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LEAD EXPOSURE IN AMERICAN BLACK DUCKS AFTER IMPLEMENTATION OF NON-TOXIC SHOT

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Abstract: Lead poisoning from the ingestion of spent shotgun pellets has been recognized as an important disease of North American waterfowl since Bellrose's (1959) research >40 years ago. Nation-wide regulations banning the use of lead shot for waterfowl hunting were established in 1991. We compared the prevalence of lead exposure in American black ducks (*Anas rubripes*) wintering on 2 areas in Tennessee before (1986–88) and after the ban (1997–99) to assess the effect of the ban on lead shot on this species. Prevalence of elevated blood lead in black ducks declined by 44% from before (11.7% prevalence) to after (6.5% prevalence) the implementation of non-toxic shot. The reduction in lead exposure was pronounced in adult black ducks (from 14.3% to 5.3%). However, prevalence in lead exposure remained similar in juvenile black ducks (from 8.2% to 8.3%). Additional evidence from lead ingestion and lead poisoning mortality events also indicates that lead exposure has declined in waterfowl in the Mississippi flyway. We believe that lead ingestion will continue to decline, despite the persistence of lead shot in some wetlands. The impact of reduced lead exposure on waterfowl populations needs to be assessed.

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Key words: American black ducks, *Anas rubripes*, blood lead, lead exposure, lead shot, Tennessee.

Lead poisoning resulting from lead shot ingestion has long been recognized as an important source of mortality for waterfowl (Bellrose 1959) and many aspects of the disease have been well documented (Sanderson and Bellrose 1986, Pain 1992). Historically, Bellrose (1959) and Feierabend (1983) estimated that lead poisoning killed 1.6–3.9 million waterfowl in North America when fall flights ranged between 80 and 130 million birds. As a result of these losses, lead poisoning in waterfowl populations and secondary poisoning of other species such as the bald eagle (*Haliaeetus leucocephalus*) has generated considerable controversy. In response, nontoxic shot zones were established in portions of the Mississippi flyway beginning in 1977, and in 1991 mandatory use of nontoxic shot for waterfowl hunting went into effect throughout the United States. These efforts were designed to reduce the availability of lead shot; however, decades of hunting have resulted in high densities of lead shot remaining on some areas (Sanderson and Bellrose 1986, U.S. Fish and Wildlife Service 1986, DeStefano et al. 1991, Rocke et al. 1997), which may continue to be ingested by waterfowl (Mauser et al. 1990; DeStefano et al. 1991, 1995; Hohman et al. 1995). Proponents of nontoxic shot predicted that lead shot exposure and lead poisoning in waterfowl would decline as a result of banning lead shot.

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When documenting the significance of lead exposure in waterfowl, many investigators relied on the prevalence of ingested lead shot in gizzards of hunter-harvested birds. These studies showed that waterfowl harvested in the Mississippi flyway had the highest reported ingestion rates, consistently documented at about 8% for mallards (*Anas platyrhynchos*) between the periods 1938 to 1954 (Bellrose 1959) and 1974 to 1982 (Sanderson and Bellrose 1986). Ingestion of lead shot by mallards was lower (3–4%) in wintering areas of the Central flyway (Sanderson and Bellrose 1986, U.S. Fish and Wildlife Service 1986). In the Mississippi flyway, ingestion of lead shot by black ducks obtained from hunters has usually exceeded that for mallards (Bellrose 1959, U.S. Fish and Wildlife Service 1986). Despite the usefulness of ingested shot to estimate and monitor lead exposure in wild waterfowl, this method has been questioned because birds with ingested lead shot may be more vulnerable to hunting, thus producing an overestimate of lead shot ingestion rates (Jordan and Bellrose 1951, Bellrose 1959, Anderson and Havera 1985, Sanderson and Bellrose 1986, DeStefano et al. 1995), and the type of food consumed may influence absorption and toxicity of ingested lead (Sanderson and Bellrose 1986). Blood lead, in contrast, is a more sensitive method for measuring lead exposure in live waterfowl (Anderson and Havera 1985), is a better indicator of the amount of lead absorbed by birds, and has been correlated with physiological effects, biochemical lesions, and cerebellar damage cause by lead poisoning (Dieter and Finley 1978, 1979; Anderson and Havera 1985).

The recent decline in the North American black duck population has generated considerable management concern (Rusch et al. 1989). This population is comprised of 2 fairly distinct subpopulations, one occurring in the Atlantic flyway and the other in the Mississippi flyway (Wright 1954, Sanders et al. 1995). Although most research and management efforts on wintering black ducks have been conducted in the Atlantic flyway (Sanders et al. 1995), a large portion of the continental population winters in the Mississippi flyway (Rusch et al. 1989). Tennessee is a key wintering area for black ducks throughout the eastern region of the Mississippi flyway. Since 1970, over 40% of the black ducks surveyed during mid-winter in the Mississippi flyway have occurred in Tennessee (Gamble and Peterson 1998) with a high percentage of these birds occurring at Cross Creeks and Tennessee National Wildlife Refuges (Rusch et al. 1989, Sanders et al. 1995). Thus, Cross Creeks and Tennessee National Wildlife Refuges are key wintering areas for Mississippi flyway black ducks as well as other waterfowl species. Banding and recovery data demonstrate that black ducks from numerous northern states and Canadian provinces winter at these 2 refuges. Although black ducks exhibit less temporal variation in distribution patterns during winter and stronger fidelity to winter areas than other more mobile species such as mallards (Diefenbach et al. 1988), blood lead levels can remain elevated for >45 days after lead ingestion (Franson et al. 1986). Thus, we believe that lead exposure in black ducks wintering in Tennessee likely is indicative of overall trends for this species within the Mississippi flyway.

Previous studies have recommended periodic monitoring of waterfowl populations to evaluate trends in lead exposure following the implementation of nontoxic shot regulations (Samuel et al. 1992, DeStefano et al. 1995). We used blood samples collected from black ducks banded in Tennessee during 1986–88 (prior to nontoxic shot regulations) and 1997–99 (post-implementation) to determine the prevalence of lead exposure in wintering birds. We assessed the prevalence of lead exposure during 1997–99 and compared these results with lead exposure in 1986–88 to test the prediction that lead exposure declined following the implementation of nontoxic shot regulations.

STUDY AREA AND METHODS

The study area was generally described by Samuel et al. (1992). Briefly, Cross Creeks National Wildlife Refuge is a 3,650-ha refuge consisting of wetlands, hardwood forest, croplands, and brush, located in northwestern Tennessee. Tennessee National Wildlife Refuge consists of 3 separate management units along the Tennessee River in western Tennessee. Duck River is the primary management unit including >10,500 ha of moist soil units, open water, upland hardwoods, and croplands. Mallards, black ducks, and American wigeon (*Anas americana*) are the major wintering duck species with numbers peaking during December and January. Although extensive hunting with lead shot occurred near the boundaries of both Cross Creeks and Tennessee National Wildlife Refuges, waterfowl hunting has occurred on these

refuges only during a few years of the 30–50 years of their existence (Samuel et al. 1992). Nontoxic shot was required for waterfowl hunting in areas surrounding Cross Creeks and Tennessee National Wildlife Refuges beginning in 1989 and 1990, respectively.

Black ducks at Tennessee and Cross Creeks National Wildlife Refuges were trapped using cannon nets and swim-in traps baited with corn during 3 winters (Jan–Mar) in 1986–88 and 2 winters (Nov–Jan) in 1997–99. Age and sex of each bird were determined according to plumage and cloacal characteristics (Carney 1964, Larson and Tabor 1980). One to 2 ml of blood was obtained from the jugular vein with a 5-cc heparinized syringe. Blood was frozen and stored for subsequent analysis at the U.S. Geological Survey National Wildlife Health Center, Madison, Wisconsin, to determine blood lead concentrations. The whole heparinized blood was diluted 10-fold in a mixture of 0.5% alkylaryl polyether alcohol and 0.2% ammonium dihydrogen phosphate. The diluted samples were stirred immediately prior to the assay. The analytical method was essentially that of Fernandez and Hilligoss (1982), except for a difference in blood dilution. In 1997–99, lead concentrations were determined using a Thermo Jarrell Ash (TJA) model 188 graphite furnace with a TJA DS-2000 autosampler coupled to a TJA Scan-1 atomic absorption spectrophotometer (Thermo Jarrell Ash Corporation, Franklin, Massachusetts, USA). The same procedure was used to analyze blood samples collected in 1986–88, with the exception of updated assay equipment (Samuel et al. 1992:556 for previous equipment). Method detection limit studies were conducted to insure that both sets of assay equipment provided comparable blood lead measurements. To maintain quality control standards, ≥15% of the samples tested included a duplicate sample, a blank, or a reference sample of known value.

Blood lead concentrations ≥0.2 ppm were considered to represent exposure to lead above the normal background levels (Friend 1985). Birds were classified as either exposed (≥0.2 ppm) or not exposed (<0.2 ppm) to lead. Chi-square and stepwise logistic regression (Dixon et al. 1985) methods were used to evaluate univariate and multivariate factors influencing the proportion of birds exposed. Because the statistical distribution of blood lead values for exposed birds was truncated below 0.2 ppm and skewed to the right, we compared the distribution of blood lead concentrations of exposed birds using a nonparametric Mann-Whitney U test (Daniel 1978) by analysis of variance on ranks (SAS Institute 1987).

RESULTS

During 1997–99, blood samples from 721 black ducks were tested for lead exposure (Table 1). Forty-seven (6.5%) had lead values ≥0.2 ppm exposure threshold. Lead exposure was the same at Cross Creeks (6.5%) and Tennessee (6.5%) National Wildlife Refuges. Blood samples from 23 (5.3%) of 432 adults and 24 (8.3%) of 289 juvenile black ducks were in the exposed category. Blood samples from 23 (5.5%) of 418 male and 24 (7.9%) of 303 female black ducks were in the exposed category. Logistic regression analysis also indicated that exposure rates by year, age, and sex were similar (χ^2_1s ≤ 2.47, *P*s ≥ 0.12). The distribution of blood lead concentrations for exposed birds was similar (Zs ≤ 1.285, *P*s ≥ 0.20) by refuge, year, age, and sex. Based on these results, samples from 1997–99 were pooled for comparison to the samples from a previous study conducted in 1986–88 (Samuel et al. 1992).

Four-hundred twenty-three black ducks were tested for lead exposure during 3 winters in 1986–89 (Samuel et al. 1992:557). Fifty-one birds (11.7%) had blood lead concentrations ≥0.2 ppm indicating exposure to lead. Based on stepwise logistic regression and χ^2 analyses, prevalence of lead exposure was similar for refuge of banding, year of banding, or sex of bird (Samuel et al. 1992). Age was the only variable that was significantly associated with prevalence of lead exposure; adults (14.4%) had a higher prevalence of lead exposure than juveniles (8.2%). Using nonparametric ANOVA, Samuel et al. (1992) found that blood lead concentrations for exposed birds was higher at Cross Creeks than at Tennessee National Wildlife Refuge; however, blood lead concentrations were similar among age and sex classes, or by year.

Logistic regression analysis of recent (1997–99) blood samples and samples collected 10 years earlier (1986–88) indicated lead exposure rates were similar (χ^2_1s ≤ 1.61, *P*s ≥ 0.20) between refuges, age, and sex categories. However, the exposure rates were lower (χ^2_1 = 10.1, *P* = 0.002) in 1997–99 (6.5%) than in 1986–88 (11.7%). Based on these results, lead exposure

Table 1. Number of individuals tested and percentage of adult–juvenile and male–female black ducks exposed to lead (≥0.2 ppm blood lead) at Cross Creeks and Tennessee National Wildlife Refuges, 1997–99.

			Cross Creeks		Tennessee	
Yr	Age	Sex	Number tested	Percent positive	Number tested	Percent positive
1997–98	A	F	21	0.0	20	10.0
		M	103	4.9	57	7.0
	J	F	55	5.5	25	4.0
		M	26	11.5	10	10.0
	Total	F	76	4.0	45	6.7
		M	129	6.2	67	7.5
1998–99	A	F	22	18.2	40	5.0
		M	99	4.0	70	2.9
	J	F	53	11.3	67	9.0
		M	20	5.0	33	9.1
	Total	F	75	13.3	107	7.5
		M	119	4.2	103	4.9
All	A	F	43	9.3	60	6.7
		M	202	4.5	127	4.7
		Total	245	5.3	187	5.4
	J	F	108	8.3	92	7.6
		M	46	8.7	43	9.3
		Total	154	8.4	135	8.2
	Total		399	6.5	322	6.5

has declined by 44% from the rates found prior to the ban on lead shot. Because exposure rates differed between adults and juveniles in the 1986–88 blood samples but not in the 1997–99 samples, we also conducted separate χ^2 analyses on these groups. We found that lead exposure rates were lower (χ^2_1 = 16.9, P = 0.0001) for adult birds in 1997–99 (5.3%) than in 1986–88 (14.3%), but exposure rates for juveniles were similar (χ^2_1 = 0.002, P = 0.96) in 1997–99 (8.3%) and 1986–88 (8.2%).

We compared the distribution of blood lead concentrations for exposed birds sampled during the period proceeding nontoxic shot regulation (1986–88) and following implementation (1997–99). We found similar concentrations of lead in exposed birds sampled 10 years ago and those recently sampled for Cross Creeks National Wildlife Refuge (Z = 1.49, P = 0.14), Tennessee National Wildlife Refuge (Z = 1.17, P = 0.24), adult birds (Z = 1.53, P = 0.13), juvenile birds (Z = 0.92, P = 0.36), males (Z = 0.86, P = 0.39), and females (Z = 1.34, P = 0.18). Although we found no significant differences between recent blood lead concentrations and those collected 10 years earlier, blood lead concentrations had lower values in the 1997–99 samples corresponding with the decline in exposure.

DISCUSSION

Lead poisoning caused an estimated annual mortality of 2–3% of the fall population of waterfowl in North America for >30 years (Bellrose 1959). For mallards, annual losses were estimated at 4% in the Mississippi flyway, where black ducks had a similar or higher prevalence of lead ingestion compared to mallards. In addition to direct mortality from lead poisoning, lead can cause weight loss (Finley and Dieter 1978, Sanderson and Bellrose 1986), neurological dysfunction (Dieter and Finley 1978, 1979), and reduced immunological function and disease resistance (Trust et al. 1990, Rocke and Samuel 1991) in waterfowl. In most previous studies of lead poisoning the prevalence of lead exposure has been assessed by determining shot ingestion rates from hunter-killed birds (Sanderson and Bellrose 1986, Anderson et al. 1987, Schwab and Daury 1989, Anderson et al. 2000). However, a few authors (Anderson and Havera 1985, Mauser et al. 1990, DeStefano et al. 1995) have estimated the exposure prevalence of waterfowl based on blood lead concentrations from free-flying wild birds. We believe this method is more likely to represent the natural prevalence of lead exposure in ducks without the bias associated with vulnerability to harvest, to provide a better indicator of the physiological

exposure of waterfowl to lead poisoning, and is a more sensitive measure for detecting lead exposure because elevated tissue lead concentrations remain after lead shot have already passed or dissolved from a bird's gizzard.

Despite some of the biases in determining lead exposure, shot ingestion studies using hunter-harvested birds can be particularly useful for evaluating long-term changes in lead pellet ingestion. Bellrose (1959) reported that 8.4% of the mallards harvested in the Mississippi flyway during 1938–54 had ingested lead shot and Anderson et al. (1987) reported a similar prevalence (7.8%) of shot ingestion for Mississippi flyway mallards during 1977–79; however, they found that 20% of the pellets were nontoxic. Anderson et al. (2000) found that Mississippi flyway mallards continue to have high shot ingestion rates (8.9%), but the proportion of nontoxic shot has subsequently increased to 75%. In essence, the long-term shot ingestion studies indicate that ducks in the Mississippi flyway continue to ingest shot pellets at a relatively high rate, but lead shot is apparently being replaced by nontoxic pellets.

Reports of waterfowl mortality where lead poisoning was the primary cause of death (National Wildlife Health Center, unpublished data) suggest that lead poisoning has been reduced in the Mississippi flyway and throughout the United States. Mean annual lead poisoning mortality declined considerably in most flyways between the 1980–84 and the 1990–94 period and continued to decline further during 1995–98. In the Mississippi flyway lead poisoning mortality declined from about 800 birds during the 1980s to <20 birds during the 1990s. Because waterfowl deaths from lead poisoning generally occur following the hunting season (Friend 1987) and large scale concentrations of lead-poisoned carcasses do not usually occur (Friend 1985), mortality events provide only a limited picture of lead poisoning. However, in addition to lead exposure studies, these data indicate that lead poisoning has declined following the nation-wide conversion to nontoxic shot.

Our data for black ducks wintering in Tennessee also support the conclusion that lead exposure has declined following the 1991 United States ban on toxic lead shot for waterfowl hunting. We found that prevalence of lead exposure declined by 44% between 1986–88 and 1997–99. This decline primarily occurred in adult black ducks, where prevalence declined by 63%, but a decline was not evident in juveniles. We can only speculate that differences in lead exposure between adults and juveniles may be related to differences in food habits, habitat use patterns, or habitat competition between paired adults and unpaired juveniles. We suggest that monitoring for lead exposure be conducted periodically to determine whether lead exposure continues to decline, especially in juvenile ducks.

MANAGEMENT IMPLICATIONS

Studies on lead exposure in black ducks wintering in Tennessee, lead shot ingestion in the Mississippi flyway, and information on lead poisoning mortality events indicate that lead exposure in ducks has declined following the conversion to nontoxic shot. Although the amount of reduction is difficult to estimate, a 50% reduction may represent a reasonable, if not conservative, estimate of the reduction of lead exposure in ducks in the Mississippi flyway, based on results from these studies. However, it should be noted that these reductions have occurred despite the persistence of lead shot in the sediments of some wetland areas. Based on current trends, we believe that lead exposure will continue to decline as lead shot use is reduced in Canada, as residual lead in wetlands is reduced, and as proportionally more nontoxic shot is available for ingestion by waterfowl.

Lead poisoning mortality in waterfowl has undoubtedly been reduced from the estimated levels of 2–4 million birds lost annually during the period of the 1950s–1970s (Bellrose 1959, Feierabend 1983). However, assessment of the demographic impact of lead exposure in waterfowl hinges on whether this mortality source is additive or compensatory with other mortality factors, especially hunting (Heitmeyer et al. 1993). Because waterfowl with ingested lead shot are more vulnerable to harvest (Sanderson and Bellrose 1986, Heitmeyer et al. 1993), some degree of compensatory mortality seems likely. In contrast, other factors suggest that lead exposure can be an additive form of mortality. Lead exposed waterfowl can have lower survival than unexposed birds (Hohman et al. 1995, Flint and Grand 1997) regardless of hunting mortality. Affected birds generally seek isolation and protective cover, making these birds more vulnerable to predators or scavengers, and making documentation of lead mortality difficult. Much of the mortality from lead poisoning oc-

curs following the hunting season, further increasing the difficulty of documenting lead poisoning and reducing the potential for direct compensation from harvest. Anderson et al. (2000) suggested that about 300,000 mallards and 1.4 million total ducks have been saved annually by banning toxic shot and reducing lead ingestion. Using a simulation model for mallards (Koford et al. 1992), where lead poisoning was considered an additive mortality factor, Samuel (1992) estimated that a 50% reduction in lead ingestion might produce an average annual mallard population growth rate of 4.5%. Further research will be needed to determine whether lead exposure continues to decline and to assess whether the nation-wide ban on toxic shot has a beneficial impact on waterfowl populations.

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