BIOLOGICAL AND SOCIETAL DIMENSIONS OF LEAD POISONING IN BIRDS IN THE USA

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ABSTRACT.—The ingestion of spent lead shot was known to cause mortality in wild waterfowl in the US a century before the implementation of nontoxic shot regulations began in 1972. The biological foundation for this transition was strongly supported by both field observations and structured scientific investigations. Despite the overwhelming evidence, various societal factors forestalled the full transition to nontoxic shot for waterfowl hunting until 1991. Now, nearly 20 years later, these same factors weigh heavily in current debates about nontoxic shot requirements for hunting other game birds, requiring nontoxic bullets for big game hunting in California Condor range and for restricting the use of small lead sinkers and jig heads for sport-fishing. As with waterfowl, a strong science-based foundation is requisite for further transitions to nontoxic ammunition and fishing weights. Our experiences have taught us that the societal aspects of this transition are as important as the biological components and must be adequately addressed before alternatives to toxic lead ammunition, fishing weights, and other materials will be accepted as an investment in wildlife conservation. *Received 16 May 2008, accepted 8 July 2008*.

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THE SCIENTIFIC ASPECTS of lead poisoning are but one component for consideration in addressing this disease in humans and animals alike. Here we address lead poisoning in waterfowl and key events associated with the transition from the use of lead shot to nontoxic shot for waterfowl hunting in the US. Historic documentation of lead poisoning in waterfowl is meshed with wildlife management factors and wildlife conservation transitions to provide issue context. We then consider the scientific foundation establishing lead poisoning as a mortality factor impacting waterfowl populations. Major issues that arose in the pursuit of a solution to address lead poisoning in waterfowl are then addressed. We conclude with an extended discussion that highlights key points for consideration by those engaged in attempts to further reduce lead exposures in wild birds.

Early Documentation.—Lead poisoning was first identified as a disease in wild birds in an 1842 scientific paper published in Berlin, Germany (von Fuchs 1842). The first published reports of this disease in the US appeared in the sporting and scientific literature of the late 1800s, and cited observations of lead poisoning of waterfowl appeared as early as the 1870s (Grinnell 1894, Hough 1894, Grinnell 1901). Additional sporadic reports can be

[1] The use of trade or product names in this report is for identification purposes only and does not constitute endorsement by the U.S. Government.

found in the literature during the first three decades of the 20th Century (Bowles 1908, McAtee 1908, Forbush 1912, Munro 1925, Van Tyne 1929, McGath 1931, Howard 1934, McLean 1939), clearly establishing lead poisoning as common in waterfowl and widely distributed geographically (Phillips and Lincoln 1930, Shillinger and Cottam 1937, Bellrose 1959, Mississippi Flyway Council Planning Committee 1965). Despite those early warnings, the first nontoxic shot requirements were not initiated until 1972, and the use of lead shot for waterfowl hunting was not completely banned in the US until the start of the 1991 waterfowl season (US Fish and Wildlife Service 1986a). The path leading to this endpoint traversed decades of observation, discovery, investigation, and controversy (Table 1), all of which are closely linked to the changing dynamics of the human interface with wildlife and that of wildlife conservation in general. Worldwide at least 20 countries had initiated some form of nontoxic shot requirements for waterfowl and/or for other hunting by the year 2000 (Figure 1). International efforts to "get the lead out" are being advanced by the African-Eurasion Migratory Waterbird Agreement and ongoing involvement of Wetlands International (formerly the International Waterfowl and Wetlands Research Bureau) (Beintema 2004).

Current arguments for retention of lead within the US for traditional uses in hunting, fishing, and shooting sports are similar to those of the past (Table 2). Thus, it is prudent for those seeking further reductions of lead poisoning in wildlife to be fully cognizant of the transition, conflicts, and factors that facilitated resolution of the lead poisoning issue in waterfowl. Application of this knowledge should expedite further transitions in the replacement of existing traditional lead uses in these sports so that past mistakes are not repeated. We highlight important benchmarks associated with the waterfowl lead poisoning issue and comment on important biological, social, economic, and political aspects of those benchmarks. In doing so, we identify motivating and inhibitory factors influencing the transition to nontoxic shot for hunting waterfowl.

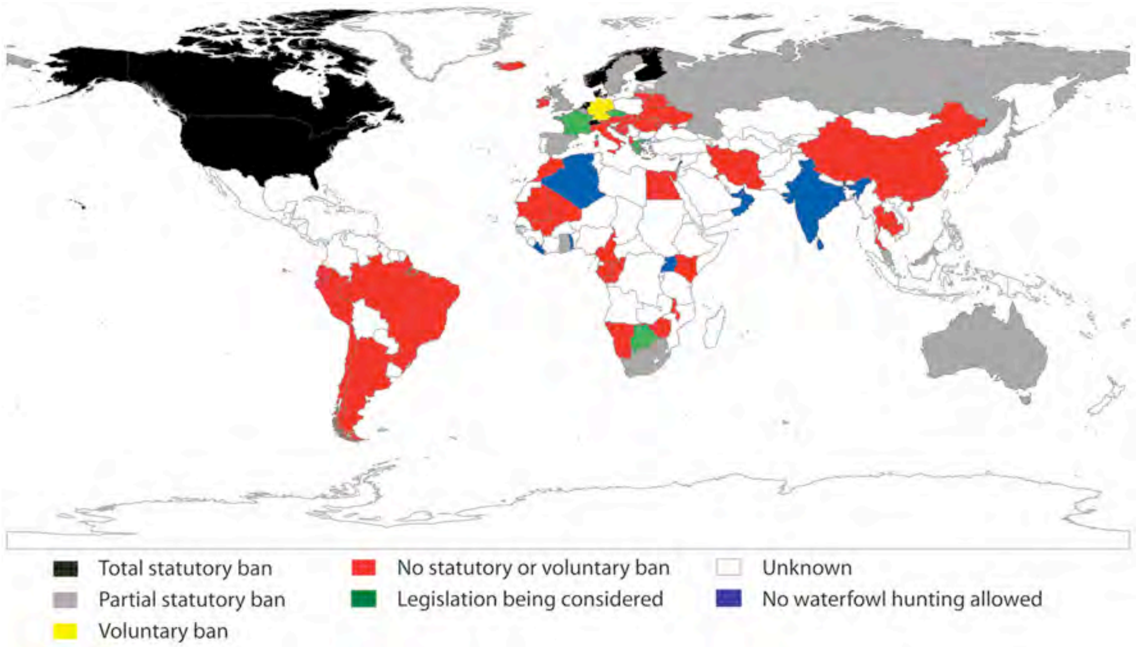

Figure 1. Countries reporting in 2000 to have various types of bans on the use of lead shot for waterbird hunting (Developed from Beintema 2004).

Table 1. Milestones in the transition to nontoxic shot use for waterfowl hunting in the US (see text for details).

Year	Discovery	Concern	Regression	First Actions
1874	Anecdotal mortality reports.			
1894	First documented mortality.			
1915	Numerous shot found in swan gizzards.			
1916	Numerous shot found in sediments near duck blinds.			
1919	First lead toxicity study in wild ducks.			
1930		Leading scientists report lead poisoning to be widespread.		
1936		Nontoxic shot development first pursued.		
1937	First broad-scale evaluation of shot ingestion by waterfowl.			
Early 1940s		Lead poisoning reported to be of great importance for ducks.		
1948		Olin Corporation initiates quest for nontoxic shot.		
Early 1950s		Expanded concerns and investigations		
Mid 1950s			Habitat conditions restore duck populations; interest in lead poisoning wanes; non-toxic shot stops development.	
1959	Bellrose report on lead as a waterfowl mortality factor.			
Early 1960s		Major waterfowl populations decline; interest in lead poisoning heightened.		
1965				First field test of nontoxic shot. Flyway Council urges development of non-toxic shot.
1972				First nontoxic shot use requirements.
1974–1976				FWS EIS proposing nationwide nontoxic shot use.
1976		First lawsuit opposing non-toxic shot regulations by FWS.	Government prevails.	
1978		Stevens Amendment prevents FWS from initiating or enforcing nontoxic shot requirements without State approval.		

Year	Discovery	Concern	Regression	First Actions
Early 1980s	NWHC documents numerous lead poisoning cases in Bald Eagles.	Lawsuits filed against state wildlife agencies and FWS nontoxic shot regulations.	Government prevails.	
Late 1980s		Lawsuit filed against FWS to prevent nontoxic shot use in California.		
1991			Nontoxic shot required nationwide for waterfowl hunting.	

[a] See Anderson 1992, Feierabend 1985.

Wildlife Management Factors.—Wildlife management within the US is often shaped by forces which are political, economic, and social, and is driven by the involvement of multiple segments of society (Heering 1986). The management of lead poisoning in waterfowl has involved all of these forces, and they will drive future efforts to manage lead poisoning in other wildlife. Therefore, it is useful to provide context for lead poisoning in birds over time, because current views of society towards wildlife and approaches towards wildlife conservation differ greatly from those of earlier decades. For example, wildlife conservation has broadened from a protective regulatory approach for limiting take as a means for species preservation to a focus on habitat management and other means to enhance and sustain wildlife populations (Leopold 1933). Further transition has redirected efforts from a species by species orientation to a biodiversity orientation in which ecosystems are the primary focus, even though species management continues. Also, today a far greater percentage of those involved in shaping the resolution of wildlife conservation issues are nonconsumptive resource-users, many of which seek different outcomes than their consumptive resource-user contemporaries (Sparrowe 1992).

Table 2. Common arguments by activity participants against nontoxic alternatives for lead uses in hunting, fishing and shooting sports.

Argument	Activity [a]				
	Waterfowl hunting	Other bird hunting	Other hunting	Shooting sports	Fishing
Magnitude of lead poisoning does not warrant ban (i.e., "the cure is worse than the disease").	X	X	X	X	X
Discrimination—alternatives not feasible for some uses (i.e., small shotshell gauges); gender and age group impacts.	X	X		X	X
Decreased achievement efficacy such as reduced effective range.	X	X			X
Increased secondary impacts (i.e., greater crippling loss).	X	X			
Equipment and personal safety hazards (i.e., ricochets, dental damage).	X	X	X	X	
Increased costs.	X	X	X	X	X
Make your own materials not available.	X				X
Loss of participants in activity if lead use is banned (i.e., lost revenues for conservation and local communities.	X	X	X		

[a] Ban on use of lead for waterfowl hunting completed in 1991 for US; few restrictions currently exist for other types of hunting. Shooting sports have not been subject to nontoxic ammunition requirements but have some restrictions on environments where spent ammunition can fall. Some requirements exist for nontoxic sinkers and jig heads for sport fishing and for some types of hunting in specific geographic and local areas.

Wildlife Conservation Transitions.—Although the origin of the US conservation movement can be traced back to late 19th century, major development did not occur until the 1920s and 1930s. Prior to that time, wildlife conservation in America was "…almost wholly a history of hunting controls" (Leopold 1933). During the 1920s and 1930s, American sportsmen were a major force in "…convincing the government to take a lead role in conserving and managing the nation's natural resources" (Heering 1986). At the federal level, the Bureau of Biological Survey (BBS) in the Department of Agriculture (USDA) was the organization addressing wildlife conservation issues. However, in 1939 the BBS was transferred to the Department of the Interior (DOI), where it was made part of the then US Fish and Wildlife Service (FWS) (Friend 1995). While part of the USDA, BBS scientists carried out landmark investigations of lead poisoning in waterfowl (Wetmore 1919, Shillinger and Cottam 1937).

Major foundational components that served the conservation and restoration of America's wildlife evolved during the pre-WWII era. The "Dirty Thirties" was a time of drought and the Dust Bowl, fiscal panic, and poverty that took a heavy toll on humans, wildlife habitat, and wildlife species that became food to sustain human life. However, the struggles of wildlife and society during those times provided stimulus for leading conservationists from the public sector and government to champion critical enactments and establish major programs that continue today. Thus, in 1935 the federal Duck Stamp and Fish and Wildlife Coordination Acts were passed, and the Cooperative Wildlife Research Unit Program was established. The National Wildlife Federation (NWF) and the first North American Wildlife and Natural Resources Conferences were initiated in 1936. The Federal Aid in Wildlife Restoration program, commonly referred to as the Pittman-Robertson (P-R) program, began in 1937 and is funded by an 11% manufacturer's excise tax on certain equipment used in hunting and by a 10% manufacturer's excise tax on handguns (Williamson 1987). The P-R program, and its later counterpart for fisheries (the D-J or Dingell-Johnson Program), were in essence sportsman-imposed taxes designed to enhance fish and wildlife resources and provide public areas for hunting, fishing, and shooting sports. The impetus for the P-R program followed WWI as the number of hunters greatly increased and impacts from the continuing diminishment of wildlife habitat due to other human needs greatly impacted opportunities for sport hunting (Kallman 1987). It is noteworthy that the first P-R project approved and funded was granted to the Utah Department of Fish and Game in 1938 to construct a 5-mile dike in the Weber River Delta of the Great Salt Lake to assist with combating avian botulism (Williamson 1987). Numerous lead poisoning investigations have been funded by the P-R program during its more than 60 years.

Following WWII, there was another major increase in the number of hunters, and interests grew in the new concepts of wildlife management championed by Aldo Leopold (Leopold 1933, McCabe 1987). By the 1950s, federal and state government agencies began to assume more and more responsibility for managing fish and game species (Heering 1986). A significant outcome of that transition was that wildlife professionals began calling for actions to address lead poisoning, partly because of greatly diminished waterfowl numbers in the early 1960s (Figure 2). At the same time, the hunting public was being disenfranchised from their leadership role in conservation. As noted by Heering (1986), "…by the 1970s, sportsmen's relationship to wildlife professionals had changed from one of 'co-worker' to 'customer.'" In retrospect, one can only wonder how the transition to nontoxic shot for waterfowl hunting might have differed if the relations between the principals involved had been more like "co-workers" rather than agency clients. A current question is what type of relations are now being forged to "get the lead out" of other sporting activities?

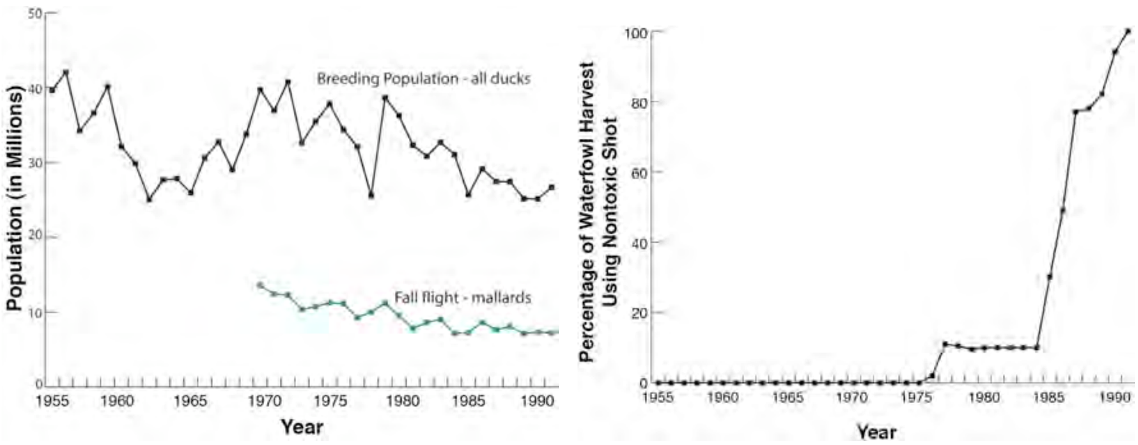

Figure 2a. North American Mallard Duck breeding population estimates, 1955–1991, and fall flight of Mallards, 1970–1991 (developed from records of the USGS Bird Banding Laboratory), and (**2b**) percentage of US waterfowl harvest using nontoxic shot during that same time period (developed from Anderson 1992).

METHODS

We utilize our personal involvement and experiences with lead poisoning in birds and as participants in the transition to nontoxic shot use (for waterfowl hunting in the US) as a foundation for our presentation of the issue. The scientific literature and other documents are used to support the evaluations provided. We begin by defining lead poisoning as a disease in birds and how exposure to lead is documented as the source for that disease.

Lead Poisoning in Birds.—We consider lead poisoning of birds to occur by primary, secondary, and environmental exposures (Figure 3). With environmental exposure, which is beyond the scope of this paper, it has been more difficult to document a cause and effect relationship for avian toxicity than for particulate lead ingestion. As a result, much work remains to be done in the area of environmental lead exposure as it relates to wild bird health. Further, some opposed to nontoxic shot have argued that environmental exposure rather than lead shot is a major source of lead residues found in waterfowl tissues (Winchester Group 1974, Sanderson and Bellrose 1986, Fisher et al. 2006).

Findings of particulate lead in the digestive tract of birds provide physical evidence of the ingestion of lead shot, as well as lead bullets, paint chips, solder, and other materials (Table 3). The presence of ingested lead shot has been an important factor in assessing lead exposure rates in waterfowl because of the relationship between hunting pressure and shot deposition in waterfowl habitat (Bellrose 1959, US Fish and Wildlife Service 1976, 1986a). However, lead exposure and poisoning of waterfowl also has occurred in areas where few hunters are present, including remote areas of Alaska (Franson et al. 1995, Flint et al. 1997, Grand et al. 1998) and in Puerto Rico, the Virgin Islands, and similar areas (Morehouse 1992a). The initial DOI Environmental Impact Statements (EIS) to establish

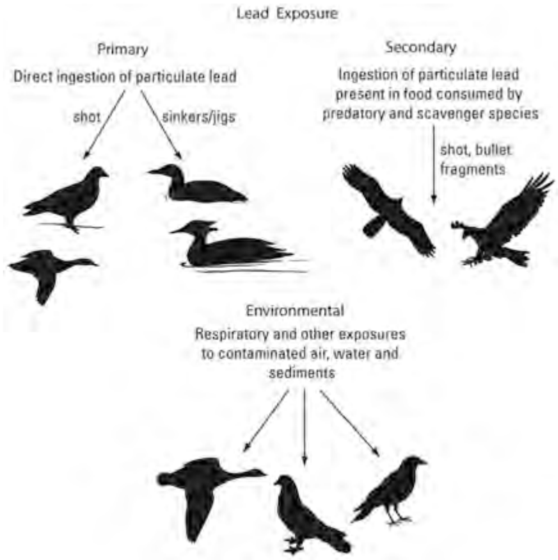

Figure 3. Primary routes for lead exposure in wild birds.

Table 3. Relative frequency of ingested particulate lead and lead poisoning by various species groups.[a]

Species Group	Minimum no. of species affected	Lead Type: Spent Shot	Bullet Fragments	Sinkers	Paint chips[b]	Mine tailings[b]	Others[c]	Selected Citations
Waterfowl	19	●		⭘		◉	○	Bellrose (1959), Anderson (1975), Blus et al. (1989), Franson et al. (1995), Beyer et al. (1998), Sileo et al. (2001), Franson et al. (2003), Degernes et al. (2006)
Coots and rails	6	◉						Jones (1939), Artmann and Martin (1975)
Shorebirds and gulls	4	⭘						Kaiser and Fry (1980), Locke et al. (1991), NWHC files
Cranes	2	⭘		○			⭘	Windingstad et al. (1984), Franson and Hereford (1994)
Pelicans	1			⭘				Franson et al. (2003)
Loons	2			●				Sidor et al. (2003), Wilson et al. (2004)
Other waterbirds	3	⭘			◉			Sileo and Fefer (1987), Franson et al. (2003)
Raptors and scavengers	10	●	●					Reichel et al. (1984), Franson et al. (1996), Meretsky et al. (2000)
Gallinaceous birds	4	⭘						Campbell (1950), Hunter and Rosen (1965), Lewis and Schweitzer (2000)
Doves	2	●						Locke and Bagley (1967), Castrale (1991), DeMent et al. (1987), Schulz et al. (2002)
Passerines	6	⭘						Vyas et al. (2000), Lewis et al. (2001)

Frequency of Findings ● Frequent ◉ Common ⭘ Occasional ○ Rare

[a]See also Scheuhammer and Norris (1995). Scheuhammer et al. (2003), Fisher et al. (2006).
[b] Locally important as numerous birds may be poisoned from this source.
[c] Occasional to rare findings of ingested materials such as solder and lead fragments which have not been identified as a specific product.

nontoxic shot zones for waterfowl hunting were based on known lead poisoning losses and the amount of hunting pressure (US Fish and Wildlife Service 1974, 1976). However, that approach was abandoned because multiple variables, in addition to pellet deposition, influence shot ingestion (Bellrose 1959, Sanderson and Bellrose 1986, DeStefano et al. 1992). Thus, a documented 5% of gizzards with ingested lead shot became one of the criteria for recommending areas for nontoxic shot use (US Fish and Wildlife Service 1986a).

Investigations by the National Wildlife Health Center (NWHC) and others have demonstrated that rates of ingested lead shot in gizzards/stomachs do not adequately reflect lead exposure. Paired liver and gizzard analyses by the NWHC were part of the US Fish and Wildlife Service (FWS) lead monitoring program of the 1980s. Lead exposure rates based on elevated lead residues in livers (≥2.0 ppm, wet weight) were generally two-fold or more higher than rates based on ingested shot found in gizzards (US Fish and Wildlife Service 1986a). Similarly, DeStefano et al. (1991, 1995) found higher exposure rates based on elevated blood lead concentrations (≥0.18 ppm, wet weight) than on ingested shot in gizzards of Canada Geese (*Branta canadensis*) in nontoxic shot areas and those where lead was still used.

Lead residues in soft tissues have become generally accepted as criteria for evaluating lead exposure in waterfowl. The International Association of Fish and Wildlife Agencies (IAFWA) proposed blood and liver concentrations of 0.2 ppm and 2.0 ppm wet weight, respectively, when found in ≥ 5% of samples, as decision criteria for recommending conversions to nontoxic shot for waterfowl hunting (US Fish and Wildlife Service 1986a). Suggested interpretations of background, elevated, and toxic levels of lead in tissues of waterfowl and other avian species were proposed by Pain (1996) and Franson (1996), respectively, based on review of laboratory and field investigations.

Primary and secondary exposures of particulate lead are well-documented causes of mortality for a broad array of avian species (Table 3). Nevertheless, the mere presence or absence of lead fragments in the digestive tract of birds is insufficient to conclude that lead was, or was not, the cause of death. Such a conclusion is subjective unless supported by other appropriate findings (Locke and Thomas 1996, Friend 1999a). In the 1970s, inadequate documentation of lead poisoning resulted in mounting disagreements associated with factors influencing lead toxicity such as diet, weather, etc., causing the FWS to designate nontoxic shot zones primarily on the basis of state recommendations. Later, however, the FWS developed recommendations for uniform criteria for monitoring lead exposure and poisoning (US Fish and Wildlife Service 1986a).

A scientifically defensible diagnosis of lead poisoning in a bird carcass is based on a combination of postmortem findings and laboratory assays including lead residues in soft tissues (Table 4). Diagnosis of an epizootic is based on field observations and environmental conditions, and include signs in clinically ill birds, in addition to postmortem findings and tissue analyses (Sanderson and Bellrose 1986, Wobeser 1997, Friend 1999a). In waterfowl, highly visible evidence of lead poisoning is generally provided by clinical signs and gross pathology (Wobeser 1997, Friend 1999a) as described by early research studies involving the pathogenesis, toxicology, and other studies of lead intoxication in birds (Wetmore 1919, Coburn et al. 1951, Bates et al. 1968, Sileo et al. 1973, Clemens et al. 1975). Data of this breadth and quality became an important factor in resolving the waterfowl lead poisoning issue and were basic features of the FWS lead monitoring program conducted by the NWHC during the 1980s.

Mortality data supported by scientific investigations that correlated levels of exposure with population impacts were also needed to establish support for transition to nontoxic shot. Foundational studies by Wetmore (1919) and those that followed (Table 5) were invaluable in establishing the magnitude of losses due to lead poisoning (Bellrose 1959, Sanderson and Bellrose 1986). The robustness of this scientific foundation repeatedly overcame challenges to the toxicity of lead for birds and the magnitude of exposure occurring.

Table 4. Blood, liver, and bone concentrations associated with lead exposure in waterfowl.[a]

	Value Levels of Exposure		
Assay	**Background**	**Elevated**	**Toxic**
Blood (ppm wet weight)	<0.2	0.2–0.5	>1.0
Liver (ppm, wet weight)	<2.0	2.0–6.0	>6.0
Bone (ppm, dry weight)	<10	10–20	>20

[a]Adapted from Pain (1996).

Table 5. Important investigations that have provided a scientific foundation for evaluating the consequences of lead exposure in waterfowl populations.

Investigators (Year of Publication)	Primary Contributions
Wetmore (1919)	▪ Dosing experiments revealed that one No. 6 lead pellet might cause deaths of Mallards but six No. 6 pellets were always fatal. ▪ Results suggested population impacts might be inferred through frequency and amount of lead shot found in waterfowl gizzards.
Shillinger and Cottam (1937)	▪ Reported on the occurrence of shot in 8,366 gizzards of 14 species of ducks and concluded that the quantity of lead constituting a fatal dose was influenced by numerous factors. ▪ Study demonstrated that lead shot ingestion was widespread.
Jordan and Bellrose (1950)	▪ Reported that the nature of the diet rather than the dose of ingested lead was the more important variable determining lead toxicity. ▪ Found "game farm" Mallards to be less susceptible to lead poisoning than wild Mallards.
Bellrose (1951)	▪ Dosing and release of wild-trapped Mallards disclosed a progressive decrease in the rate of movement. ▪ Fluoroscoped wild-trapped Mallards had a progressive increase in ingested pellets from 3–4% prior to the hunting season to 12% by early December, thereby suggesting the importance of annual lead deposition on ingestion rates.
Coburn et al. (1951)	▪ Related the metabolism and deposition of lead in the tissues of ducks to the extent that clinical signs of intoxication could be predicted. ▪ Concluded that soft tissues from ducks could be collected as field samples for the determination of lead poisoning by chemical analysis.
Jordan and Bellrose (1951)	▪ Lead poisoning losses reported to be associated with waterfowl moving into heavily shot-over areas during late fall or winter. ▪ Reported that the majority (69.3%) of gizzards examined that contained shot had only 1 shot. ▪ Attributed differences in species ingestion rates of lead shot to variations in methods of feeding and types of habitat preferred.
Bellrose (1959)	▪ Classic report that placed lead poisoning in waterfowl in perspective. ▪ Documented the ecology of lead poisoning in waterfowl relative to the frequency and geographic distribution of epizootics, seasonality of occurrence, species affected, variations in shot ingestion among species and the effects of this disease on vulnerability to hunting, bird movements and year-of-banding mortality rate.
Longcore et al. (1974)	▪ Provided a basis for evaluating the significance of lead levels found in the tissues of waterfowl.
Clemens et al. (1975)	▪ Described the pathogenisis and associated pathology of lead poisoning in waterfowl. ▪ Found that rate of shot excretion by bird depends on shot size.
Sanderson and Bellrose (1986)	▪ Important comprehensive review of what was known about this disease, issued at a critical time in the transition to nontoxic shot use.
Rocke et al. (1997)	▪ Reported that the rates of lead exposure and lead poisoning mortality in sentinel Mallards maintained on previously hunted areas coincided with lead pellet density in sediments.

Adverse sublethal effects also have been reported in birds exposed to lead. Lead inhibits enzymes involved with heme synthesis, notably delta-aminolevulinic acid dehydratase (ALAD) and heme synthetase. Inhibition of heme synthetase allows protoporphyrin to accumulate in the blood. Thus, reduced ALAD activity and increased protoporphyrin concentrations in the blood have both been used as biomarkers for lead exposure (Finley et al. 1976, Roscoe et al. 1979). Kendall et al. (1996) reviewed sublethal effects of lead in non-waterfowl avian species and, although several studies reported no changes in reproductive parameters, reduced hatchability and testicular atrophy were reported in lead-dosed Mourning Doves (*Zenaida macroura*) and Ringed Turtle-doves (*Streptopelia risoria*), respectively (Veit et al. 1983, Buerger et al. 1986). In a study with Mallards (*Anas platyrhynchos*), no effects were noted on fertility, embryonic viability, or hatchability, but over a 2-year period, controls laid more eggs than lead-exposed birds (Elder 1954). Although the impact of lead exposure on the immune system of birds is poorly understood, studies with lead-exposed Mallards have demonstrated reduced antibody production and immunologic cell numbers (Trust et al. 1990, Rocke and Samuel 1991). Aspergillosis has been associated with lead exposure compromising the immune system of Canada Geese, thereby facilitating opportunistic infection by this fungal disease (Friend 1999b).

Although much of the information about lead poisoning in waterfowl is directly applicable for other species, extrapolation to other birds transforms specific findings to more general situations and consequently increases the risk of misuse and misinterpretation of data. A case in point is the Bald Eagle (*Haliaeetus leucocephalus*). Because documentation of lead poisoning in Bald Eagles did not occur until 1970 (Mulhern et al. 1970), and differences exist from waterfowl in food habits and in the digestive processing of food items, it became necessary to establish specific data for the Bald Eagle. A lead shot dosing study using non-releasable captive birds (Pattee et al. 1981) was conducted for this purpose as part of the assemblage of scientific findings used to assess lead poisoning in this then endangered species (US Fish and Wildlife Service 1986a).

RESULTS

The pursuit of nontoxic alternatives for lead shot was not closely associated timewise with initial recognition of lead poisoning as a cause of waterfowl mortality. Although lead poisoning of waterfowl was known to occur in the US as early as the 1870s, there was little motivation or urgency to act. Instead, from the late 1800s until the 1960s, leading conservationists of each decade drew attention to lead poisoning and noted the need to monitor the situation for possible future action (Grinnell 1901, McAtee 1908, Forbush 1912, Van Tyne 1929, Phillips and Lincoln 1930, Osmer 1940, Alder 1942, Day 1949, Bellrose 1951). As recently as 1959, noted waterfowl biologist, researcher, and lead poisoning investigator, Dr. Frank Bellrose, concluded his landmark scientific publications on lead poisoning with the following statement:

"At the present time, lead poisoning losses do not appear to be of sufficient magnitude to warrant such drastic regulations as, for example, prohibition of the use of lead shot in waterfowl hunting." (Bellrose 1959).

However, Bellrose went on to state that, "Should lead poisoning become a more serious menace to waterfowl populations, iron shot provides a possible means for overcoming it." That serious menace soon materialized. Now basic questions on this subject are: 1) What changed to create a need to act; 2) Why did it take nearly 20 years to complete the transition once there was involvement by the federal government to require nontoxic shot use; 3) Why was this effort totally focused on waterfowl hunting; 4) Was a nontoxic shot alternative already available at that time? The answer to the last question provides foundation for answers to the other three questions.

The Pursuit of Change.—There was early recognition by a number of conservationists that if lead poisoning was to be effectively addressed, it would be necessary to "get the lead out" (Phillips and Lincoln 1930, Alder 1942, Day 1959). In response to that need, the development of a lead-magnesium alloy shot pellet that would disintegrate in water, thus making spent shot unavailable to birds feeding in aquatic environments, was pursued (Dowdell and Green 1937, Green and Dowdell 1936). Those unsuccessful efforts of the mid-1930s were followed a decade later by major exploration for an alternative shot type. Olin Corporation assumed a leadership role in this effort, including a 1948 collaborative project involving its subsidiary, Western Cartridge (now Winchester), the Illinois Natural History Survey, and the University of Illinois School of

Table 6. Alternative shot types for lead tested during 1948–1949 collaborative project (developed from Jordan and Bellrose 1950).

Shot type	Comments
Lubaloy	▪ Thin copper coating over lead pellet Concept is delay of pellet erosion to provide time for pellet to be voided from the gizzard
Lead-tin-phosphorous	▪ Associated patent claims shot will be nontoxic if ingested ▪ Concept is phosphorus will act as neutralizing agent on lead dissolved in the gizzard
Lead-magnesium	▪ Magnesium used as substitute for arsenic and antimony components needed to provide hardness and spherical shape of lead shot ▪ Concept is magnesium will hydrolyze when shot is in water, causing irregular cracks across surface of the pellet and facilitate rapid disintegration of spent shot pellets
Lead-calcium	▪ Concept is that physiological advantage could result by introducing calcium along with lead since metabolism and storage of these elements follow similar pathways ▪ Thought that harmless storage in skeleton would take place following removal of harmful circulating lead

Veterinary Medicine (Jordan and Bellrose 1950). None of the alternatives evaluated by that project (Table 6) proved to be nontoxic. However, other research and development by Olin Corporation indicated that iron (steel) shot had potential as an alternative shot type (Bellrose 1959).

It also was recognized that there were considerations that needed to be overcome for further pursuit of iron shot. Specifically, "…the required manufacturing investment would be large, and this factor, coupled with uncertainty concerning customer acceptance, convinced Winchester-Western that manufacture of iron shot was not feasible unless drastic action was needed to save waterfowl from serious lead poisoning losses…" (Bellrose 1959). Further exploration of nontoxic shot began in the 1960s following major declines in North American waterfowl populations (Sparrowe 1992).

In 1964, the Mississippi Flyway Council Planning Committee formally recommended finding a nontoxic replacement for lead shot for waterfowl hunting. That recommendation was consistent with an opinion by many within the conservation community that lead poisoning was the easiest form of "wasted waterfowl" to address, and that by doing so continental waterfowl populations would benefit greatly (Mississippi Flyway Council Planning Committee 1965).

In the summer of 1964, the Olin Corporation offered the Mississippi Flyway Council the necessary materials and facilities for field testing iron and lead shot. Olin's Nilo Farms Shooting Preserve was used from December 1964 – January 1965 for a field test that yielded positive results for iron shot under standard shooting preserve conditions of pass shooting that averaged about 30 yards in distance (Mikula 1965). In 1965, staff of the FWS met with members of the Sporting Arms and Ammunition Manufacturer's Institute (SAAMI) to discuss the development of nontoxic shot. Research that followed at the Illinois Institute of Technology, the Patuxent Wildlife Research Center (PWRC) of the FWS, and elsewhere generally supported an evaluation by SAAMI that steel shot (soft iron) was the only viable substitute for lead shot for waterfowl hunting (SAAMI 1969).

Alternative shot types tested prior to FWS implementation of nontoxic shot requirements included various coatings on lead shot to prevent erosion and absorption of lead within the bird, alloys to reduce toxicity by reducing the amount of lead in the pellet, disintegrating shot to make the pellets/lead unavailable to birds, shot with antidotal components to offset the effects of lead, and substitute metals (Table 7). This testing included previously tested alternative shot types (Table 6) and a wide variety of other alternatives (US Fish and Wildlife Service 1986a). Although several of these shot types were found to be acceptable based on toxicology, industry criteria for production of acceptable shotshells were not satisfactory (Table 8). Tin was not toxic, but its density was too low for shotgun ballistics.

Table 7. Summary of alternative shot types tested prior to the initiation of nontoxic shot requirements for hunting waterfowl in selected areas of the US (developed, with modifications, from US Fish and Wildlife Service 1986 EIS on lead shot).

Shot type	Concepts	Types Tested
Shot coatings	Resistant enough to withstand acids in digestive tract and grinding action of gizzard, thereby facilitating expulsion by the bird. Overcome hardness and density issues associated with non-lead shot.	• Nickel on lead • Thin-nickel on lead • Lead on steel • Copper on lead • Plastic on lead • Zinc on iron • Molybdenum on iron • Teflon on steel
Alloys	Render the lead less toxic by reducing its content.	• Lead-tin-phosphorous • Lead-tin • Lead-iron
Disintegrating shot	Disintegrate in water to make shot unavailable to birds or disintegrate in digestive tract.	• Lead-magnesium • Lead-resin
Antidote components	Biochemical formation of a chelating ring to prevent lead absorption.	• Lead-calcium • Lead-tin-phosphorous • Others such as additives of EDTA and creatinine.
Substitute metals	Use a metal other than lead as the pellet core	• Copper • Zinc • Tin • Nickel • Steel • Iron • Uranium

Table 8. Industry criteria for acceptable shot characteristics (developed, with modifications, from US Fish and Wildlife 1986 EIS on lead shot).

Characteristic	Purpose
High density	Velocity and energy retention ($E = mv^2$) and weight effectiveness.
Reasonable cost	Readily available base material that is cost effective as shot is the most costly component of the shotshell.
Easily processed	Cost control issue for shot fabrication and facility/equipment requirements.
Relatively inert	Not reactive to other shotshell components and non-corrosive in shelf life.
Soft surface	Needed to prevent damage to gun barrel or chokes.
Nontoxic	Not poisonous to birds, must not contaminate the meat, and must be able to withstand corrosive acids of the digestive tract and grinding action of waterfowl gizzards to the extent that will be passed by the bird before any toxins are absorbed.

Limited testing with depleted uranium revealed no toxicity for Black Ducks (*A. rubripes*), but unanswered environmental fate questions also needed exploration. Neither steel nor nickel were found to be toxic, but had other issues that surfaced. Health impacts of copper were delayed but eventually manifested as significant weight losses from which captive birds could recover from but which might prove fatal for wild birds (Bellrose 1965, Irby et al. 1967, US Fish and Wildlife Service 1986a).

The Dilemma of Change.—Industry was faced with a dilemma. Steel shot (soft iron) was the only nontoxic shot option available in the 1960s, and the performance from steel shotshells being produced at that time was inferior to that from lead shotshells commonly used for waterfowl hunting. However, the major decline occurring in North American waterfowl populations (Figure 2) resulted in a focus on lead poisoning by the waterfowl management community as an issue requiring attention as a remedial action (Mississippi Flyway Council Planning Committee 1965). The magnitude of losses associated with this disease (Bellrose 1959) could no longer be tolerated, and the use of nontoxic shot alternatives was a logical means for significantly reducing those losses. However, major questions arose regarding the timing and the extent of government actions for the use of nontoxic shot.

By 1970, it was clear that nontoxic shot requirements were imminent, and that despite early discussions by some about lead poisoning in Mourning Doves (Shillinger and Cottam 1937) and other species, insufficient data existed to justify nontoxic shot use for hunting upland game birds (Jones 1939, Campbell 1950, Locke and Bagley 1967, Lewis and Legler 1968, McConnell 1968, Kendall 1980). Thus, the FWS limited their focus to waterfowl and associated wetland avian species hunted in waterfowl habitat (Morehouse 1992a).

Change and Controversy.—A paradox of the nontoxic shot controversy is that the Olin Corporation was a leader in early research and development efforts for alternative shot types, then subsequently opposed nontoxic shot requirements, and later once again became a leader in developing and producing high quality nontoxic shotshells. Substantial corporate investments were made in all of these situations. Concerns about lead shortages during the post-WWII era stimulated self-interest in pursuing shot alternatives. With similarity to the current larger-scale issue of alternative fuel to power transportation, those who first succeed in developing suitable alternatives would realize a market place advantage. Also, the 1948 alternative shot project enhanced the public image of the Olin Corporation as a contributor to wildlife conservation (Jordan and Bellrose 1951) and as a respondee to the highly visible dramatic lead poisoning die-offs of Mallards in nearby Grafton, Illinois, in 1947 and 1948.

The oppositional role of Olin Corporation when nontoxic shot requirements were being formulated by the FWS may have been driven by the changing dynamics of the marketplace. Profit margins were being challenged by increased cost for steel shot vs. lead shot. As noted by Coburn (1992), "we are not in either the lead or the steel business; we are in the ammunition business. The shot material is important to us only as it affects shotshell (cartridge) performance and cost." Steel and lead shot are produced by different methodologies, with the former requiring costly investments in manufacturing equipment for production.

Waterfowl hunting loads are not the major segment of the shotshell market. Thus, a total ban on lead shot use for any purpose may have been more acceptable across industry, even though the official Olin Industries position was that nontoxic shot use could only be justified on areas where lead poisoning of waterfowl was documented as a significant mortality factor (Coburn 1992). Previously, representatives of the ammunition industry had informally indicated that if a sufficiently competitive shotshell could be developed, "…ammunition companies would completely abandon the use of lead even for upland game shooting." Also noted was the need for legislation to provide a smooth transition over time and an opportunity to deplete existing lead stocks (Mississippi Flyway Council Planning Report 1965). It is noteworthy that a similar industry position of limiting nontoxic ammunition requirements for other species to well-documented lead poisoning problems was recently issued by Federal Cartridge Company, a leading proponent of the use of nontoxic shot for waterfowl hunting during the 1970s and 1980s: "…when regulating agencies seek to expand the use of lead-free ammunition to species other than waterfowl, the regulating agencies should do so only after they have fully gathered and analyzed thorough, scientifically based, and fully documented evidence that establishes a direct connection to the health and welfare of the species in question" (Federal Cartridge Company 2006). Similarly, the American Sportfishing Association has expressed concern "…about statewide restrictions on the sale and use of lead sinkers [to protect birds from lead poisoning] when research doesn't warrant such broad measures" (Tennyson 2002).

Transition to Nontoxic Shot Use.—Steel shot regulations for waterfowl hunting were initiated in 1972 with requirements to use nontoxic ammunition on seven NWRs selected to participate in field trials. Shotgun shells were provided by each of the major manufacturers: Winchester-Western, Remington Arms, and Federal Cartridge Company. The purposes for those trials was for the FWS to introduce hunters to the use of steel shot and to obtain data on steel shot performances and hunter reactions to its use (US Fish and Wildlife Service 1974). Author Milton Friend participated in the Monte Vista NWR trial in Colorado. The following year, special steel and lead shot comparisons, using unmarked shells, were held on selected public hunting areas. Observers accompanied hunters to dispense shells and record data. Results from these and other comparative studies were variable (Morehouse 1992b), but overall did not support the contention that the use of steel shot resulted in increased losses of waterfowl from crippling (Sanderson and Bellrose 1986a, US Fish and Wildlife Service 1986a). At the state level, Colorado and Oregon each required nontoxic shot on a single hunting area for the 1974 hunting season.

Despite these initiatives, little additional progress was realized in "getting the lead out" for waterfowl hunting until the 1985 hunting season. Until then, legislation was a major factor in suppressing nontoxic shot requirements. However, beginning in 1985, litigation opened the flood gates for the nontoxic shot use that followed. It is worth noting that all of the legal challenges to nontoxic shot regulations were instigated by organizations and/or groups of individuals affiliated with sport hunting. It is also of interest that, Sparrowe (1992) wrote, "Deposition of lead into the environment is still being used by major anti-hunting groups in the United States to argue against hunting. Removal of that argument is a big plus for retaining the social, economic, cultural, and recreational values of hunting." Sparrowe's comments from 16 years ago have even greater relevance today because of the continuing shift in the values of US society towards nonconsumptive wildlife uses.

Change and Litigation.—The first litigation challenge immediately followed issuance of the 1976 DOI Final Environmental Impact Statement (EIS) on the proposed use of nontoxic shot for waterfowl hunting (US Fish and Wildlife Service 1976). A previous proposal, drafted in 1974, called for phased-in flyway-wide bans of lead shot use beginning in 1976 for the Atlantic Flyway and 1977 for the Mississippi Flyway. Beginning in 1978, specifically designated areas in the Central and Pacific Flyways would implement nontoxic shot requirements for waterfowl hunting (US Fish and Wildlife Service 1974). The implementation time table was based on several factors, including needs by industry to deplete existing inventories of lead shot and time to produce adequate supplies of nontoxic shotshells to meet the needs of hunters across the US. Following public comment and review, the 1974 draft proposal was modified in 1976 to require nontoxic shot use for waterfowl hunting only in "problem areas" in each flyway and following the same time line for implementation as appeared in the 1974 draft (US Fish and Wildlife Service 1976).

The National Rifle Association (NRA), an organization whose leadership represents a large contingency of gun owners and sportsmen, challenged the proposal in court. They contended that steel shot (soft iron) posed human health and safety risks, increased waterfowl crippling, and damaged firearms, other property, and the environment. They also alleged that the EIS was inadequate. The court ruled in favor of the government, and an appeal by the NRA also failed (Anderson 1992).

In 1978, the "Stevens Amendment" to the Interior Department appropriations bill prohibited the FWS from using funds to implement or enforce nontoxic shot use for hunting waterfowl without approval of the states involved. That amendment was reenacted annually until 22 December 1987 when it was allowed to expire. During most of that time, the Stevens Amendment stifled implementation of nontoxic shot regulations. That effectiveness was a result of the individual states generally being more vulnerable to "political pressure" on this matter than the federal government.

Lawsuits were filed by groups of sportsmen against four states that initiated limited steel shot zones for waterfowl hunting following passage of the Stevens Amendment. Author Friend testified on behalf of the state in the South Dakota and Florida cases. Another NWHC staff member, Dr. Louis Locke, testified on behalf of the state of Texas in that lawsuit. The New York case was never tried, as the state was granted a motion for summary judgment. The states prevailed in all the judgments, including appeals filed in the South Dakota and Texas cases (Anderson 1992).

Illinois, Maryland, and Wyoming used the Stevens Amendment "states' rights" approach to pass legislation banning or restricting nontoxic shot use for waterfowl hunting in their states. Wisconsin was the only state to "swim upstream" while the Stevens Amendment was in place, passing 1985 legislation mandating statewide use of nontoxic shot for waterfowl hunting. Kansas followed with similar legislation five years later, after the Stevens Amendment had expired.

Lead poisoning of Bald Eagles eventually trumped the Stevens Amendment on the legislative/litigation battlefield. The first case of lead poisoning in a Bald Eagle was an incidental finding by the PWRC's environmental contaminant program (Mulhern et al. 1970). However, the 1975 establishment of the National Wildlife Health Center (NWHC) greatly expanded investigations of mortality in wildlife under FWS stewardship. The NWHC disease diagnostic database soon contained numerous records of Bald Eagle mortality due to lead poisoning (National Wildlife Health Center 1985). In response to what appeared to be a growing problem, the FWS proposed nontoxic shot regulations for waterfowl hunting in portions of eight states beginning in 1985.

Five of the states, acting under the auspices of the Stevens Amendment, did not consent to the regulations. As a result, the federal government announced that unless those states reversed their decisions, the FWS would not open the disputed areas for waterfowl hunting in 1986 as a means for protecting Bald Eagles from lead poisoning. At that point, the National Wildlife Federation (NWF) sued the federal government (Anderson and Havera 1989) to obtain a ban on lead shot for waterfowl hunting in the areas in question (Anderson 1992). The NWF prevailed because it was well-fortified with data obtained under the Freedom of Information Act and through other interactions with the NWHC and others (Feierabend and Myers 1984). The court ruled that the areas in question be closed to waterfowl hunting for the 1985 hunting season unless only nontoxic shot was used. That ruling increased the percentage of the US waterfowl harvest covered by nontoxic shot regulations three-fold (Anderson 1992) (Figure 4).

In 1986, the NWF again initiated legal action against DOI to prevent authorization of lead shot for waterfowl hunting throughout the continental United States beginning with the 1987 season. In response, the DOI unveiled a plan to phase out lead shot for waterfowl hunting over a period of several years, culminating in a nationwide ban in 1991. The court

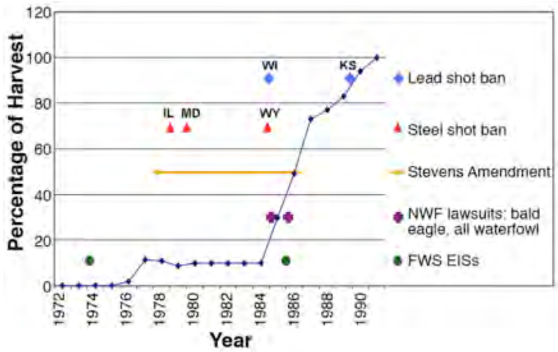

Figure 4. Effects of legislation on lead shot use for waterfowl hunting in the US as a function of the percentage of waterfowl harvest in nontoxic shot zones (Modified from Anderson 1992).

noted that the DOI had conceded on all aspects of the dispute except timing and dismissed the case for "want of ripeness." A countersuit and an appeal were unsuccessful (Anderson and Havera 1989). In response to the rulings of the court, the percentage of the waterfowl harvest in nontoxic zones increased to 49% in1986 as the FWS and some state wildlife agencies designed additional nontoxic shot areas (Figure 4).

The last lawsuit to challenge nontoxic shot regulations was initiated by the California Game and Fish Commission in the US District Court for the Eastern District of California in 1987. The NRA intervened on behalf of the plaintiff, and the NWF intervened on behalf of the defendant. Following the court's ruling

Table 9. Primary federal statutory authorities relevant to addressing lead poisoning in wildlife (developed from Anderson 1992).

Legislation		Relevance
Migratory Bird Treaty Act	1918	• Empowers federal government to *determine whether, to what extent, and by what means* hunting of migratory birds is allowed in the U. S.
Bald Eagle Protection Act	1940	• *Prohibits the take* of eagles without special authorization. • "Take" includes…"shoot at, poison, wound, kill…"
Bald and Golden Eagle Protection Act	1962	
Endangered Species Act	1976	• Bald Eagle listed as endangered in 43 of the conterminous states and as threatened in the other 5 states at the time of enactment. • Requires that listed species be conserved. • "Conserved" means *"…the use of all methods and procedures which are necessary to bring any endangered species…" to a point of recovery* consistent with delisting.
National Environmental Policy Act	1970	• Policy and responsibility for maintaining the quality of the environment and renewable resources. • Directs government to prevent environmental degradation "…or other undesirable and unintended consequences…" and to "…enhance the quality of renewable resources…"

in favor of nontoxic shot, plaintiffs filed a notice of appeal, but it was dismissed. The percentage of the waterfowl harvest in nontoxic shot zones increased to 73% in 1987 and to 100% in 1991 (Figure 4).

The arguments forwarded in the various lawsuits involved biological, socio-economic, and political issues – the last primarily consisting of challenges of agency authorities. In general, the issues involved had been identified in the 1965 Mississippi Flyway Planning Committee Progress Report as factors that needed to be addressed. In all cases, the courts ruled that the agencies whose actions were contested had fundamental authority and responsibilities under various statutes, legislation, and treaties to take those actions. Authority at the federal level relevant to addressing lead poisoning in migratory birds is vested in major legislation and international treaties (Table 9). In essence, in the California case, the Court found that, under the Migratory Bird Treaty Act and the Endangered Species Act, the FWS has almost carte blanche authority to take whatever steps are necessary to protect migratory birds and endangered species (US Fish and Wildlife Service 1988).

Biological challenges (Table 10) were answered by the sound science available to support problem identification and the need for action. However, science was helpful in addressing only a small number of the socio-economic issues (Table 11). These needs required continued attention throughout the transition process.

DISCUSSION

Little of what we have presented here reflects the bitterness that characterized much of the struggle to transition to the use of nontoxic shot for waterfowl hunting in the US. Nor does it reflect the heavy personal costs to those who championed the use of nontoxic shot, among them state and federal employees, outdoor columnists, members of the general public, academicians, researchers, and others. Although personal feelings on both sides were often emotionally charged, it would be folly to view this issue in terms of "we vs. them," for there was as much conflict within the professional wildlife conservation community as there was between agencies of that community and external parties. Similar conflicts existed within industry and elsewhere. For example, in contrast to Winchester, Federal Cartridge Company was aggressively pro-steel shot during the entire conflict period while Remington Arms remained rather neutral. In essence, both sides failed to adequately grasp the complexity of this issue, and in some instances, were so motivated for their causes that their actions ignored alternative

Table 10. Biological issues highlighted in court cases challenging nontoxic shot (steel) use for hunting waterfowl in the US.

Issue	Case(s)					
	NRA	South Dakota	New York	Texas	Florida	California
Poor/inadequate science			X	X		X
Population impacts from lead vs. benefits				X		
Increased crippling	X				X	
Steel shot boundary delineations		X	X	X		
Effects of diet			X			

Table 11. Socio-economic issues highlighted in court cases challenging nontoxic shot (steel) use for hunting waterfowl in the US.

	Case(s)					
Issue	NRA	South Dakota	New York	Texas	Florida	California
Human health and safety risks (ricochets and dental)	X				X	
Firearms damage, other property damages	X	X	X	X	X	
Reloading components not available				X		
Availability of steel shot shells				X		
Discrimination against females, children, aged				X		
Increased costs to hunters			X		X	
Economic losses from lead shot stocks				X		

considerations. The following statement, made in 1965, serves as an example of an overly simplified perspective of the challenges involved:

"Public relations experts are confident that paving the way for public acceptance of a new type of shotgun shell is not a difficult problem…a well-planned program should be ready to go as soon as the new product is announced. Preliminary conditioning of the public can even precede that." (Cox 1965).

To a large extent, "public education" needed to begin within the conservation agencies, because there were many employees who interfaced with hunters and other members of the public who knew too little about lead poisoning and/or were opposed to nontoxic shot use. Further, reaction drove public education efforts for too long and was a poor substitute for a progressive, well-rounded education program. The US Cooperative Lead Poisoning Control Information Program (CLPCIP) arose from this need (Bishop and Wagner 1992). However, that program was not initiated until 1982, well after the conflict over nontoxic shot use had become well entrenched. CLPCIP has since become the Cooperative Non-toxic Shot Education Program.

Informational and educational activities assumed many forms during the conflict over nontoxic shot. They also consumed large amounts of personnel and fiscal resources from agency, non-government organization (NGO), industry, and others. At times, prolonged skirmishes initiated by both sides took place via articles in sporting magazines and newspapers and via news releases and various public consumption publications. Anti-steel shot factions did verbal battle with pro-steel shot advocates over the interpretation of shooting trials and ballistics data. Unique statistical approaches and carefully worded evaluations were sometimes used to interpret data and support conclusions (Kozicky and Madson 1973, Lowry 1974, Bockstruck 1978, Coburn 1992, Carmichael 2002). As a result, waterfowl hunters and others were left awash in a sea of conflicting information and presentations.

The encouragement of hands-on involvement by the public were powerful tools for “perspective and attitude adjustments” regarding the lead poisoning issue. A case in point is the assistance of Wisconsin hunters in the clean-up of a major lead poisoning die-off of Canada Geese. Another example is the encouragement of hunters in conducting their own lead shot ingestion studies using gizzards from birds they personally harvested. Steel shot shooting clinics sponsored by the CLPCIP were invaluable educational forums for influencing hunters about steel shot and enhancing their shooting skills. A modified shooting clinic and education program organized by the FWS for the Congressional Sportsmen Coalition and held at Andrews Air Force Base in the Washington, DC area was attended by the Secretary of the Interior, the FWS Director, and others involved in managing the direction of FWS actions on nontoxic shot requirements.

Two graphic movies also served important educational roles. The first, on lead poisoning in waterfowl and Bald Eagles, utilized footage from lead poisoning field outbreaks and other visual materials to address commonly asked questions about this disease (US Fish and Wildlife Service 1986b). The second focused on bagging waterfowl with steel shot. Footage of waterfowl being taken under field conditions and follow-up laboratory measurements of those birds were used to assess steel shot performance (US Fish and Wildlife Service 1986c). The lead poisoning movie was widely viewed and has served as an educational tool for use by those in other countries pursuing nontoxic shot use for waterfowl hunting. The steel shot shooting movie was found to be unacceptable by some DOI administrators after a preliminary showing, and was not released for general use. However, an unofficial copy obtained by non-government sources was seen by numerous audiences. Eventually, a shorter version of this movie was released by the FWS for general use. Both movies were converted to video format to enhance distribution and use by external parties. A variety of industry and other public sector videos on shooting steel shot followed (Table 12).

Table 12. Examples of video presentations on lead poisoning in waterfowl and on the use of steel shot for waterfowl hunting.

Title	Year of Issue	Source	Running Time (minutes:seconds)
Steel Shot Facts for the Waterfowl Hunter	1986	Federal Cartridge Company Minneapolis, MN	11:18
World Champion’s Guide to Hunting Waterfowl with Steel Shot	1988	W.C. Badorek and D. Beleha Klamath Falls, OR	45:00
The Duck Hunter Shooting and Shot	1987	Videolore Emeryville, CA	Not given
Field Testing Steel Shot	1986	FWS Washington, DC	30:00
Lead Poisoning in Waterfowl	1986	FWS Washington, DC	27:49

The FWS utilized a three person team of subject matter experts with established credentials in waterfowl/migratory bird management (Office of Migratory Bird Management), in lead poisoning/avian diseases (NWHC), and in shooting steel shot (contractor) to provide presentations and respond to questions at various public forums involving the nontoxic shot issue. The same individuals appeared together at nearly all of those events. That approach provided consistent commentary, technical breadth to respond to the broad array of questions received and a great deal of useful insight for guiding FWS management of this issue by listening to concerns and commentary by others across the country.

An organized "opposition team" often also presented at these forums and typically included at least one individual known to the local audience. There also was a private sector individual that attended a number of these forums and tape-recorded commentary, by at least the nontoxic shot advocates, as a basis for his "writings." Some of these forums were aggressively hostile towards presenters supporting nontoxic shot. Their commentary and response to questions were disrupted, and in some instances, their safety was threatened. Some forums were conducted in ways that facilitated comment from those opposing nontoxic shot, but suppressed commentary from those supporting nontoxic shot. Those situations were preplanned and orchestrated to prevent dissemination of information on non-toxic shot and open discussion.

In addition to the larger public forums/hearings, a great deal of time was devoted by NWHC personnel to speaking on lead poisoning at sportsman clubs and civic group meetings, and conducting agency workshops involving state and federal biologists, law enforcement, and management personnel. Information from ongoing NWHC disease investigations and the FWS lead monitoring program was incorporated in workshop presentations. Hard copy brochures, pamphlets, and other materials specifically developed for informational and educational purposes were provided as handouts for important adjuncts to presentations. Some handouts, such as the "Kansas Wildlife" magazine reprint Are We Wasting Our Waterfowl? (Kraft 1984) and a FWS brochure depicting the clinical signs and gross lesions of lead poisoning in waterfowl (US Fish and Wildlife Service 1986d) were made available for additional use and distribution by workshop participants that requested them.

A relevant question is, "What has been accomplished?" Clearly, the implementation of nontoxic shot requirements for hunting waterfowl has dramatically reduced lead shot ingestion by waterfowl and subsequent losses from lead poisoning. Anderson et al. (2000) found in their 16,651 samples from the Mississippi Flyway during 1996 and 1997 that gizzards of 44% to 71% of major duck species contained only nontoxic shot. These authors estimated that nontoxic shot reduced mortality from lead poisoning in Mississippi Flyway Mallards by 64% and extrapolated their data to a saving from lead poisoning of 1.4 million ducks nationwide in the 1997 fall continental flight of 90 million ducks (Anderson et al. 2000). Smaller scale post-nontoxic shot implementation evaluations also disclosed major reductions in lead exposure (DeStefano et al. 1995, Calle et al. 1982). Additionally, it appears that reduced exposure to lead shot has not been offset by increased crippling caused by the use of nontoxic shot. A recent review of historical waterfowl harvest data by Schulz et al. (2006) revealed that after an initial increase in reported crippling rates, current reported rates were lower than those of pre-nontoxic shot rates for both ducks and geese (see also: US Fish and Wildlife Service 1986a, Morehouse 1992b).

Once the FWS implemented a total ban on the use of lead shot for hunting waterfowl, industry responded by developing high quality nontoxic shotshells. As noted by Coburn (1992), Winchester was marketing a total of 59 different steel shot loads, including 10-, 12-, 16-, and 20-gauge sizes by 1992. This variety of shells reflects major advancement from the first steel load marketed in 1976, a 12-gauge, 2¾", 1¼ ounce shotshell. Hunter education programs and shooting clinics also have enhanced hunter performance in bagging waterfowl with nontoxic shells.

Not only are steel shot shells of today far superior in quality and performance than those first provided to hunters in 1972, but steel shot is no longer the only choice (Table 13). In addition to multiple types of nontoxic shotshells produced by an increased number of manufacturers, these shells are now available in a greater range of gauges and shell lengths. Industry has developed a 3½" chamber 12-gauge shotgun as a new consumer product. Hand-loading components and equipment for nontoxic shotshells are also marketed along with a wide array of educational materials for improving hunter performance. These transitions have involved social change for waterfowl hunters by replacing traditional methods with new ones. The variety and high quality of today's nontoxic shotshells are clearly products of the competitive marketplace responding to firm regulatory schedules for nontoxic shot implementation (Coburn 1992). Current nontoxic shotshells also represent a response by industry to the needs of both conservation and contemporary hunters.

Points to Ponder.—We close by suggesting that further resolution of lead poisoning issues will benefit from a three-legged stool approach (Figure 5a). The legs supporting the platform for that proverbial stool are problem identification, acceptable alternatives, and authority to act. Each leg is comprised of a different substance. Material failure in any of the legs will cause the platform to collapse because the tensile strength achieved by the

Table 13. Entry of various nontoxic shotshells into the United States market.

Year	Approximate percentage of waterfowl harvest within non-toxic shot zone[a]	Shell type entry by Federal Cartridge Company[b]
1972	<1	2 ¾" 12-gauge steel[c]
1977	12	3" 12-gauge steel
1980	10	3" 20-gauge and 3 ½" 10-gauge steel
1982	10	2 ¾" 20-gauge steel
1987	73	2 ¾" 16-gauge steel
1989	82	3 ½" 12-gauge steel
1991	100	(start of nationwide requirement for nontoxic shot use for waterfowl hunting)
1992–1995	100	Bismuth
1996	100	Tungston-iron alloy 2 ¾" and 3" 12-gauge)
1997	100	Tungston-polymer (3 ¾" and 3" 12-gauge)[d]
1998	100	Tungston-iron alloy (3 ½" 10- and 12-gauge)[e]
2003–2004	100	Tungsten-iron-nickel alloy[f]
		Other[g]

[a] Anderson 1992.
[b] Contributed by William F. Stevens.
[c] Federal, Remington and Winchester all introduced this shell type at the same time; Federal was the first company to offer all of the other loads listed except for bismuth shot.
[d] Discontinued after 3 or 4 years due to high production cost; marketed by Kent Cartridge Company under the trade name of Tungsten Matrix.
[e] Currently sold under the trade name of High Energy.
[f] Sold under the trade name of Heavyweight; most dense nontoxic shot pellet on the market.
[g] Remington, Winchester, and small independent companies have contributed other shell types since nationwide nontoxic shot requirements were implemented; for example, Hevi-shot loads have a tungsten base combined with iron, nickel, bronze, and perhaps something else; bismuth/tin alloy only nontoxic shot pelts in 28 and .410 gauges but Hevi-Shot Classic Doubles Shot (tungsten alloy) plans to provide 16, 28, and .410 gauge loads in the near future (Bourjaily 2008).

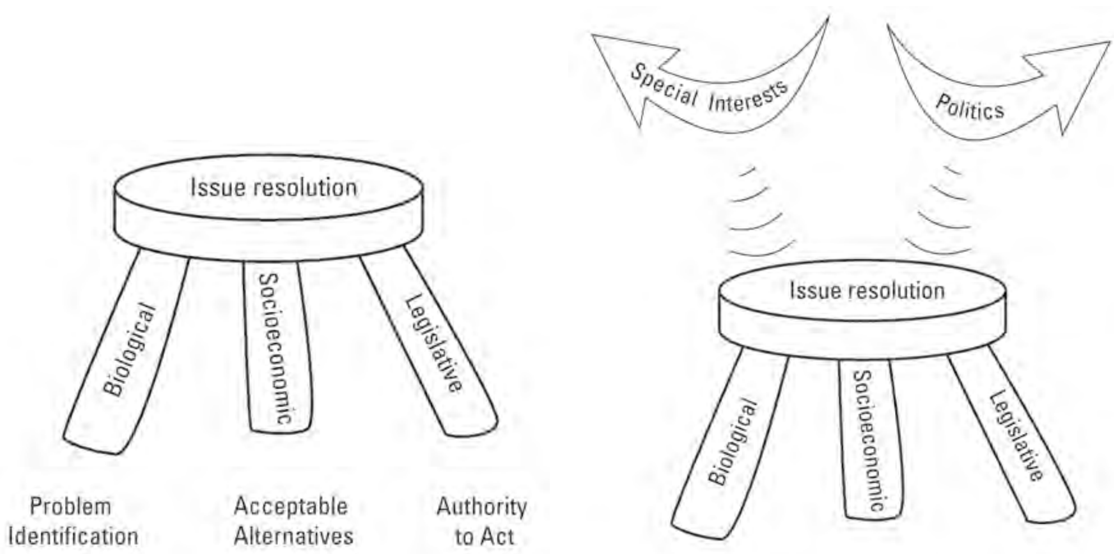

Figure 5. Three-legged stool approach for addressing lead poisoning in wildlife. (A) Each leg provides support for a different aspect of the issue. (B) The collective strength of the platform supported by the legs can withstand the pressures exerted upon it by external forces, thereby facilitating issue resolution.

combination of all three substances is required to withstand the pressures that will be exerted on the stool (Figure 5b).

Problem identification is the biological leg and provides foundation by soundly identifying the who, what, when, where, and why aspects of the problem (Table 14). The socio-economic leg provides support through the continued conduct of acceptable alternatives for traditional activities. Authority to act is the legislative leg, and it provides support through a willingness to act by discharging vested authorities and responsibilities.

The challenges in moving forward in reducing lead poisoning in avian species are great. Nevertheless, we believe that by applying the lessons learned in the waterfowl lead poisoning struggle, a sound platform for success can be built that will withstand forthcoming pressures. Many of the lessons learned are highlighted in the conclusions section of the "Lead Poisoning in Waterfowl" proceedings from the 1991 International Waterfowl Research Bureau workshop held in Brussels, Belgium (Pain 1992). Among the concluding comments are nine recommendations for implementing the solutions to lead poisoning (Moser 1992). We offer one of those for our concluding comments:

"It is essential to have an effective information, awareness and education programme prior to, and during, the implementation of a lead shot replacement programme. This should include definition of the problem, an explanation of the options considered for the solution, and hands-on demonstrations for hunters to see for themselves the efficacy of non-toxic shot…"

Table 14. Basic foundational considerations needing to be addressed in developing a biological justifications for the replacement of lead used in recreational sports.

Considerations	Dimensions
Who is affected?	Species impacts that are to be addressed.
What is the problem?	Magnitude of impacts relative to population or other costs that require remedial action.
When does it occur	Seasonality considerations that may guide approaches for addressing the problem.
Where does it occur?	Delineation of the problem geographically to guide remedial and preemptive actions.
Why does it occur?	Determination of the factors contributing to the undesirable outcome(s) to be addressed.

The concept cited is as valid for the replacement of lead in fishing tackle, shooting sports, and other sporting activities that deposit lead in the environment as it is for waterfowl hunting. A critical aspect governing the effectiveness of this concept is the involvement of all stakeholders in its development and implementation.

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