BIOLOGICAL CONSERVATION 131 (2006) 421–432

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A review of lead poisoning from ammunition sources in terrestrial birds

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ARTICLE INFO

Article history:
Received 7 October 2005
Received in revised form
20 February 2006
Accepted 28 February 2006
Available online 5 June 2006

Keywords:
Bullet fragment
Game bird
Lead shot
Raptor

ABSTRACT

Poisoning from lead shot in waterbirds has been well documented globally and, in some countries, legislation exists to combat lead toxicosis at wetlands and/or in waterbirds. However, poisoning of terrestrial species such as raptors and upland game birds, while of potential conservation concern, remains largely to be addressed. For several species, shot are not the only ammunition source of lead, as bullet fragments can be ingested from hunter-killed animal carcasses and gut piles left in the field. This review collates the current knowledge of lead poisoning from ammunition in non-waterbirds. Fifty-nine terrestrial bird species have so far been documented to have ingested lead or suffered lead poisoning from ammunition sources, including nine Globally Threatened or Near Threatened species. We discuss the conservation significance of continued lead use, and detail measures needed to combat lead poisoning.

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1. Introduction

Lead has long been recognised as a poison to living organisms, with negative effects on general health, reproduction, behaviour, and potentially leading to death. Ingestion and inhalation are the two most common entry routes of lead into animals (Demayo et al., 1982; Eisler, 1988; Pain, 1995; Mateo, 1998b; Guitart et al., 1999). Numerous studies and reviews exist of the ingestion of lead shot, fishing sinkers and jigs and subsequent poisoning of waterfowl (Pain, 1990a, 1991a, 1992, 1996; Sharley et al., 1992; Scheuhammer and Norris, 1995, 1996) and waders (Kaiser et al., 1980a; Hall and Fisher, 1985; Veiga, 1985; Pain, 1990b; Locke et al., 1991; Locke and Friend, 1992; Beck and Granval, 1997). Less well documented, although increasingly so, are the effects on non-waterbird species that ingest shot or bullet fragments in quarry species or as grit to aid digestion (Miller et al., 2002).

A further route of lead toxicosis in birds is uptake from diverse environmental sources in food. Most cases of poisoning occur following exposure to very elevated lead concentrations, such as may be found in the vicinity of mines, waste dumps, and industrial plants (Blus et al., 1977; Custer and Mulhern, 1983; Henny et al., 1991, 1994; García-Fernández et al., 1995). Sludge from sewage treatment facilities is often added to agricultural land and can be a source of lead (Pain, 1995; Pattee and Pain, 2003), and lead in paint chips has been shown to poison both captive birds, such as the sandhill crane (*Grus canadensis*) (Kennedy et al., 1977), and wild species, for example the Laysan albatross (*Phoebastria immutabilis*) (Sileo and Fefer, 1987; Work and Smith, 1996; Finkelstein et al., 2003). Although some species are exposed to high levels of lead in their food (Mayes et al., 1977; Eldeman et al., 1983; Bengtsson and Rundgren, 1984; Ma, 1989; Manninen and Tanskanen, 1993; Pankakoski et al., 1994; Stansley and Roscoe, 1996; Darling and Thomas, 2005), compared to ingestion of shot and bullet fragments, contamination of birds from other sources of lead is generally only locally significant or relatively minor, and increasingly so as the use of lead is

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0006-3207/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2006.02.018

being phased out globally (Stendell et al., 1989; Scheuhammer et al., 2003).

2. Ammunition lead poisoning effects and incidents

2.1. *Effects of lead poisoning*

Terrestrial birds are exposed to lead mainly through ingestion. Galliforms and doves probably ingest spent shot as grit which is retained in their gizzards, while raptors are usually poisoned through ingesting lead shot or bullet fragments in dead or injured prey or gut piles (Friend, 1987; Kendall et al., 1996). In Canada, upland game birds and mammals, the primary food source of many raptors, are now more likely to contain lead shot than waterfowl, as shot is prohibited for waterfowl hunting (Clark and Scheuhammer, 2003).

Ingested lead fragments may be rapidly regurgitated, for example in the pellets of raptors, may be retained for varying periods, or completely dissolved with the resulting lead salts absorbed into the bloodstream. The likelihood of a bird becoming poisoned is related to the retention time of lead items, frequency and history of exposure to lead, and factors such as nutritional status and environmental stress (Pattee and Pain, 2003). A proportion of exposed birds will die, and mortality can occur following the ingestion of just one lead gunshot (Pain and Rattner, 1988). Ingestion of lead particles usually means at least some absorption, and in cases where sufficient lead is absorbed, poisoning ensues.

Lead concentrations are generally highest in the blood directly after absorption, and in liver and kidneys for days to months after absorption. Lead deposited in bone can remain for years, and reflects lifetime exposure (Pain, 1996). Lead is a non-essential element and the activity of blood enzymes appears to be affected by extremely low concentrations. Various authors have attempted to define tissue concentrations in birds indicative of excessive exposure, sub-lethal poisoning and acute poisoning (Franson et al., 1996; Pain, 1996). These concentrations vary somewhat between taxa, and the diagnosis of poisoning is usually based on signs of poisoning in combination with blood lead levels in live birds, and on tissue concentrations, sometimes, but not necessarily, in combination with evidence of exposure to lead in dead birds. Other than in cases of point source contamination, high concentrations in the tissues of birds result primarily from the ingestion of ammunition or anglers' weights.

Lead is a non-specific poison affecting all body systems. The effects of toxicosis in birds commonly include distension of the proventriculus, green watery faeces, weight loss, anaemia and drooping posture (Redig et al., 1980; Reiser and Temple, 1981; Franson et al., 1983; Custer et al., 1984; Sanderson and Bellrose, 1986; Mateo, 1998b). Sub-lethal toxic effects are exerted on the nervous system, kidneys and circulatory system, resulting in physiological, biochemical and behavioural changes (Scheuhammer, 1987). Vitamin metabolism can be affected (Baksi and Kenny, 1978), and birds can go blind (Pattee et al., 1981). Lead toxicosis depresses the activity of certain blood enzymes, such as delta aminolevulinic acid dehydratase (ALAD), essential for haemoglobin production, and may impair immune function (Grasman and Scanlon, 1995; Redig et al., 1991). Over longer periods, haematocrit and haemoglobin levels are often reduced.

As a result of physiological and behavioural changes, birds may become increasingly susceptible to predation, starvation and infection by disease, increasing the probability of death from other causes (Scheuhammer and Norris, 1996).

Lead can affect reproductive success. Grandjean (1976) showed a correlation between thin eggshells and high concentrations of lead in European kestrels (*Falco tinnunculus*), and poisoning significantly decreased egg production in captive Japanese quail (*Coturnix japonica*) (Edens and Garlich, 1983). However, in the Spanish imperial eagle (*Aquila adalberti*) only low lead levels were found in eggs, despite adult contamination (González and Hiraldo, 1988). In ringed turtle doves (*Streptopelia risoria*), significant testicular degeneration has been reported in adults following shot ingestion (Kendall and Scanlon, 1981; Veit et al., 1982) and seminiferous tubules may be devoid of sperm (Kendall et al., 1981).

Experimental studies on Cooper's hawks (*Accipiter cooperii*) showed detectable amounts of lead in eggs when adults had high levels in their blood (Snyder et al., 1973), and in nestlings of altricial species, such as the American kestrel (*Falco sparverius*), body length, brain, liver and kidney weights can be affected (Hoffman et al., 1985a), along with reduced survival and disrupted brain, liver and kidney function (Hoffman et al., 1985b). However, despite experimentally elevated levels of lead in bones and liver, with higher deposition in females than males, there appeared to be no adverse effect on egg laying, initiation of incubation or eggshell thickness in American kestrels (Pattee, 1984).

Under some circumstances, there may be sex differences in the probability of exposure to or poisoning by lead, at least in western marsh-harriers (*Circus aeruginosus*) (Pain et al., 1993), as significantly more females than males trapped had elevated lead concentrations. Finally, lead exposure may also reduce the likelihood of birds returning to an area to breed (Mateo et al., 1999).

Locke and Friend (1992) concluded from their wide-ranging study that all bird species would be susceptible to lead poisoning after ingesting and retaining shot. All raptor species that feed on game could potentially be exposed at some time to ingestion, the likelihood varying according to the proportion of game in the diet, the size of game taken, the season, and the local hunting intensity (Pain et al., 1993).

2.2. *Species affected by lead shot*

Table 1 documents cases of lead shot ingestion and/or poisoning in terrestrial birds.

2.2.1. *Raptors*

One of the main groups to be affected by ingestion of lead shot and poisoning is raptors (Miller et al., 2002). Lead is rapidly dissolved by the low pH in raptor stomachs, and subsequently absorbed. When large amounts of lead are rapidly absorbed, illness and death can be sudden, and birds may die in apparently good physical condition (Gill and Langelier, 1994).

In wetlands where hunters use lead shot, raptors that feed on un-retrieved game are more likely to ingest shot in their prey than those in wetlands with no hunting (Mateo, 1998a).

Table 1 – Lead shot ingestion and poisoning

Species	Status	Evidence	Countries	References
Chukar (*Alectoris chukar*)	LC	Ingestion	USA	Walter and Reese (2003)
Grey partridge (*Perdix perdix*)	LC	Ingestion and Poisoning	Denmark, UK	Clausen and Wolstrup (1979); Keymer and Stebbings (1987); Potts (2005)
Common pheasant (*Phasianus colchicus*)	LC	Poisoning	Denmark, UK, USA	Calvert (1876); Elder (1955); Clausen and Wolstrup (1979); National Wildlife Health Laboratory (1985); Dutton and Bolen (2000)
Wild turkey (*Meleagris gallopavo*)	LC	Ingestion	USA	Stone and Butkas (1978)
Scaled quail (*Callipepla squamata*)	LC	Ingestion	USA	Campbell (1950)
Northern bobwhite quail (*Colinus virginianus*)	NT	Ingestion	USA	Stoddard (1931); Keel et al. (2002)
Great horned owl (*Bubo virginianus*)	LC	Poisoning	Canada	Clark and Scheuhammer (2003)
Eurasian eagle owl (*B. bubo*)	LC	Poisoning	Spain	Mateo et al. (2003)
Snowy owl (*Nyctea scandiaca*)	LC	Poisoning	Captive	MacDonald et al. (1983)
Long-eared owl (*Asio otus*)	LC	Poisoning	Spain	Brinzal (1996)
Rock pigeon (*Columba livia*)	LC	Ingestion	USA	Dement et al. (1987)
Common wood-pigeon (*C. palumbus*)	LC	Poisoning	Denmark	Clausen and Wolstrup (1979)
Mourning dove (*Zenaida macroura*)	LC	Ingestion	USA	Locke and Bagley (1967); Lewis and Legler (1968); Best et al. (1992)
Sandhill crane (*Grus canadensis*)	LC	Ingestion	USA	Windingstad et al. (1984); National Wildlife Health Laboratory (1985)
Whooping crane (*G. americana*)	EN	Poisoning	USA	Hall and Fisher (1985)
Clapper rail (*Rallus longirostris*)	LC	Ingestion	USA	Jones (1939)
King rail (*R. elegans*)	LC	Ingestion	USA	Jones (1939)
Virginia rail (*R. limicola*)	LC	Ingestion	USA	Jones (1939)
Sora (*Porzana carolina*)	LC	Poisoning	USA	Jones (1939); Artmann and Martin (1975); Stendell et al. (1980)
Common moorhen (*Gallinula chloropus*)	LC	Ingestion	Europe, USA	Jones (1939); Locke and Friend (1992)
Common coot (*Fulica atra*)	LC	Ingestion	France	Pain (1990a)
American coot (*F. americana*)	LC	Ingestion	USA	Jones (1939)
American woodcock (*Scolopax minor*)	LC	Ingestion	Canada	Scheuhammer et al. (1999, 2003)
Ruffed grouse (*Bonasa umbellus*)	LC	Ingestion	Canada	Rodrigue et al. (2005)
California gull (*Larus californicus*)	LC	Ingestion	USA	Quortrup and Shillinger (1941)
Glaucous-winged gull (*L. glaucescens*)	LC	Ingestion	USA	National Wildlife Health Laboratory (1985)
Herring gull (*L. argentatus*)	LC	Ingestion	USA	National Wildlife Health Laboratory (1985)
European honey-buzzard (*Pernis apivorus*)	LC	Unknown (ingestion or shot)	Netherlands	Lumeiji et al. (1985)
Red kite (*Milvus milvus*)	LC	Ingestion or poisoning	Germany, Spain, UK	Mateo (1998a); Mateo et al. (2001, 2003); Kenntner et al. (2005)
Bald eagle (*Haliaeetus leucocephalus*)	LC	Poisoning	Canada, USA	Platt (1976); Jacobson et al. (1977); Kaiser et al. (1980b); Pattee and Hennes (1983); Reichel et al. (1984); Frenzel and Anthony (1989); Craig et al. (1990); Langelier et al. (1991); Elliott et al. (1992); Scheuhammer and Norris (1996); Wayland and Bollinger (1999); Miller et al. (2000, 2001); Clark and Scheuhammer (2003); Wayland et al. (2003)
White-rumped vulture (*Gyps bengalensis*)	CR	Poisoning (origin unknown)	India	Oaks et al. (2004)
Eurasian griffon (*G. fulvus*)	LC	Poisoning	Spain	Mateo et al. (1997); Guitart (1998); Mateo et al. (2003)
Western marsh-harrier (*Circus aeruginosus*)	LC	Poisoning	France, Germany, Spain	Pain et al. (1993, 1997); Mateo et al. (1999); Kenntner et al. (2005)
Northern harrier (*C. cyaneus*)	LC	Ingestion	Canada, USA	Martin and Barrett (2001); Martin et al. (2003)

(*continued on next page*)

Table 1 – *continued*

Species	Status	Evidence	Countries	References
Eurasian sparrowhawk (*Accipiter nisus*)	LC	Ingestion	France, Captive	MacDonald et al. (1983); Pain and Amiard-Triquet (1993)
Sharp-shinned hawk (*A. striatus*)	LC	Ingestion	Canada, USA	Martin and Barrett (2001)
Cooper's hawk (*A. cooperii*)	LC	Ingestion	Canada, USA	Snyder et al. (1973); Martin and Barrett (2001)
Northern goshawk (*A. gentilis*)	LC	Poisoning	Canada, France, Germany, USA, Captive	Stehle (1980); Pain and Amiard-Triquet (1993); Martin and Barrett (2001); Kenntner et al. (2003, 2005)
Red-tailed hawk (*Buteo jamaicensis*)	LC	Poisoning	Canada, USA	Franson et al. (1996); Martin and Barrett (2001); Clark and Scheuhammer (2003)
Common buzzard (*B. buteo*)	LC	Poisoning	France, Germany; UK, Captive	Stehle (1980); MacDonald et al. (1983); Pain and Amiard-Triquet (1993); Pain et al. (1995); Kenntner et al. (2005)
Rough-legged buzzard (*B. lagopus*)	LC	Poisoning	USA	Locke and Friend (1992)
Spanish imperial eagle (*Aquila adalberti*)	EN	Poisoning	Spain	González and Hiraldo (1988); Mateo (1998a); Mateo et al. (2001); Pain et al. (2004)
Golden eagle (*A. chrysaetos*)	LC	Poisoning	Canada, Spain, USA	Bloom et al. (1989); Craig et al. (1990); Cerradelo et al. (1992); Scheuhammer and Norris (1996); Wayland and Bollinger (1999); Clark and Scheuhammer (2003); Wayland et al. (2003)
White-tailed eagle (*Haliaeetus albicilla*)	NT	Poisoning	Greenland	Krone et al. (2004)
American kestrel (*Falco sparverius*)	LC	Ingestion	Canada, USA	Martin and Barrett (2001)
Laggar falcon (*F. jugger*)	NT	Poisoning	Captive	MacDonald et al. (1983)
Prairie falcon (*F. mexicanus*)	LC	Poisoning	Captive	Benson et al. (1974); Stehle (1980)
Peregrine falcon (*F. peregrinus*)	LC	Poisoning	UK, Captive	MacDonald et al. (1983); Pain et al. (1995)
Turkey vulture (*Cathartes aura*)	LC	Ingestion	Canada, USA	Wiemeyer et al. (1986); Martin et al. (2003)
Andean condor (*Vultur gryphus*)	NT	Poisoning	Captive	Locke et al. (1969)
King vulture (*Sarcorhampus papa*)	LC	Poisoning	Captive	Decker et al. (1979)
White-throated sparrow (*Zonotrichia albicollis*)	LC	Ingestion	USA	Vyas et al. (2000)
Dark-eyed junco (*Junco hyemalis*)	LC	Ingestion	USA	Vyas et al. (2000)
Brown-headed cowbird (*Molothrus atar*)	LC	Ingestion	USA	Vyas et al. (2000)
Yellow-rumped warbler (*Dendroica coronata*)	LC	Poisoning	USA	Lewis et al. (2001)
Brown thrasher (*Toxostoma rufum*)	LC	Poisoning	USA	Lewis et al. (2001)
Blue-headed vireo (*Vireo solitarius*)	LC	Poisoning	USA	Lewis et al. (2001)

Countries are given for wild birds; captive birds are simply listed as captive, and were poisoned through shot present in their feed. Conservation status is from BirdLife International (2004) and is coded as: CR, critically endangered; EN, endangered; NT, near threatened; LC, least concern. Evidence of 'Poisoning' indicates tissue lead concentrations indicative of poisoning (e.g. Franson et al. (1996)) with the source of poisoning most likely to be lead gunshot and/or diagnosis of lead poisoning in one or more individuals; 'Ingestion' indicates evidence of ingestion of shot usually in the absence of tissue analysis. Species are ordered using Sibley and Monroe (1990).

Pain (1991b) showed that when carcass densities are high, as in wetland hunting areas, carcass removal by scavengers and predators (likely to include both birds and mammals) can be rapid. Peterson et al. (2001) showed in British Columbia that 77.8% of carcasses were found within 24 h of death. A single duck carcass attracted a mean of 16.6 individual scavengers, so one poisoned carcass can place several scavengers at risk of secondary poisoning. Simulated die-off models also predict the rapid elimination of carcasses by scavengers (Wobester and Wobester, 1992).

In Canada and the United States, lead poisoning in bald (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*) from ingestion of shot from prey animals accounted for an estimated 10–5% of the recorded post-fledging mortality (Scheuhammer and Norris, 1996). Elliott et al. (1992) found 37% of 294 sick, injured or dead bald eagles in British Columbia exhibited significant lead exposure, 23% were sub-clinically exposed, while 14% were poisoned. The greatest number of these occurred during January to March, when the birds were feeding heavily on wintering wildfowl. Wayland and Bollinger (1999) demonstrated a greater prevalence of high lead exposure in bald eagles found in areas of high waterfowl hunting than low intensity hunting, while Frenzel and Anthony (1989) showed that eagles' prey were relatively free of contaminants with the exception of lead shot embedded in waterfowl. In the Utah desert, bald eagles feeding on jack rabbits (*Lepus californicus*) killed by hunters may frequently ingest shot, with 71% of regurgitated pellets containing one or more (Platt, 1976). Fortunately, regurgitation of pellets by raptors and owls may reduce the prevalence of ingested lead in the ventriculus.

Golden eagles have also been found with lead toxicosis from shot in Spain, where one bird had 40 pellets in its proventriculus (Cerradelo et al., 1992), as have globally threatened Spanish imperial eagles (Mateo, 1998a; Mateo et al., 2001; Pain et al., 2004), with an estimated 11% of birds sampled having ingested shot (Mateo et al., 2001).

As obligate scavengers, most old and new world vultures are also potentially susceptible to the ingestion of lead shot. Examples come from Spain, with poisoned Eurasian griffon vultures (*Gyps fulvus*) (Mateo et al., 1997, 2003; Guitart, 1998); from Canada, where turkey vultures (*Cathartes aura*) have been shown to have bone lead levels indicating elevated lifetime exposure, with scavenged hunter-shot carcasses the likely cause (Martin et al., 2003); and from turkey vultures in the United States (Wiemeyer et al., 1986). In India, an oriental white-rumped vulture (*Gyps bengalensis*) was found to have died from lead poisoning, although the origin of the lead is uncertain (Oaks et al., 2004).

Several other raptor species have been found exposed to lead through shot. In 1999, Martin and Barrett (2001) used stable lead isotope ratios to determine the source of lead exposure to wildlife on the north shore of Lake Eire. None of the migrating birds sampled had levels indicating lead poisoning, but one or more individuals of the following were found to have levels indicative of sub-lethal exposure, with the lead isotope ratios for most of the samples falling within the range of shot pellets: American kestrel, sharp-shinned hawk (*Accipiter striatus*), Cooper's hawk, northern goshawk (*Accipiter gentilis*), northern harrier (*Circus cyaneus*) and red-tailed hawk (*Buteo jamaicensis*). Rough-legged buzzards (*Buteo lagopus*) have also been poisoned following shot ingestion (Locke and Friend, 1992). In Canada, Clark and Scheuhammer (2003) found lead poisoned great-horned owls (*Bubo virginianus*), which are likely to ingest lead shot embedded in their main prey species, cottontail rabbits (*Sylvilagus floridanus*) and hares (*Lepus americanus*) (Weir and Hanson, 1989; Von Kuster and Schneberger, 1992).

In Europe, species found to have elevated levels of lead in their liver indicative of shot ingestion include Eurasian eagle-owl (*Bubo bubo*), long-eared owl (*Asio otus*), red kite (*Milvus milvus*,) western marsh-harrier, Eurasian sparrowhawk (*Accipiter nisus*), northern goshawk, common buzzard (*Buteo buteo*), and peregrine falcon (*Falco peregrinus*) (Pain and Amiard-Triquet, 1993; Pain et al., 1993, 1995, 1997, author's unpublished data; Brinzal, 1996; Mateo, 1998a; Mateo et al., 1999, 2001, 2003; Kenntner et al., 2003). In the Netherlands, a European honey-buzzard (*Pernis apivorus*) was poisoned by lead shot in its intestine, although the presence of another pellet in the wing may mean that this bird was the victim of a shooting incident (Lumeiji et al., 1985).

Raptors in captivity have been poisoned accidentally from lead in food carcases, usually hunter-killed rabbits, squirrels and other small mammals. Documented cases include snowy owl (*Nyctea scandiaca*), king vulture (*Sarcorhampus papa*), Andean condor (*Vultur gryphus*), common buzzard, Eurasian sparrowhawk, peregrine falcon, Laggar falcon (*Falco jugger*), northern goshawk, and prairie falcon (*Falco mexicanus*) (Locke et al., 1969; Benson et al., 1974; Decker et al., 1979; Jacobson et al., 1977; Stehle, 1980; MacDonald et al., 1983).

2.2.2. *Galliforms*

Not only raptors are affected by shot ingestion; galliforms also pick up pellets along with grit for their gizzards. One of the earliest reports of non-waterfowl lead poisoning is for common pheasants (*Phasianus colchicus*) in the United Kingdom (Calvert, 1876), and there are reports of pellets in pheasant gizzards from across Europe and North America (Elder, 1955; Clausen and Wolstrup, 1979; National Wildlife Health Laboratory, 1985; Dutton and Bolen, 2000).

In the United Kingdom and Denmark, lead poisoning from gunshot pellets has been recorded in the grey partridge (*Perdix perdix*) (Clausen and Wolstrup, 1979; Keymer and Stebbings, 1987; Potts, 2005), while in North America, chukar (*Alectoris chukar*), scaled quail (*Callipepla squamata*), northern bobwhite quail (*Colinus virginianus*), and ruffed grouse (*Bonasa umbellus*) also pick up shot (Stoddard, 1931; Campbell, 1950; Keel et al., 2002; Walter and Reese, 2003; Rodrigue et al., 2005). Even a wild turkey (*Meleagris gallopavo*), seldom expected to encounter shot, has been found with pellets in its gizzard (Stone and Butkas, 1978).

2.2.3. *Gruiforms*

Gruiforms pick up shot in a similar way to galliforms. In 1939 in North Carolina, dozens of dead and dying rails were found poisoned by picking up shot as grit (Jones, 1939). Lead shot has been found in the crops and gizzards of sora (*Porzana carolina*), King rail (*Rallus elegans*), Clapper rail (*Rallus longirostris*), Virginia rail (*Rallus limicola*), common moorhen (*Gallinula chloropus*) and the American coot (*Fulica americana*) across North America (Jones, 1939; Artmann and Martin, 1975; Stendell et al., 1980). Common moorhen and common coot (*Fulica atra*) have been poisoned in Europe (Pain, 1990a; Locke and Friend, 1992).

Lead shot has been found in the intestines of the globally threatened whooping crane (*Grus americana*); one individual ingested more than 75 shot (Hall and Fisher, 1985). Sandhill cranes have also picked up pellets, both in the wild and in captivity (Windingstad et al., 1984; National Wildlife Health Laboratory, 1985).

2.2.4. *Other species*

Other species have been shown to have ingested shot, although many are isolated reports: rock pigeon (*Columba livia*); woodpigeon (*Columba palumbus*), mourning dove (*Zenaida macroura*), American woodcock (*Scolopax minor*), California gull (*Larus californicus*), herring gull (*Larus argentatus*) and glaucous-winged gull (*Larus glaucescens*) (Quortrup and Shillinger, 1941; Locke and Bagley, 1967; Lewis and Legler, 1968; Clausen and Wolstrup, 1979; National Wildlife Health Laboratory, 1985; Dement et al., 1987; Best et al., 1992; Scheuhammer et al., 1999, 2003). Several passerine species are also known to have been exposed to lead at shooting ranges (Vyas et al., 2000; Lewis et al., 2001).

2.3. Species affected by bullet fragments

Table 2 documents cases of lead ingestion and/or poisoning likely to have resulted from bullets or bullet fragments in terrestrial birds.

A second source of poisoning is through the ingestion of lead bullet fragments. Recent evidence indicates that lead bullets fragment as they pass through prey items, leaving a trail of small pieces of lead that can be widely distributed within the body of the prey (Hunt et al., in press). Consequently, scavengers can be exposed to high lead concentrations even when feeding on body parts far from the bullet's final destination.

Much work on poisoning from bullets comes from Japan, where it is customary for hunters to leave whole and partial shot deer carcasses in the field. These then become a source of bullet fragments that are ingested by scavenging raptors during and after the hunting season, most notably Stellar's sea-eagle (*Haliaeetus pelagicus*) and white-tailed eagles (*Haliaeetus albicilla*) (Falandysz et al., 1988; Kim et al., 1999; Iwata et al., 2000). Kurosawa (2000) found 39 Stellar's and 15 white-tailed eagles in Hokkaido had died from lead poisoning during the winters from 1996 to 1998. If this rate of mortality is an accurate measure of the proportion of deaths due to lead poisoning, then it represents a threefold increase in the known yearly eagle mortality.

Elsewhere, white-tailed eagles have been found with lead fragments from shot and/or bullets and poisoning in Germany and Austria (Kenntner et al., 2001, 2004). Kenntner et al. (2005) reported that 24% of 277 white-tailed eagles found dead or moribund in Germany between 1979 and 2005 had liver lead concentrations indicative of acute poisoning.

In the United States and the Canadian prairie provinces, studies of bald and golden eagles show that the latter are more likely to be being poisoned by lead ammunition (shot and bullets) in upland game birds and mammals than shot associated with waterfowl (Wayland and Bollinger, 1999; Clark and Scheuhammer, 2003; Wayland et al., 2003), although the former are also susceptible (Gill and Langelier, 1994). In Germany, golden eagles have been found with ingested lead fragments from eating the entrails of chamonix (*Rupicapra rupicapra*) during a culling programme (Bezzel and Fünfstück, 1995).

California condors (*Gymnogyps californianus*), a critically endangered species, have been exposed to lead bullet fragments when released into the wild (Wiemeyer et al., 1983, 1986, 1988; Janssen et al., 1986; Bloom et al., 1989; Pattee et al., 1990), and poisoning from bullet fragment ingestion is the leading cause of mortality for this species (Meretsky et al., 2000; Snyder and Snyer, 2000). One of the favoured food sources for these condors are the gut piles left by hunters, and bullet fragments may be deliberately ingested when mistaken for bone chips, the result of apparent difficultly in obtaining enough calcium in the diet (Snyder and Snyer, 2000).

Carcasses of rifle-shot rodent pests discarded in fields are a further source of bullet fragments that may be ingested by raptors. Ideal ammunition for this sort of pest control must be highly frangible, with limited penetration, so leading to small lead fragments distributed in the carcass tissues (Firearms Tactical Institute, 1999).

3. Conservation significance of lead poisoning

The international conservation status of the species known to have ingested or been poisoned by lead shot or bullet fragments in the wild can be summarised as follows: two are Near Threatened (white-tailed eagle and northern bobwhite quail), one is Vulnerable (Stellar's sea-eagle), two are Endangered (Spanish imperial eagle and whooping crane) and two are Critically Endangered (Californian condor and white-rumped

Table 2 – Poisoning from bullet fragments

Species	Status	Evidence	Countries	References
Snowy owl (*Nyctea scandiaca*)	LC	Poisoning	Captive	MacDonald et al. (1983)
White-tailed eagle (*Haliaeetus albicilla*)	NT	Poisoning	Austria, Germany, Japan	Falandysz et al. (1988); Kim et al. (1999); Iwata et al. (2000); Kurosawa (2000); Kenntner et al. (2001, 2004, 2005)
Bald eagle (H. *leucocephalus*)	LC	Poisoning	Canada, USA	Gill and Langelier (1994); Wayland and Bollinger (1999); Clark and Scheuhammer (2003); Wayland et al. (2003)
Stellar's sea-eagle (*H. pelagicus*)	VU	Poisoning	Japan	Kim et al. (1999); Iwata et al. (2000); Kurosawa (2000)
Golden eagle (*Aquila chrysaetos*)	LC	Poisoning	Canada, Germany, USA	Craig et al. (1990); Pattee et al. (1990); Bezzel and Fünfstück (1995); Wayland and Bollinger (1999); Clark and Scheuhammer (2003); Wayland et al. (2003)
California condor (*Gymnogyps californianus*)	CR	Poisoning	USA	Wiemeyer et al. (1983, 1986, 1988); Janssen et al. (1986); Bloom et al. (1989); Pattee et al. (1990); Meretsky et al. (2000); Snyder and Snyer (2000)

Countries are given for wild birds; captive birds are simply listed as captive, and were poisoned through bullet fragments present in their feed. Conservation status is from BirdLife International (2004) and is coded as: CR, critically endangered; VU, vulnerable; NT, near threatened; LC, least concern. Evidence of 'Poisoning' indicates tissue lead concentrations indicative of poisoning (e.g. Franson et al., 1996)) with the source of poisoning most likely to be lead bullet fragments, and/or diagnosis of lead poisoning in one or more individuals; 'Ingestion' indicates evidence of ingestion of bullet fragments usually in the absence of tissue analysis. Species are ordered using Sibley and Monroe (1990).

vulture) (BirdLife International, 2004). Clearly any mortality that can be avoided for these species in particular is of key conservation importance. National conservation priorities must also be considered. For example, in the United Kingdom, two of the species listed in Tables 1 and 2 are 'red' and therefore of highest concern (grey partridge and white-tailed eagle), while five are 'amber' and of medium concern (red kite, western marsh-harrier, honey buzzard, golden eagle and peregrine falcon) (Gregory et al., 2002).

More specifically, lead poisoning is of concern for long-lived slow-breeding species with small initial populations, such as the endangered and declining Spanish imperial eagle, as these are particularly vulnerable to increases in adult mortality (Grier, 1980). With a population estimated at 350 individuals (BirdLife International, 2004), this species cannot sustain high, especially adult, mortality (Ferrer, 2001), and lead poses an additional problem for this species which has been declining from other causes in recent years (Ferrer et al., 2003).

Bald eagle populations were depressed through losses due to pesticide abuses in the 1950s and 1960s, and individuals are often closely associated with the same wetland complexes frequented by hunted wildfowl. Repeated re-exposure to lead is hazardous, successive ingestion and regurgitation of pellets resulting in poisoning (Pattee et al., 1981). As bald eagles and their waterfowl prey become concentrated in smaller areas, the likelihood of eagles picking up shot increases (Pattee and Hennes, 1983). Potential for exposure to lead can be extremely high in areas such as state game lands and hunting preserves, especially where these are conducive to high densities of game bird populations (Kendall et al., 1996).

Until a ban on the use of lead bullets for deer hunting, the high levels of adult mortality of Stellar's sea-eagles and white-tailed eagles in Hokkaido were of great concern (Kurosawa, 2000). Death of adult raptors has a larger influence on a population than juveniles, and relatively smaller increases in adult mortality can lead to population declines. Ueta and Masterov (2000) demonstrated through computer simulation that populations of Stellar's sea eagles would slowly decrease, adult mortality having the strongest effect on population trends. In their study on eagles in western Canada from 1986 to 1998, Wayland et al. (2003) found higher levels of lead in adults and sub-adults than immature birds.

Re-introduction programmes may also be hampered by lead ammunition. Meretsky et al. (2000) state that until sources of lead contamination are removed, the release of California condors into the wild cannot result in viable populations. Between 1994 and 1999, there were six cases of released condors being poisoned by lead. These birds survived only due to the administration of chelation therapy (Snyder and Snyer, 2000). Risks to this species can only be removed through hunting bans, no-hunting preserves, or changes to non-toxic ammunition types.

Further, if similar species are susceptible to lead in similar ways, as is suggested by Locke and Friend (1992), then lack of evidence of ingestion or poisoning does not suggest that those species are not being affected. For example, greater spotted eagles (*Aquila clanga*), a vulnerable species, may include sick and injured shot waterfowl in their diet in the Evros Delta in Greece (Pain and Handrinos, 1990).

Finally, rare subspecies may also be threatened. The greater sandhill crane (*Grus canadensis tabida*) has been shown to ingest lead shot (Windingstad et al., 1984). While a few deaths in this subspecies would have little effect on the overall population, the consequences of poisoning incidents for the critically endangered Mississippi sandhill (*Grus canadensis pulla*) could be considerable, given a population that has only recently grown to about 100 individuals (Johnsgard, 1983; LaRoe et al., 1995).

4. Conservation measures to combat lead toxicosis from ammunition sources

Most voluntary or legislative action taken to limit the use of lead ammunition imposes restrictions on its use in and around wetlands, and/or for the hunting of waterbirds, with the exceptions of Denmark and the Netherlands where the ban was extended to include all hunted species (Beintema, 2001). Such legislation has been aimed primarily at reducing the risk of lead ingestion by waterfowl. However, Wetlands International conducted a questionnaire that showed that more than three quarters of 74 countries responding still used lead shot (Beintema, 2001). Even in many signatory countries to international conventions which require judicious and sustainable use of wetlands and protection of birds, such as the African-Eurasian Migratory Waterbird Agreement (AEWA), the 79/409/EEX Directive on the Conservation of Birds, and the RAMSAR Convention on Wetlands of International Importance, lead poisoning in wetland habitats is not being adequately addressed (Beintema, 2001; Pain et al., 2004; Thomas and Guitart, 2005).

Occasionally, legislation has been introduced to protect raptors from lead poisoning. In the USA in 1991, the federal government introduced nationwide legislation banning the use of lead shot for all waterfowl and coot hunting to prevent further secondary lead toxicosis of their national emblem, the bald eagle (Anderson, 1992). However, little action has been taken against the use of lead bullets; one exception is in Japan where the use of lead bullets for deer hunting on Hokkaido island is illegal (Matsuda, 2003).

While bans on the use of lead shot for hunting waterfowl will inevitably reduce the likelihood of poisoning of raptors that prey on or scavenge waterfowl, they do nothing to prevent the poisoning of raptors that feed on hunted species away from wetlands, or those that feed on a range of avian and mammalian prey. Additionally, large volumes of lead shot end up in terrestrial ecosystems such as shooting areas, firing ranges and clay-pigeon shoots, where they can be directly ingested by a range of terrestrial birds (Vyas et al., 2000; Lewis et al., 2001).

Various approaches to alleviating the problems caused to birds by accumulation of shot in the environment have been trialed, including voluntary codes of practice, redistribution of shot through sediment cultivation, raising water levels to reduce access to shot, providing grit and suitable foods, and the treatment of sick birds (Mudge, 1992). However, while these have had variable success locally, the only demonstrably effective solution is a ban on hunting or a move to non-toxic shot (Scheuhammer and Norris, 1995). Moving to non-toxic shot has often been resisted by the hunting fraternity, and despite substantial reductions in lead poisoning with the introduction of steel shot in the USA, strong traditions and prejudices are hard to break even when the available information overwhelmingly favours change (Szymczak, 1978; Bishop and Wagner, 1992; Thomas, 1997).

It is clear that the only practical way of removing the risk of lead poisoning from ammunition to avian species is to replace the use of lead with non-toxic alternatives, for all hunting and other purposes, and in all habitats. In limited cases where no non-toxic alternatives are currently readily available, such as with lead bullets, hunting-free zones could be instigated in areas where wildlife is at risk. Until this happens, large numbers of birds, some of which are already of unfavourable conservation status, will continue to die from lead poisoning.

The replacement of lead gunshot by steel and other non-toxic alternatives has already been implemented in the USA for waterfowl hunting, and to a limited and variable extent in countries across Europe and other global regions. It is a simple problem for which a simple solution has existed for in excess of 15 years. For gunshot, alternative non-toxic shot types are produced and widely available; 11 products have been approved unconditionally for hunting waterfowl in the USA and these can be used effectively for hunting all species of waterfowl and upland game (Thomas and Guitart, 2005). Steel shot and other alternatives are marketed in countries where the use of non-toxic shot is mandated by law.

5. Conclusion

From the wide-ranging evidence of lead ingestion and poisoning from around the world, it is clear that many non-waterfowl species are at risk from, and being affected by lead shot and bullet fragments. Although progress has been made in a handful of countries, generally little has been done to combat this problem or take measures to conserve threatened and vulnerable species. At present, in the majority of countries, the use of lead ammunition results in the following: (1) additional mortality of waterbirds and terrestrial species through lead poisoning following the ingestion of spent shot; (2) poisoning of raptors, including threatened species, through the ingestion of shot or bullet fragments in the flesh of prey; (3) long-term environmental contamination through the deposition of lead, with potentially huge environmental mitigation costs as is becoming apparent in the USA. Most other forms of environmental lead contamination have been, or are being, removed or significantly reduced, as with lead in petrol. Alternative non-toxic shot types have long been available. It is consequently highly questionable as to whether any uses of lead shot can be considered to be environmentally responsible.

To date, the policy approach in Europe aimed at reducing and removing environmental pollution by lead has been piecemeal and inconsistent (Thomas and Guitart, 2005). For example, while the European Commission passed a Directive to eliminate the use of lead wheel balance weights by 2005 (European Commission, 2002), it decided to take no action to reduce lead shot (CSTEE, 2003), the latter decision being inconsistent with the position taken by the Bern Convention or AEWA. Pollution of the environment and wildlife from lead ammunition should be dealt with using the same legal instruments as applied to lead pollution by industry.

The case is clear for the removal of lead ammunition as an environmental pollutant that causes unnecessary mortality of wildlife. Ways of moving towards the use of non-toxic ammunition must be found, and must be practically workable. Denmark adopted an approach that could be taken by other countries: a prohibition on the sale or use of lead for hunting in 1996, supplemented by a prohibition on the possession of lead gunshot from 2000. It is important that governments that are committed to removing lead from the environment include lead ammunition in their remediation agendas, and use a combination of legislation and education to bring about change. Until they do, a diverse group of bird species will continue to suffer from lead toxicosis, in some cases with seriously negative impacts on populations.

Acknowledgements

We thank Ian Dawson, Gonzalez Garcia, Lynn Giddings, Rachel Roberts, staff at Brinzal, Jean-Yves Mondain-Monval and the British Library.

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