites for hooks, which either were absent or rusted" (Zabka et al. 2006). Necropsy findings indicated that the animal had died from acute lead toxicosis. While this report certainly indicates that individual marine mammals can ingest lead fishing tackle and subsequently die from lead toxicosis, the potential for population-level effects has not yet been demonstrated for any marine mammal species.

Other Taxa

Rattner et al. (2008) did not find any reports in the scientific literature of lead toxicosis resulting from lead fishing tackle in any species of fish, amphibians, or invertebrates. The present review likewise failed to find any such reports. With regards to fish and lead tackle, Rattner et al. (2008) note that "[i]t 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."

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