INGESTED SHOT AND TISSUE LEAD CONCENTRATIONS IN MOURNING DOVES

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ABSTRACT.—A more complete understanding of nonhunting and harvest mortality for Mourning Doves (*Zenaida macroura*) will be critical to improving regional and national harvest management decisions. Poisoning from ingested lead shot is of particular concern in Mourning Doves, which are often hunted on managed shooting fields where lead shot densities can be high, potentially increasing the risk of lead exposure. Previous studies of lead exposure in Mourning Doves have been local in scope and sample sizes have varied widely among areas. We provide an evaluation of lead exposure in 4,884 hunter-harvested Mourning Doves from Arizona, Georgia, Missouri, Oklahoma, Pennsylvania, South Carolina, and Tennessee. Overall, the frequency of ingested lead pellets in gizzards of doves on hunting areas where the use of lead shot was permitted was 2.5%, although we found a high degree of variability among locations. On areas where nontoxic shot was required, 2.4% of Mourning Doves had ingested steel shot. Hatch year (HY) doves had a greater frequency of ingested lead and steel pellets than after hatch year (AHY) birds, suggesting that they either ingested pellets more frequently or that young birds with ingested shot were preferentially harvested over older birds with ingested pellets. In doves without ingested lead pellets, bone lead concentrations were lower on an area requiring the use of nontoxic shot than on areas allowing the use of lead shot. *Received 3 June 2008, accepted 8 August 2008.*

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THE MOURNING DOVE National Strategic Harvest Management Plan (National Plan) provides a long-range vision for Mourning Dove management by development, implementation, and continuous improvement of harvest strategies based on mechanistic population models. The National Plan was adopted in 2003 by the four Flyway Councils, in 2004 by the Association of Fish and Wildlife Agencies (AFWA), and Migratory Shore and Upland Game Bird Working Group, and subsequently published by the US Fish and Wildlife Service (US Fish and Wildlife Service 2005).

The use of quantitative population models that synthesize knowledge of life history parameters, and the effects of intrinsic and extrinsic factors, has

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a long history in wildlife management (Shenk and Franklin 2001). This modeling approach provides a framework for tracking population change as a function of changes in factors impacting life history. Thus, the model fulfills a dual role of providing a rigorous context for harvest management and improving our understanding of the population dynamics of the species by evaluating vital population rates as functions of extrinsic factors such as amount of available breeding habitat, climatic conditions, nonhunting mortality, or hunting pressure. Within this context, a better understanding of specific causes of nonhunting mortality and their relative importance for Mourning Doves contributes critical information to the modeling process and requires empirically based input data. Poisoning from ingested spent lead shot in Mourning Doves has been identified as a conservation and management issue, with a need for better understanding of its potential population effects (Mirarchi and Baskett 1994, Tomlinson et al. 1994). Although the magnitude of lead exposure and poisoning in Mourning Doves is unknown, a risk assessment of lead shot exposure in upland birds and raptors concluded that Mourning Doves are particularly likely to ingest spent lead shot (Kendall et al. 1996), and Schulz et al. (2006b) have suggested that the number poisoned may approach the number harvested on an annual basis.

In the United States, Mourning Doves are commonly hunted in selectively managed fields. In 2007, 5–6 shots per dove bagged were reported for managed shooting fields in Missouri (Missouri Department of Conservation, unpublished report), and an earlier study in Tennessee found as many as eight shotshells were expended per bird taken (Lewis and Legler 1968). Lead shot densities of greater than 860,000 pellets per hectare have been reported from heavily hunted fields after the end of the dove hunting season (Best et al. 1992). In several regional studies, ingested lead shot were found in 0.3% to 6.4% of Mourning Doves (Castrale 1991, Kendall et al. 1996, Schulz et al. 2002). Kendall et al. (1996) suggested that a conservative estimate of the frequency of ingested lead shot in upland game birds, based largely on data for Mourning Doves, is about 3%.

Lead poisoning in birds is typically a chronic disease which often results in the development of clinical signs that include weakness, emaciation, and anemia. Although the relationship between ingested lead shot and toxicological effects depends on many factors, including species, diet, body condition, and environmental factors, one #7.5 or #8 ingested lead pellet may cause acute mortality in Mourning Doves (Buerger et al. 1986, Schulz et al. 2006a). Even in the absence of direct mortality from lead toxicosis, one ingested lead pellet may result in sublethal effects on physiology and behavior that can lead to death from starvation, predation, or disease (Scheuhammer and Norris 1996, Schulz et al. 2006a). Liver is the tissue often used as an indicator of recent lead exposure. Liver lead concentrations of 2 parts per million (ppm) wet weight (about 6 ppm dry weight) or greater are generally considered elevated in birds, including Mourning Doves, while concentrations of 6 ppm wet weight (about 20 ppm dry weight) or greater are potentially toxic (Franson 1996, Pain 1996). In a recent experimental lead shot dosing study in Mourning Doves, surviving birds had a mean liver lead concentration of 3.4 ppm, wet weight, while the mean of those that died was 49.2 ppm (Schulz et al. 2006a). Bone lead concentrations are often used as a measure of chronic exposure, because lead is lost from bone very slowly (Sanderson and Bellrose 1986, Pain 1996). Doves experimentally dosed with lead shot may accumulate up to 400–500 ppm dry weight of lead in bone (Kendall et al. 1983), whereas bone lead concentrations in apparently normal doves from rural areas usually average less than 50 ppm dry weight (Kendall and Scanlon 1979, 1982).

To evaluate the prevalence of lead exposure in Mourning Doves, we studied the frequency of ingested lead shot and lead concentrations in liver and wing bones in a sample of hunter-harvested birds from locations in seven states where lead shot was permitted for hunting. In addition, we examined hunter-harvested doves from two areas where nontoxic shot was required for hunting Mourning Doves. We studied the frequency of ingested pellets at both of these locations and liver and bone lead concentrations at one.

METHODS

Sample Collection and Processing.—With the assistance of personnel from State natural resource agencies, we examined 4,884 dove carcasses (after the breast was removed in most cases) collected from cooperating hunters during 1998–2000 in Arizona, Georgia, Missouri, Oklahoma, Pennsylvania, South Carolina, and Tennessee. Carcasses were shipped to the USGS National Wildlife Health Center (NWHC), Madison, Wisconsin. Age (i.e., hatch year (HY) and after hatch year (AHY)) was determined for 4,758 birds by plumage characteristics (Mirarchi 1993, Schulz et al. 1995). Sex was determined for 4,535 birds by visual examination of gonads, and the gizzard, liver, and one wing were removed from each carcass. All gizzards were individually identified and radiographed in groups, and those that contained metallic densities were examined visually for the recovery of metal. Pellets in the gizzard lumen that had penetrated the gizzard muscle as a result of gunshot were differentiated from ingested pellets by confirming the presence of entry wounds in the gizzard, by finding feathers enveloping the pellets and carried into the gizzard lumen, and by the examination of pellets for deformities (in the case of lead shot) indicating that they had contacted hard tissues. Steel pellets were identified by visual examination and the use of a magnet. Nonmagnetic pellets were evaluated for characteristics of lead (such as softness; tendency to deform or be cut, rather than to flake; appearance of a sheen on a cut or scratched surface) by pressing the pellet with the tip of a stainless steel scalpel blade or scissors.

Lead Analysis.—Livers and wing bones (radius/ulna) were examined visually and those with damage indicative of penetration by pellets were trimmed or discarded. Livers were stored frozen at –20ºC until analysis. Wing bones were stored in paper envelopes until preparation for lead analysis, when skin, feathers, and flesh were removed. Lead concentrations were measured in all livers and wing bones (except four wings damaged by pellets) from doves with ingested lead shot. In addition, we analyzed livers and wing bones from 1,989 and 691, respectively, doves without ingested lead or steel pellets. Although the majority of these samples came from areas where lead shot was permitted, we also analyzed livers and wing bones from one area (Hackberry Flat in Oklahoma) that required the use of nontoxic shot. Livers and bones for lead analysis from birds without ingested pellets were selected at random from within individual shipments, such that all states were represented in the sample. Lead analysis of tissues was done by atomic absorption spectroscopy (AAS) at the Illinois Department of Agriculture Animal Disease Laboratory, Centralia, Illinois and the NWHC. Most (95%) of the livers and all wing bones were analyzed for lead by graphite furnace AAS (Varian SpectrAA 220 FS, Varian, Inc., Palo Alto, CA or Thermo Jarrell Ash Scan 1 Thermo Jarrell Ash, Franklin, MA), using methods described by Ihnat (1999). Samples were dried to constant weight, digested in 1–5 ml trace metal grade nitric acid, and diluted with reagent grade deionized water to 50 ml. For the remaining 5% of the livers, samples were prepared and analyzed for lead according to Franson and Smith (1999), using flame AAS (Thermo Jarrell Ash Scan 1, Thermo Jarrell Ash, Franklin, MA). Quality assurance and quality control procedures for all analyses included the preparation of one sample spiked with a known amount of lead per each batch of 12–24 samples. Lower limits of detection were 0.05 ppm dry weight (Illinois Department of Agriculture) and 0.15 ppm dry weight (NWHC) for graphite furnace AAS and 0.70 ppm dry weight for flame AAS (NWHC). Mean recoveries from spiked samples were 100.5% for graphite furnace AAS and 100.1% for flame AAS. Average moisture content for livers and bones were 70.3% and 7.9%, respectively. All results are expressed as ppm on dry weight basis.

Statistics.—We calculated frequencies of liver and bone concentrations of ≥6 ppm and ≥20 ppm, respectively, as indicators of lead exposure (Franson 1996, Pain 1996). All liver data (from graphite furnace and flame AAS) were used in these calculations and in data summaries from doves with ingested lead shot. However, because of the much higher limit of detection, we excluded liver flame AAS data (n = 89) from calculations of summary statistics and comparisons of liver concentrations in doves without ingested lead shot. For those analyses, we used only the graphite furnace AAS data (n = 1,900). For analysis of bone data, we excluded three samples that fell below the NWHC detection

limit of 0.15 ppm dry weight, yielding n = 688. Thus, our lower limit of detection was effectively 0.05 ppm dry weight and we assigned a concentration of 0.025 ppm dry weight to those samples below the lower limit of detection (8.0 % of liver samples and 0.6 % of wing bones). We used nonparametric statistics as these methods require only the relative order of the lead concentrations and because samples below the detection limit of 0.05 ppm were assigned a value of 0.025 ppm, they were consistently ranked lowest (Helsel 2005). We used the Wilcoxon rank sums test to evaluate differences in lead concentrations by age and sex, Fisher's exact test to compare categorical data, Spearman correlation coefficient to compare lead concentrations in liver and bone, and factorial analysis of variance (ANOVA) to compare bone lead concentrations in doves without ingested shot by age and area (lead shot or nontoxic shot) (SAS Institute, Inc. 1996).

RESULTS

Samples Collected.—Most Mourning Dove carcasses (4,229) came from areas where the use of lead shot was permitted, but 655 were collected at two areas where nontoxic shot was required (Tables 1, 2), and the overall frequency of ingested pellets (lead and steel) was 2.5%. The majority of dove carcasses (2,832 from lead shot areas and 580 from nontoxic shot areas) were collected from September 1 through September 7, with the remainder (1,397 from lead shot areas and 75 from nontoxic shot areas) collected from September 8 through December 24 (Table 3). Of the dove carcasses for which age and sex were determined, 69.9% were HY, 30.1% were AHY, 55.5% were males, and 44.5% were females.

Ingested Pellets on Lead Shot Areas.—Combining results from all areas where lead shot was allowed for hunting, we found 106 (2.5%) doves with ingested lead pellets (Table 1). Frequencies of ingested lead pellets ranged from 0% at many of the areas sampled to 19.9% and 13.3% at Gila Valley and Yuma Valley, Arizona, respectively (Table 1). The number of ingested lead pellets per dove ranged from one, in 42% of birds with ingested lead pellets, to 43 (Table 3). Gizzards of two doves collected from lead shot areas (one each from Northampton County, Pennsylvania and Lake Wallace, South Carolina) contained ingested steel pellets, but no ingested lead pellets. All doves with ingested lead pellets, except one, were HY birds. The frequency of ingested lead pellets did not differ by sex or by early versus late sampling period (Table 4).

Ingested Pellets on Nontoxic Shot Areas.—At two of the areas sampled, nontoxic shot was required because of the presence of relatively newly constructed and restored wetlands. Ingested pellets were found in 16 of 655 (2.4%) Mourning Doves on these areas (Table 2). All 16 birds had ingested one or more steel pellets and gizzards of two doves contained ingested steel and lead pellets. The number of ingested steel pellets ranged from one to 23 (Table 3). Of the 12 doves having ingested shot for which age was determined, all were HY. The frequency of ingested steel pellets was similar for males and females and none of the doves collected after September 7 had ingested shot in their gizzards (Table 4).

Liver and Bone Lead Concentrations.—Liver and bone lead concentrations of doves with ingested lead pellets (Table 5) did not differ by sex (P = 0.4524 and 0.1055, respectively). Lead concentrations in tissues of birds with ingested lead pellets were not compared by age because all but one were HY birds. Liver and bone lead concentrations were significantly correlated in birds with (r = 0.328, n = 103, P = 0.0007) and without (r = 0.337, n = 598, P <0.0001) ingested lead pellets. Combining the data from all doves (with and without ingested pellets), frequencies of elevated liver (≥6 ppm dry weight) and bone (≥20 ppm dry weight) lead concentrations were 8.3% and 26.8%, respectively, on areas where lead shot was allowed and 2.0% and 11.1%, respectively, on the area requiring nontoxic shot.

In doves without ingested lead pellets, lead concentrations in liver differed by sex (females >males, P = 0.0053), but not age (P = 0.0666), and concentrations in bone differed by age (AHY >HY, P = <0.0001), but not sex (P = 0.1917) (Tables 6, 7). Lead concentrations in wing bones of Mourning Doves without ingested lead pellets were greater in birds from areas where lead shot was allowed than from the area where nontoxic shot was required (P <0.0001) (Table 8), but concentrations of lead in liver did not differ between lead and nontoxic shot areas (P = 0.2198).

Table 1. Number of hunter-harvested Mourning Doves collected from areas where the use of lead shot was permitted and the number with ingested lead pellets, 1998–2000.

State/Place name	Location	No. doves collected	No. with ingested pellets (%)
Arizona			
Buckeye Granary	33°22'N, 112°35'W	10	0
Curtis Road	32°36'N, 111°34'W	100	4 (4.0)
Gila Bend (14 mi SE)	33°09'N, 112°44'W	24	0
Gila River	32°43'N, 114°31'W	6	0
Gila Valley	32°46'N, 114°31'W	221	44 (19.9)
Hog Canyon (Unit 43-A)	31°40'N, 111°43'W	8	0
Milligan Road	32°44'N, 111°29'W	141	1 (0.7)
Robbins/Powers Butte	33°19'N, 112°38'W	128	0
Wilcox (12 mi SE)	32°07'N, 109°59'W	10	0
Yuma Mesa	32°41'N, 114°36'W	30	2 (6.7)
Yuma South	32°35'N, 114°38'W	20	0
Yuma Valley	32°40'N, 114°43'W	83	11 (13.3)
Arizona Total		**781**	**62 (7.9)**
Georgia			
Di-Lane	32°57'N, 82°04'W	90	0
Rum Creek	33°04'N, 83°52'W	204	0
Georgia Total		**294**	**0**
Missouri			
James Reed	38°53'N, 94°20'W	574	2 (0.3)
Missouri Total		**574**	**2[a] (0.3)**
Oklahoma			
Beaver	36°49'N, 100°31'W	91	1 (1.1)
Blue River	34°19'N, 96°35'W	96	0
Council Hill (1 mi NE)	35°38'N, 95°38'W	53	1 (1.9)
Harper Co. Ranch	36°41'N, 99°41'W	198	0
Keefeton (2 mi SW)	35°38'N, 95°21'W	16	0
Love Co.	33°58'N, 97°11'W	111	0
Packsaddle	36°20'N, 96°15'W	103	1 (1.0)
Skiatook	35°56'N, 99°44'W	80	1 (1.3)
Oklahoma Total		**748**	**4 (0.5)**
Pennsylvania			
Bedminster	40°26'N, 75°11'W	36	0
Girard (2 mi NE)	41°59'N, 80°14'W	19	0
Lancaster Co.	40°02'N, 76°15'W	144	3 (2.1)
Lebanon Co.	40°22'N, 76°28'W	31	0
Lehigh Co.	40°37'N, 75°35'W	25	0
Northampton Co.	40°45'N, 75°18'W	59	1[b] (1.7)
Oakville	40°07'N, 77°27'W	9	0
Pennsylvania Total		**323**	**4 (1.2)**
South Carolina			
Lake Wallace	34°39'N, 79°41'W	498	9[c] (1.8)
Oakland Hunt Club	33°25'N, 80°06'W	348	17 (4.9)
Westvaco-Walworth	33°21'N, 80°16'W	359	9 (2.5)
South Carolina Total		**1205**	**35 (2.9)**
Tennessee			
Hermitage Field	36°14'N, 86°36'W	4	0
Larry Kent Field	36°11'N, 86°32'W	264	0
Percy Priest	36°01'N, 86°31'W	36	1 (2.8)
Tennessee Total		**304**	**1 (0.3)**
Total		**4229**	**108[d] (2.6)**
Total with ingested lead pellets			**106 (2.5)**

[a]See Schulz et al. (2002). [b]This dove had two ingested steel shot, no ingested lead shot.
[c]One of the nine doves had one ingested steel shot, no ingested lead shot.
[d]Includes two doves with ingested steel shot only.

Table 2. Number of hunter-harvested Mourning Doves collected from areas where the use of nontoxic shot was required and the number with ingested pellets, 1998–2000.

State/Place name	Location	No. doves collected	No. with ingested pellets (%)
Missouri			
EBCA	38°50'N, 92°30'W	310	15[a,b] (4.8)
Oklahoma			
Hackberry Flat	34°17'N, 98°58'W	345	1[c] (0.3)
Totals		655	16 (2.4)

[a]See Schulz et al. (2002).
[b]One of the 15 doves had 17 ingested steel shot and 4 ingested lead shot.
[c]This dove had 18 ingested steel shot and 2 ingested lead shot.

Table 3. Frequency of one or more ingested pellets in Mourning Doves collected on areas where lead shot was permitted and where nontoxic shot was required, 1998–2000.

Lead shot permitted				Nontoxic shot required	
No. lead pellets	No. doves (%)	No. lead pellets	No. doves (%)	No. steel pellets	No. doves (%)
1	45 (42.45)	10	1 (0.94)	1	5 (31.25)
2	20 (18.87)	11	2 (1.89)	2	2 (12.50)
3	8 (7.55)	13	2 (1.89)	3	2 (12.50)
4	11 (10.38)	14	1 (0.94)	7	2 (12.50)
5	1 (0.94)	15	1 (0.94)	8	1 (6.25)
6	4 (3.77)	17	1 (0.94)	20	1 (6.25)
8	4 (3.77)	23	1 (0.94)	21	2 (12.50)
9	3 (2.83)	43	1 (0.94)	23	1 (6.25)

Table 4. Frequency of ingested pellets (%) in Mourning Doves on areas where lead shot was allowed, and on nontoxic shot areas according to age, sex, and time of carcass collection, 1998–2000.

	Lead shot permitted[a]	Nontoxic shot required[b]
HY[c] (hatch year)	3.5 (105/2982)	2.9 (12/409)
AHY (after hatch year)	0.08 (1/1218)	0 (0/149)
HY male[d]	3.4 (52/1519)	2.8 (6/217)
HY female	3.0 (37/1244)	3.5 (6/172)
September 1–7	2.3[e] (64/2832)	2.8 (16/580)
September 8–December 24	3.0 (42/1397)	0 (0/75)

[a]Two doves collected on lead shot areas, each with one ingested steel pellet (but no ingested lead pellets) were excluded from these summaries. Sex was not determined for 16 doves with ingested pellets.
[b]Two birds collected on nontoxic areas had ingested both lead and steel pellets. Because ingested steel was present, they were included in the summaries. Sex was not determined for four doves with ingested pellets.
[c]The frequency of HY (hatch year) doves with ingested shot was significantly greater than the frequency for AHY (after hatch year) on lead shot areas (Fisher's exact test, $P < 0.0001$) and nontoxic shot areas (Fisher's exact test, $P = 0.0424$).
[d]For HY doves, the frequency of ingested pellets did not differ by sex on lead shot areas (Fisher's exact test, $P = 0.5182$) or nontoxic shot areas (Fisher's exact test, $P = 0.7716$).
[e]Not significantly different (Fisher's exact test, $P = 0.1446$) than the frequency of ingested lead pellets in doves that were collected between September 8 and December 24.

Table 5. Lead concentrations (ppm dry weight) in livers and wing bones of Mourning Doves with ingested lead or steel pellets (all hatch year birds, except one after hatch year dove from Arizona), 1998–2000.

	Liver				Wing bones			
State	**n**	**Median**	**Q1[a]**	**Q3[b]**	**N**	**Median**	**Q1**	**Q3**
Arizona	62	45.64	15.42	67.44	60	66.69	29.56	195.60
Missouri	2	0.22	0.11	0.32	2	70.21	48.30	92.11
Oklahoma	5	20.23	14.06	106.85	4	24.97	12.23	62.68
Pennsylvania	3	19.05	13.60	22.85	3	236.89	27.71	457.39
South Carolina	34	36.79	19.38	73.80	33	187.94	63.49	405.76
Tennessee	1[c]				1[d]			
Total	107[e]	36.89	14.22	72.03	103[f]	89.33	33.04	236.89

[a]Quartile 1, 25th percentile.
[b]Quartile 3, 75th percentile.
[c]Liver lead concentration = 11.96 ppm dw.
[d]Bone lead concentration = 27.29 ppm dw.
[e]Includes livers from 106 doves with ingested lead shot from areas where lead shot was allowed for hunting doves, and one dove with ingested lead shot from a nontoxic shot area (Hackberry Flat, OK).
[f]Wing bones from four doves were not analyzed because they were damaged by pellets.

Table 6. Lead concentrations (ppm dry weight) in livers of Mourning Doves without ingested lead or steel pellets, by sex (excludes 37 doves of undetermined sex), 1998–2000.

	Male				Female			
State	**n**	**Median**	**Q1[a]**	**Q3[b]**	**n**	**Median**	**Q1**	**Q3**
Arizona	228	0.26	0.13	0.59	115	0.29	0.16	0.60
Georgia	103	0.17	0.08	0.38	85	0.25	0.10	0.71
Missouri	74	0.33	0.14	0.98	65	0.30	0.11	0.52
Oklahoma[c]	110	0.21	0.08	0.47	90	0.22	0.09	1.44
Pennsylvania	141	0.28	0.16	0.75	149	0.33	0.19	0.65
South Carolina	283	0.34	0.16	0.73	319	0.44	0.20	0.86
Tennessee	52	0.24	0.14	0.43	49	0.31	0.16	0.61
Total	991	0.27[d]	0.13	0.62	872	0.34	0.15	0.73

[a]Quartile 1, 25th percentile.
[b]Quartile 3, 75th percentile.
[c]Includes samples from 100 Mourning Doves (55 males and 45 females) collected at an area where nontoxic shot was required.
[d]Significantly different than females (P = 0.0053).

Table 7. Lead concentrations (ppm dry weight) in wing bones of Mourning Doves without ingested lead or steel pellets, by age (excludes one dove of undetermined age), 1998–2000.

	HY (hatch year)				AHY (after hatch year)			
State	**n**	**Median**	**Q1[a]**	**Q3[b]**	**n**	**Median**	**Q1**	**Q3**
Arizona	34	2.70	1.00	53.03	27	2.09	1.33	5.44
Georgia	61	1.31	0.74	2.96	50	2.61	1.64	4.88
Missouri	66	1.94	1.14	5.26	63	2.92	1.78	6.22
Oklahoma[c]	80	0.57	0.28	1.32	36	1.30	0.78	2.86
Pennsylvania	65	5.30	2.73	21.34	15	11.33	6.42	43.52
South Carolina	62	1.88	0.87	11.75	58	2.91	1.44	14.38
Tennessee	52	1.16	0.68	2.06	18	2.04	1.35	3.21
Total	420	1.56[d]	0.75	6.14	267	2.67	1.44	9.65

[a]Quartile 1, 25th percentile.
[b]Quartile 3, 75th percentile.
[c]Includes samples from 62 Mourning Doves (52 HY and 10 AHY) collected at an area where nontoxic shot was required.
[d]Significantly different than AHY (P <0.0001).

Table 8. Lead concentrations (ppm dry weight) in wing bones of Mourning Doves without ingested lead pellets by age and area (excludes one dove of undetermined age)[a], 1998–2000.

	Lead shot permitted				Nontoxic shot required			
	n	Median	Q1[b]	Q3[c]	n	Median	Q1	Q3
HY (hatch year)	368	1.74	0.89	6.88	52	0.56	0.24	1.12
AHY (after hatch year)	257	2.74	1.51	9.65	10	1.05	0.61	1.55

[a]Significantly different by age and area (factorial ANOVA, P <0.0001).
[b]Quartile 1, 25th percentile.
[c]Quartile 3, 75th percentile.

DISCUSSION

In our study, the combined frequency of ingested lead and steel pellets (2.5%) was the same as that found in an Indiana study (Castrale 1991) and the frequency of ingested lead pellets found in our study (also 2.5%) is within the range (<1% to 6.4%) previously reported in studies of lead exposure in Mourning Doves that were more restricted in geographic scope (see Kendall et al. 1996). However, we found considerable variation among locations. Although our study was not designed to compare managed versus unmanaged dove hunting fields, it is interesting to note that the greatest frequencies of ingested lead pellets (13.3% and 19.9%) were on two agricultural areas (Gila Valley and Yuma Valley in Arizona) not specifically managed for dove hunting and that frequencies of ingested pellets on managed areas varied considerably. For example, no ingested pellets were found in doves from two managed areas in Georgia (Di-Lane and Rum Creek), although lead poisoning has been reported in a Northern Bobwhite (*Colinus virginianus*) found dead at Di-Lane (Lewis and Schweitzer 2000). At another managed area, Oakland Hunt Club in South Carolina, 4.9% of doves had ingested lead pellets. Variation in the types of agricultural and management practices, particularly the frequency and timing of cultivation in relation to the hunting season, are among the factors expected to influence the availability of shot for foraging doves (Kendall et al. 1996).

Some previous studies have indicated that the progression of the hunting season was accompanied by increased densities of spent shot and greater frequencies of ingested lead pellets in Mourning Doves (see Kendall et al. 1996). On areas where the use of lead shot was allowed, we found no difference in the frequency of ingested pellets in doves collected during the first week of the hunting season (September 1 through 7) compared with the frequency in doves collected in the latter part of the season (September 8 through December 24) (Table 4). Although we sampled large numbers of doves early (n = 2,832) and late (n = 1,397) in the hunting season, few areas were sampled during both periods. Thus, variation in frequencies of ingested pellets among locations may have masked variation within locations through time.

Of the Mourning Doves for which age was determined, 69.9% were HY and 30.1% were AHY birds, but 105 of 106 doves with ingested lead pellets and 12 of 12 doves with ingested steel pellets were HY birds (Table 4). Previously published studies of ingested shot in Mourning Doves, where age was determined, include reports of ingested pellets in immature doves only (Best et al. 1992, Locke and Bagley 1967) and a report in which adults and immatures had ingested pellets, but with no significant difference between the age classes (Castrale 1991). It is unknown why HY doves in our study had a higher frequency of ingested pellets than AHY birds, but it is possible that a collection bias occurred because HY doves with ingested pellets, of either lead or steel, were more likely to be harvested than AHY birds with ingested pellets. A similar bias could occur if adult doves were more susceptible to the effects of lead exposure than HY birds and thus became incapacitated more quickly and were not available for harvest. If that were the case, we would expect to see different patterns of age-related pellet ingestion on areas where lead shot was allowed vs. nontoxic shot areas. Thus, of these two hypotheses, our limited results from nontoxic shot areas support the former, because we found no AHY doves with ingested steel shot. It is

also possible that HY doves simply ingest pellets more frequently than older doves.

The liver and bone lead concentrations (Table 5) that we found in Mourning Doves with ingested lead shot were generally lower than the lead concentrations reported in experimental dosing studies and in field cases of lead poisoning in Mourning Doves, where liver and bone lead concentrations have ranged from about 80 to >200 ppm dry weight and 115 to >400 ppm dry weight, respectively (Locke and Bagley 1967, Kendall et al. 1983, Buerger et al. 1986, Schulz et al. 2006a). It is not surprising that the hunter-harvested doves with ingested lead pellets in our sample had lower concentrations of lead in their tissues than birds that died of lead poisoning, because the severity of poisoning would not have progressed to a near-terminal stage in birds still able to take flight. Although sample sizes were small, we found that bone lead concentrations in HY and AHY doves without ingested lead pellets were lower on the area where nontoxic shot was required than on the areas where lead shot was allowed (Table 8). This finding suggests a lower level of lead exposure may occur in doves on areas where nontoxic shot is required, at least based on lead concentrations that we found in bones from a hunter-harvested sample of doves.

In two studies where doves were dosed with multiple lead shot, mortality started to occur after two and six days (McConnell 1967, Buerger et al. 1986). In Mourning Doves receiving 2 to 24 lead pellets, each additional pellet increased the hazard of death by 18% and the 19 to 21 day survival estimate for doves with 13 to 19 pellets was 8.3% (Schulz et al. 2006a). Even in doves with ≤2 ingested pellets, survival estimates were reduced to 57% (Schulz et al. 2006a). The results of these reports suggest that the doves in our study with lead pellets in their gizzards had recently ingested them. However, 92.5% had elevated liver lead concentrations (≥6 ppm dry weight) and 85.4% had elevated bone lead concentrations (≥20 ppm dry weight), and it is likely that they were experiencing physiological effects of lead exposure. Possible adverse effects include changes in the hematopoietic system, including increased heterophil/lymphocyte ratios and reductions in heme synthesis and packed cell volume (Pain 1996, Schulz et al. 2006a). Based on results of the dosing studies and the likelihood of physiological effects, we suspect that many of the doves with ingested lead pellets in our study would soon have succumbed to lead poisoning, or causes related to lead poisoning morbidity (such as predation), had they not been harvested.

The frequencies of elevated liver (≥6 ppm dry weight) and bone (≥20 ppm dry weight) lead concentrations (8.3% and 26.8%, respectively) in doves from areas where lead shot was permitted for hunting were greater than the frequency of ingested pellets (2.5%). Concentrations of lead in the blood, liver, and other soft tissues are somewhat mobile and reflect relatively recent exposure. Lead also moves quickly from the bloodstream into bone, but it tends to remain there and to accumulate in bone over time (Pain 1996). Experimental studies have shown that a portion of Mourning Doves may survive exposure to lead shot, and that some of the lead pellets will be passed in the feces (Buerger et al. 1986, Marn et al. 1988, Schulz et al. 2006a, Schulz et al. 2007). Thus, it is possible that some wild doves could have elevated concentrations of lead in their tissues caused by ingested lead shot which had been voided from the gizzard by the time the birds were collected. Because shot may be voided, it is to be expected that estimates of lead exposure based on frequency of ingested pellets will be lower than estimates based on tissue concentrations of lead. Previous work with waterfowl indicates that lead surveys based only on the prevalence of ingested lead shot will underestimate the extent of lead exposure when compared to other testing criteria, such as analysis of blood samples for lead (Anderson and Havera 1985), and our results suggest that a similar situation exists for Mourning Doves.

Our results include findings that frequencies of ingested shot in Mourning Doves were highly variable among locations, hunter-harvested HY doves were more likely to have ingested pellets than AHY birds, and that concentrations of lead in bone of doves without ingested lead pellets were lower on an area where nontoxic shot was required than on areas where lead shot was permitted. A number of questions remain to be addressed, however, for a better understanding of the full significance of lead shot ingestion by doves. First, what is the true fre-

quency of ingested lead pellets in Mourning Doves? The answer to this question requires investigation of possible biases associated with hunter-harvested samples of birds. The fact that studies have shown that even small numbers of lead shot can kill doves raises the question of the role that Mourning Doves play in secondary lead poisoning of scavengers and predators that consume doves dead or dying of lead poisoning. A variety of raptor species has been reported to have died of lead shot poisoning, presumably from the consumption of shot in prey items (see Fisher et al. 2006). The poisoning of these and other avian and mammalian scavengers may be the result of consuming lead pellets ingested by doves or embedded in muscle. Finally, how many doves actually die of lead poisoning annually? If we assume a frequency in the range of 3% lead shot ingestion, as proposed by Kendal et al. (1996) for upland game birds, and supported by this study for Mourning Doves, what is the impact on dove numbers? Based on the toxicity of lead shot for Mourning Doves and reported frequencies of ingested lead pellets, Schulz et al. (2006b) suggested that annual losses due to lead poisoning may approach annual harvest estimates.

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