Wildlife Society Bulletin 39(1):94–102; 2015; DOI: 10.1002/wsb.527

Original Article

Widespread Ingestion of Lead Pellets by Wild Chukars in Northwestern Utah

RICHARD J. BINGHAM,[1,2] *Department of Wildland Resources, Utah State University, Logan, UT 84322-5290, USA*

RANDY T. LARSEN, *Plant and Wildlife Sciences Department and the Monte L. Bean Life Science Museum,, Brigham Young University, 407 WIDB, Provo, UT 84602, USA*

JOHN A. BISSONETTE, *United States Geological Survey, Utah Cooperative Fish and Wildlife Research Unit, Department of Wildland Resources, Utah State University, 5230 Old Main Hill, Logan, UT 84322, USA*

JEFFERY O. HALL, *Department of Animal, Dairy, and Veterinary Sciences and the Utah Veterinary Diagnostic Lab, Utah State University, 950 E 1400 N, North Logan, UT 84341, USA*

ABSTRACT The use of lead ammunition has generated much debate because lead is toxic and elevated lead exposure is documented in >130 wildlife species. We expanded on prior reports of ingested lead in chukars (*Alectoris chukar*) to assess lead exposure at greater spatial and temporal extents. Our specific objectives concerning lead exposure in chukars from northwestern Utah, USA (approx. 49,000 km^2) were to: 1) approximate a threshold for background versus elevated lead exposure; 2) investigate spatial and temporal variation of lead exposure; and 3) assess the utility of combining frequencies of ingested gizzard lead and elevated liver lead to estimate lead ingestion rates. We obtained hunter and volunteer-harvested chukars collected during July–January, 2003–2011. Using liver lead residues from wild chukars, we estimated a threshold of 1 μg/g wet weight to separate background versus elevated lead exposure for our data set. For wild chukars, we documented elevated lead exposure (ingested gizzard lead or elevated liver lead) in 5 counties and 8 mountain ranges in years 2003–2007. We estimated lead ingestion rates of 9.3% (43 of 461) using ingested gizzard lead and 8.3% (10 of 121) employing elevated liver lead (≥1 μg/g wet weight), respectively. These frequencies were respectively 1.5% and 2.5% less than the combined frequency of ingested gizzard lead and elevated liver lead (10.8%; 52 of 481). Our observed rates of elevated lead exposure were among the highest in the literature for upland birds, suggesting that chukars in northwestern Utah risk lead poisoning. These results corroborate previous findings identifying elevated lead exposure as an issue affecting non waterfowl avian species.

KEY WORDS *Alectoris chukar*, background, chukar, elevated, exposure, poisoning, shot, toxicity, Utah.

Elevated lead exposure adversely affects wildlife (Pokras and Kneeland 2009) with instances of ingested lead pellets, bullet fragments, and fishing weights documented in ≥130 wildlife species (Tranel and Kimmel 2009). Although lead occurs naturally, abundantly, and is widely used, it is highly toxic and shows no documented biological function in living organisms (Pain 1996, Scheuhammer et al. 1998). In highly acidic media (pH = 1–2.5), lead becomes increasingly soluble (Rattner et al. 2009). Conversely, lead is mostly present in non-soluble forms in basic media where pH is >7 (Casas and Sordo 2006). Consequently, areas with alkaline soils tend to accumulate more lead shot than areas with acidic soils (Schranck and Dollahon 1975). Even acidic soils, however, can potentially harbor lead shot for many years (Jorgensen and Willems 1987), with basic soils preventing lead dissolution for much longer (De Francisco et al. 2003, Casas and Sordo 2006).

Lead shot deposited through hunting and shooting activities is available to birds that can mistake these pellets for food or grit (Gionfriddo and Best 1999, Schulz et al. 2002). Trainer (1982) reported an estimate by the National Wildlife Federation, which stated that before the discontinuance of lead for waterfowl hunting, 3,000 tons of spent lead was introduced into the environment annually by waterfowl hunters in the United States. These and other findings (Bellrose 1959, Longcore et al. 1974, Sanderson and Bellrose 1986) led to a regulatory phase-out (ending in 1991) of lead shot for waterfowl hunting. Nevertheless, use of lead shot continues in many areas for hunting upland species.

Recent research suggests that lead-pellet ingestion can be a problem for birds other than waterfowl (Kendall et al. 1996, Fisher et al. 2006). For example, multiple field studies of wild mourning doves (*Zenaida macroura*) and areas used frequently by dove hunters have assessed elevated lead exposure and occurrence of lead pellets in soils (Locke and

Received: 26 March 2014; Accepted: 15 September 2014

[1]*E-mail: r.j.bing@aggiemail.usu.edu*
[2]*Present address: Plant and Wildlife Sciences Department, Brigham Young University, 275WIDB, Provo, UT 84602, USA.*

Bagley 1967, Lewis and Legler 1968, Best et al. 1992, Schulz et al. 2002). Additionally, dosing experiments with captive mourning doves have addressed the susceptibility of these birds to lead toxicosis (Buerger et al. 1986, Schulz et al. 2006). Nonetheless, available literature on elevated lead exposure in upland birds other than mourning doves often consists simply of documenting individuals with ingested lead pellets (Walter and Reese 2003, Butler 2005), or diagnosing that a bird has succumbed to lead poisoning as a result of lead ingestion and absorption (Keymer and Stebbings 1987, Lewis and Schweitzer 2000). More recently, chukars (*Alectoris chukar*) have been documented to ingest lead pellets in Oregon (Walter and Reese 2003) and Utah (Larsen et al. 2007*b*), USA, and in Ontario, Canada (Kreager et al. 2008), with high reported prevalence of ingested shot in gizzards (5.7%, $n = 123$; 10.7%, $n = 75$; and 8.0%, $n = 76$; respectively). The spatial and temporal magnitude of this ingestion, however, remains unclear because sample sizes were relatively small, sampling coverage was localized in space and time, and tissue-lead concentrations were not measured.

Determining the frequency and extent of elevated lead exposure in chukars is one essential step in assessing the risk of lead poisoning for this species. The potential for lead poisoning is high in chukars, not only because they have been documented to ingest lead shot, but because they possess a well-developed gizzard, which creates an ideal environment for lead dissolution because of low pH and grinding contractions against rocks and seeds (Trainer 1982; Pain 1996; Pain et al. 2009). Additionally, these birds typically inhabit areas containing alkaline, dry, and rocky soils (Walter and Reese 2003, Rattner et al. 2009), all of which are conditions conducive to harboring lead pellets for long periods of time. Also, during the summer months, chukars congregate near water. Soils surrounding water sources can collect high densities of lead shot because of concentrated hunting pressure (Best et al. 1992). Finally, because desert habitats where chukars live have abundant bare ground, finding lead shot in soils may be easier than in areas with large amounts of organic litter on the soil surface.

The first obstacle in determining the spatial and temporal extent of elevated lead exposure is determining the threshold that describes the difference between background and elevated lead concentrations. Background concentrations of lead are consistent with chronic exposure to atmospheric lead; whereas elevated concentrations of lead represent acute exposure to concentrated amounts of lead like those originating from ammunition sources (Pain 1996; Pain et al. 2009). When assessing elevated lead exposure, the frequency distribution of values for tissue lead (in populations with a proportion of individuals that ingest acute sources of lead) is typically described by background concentrations that approximate a normal distribution (individuals exposed only to atmospheric lead) separated by elevated outliers that represent acute ingestion events (Dieter and Finley 1979; Pain 1996; Pain et al. 2009). This abnormal frequency distribution occurs because acute sources of lead exposure usually contain concentrations that are orders of magnitude higher than those present in background sources of lead.

Our specific objectives concerning lead exposure in chukars from northwestern Utah (approx. 49,000 km^2) comprised: 1) approximating a threshold separating background lead exposure from elevated lead exposure; 2) investigating variation of elevated lead exposure by mountain range, month, season, and year; and 3) assessing the utility of combining frequencies of ingested gizzard lead (presence of lead pellet in gizzard) and elevated liver lead (lead concentrations in liver consistent with acute exposure) to estimate lead ingestion rates. We predicted that the threshold bisecting background and elevated lead exposure in chukars would be located within the frequency distribution of samples in a gap between apparent background concentrations and elevated outliers. Because lead ingestion by chukars has been reported in 3 studies surveying multiple populations, we postulated that lead ingestion by chukars in Utah would be widespread. We also posited that by using a combined frequency of ingested gizzard lead and elevated liver lead, we would detect a higher rate of elevated lead exposure than by using either measure alone.

STUDY AREA

We sampled wild chukars from mountain ranges in Box Elder, Juab, Millard, Tooele, and Utah Counties of northwestern Utah (Fig. 1). Sampled mountain ranges comprised the following: Blue Creek, Cedar Mountains, Chukar Knolls, Deep Creek Mountains, Fish Springs Range, Gilson Mountains, Hogup Mountains, Keg Mountain, Lakeside Mountains, Promontory Mountains, Sheeprock Mountains, Stansbury Mountains, Thomas–Dugway Mountains, Tintic Mountains, and West Mountain.

Our study sites were located in the Great Basin physiographic region with specific climatic, vegetation, and other characteristics described in Larsen et al. (2007*a*). Generalized vegetation communities found in the study sites according to the 2004 Southwestern Regional Gap Analysis (Lowry et al. 2005) included Great Basin Xeric Mixed and Intermountain Basins Sagebrush Shrubland, Great Basin Pinyon Juniper Woodland, Intermountain Basins Mixed Salt Desert Scrub, Invasive Annual and Perennial Grasslands, and Intermountain Basins Semi-Desert Grassland. Topographically, northwestern Utah is characterized by semi-arid mountain ranges running roughly parallel, approximately north to south, separated by desert basins (Fenneman 1931). Our study area was typical of other sites inhabited by chukars, which have been described as containing hard, dry, and rocky soils with an alkaline pH and minimal rainfall (Walter and Reese 2003, Rattner et al. 2009).

MATERIALS AND METHODS

Collection and Processing

We included harvested chukars collected in August 2003–January 2005 from Larsen et al. (2007*b*) into our analyses, but used additional individuals collected from July 2005 to

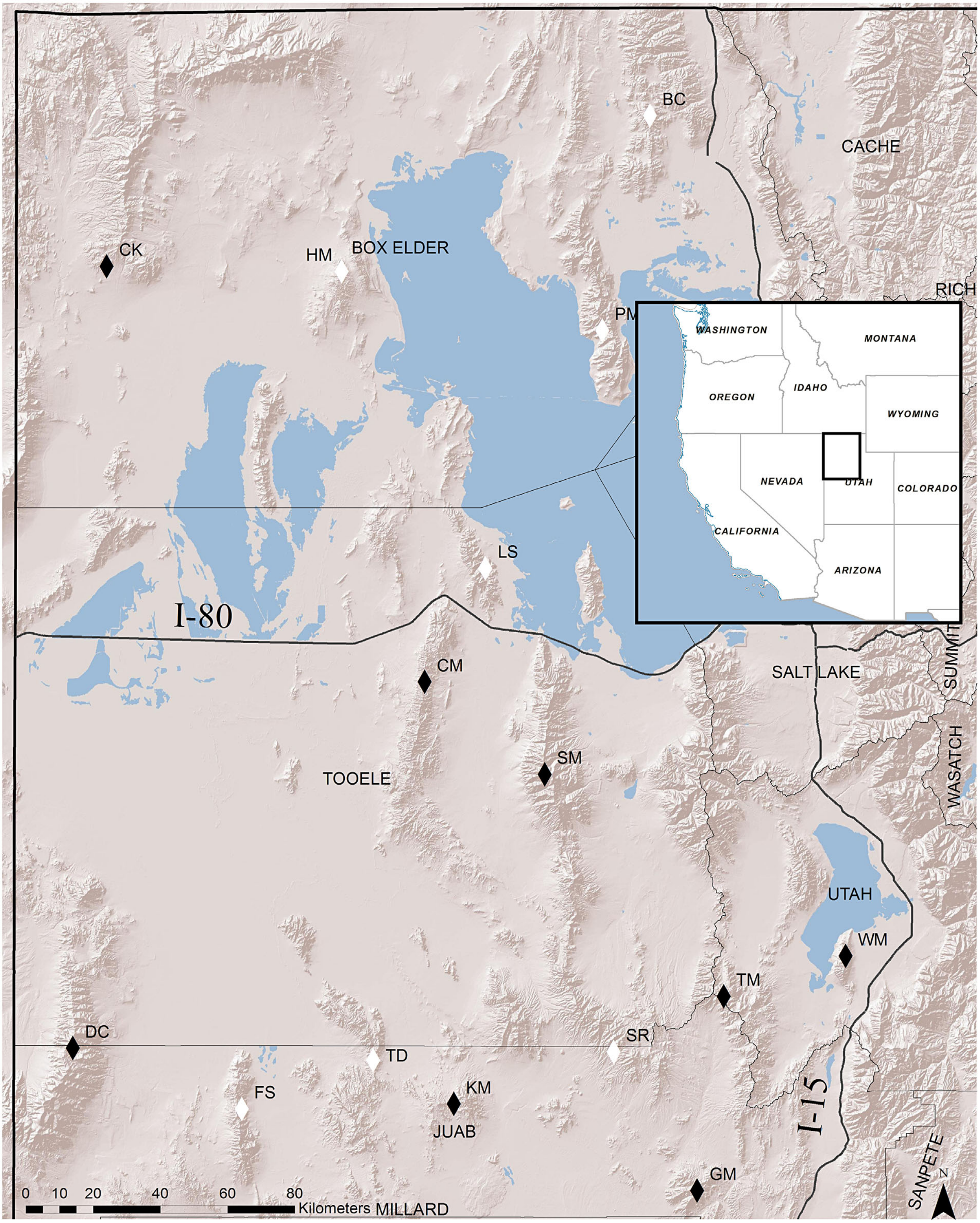

Figure 1. Collection sites for chukars used to analyze elevated lead exposure in chukars from northwestern Utah, USA, 2003–2011. Sampled mountain ranges comprised the following: Blue Creek (BC), Cedar Mountains (CM), Chukar Knolls (CK), Deep Creek Mountains (DC), Fish Springs Range (FS), Gilson Mountains (GM), Hogup Mountains (HM), Keg Mountain (KM), Lakeside Mountains (LS), Promontory Mountains (PM), Sheeprock Mountains (SR), Stansbury Mountains (SM), Thomas–Dugway Mountains (TD), Tintic Mountains (TM), and West Mountain (WM). Colored shapes denote elevated lead exposure; whereas uncolored shapes depict no elevated lead exposure.

September 2011. We recorded GPS locations if available. Our data set comprised chukars collected annually during July–January, 2003–2011. Chukars taken prior to the hunting season (July to early September) were collected with shotguns and lead shot by hunters with approval of the Utah Division of Wildlife Resources (permit no. 1COLL6160). Birds collected during the chukar season (Sep–Jan) were hunter-harvested in the same manner. Lead shot was legal in all of the areas where chukars were taken. This study was performed under the auspices of Utah State University Institutional Animal Care and Use Committee guidelines (approval no. 1363).

Following the protocols of previous ingestion studies with lead shot and mourning doves (Lewis and Legler 1968, Best et al. 1992, Schulz et al. 2002), we visually examined chukar gizzards for entry wounds to distinguish between ingested and embedded lead shot and excluded samples with penetration wounds, leaving 461 acceptable gizzards. We washed gizzard contents to facilitate removal of animal and vegetable material, then dried and sifted through the contents by hand to identify lead pellets. In an initial strategy to separate steel shot from other types, we used magnets. Because we encountered no steel pellets, we employed pliers in an attempt to flatten pellets to differentiate between lead and any nontoxic shot types. As a pilot effort, we purchased all commonly available forms of nontoxic shot (bismuth, multiple denser-than-lead alloys, steel, and tungsten) from an ammunition supplier. We were unable to flatten these nontoxic types with pliers, but rather made small indentations in the surface (Fig. 2). Consequently, if pellets we encountered in harvested chukars were malleable, we classified them as lead. All pellets taken from chukar gizzards were classified as lead.

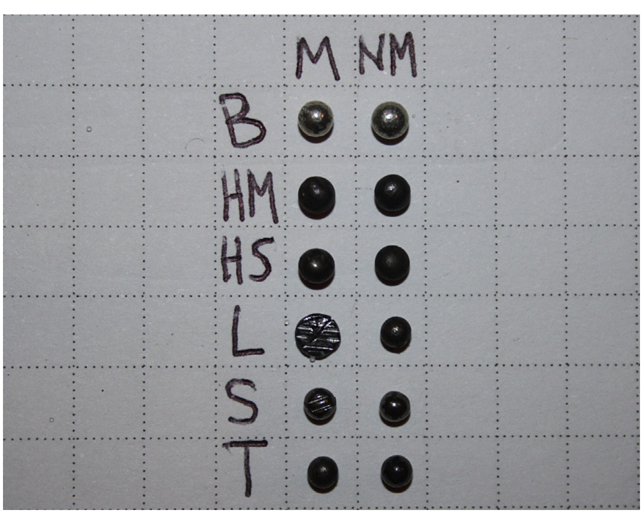

Figure 2. Photo showing results of the test we performed with pliers on various types of shot, as part of our study analyzing lead exposure in chukars from northwestern Utah, USA, 2003–2011. We attempted to flatten pellets using pliers to differentiate lead shot from nontoxic types. Column headings: 1) M = manipulated, and 2) NM = not manipulated. Row headings: B = bismuth, HM = hevi-metal® alloy, HS = hevi-shot® alloy, L = lead, S = steel, and T = tungsten. Because we were unable to flatten any shot types except for lead, any shot found in chukar gizzards during our sampling effort was classified as lead if susceptible to flattening. We obtained test pellets by extracting them from shotshells purchased at sporting goods stores.

Lead-residue analysis was conducted on 121 livers by removing the rightmost liver lobe using only samples lacking shot trauma. We stored livers by freezing them at $\leq -18^{\circ}$ C until analysis for lead at the Utah Veterinary Diagnostic Laboratory at Utah State University. To remove organic materials, we digested samples in nitric acid (HNO_3) under a heating block in labeled tubes. We weighed each tissue sample to 0.0001 g and diluted them to a final nitric acid concentration of 5%. We determined lead concentrations using Inductively Coupled Plasma/Mass Spectroscopy and compared acquired values with curves of certified National Institute of Standards and Technology lead standard (no. 3128) after every 5th liver sample. Our accuracy threshold was $\pm$ 5% from the value of the National Institute of Standards and Technology lead standard. We obtained all liver lead concentrations in μg/g wet weight. The lower limit of detection for lead was 0.001 μg/g wet weight and all analyzed samples contained detectable concentrations of lead.

We set a dividing threshold for background versus elevated lead exposure using the frequency distribution of liver lead concentrations for wild-harvested chukars. We based our threshold on the observations that background concentrations of lead follow an approximately normal distribution with elevated outliers in a frequency distribution being indicative of acute lead-ingestion events (Dieter and Finley 1979; Pain 1996; Pain et al. 2009). The dividing line we present for the frequency distribution of lead concentrations in wild chukars is specific to our data set.

Statistical Analysis

After setting a threshold value for elevated liver lead, we analyzed frequencies of 1) ingested gizzard lead and 2) elevated liver lead (relative to the threshold) by mountain range, month, and year of collection. We used Fisher's exact tests to assess differences in frequencies among explanatory variables. We conducted additional Fisher's exact tests grouping months (Jul–Sep vs. Oct–Jan) to test for a seasonal difference. We also directly compared the overall frequencies of ingested gizzard lead against those of elevated liver lead by month to determine whether these 2 rates were similar across each month of the annual July–January collection period. We excluded samples with unknown mountain range, month, or year from applicable tests.

Finally, we compared the accuracy of using either the frequency of ingested gizzard lead or elevated liver lead alone against that of a combined value using both frequencies by calculating these values separately and combined. For this analysis, the sample size was 481 (360 chukars with gizzards only; 101 chukars with gizzards and livers; 20 chukars with livers only).

For all inferential tests, we set α at 0.05. All statistical analyses were run in Program R (version 2.15; R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

We used 1.0 μg/g liver lead as the approximate threshold value for dividing background versus elevated lead exposure in chukars from our study area. Liver lead concentrations for

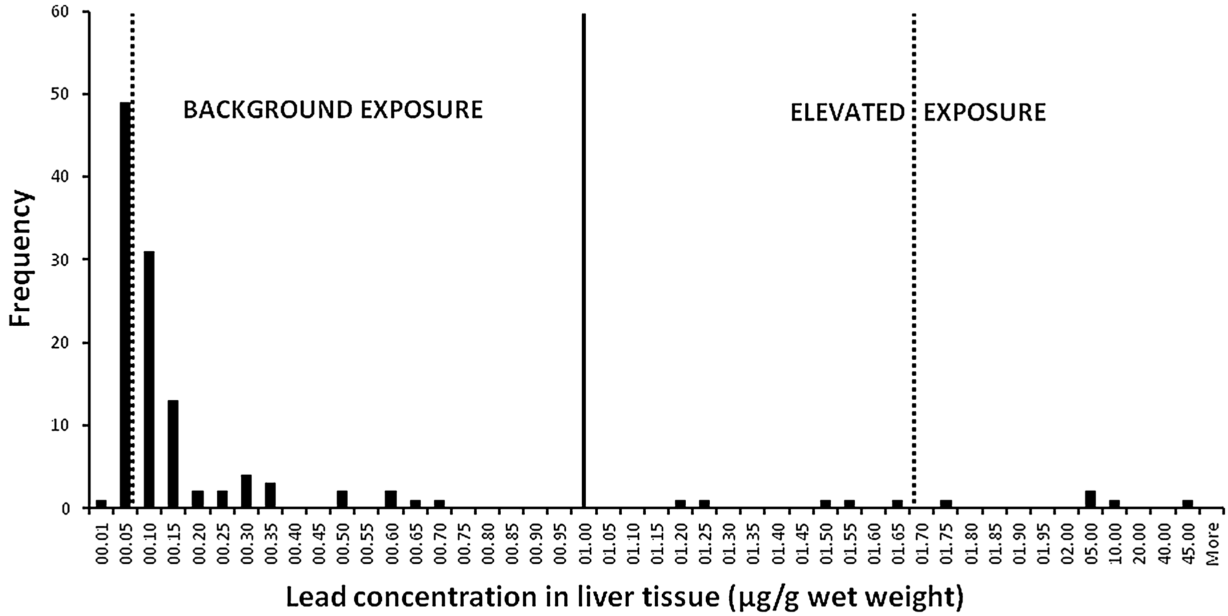

Figure 3. Frequency distribution of liver lead concentrations for wild chukars with estimated threshold (solid line) and respective median values (dashed lines) for background versus elevated lead exposure (≥1 μg/g wet weight), collected from northwestern Utah, USA, 2003–2011.

wild chukars contained a large gap in the distribution between 0.70 μg/g and 1.15 μg/g (9 consecutive 0.05 μg/g bins) with elevated outliers present from 1.15 μg/g to 42.61 μg/g (Fig. 3). Relative to our threshold, the range of background values for lead concentration was 0.010–0.681 μg/g with a median value of 0.058; whereas the range for elevated values of lead concentration was 1.161–42.611 μg/g with a median of 1.669 (Fig. 3).

We analyzed 461 gizzards and 121 liver samples from wild chukars collected annually during July–January between August 2003 and September 2011. Forty three (9.3%) of 461 chukar gizzards contained an ingested lead pellet. We confirmed the presence of ingested gizzard lead in chukars from all 5 surveyed counties and 8 of 15 (53%) sampled mountain ranges (Table 1). Each bird with ingested gizzard lead contained only a single pellet and all pellets observed were malleable and thus classified as lead. We encountered birds with ingested gizzard lead during August–January (Table 2) and from 2003 to 2007 (Table 3), but not during July, 2008–2011, when sample sizes were small. Liver lead concentrations in wild chukars ranged from 0.01 μg/g to 42.61 μg/g (Fig. 3) and 10 (8.3%) of 121 livers had elevated liver lead (≥1.0 μg/g). We documented elevated liver lead in 3 of 4 (75%) counties and 4 of 9 (44%) mountain ranges (Table 1). We observed all 10 instances of elevated liver lead in the months of July–September (Table 2) and during 2005–2007 (Table 3), but none during October–January of this time span, despite analyzing 36 livers and recording ingested lead in 10.7% (27 of 252) of gizzards throughout this autumn–winter period (Fig. 4). Elevated liver lead was found during 2005–2007, the only years we obtained liver samples.

Frequency of ingested gizzard lead did not differ by mountain range ($P = 0.18$; Table 1), month ($P = 0.69$; Table 2), season ($P = 0.39$; Table 2), or year ($P = 0.96$; Table 3). Similarly, frequency of elevated liver lead (≥1 μg/g) did not vary by mountain range ($P = 0.55$; Table 1), month ($P = 0.23$; Table 2), or year ($P = 0.90$; Table 3), but did vary by season ($P = 0.03$; Table 2). The separate frequencies of ingested gizzard lead (9.3%; 43 of 461) and elevated liver lead (8.3%; 10 of 121) were, respectively, 1.5% and 2.5% less than the combined frequency of ingested gizzard lead or elevated liver lead (10.8%; 52 of 481). Specifically noteworthy, our July results showed no evidence of ingested gizzard lead in 21 samples, but we found that 30% (3 of 10) of livers during this month had elevated lead. Combining the 2 frequencies, we estimated that 12.5% (3 of 24) of chukars collected during July had experienced elevated lead exposure, which was consistent with exposure during other collection months.

DISCUSSION

Elevated lead exposure in chukars from northwestern Utah is temporally and spatially widespread. Moreover, the frequency of ingested gizzard lead we observed was greater than any other we found in the documented literature for wild upland game birds (Best et al. 1992, Keel et al. 2002, Schulz et al. 2002, Walter and Reese 2003, Franson et al. 2009) except for mourning doves from the Gila and Yuma valleys in Arizona, USA (Franson et al. 2009). The localized results for these 2 sites are, however, comparable to our highest site-specific ingestion frequencies at the Gilson and Stansbury mountains. The overall frequency of lead ingestion for mourning doves in Arizona (7.9%) reported in Franson et al. (2009) was more comparable to our overall frequency of ingested lead in wild chukars from northwestern Utah.

The most commonly used threshold for background versus elevated lead exposure using livers is 2 μg/g wet weight (Friend 1985, USFWS 1986). Nonetheless, this threshold

Table 1. Frequencies and test results of ingested gizzard lead (IGL) and elevated liver lead (ELL) in chukars, classified by harvest location in northwestern Utah, USA, collected between 2 August 2003 and 29 September 2011. We used Fisher's Exact Test (FET) to check for differences in frequencies of elevated lead exposure among individual mountain ranges. We excluded birds with unknown harvest location from the statistical test.

Mountain range	*N* gizzard	No. IGL	% IGL	*N* liver	No. ELL	% ELL	*N* liver + gizzard[a]	No. IGL or ELL	% IGL or ELL
Blue Creek	5	0	0	1	0	0	6	0	0
Cedar	103	10	9.7	35	4	11.4	111	13[b]	11.7
Chukar Knolls	97	6	6.2	14	0	0	98	6	6.1
Deep Creek	20	1	5	14	3	21.4	21	4	19
Fish Springs	6	0	0	0	0	0	6	0	0
Gilson	61	13	21.3	18	1	5.6	66	14	21.2
Hogup	1	0	0	0	0	0	1	0	0
Keg	6	1	16.7	2	0	0	6	1	16.7
Lakeside	24	0	0	11	0	0	24	0	0
Promontory	2	0	0	0	0	0	2	0	0
Sheeprock	7	0	0	0	0	0	7	0	0
Stansbury	21	4	19	15	2	13.3	25	6	24
Thomas–Dugway	4	0	0	0	0	0	4	0	0
Tintic	19	1	5.3	8	0	0	19	1	5.3
West	18	1	5.6	0	0	0	18	1	5.6
Unknown	67	6	9	3	0	0	67	6	9
Total	461	43	9.3	121	10	8.3	481[a]	52[b]	10.8
Test results									
FET		$P = 0.18$			$P = 0.55$			$P = 0.08$	

[a] Not the overall sum of individual gizzards and livers, but rather 360 chukars with gizzards only + 101 chukars with gizzards and livers + 20 chukars with livers only.
[b] We subtracted 1 from the total of 14 for Cedar and 53 for the entire sample to avoid double-counting because bird 157 had both IGL and ELL.

estimate was developed for waterfowl (Friend 1985, USFWS 1986, Pain 1996), and is only a relative measure because background concentrations vary among species and populations (Pain 1996; Pain et al. 2009). For populations with infrequent lead ingestion (low ratio of individuals with ingested lead), liver lead concentrations consistent with background exposure will likely follow an approximately normal distribution with events of elevated lead ingestion depicted as heightened outliers (Dieter and Finley 1979; Pain 1996; Pain et al. 2009). For wild chukars in our sample, the large gap in lead concentrations, and approximately normal distribution of values below the gap, indicated that a threshold of elevated lead exposure was likely between 0.70 μg/g and 1.15 μg/g.

Our results demonstrate that frequencies of elevated lead exposure can be estimated more accurately by combining ingested gizzard lead with elevated liver lead, particularly when samples sizes are small. When we combined the frequencies of ingested gizzard lead and elevated liver lead, the rate of elevated lead exposure increased compared with these frequencies when estimated separately. Lead pellets can be voided, or fully eroded, and a delay may occur between ingestion of lead shot and the rise of liver lead concentrations, all of which could bias results. For example, our

Table 2. Frequencies and test results for ingested gizzard lead (IGL) and elevated liver lead (ELL) of chukars, classified by harvest month in northwestern Utah, USA, collected between 2 August 2003 and 29 September 2011. We used Fisher's Exact Test (FET) for differences in frequencies among: 1) all months and 2) season (Jul–Sep vs. Oct–Jan). For both tests, we excluded birds with unknown harvest month.

Month	*N* gizzards	No. IGL	% IGL	*N* livers	No. ELL	% ELL	*N* livers + gizzards[a]	No. IGL or ELL	% IGL or ELL
Jul	21	0	0	10	3	30	24	3	12.5
Aug	47	5	10.6	24	2	8.3	52	7	13.5
Sep	90	7	7.8	51	5	9.8	98	11[b]	11.2
Oct	69	6	8.7	12	0	0	70	6	8.6
Nov	27	2	7.4	1	0	0	27	2	7.4
Dec	66	9	13.6	8	0	0	68	9	13.2
Jan	88	9	10.2	15	0	0	89	9	10.1
Unknown	53	5	9.4	0	0	0	53	5	9.4
Total	461	43	9.3	121	10	8.3	481[a]	52[b]	10.8
Test results									
FET (1)		$P = 0.69$			$P = 0.23$			$P = 0.96$	
FET (2)		$P = 0.39$			$P = 0.03^{*}$			$P = 0.64$	

[a] Not the overall sum of individual gizzards and livers, but rather 360 chukars with gizzards only + 101 chukars with gizzards and livers + 20 chukars with livers only.
[b] We subtracted 1 from the actual total of 12 (Sep) and 53 (entire sample) to avoid double-counting because bird 157 had both IGL and ELL.
[*] $P < 0.05$.

Table 3. Frequencies and test results for ingested gizzard lead (IGL) and elevated liver lead (ELL) of chukars, classified by harvest year in northwestern Utah, USA, collected between 2 August 2003 and 29 September 2011. We used Fisher's Exact Test (FET) for differences in frequencies among all sampled years. We excluded birds with unknown harvest year from the statistical test.

Year	*N* gizzards	No. IGL	% IGL	*N* livers	No. ELL	% ELL	*N* livers + gizzards[a]	No. IGL or ELL	% IGL or ELL
2003	12	1	8.3	0	0	0	12	1	8.3
2004	32	2	6.3	1	0	0	32	2	6.3
2005	182	17	9.3	59	5	8.5	188	21[b]	11.7
2006	144	15	10.4	52	4	7.7	155	19	12.3
2007	22	4	18.2	9	1	11.1	25	5	20
2008	1	0	0	0	0	0	1	0	0
2009	0	0	0	0	0	0	0	0	0
2010	13	0	0	0	0	0	0	0	0
2011	1	0	0	0	0	0	0	0	0
Unknown	54	4	7.4	0	0	0	54	4	7.4
Total	461	43	9.3	121	10	8.3	481[a]	52[b]	10.8
Test results									
FET		$P = 0.96$			$P = 0.90$			$P = 0.86$	

[a] Not the overall sum of individual gizzards and livers, but rather 360 chukars with gizzards only + 101 chukars with gizzards and livers + 20 chukars with livers only.

[b] We subtracted 1 from the actual total of 22 (2005) and 53 (entire sample) to avoid double-counting because bird 157 had both IGL and ELL.

observed frequencies of ingested gizzard lead and elevated liver lead from July, when calculated separately, presented information that was inconsistent with that of other collections months, likely because of small sample sizes in July. However, combined frequencies of ingested gizzard lead and elevated liver lead aligned our findings from July with those of other harvest months.

We did not observe elevated liver lead during October–January despite documenting typical rates of ingested gizzard lead during the same period. These results may indicate that chukars more commonly succumb to the effects of lead absorption during autumn and winter. Adverse effects of lead-pellet ingestion in avian species can be magnified under cold temperatures (Kendall and Scanlon 1984, Buerger et al. 1986), and may be further exacerbated for wild birds when the stresses of disease, predation, and starvation are included (Scheuhammer and Norris 1996). Conversely, chukars might switch their diets during autumn and winter, potentially reducing the absorption of ingested lead. Additionally, during the autumn, chukars cease using water sources, near which abnormally high densities of lead shot can occur in soils (Best et al. 1992). Consequently, birds may be exposed less to lead in soils during autumn–winter periods. Nonetheless, our data show that chukars commonly ingest lead shot during the winter, but merely lack elevated lead in liver tissue. However, we might have simply missed individuals with elevated liver lead because of relatively small sample sizes during October–January. Lead-dosing

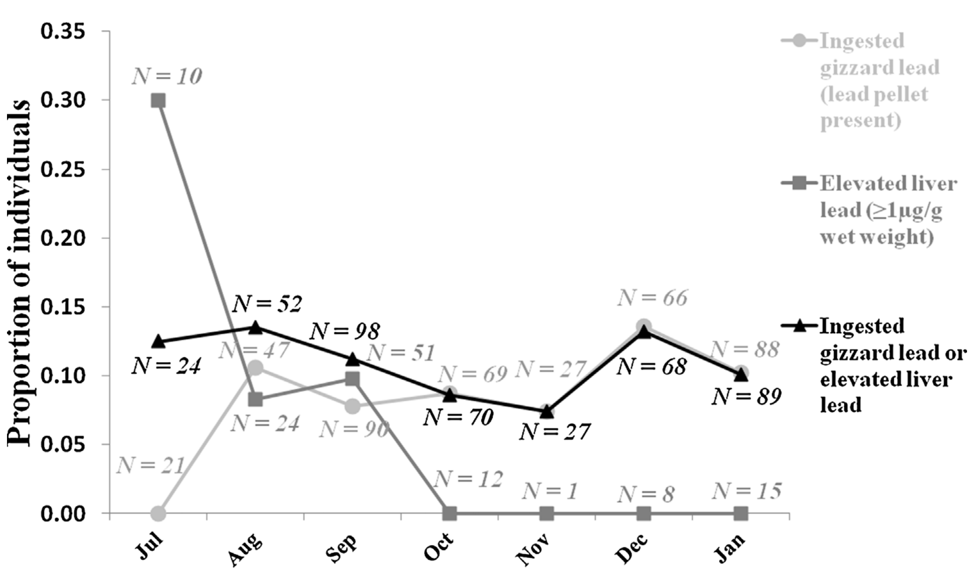

Figure 4. Proportion of wild chukars with ingested gizzard lead or elevated liver lead (≥1 µg/g wet weight), sorted by month, collected from northwestern Utah, USA, 2003–2011. Overall sample size was 461 gizzards and 121 livers. For combined frequencies of ingested gizzard lead and elevated liver lead; sample size was 481 (360 chukars with gizzards only, 101 chukars with gizzards and livers, and 20 chukars with livers only).

wild chukars would likely be required to properly address the potential for an increased risk of lead poisoning during autumn and winter.

Lead pellet densities in soils may be accumulative in our study area. Lead shot can build up faster in firm compared with soft soils (Schranck and Dollahon 1975), particularly in the rocky, dry, and alkaline soils typical of chukar habitat (Walter and Reese 2003, Rattner et al. 2009). Two recent diet studies documented ingested lead in chukars (Walter and Reese 2003, Larsen et al. 2007*b*); whereas, lead ingestion was not previously reported despite multiple diet studies (Zembel 1977, Knight et al. 1979). These early diet studies may have simply neglected to record ingested lead in chukars. However, given contemporary research on lead and upland birds in multiple reports (Westemeier 1966, Locke and Bagley 1967), field studies (Lewis and Legler 1968, Kendall and Scanlon 1979), and dosing trials (McConnell 1968, Damron and Wilson 1975), it seems unlikely that ingested lead in chukars during this period would go unmentioned.

MANAGEMENT IMPLICATIONS

Chukars in northwestern Utah show one of the highest rates of lead ingestion in upland birds and elevated lead exposure in this population is spatially and temporally widespread. These results corroborate findings of many researchers identifying elevated lead exposure as an issue affecting avian species other than waterfowl (Kendall et al. 1996, Fisher et al. 2006). Lead is toxic to chukars, and one number 6 lead pellet can kill captive individuals (Bingham 2011). Although we lack specific data for the consequences of elevated lead exposure in wild chukars, widespread ingestion and absorption of lead pellets present the potential for lead poisoning. Our data depict a likely threshold for detecting elevated lead exposure in chukars from our study area. These findings can help determine where management action is most needed.

ACKNOWLEDGMENTS

We thank Brigham Young University, Carson Valley Chukar Club, Nevada Chukar Foundation, Pershing County Chukars Unlimited, Pheasants Forever, Salt Lake County Fish and Game Association, Sportsmen for Fish and Wildlife, U.S. Geological Survey Utah Cooperative Fish and Wildlife Research Unit, Utah Chukar and Wildlife Foundation, Utah Division of Parks and Recreation, Utah Division of Wildlife Resources, Utah State University, Utah Veterinary Diagnostic Laboratory, and Water for Wildlife for providing financial and logistical support for this research. Additionally, we are grateful to colleagues, family, friends, and volunteers for their assistance and time, without which this study would have been impossible. We would also like to thank the Associate Editor and manuscript reviewers for their many constructive comments, which greatly improved the clarity and flow of this article. Finally, we wish to clarify that the use of trade names or products does not constitute endorsement by the U.S. Government.

LITERATURE CITED

Bellrose, F. C. 1959. Lead poisoning as a mortality factor in waterfowl populations. Bulletin of the Illinois Natural History Survey 27:231–288.

Best, T. L., T. E. Garrison, and C. G. Schmitt. 1992. Availability and ingestion of lead shot by mourning doves (*Zenaida macroura*) in southeastern New Mexico. Southwest Naturalist 37:287–292.

Bingham, R. J. 2011. Causes, extent, and consequences of lead-pellet ingestion by chukars (*Alectoris chukar*) in Western Utah: examining habitat, search images, and toxicology. Thesis, Utah State University, Logan, USA.

Buerger, T. T., R. E. Mirarchi, and M. E. Lisano. 1986. Effects of lead shot ingestion on captive mourning dove survivability and reproduction. Journal of Wildlife Management 50:1–8.

Butler, D. A. 2005. Incidence of lead shot ingestion in red-legged partridges (*Alectoris rufa*) in Great Britain. Veterinary Record 157:661–662.

Casas, J. S., and J. Sordo, editors. 2006. Lead: chemistry, analytical aspects, environmental impact and health effects. Elsevier, Amsterdam, The Netherlands.

Damron, B. L., and H. R. Wilson. 1975. Lead toxicity of bobwhite quail. Bulletin of Environmental Contamination and Toxicology 14: 489–496.

De Francisco, N., J. D. Ruiz Troya, and E. I. Aguera. 2003. Lead and lead toxicity in domestic and free living birds. Avian Pathology 32:3–13.

Dieter, M. P., and M. T. Finley. 1979. Delta-aminolevulinic-acid dehydratase enzyme-activity in blood, brain, and liver of lead-dosed ducks. Environmental Research 19:127–135.

Fenneman, N. M. 1931. Physiography of the western United States. McGraw-Hill, New York, New York, USA.

Fisher, I. J., D. J. Pain, and V. G. Thomas. 2006. A review of lead poisoning from ammunition sources in terrestrial birds. Biological Conservation 131:421–432.

Franson, J. C., S. P. Hansen, and J. H. Schulz. 2009. Ingested shot and tissue lead concentrations in mourning doves. Pages 175–186 *in* R. T. Watson, M. Fuller, M. Pokras, and G. Hunt, editors. Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, Idaho, USA.

Friend, M. 1985. Interpretation of criteria commonly used to determine lead poisoning problem areas. Fish and wildlife leaflet 24. U.S. Fish and Wildlife Service, Washington, D.C., USA.

Gionfriddo, J. P., and L. B. Best. 1999. Grit use by birds. A review. Current Ornithology 15:89–148.

Jorgensen, S. S., and M. Willems. 1987. The fate of lead in soils—the transformation of lead pellets in shooting-range soils. Ambio 16: 11–15.

Keel, M. K., W. R. Davidson, G. L. Doster, and L. A. Lewis. 2002. Northern bobwhite and lead shot deposition in an upland habitat. Archives of Environmental Contamination and Toxicology 43: 318–322.

Kendall, R. J., T. E. Lacher Jr., C. Bunck, B. Daniel, C. Driver, C. E. Grue, F. Leighton, W. Stansley, P. G. Watanabe, and M. Whitworth. 1996. An ecological risk assessment of lead shot exposure in non-waterfowl avian species: upland game birds and raptors. Environmental Toxicology and Chemistry 15:4–20.

Kendall, R. J., and P. F. Scanlon. 1979. Lead concentrations from mourning doves collected from middle Atlantic game management areas. Proceedings Annual Conference Southeast Association of Fish and Wildlife Agencies 33:165–172.

Kendall, R. J., and P. F. Scanlon. 1984. The toxicology of lead shot ingestion in ringed turtle doves under conditions of cold exposure. Journal of Environmental Pathology Toxicology and Oncology 5:183–192.

Keymer, I. F., and R. S. Stebbings. 1987. Lead poisoning in a partridge (*Perdix perdix*) after ingestion of gunshot. Veterinary Record 120:276–277.

Knight, R. L., D. A. Every, and A. W. Erickson. 1979. Seasonal food habits of four game bird species in Okanogan County, Washington. Murrelet 60:58–66.

Kreager, N., B. C. Wainman, R. K. Jayasinghe, and L. J. S. Tsuji. 2008. Lead pellet ingestion and liver-lead concentrations in upland game birds from southern Ontario, Canada. Archives of Environmental Contamination and Toxicology 54:331–336.

Larsen, R. T., J. T. Flinders, D. L. Mitchell, and E. R. Perkins. 2007*a*. Chukar watering patterns and water site selection. Rangeland Ecology and Management 60:559–565.

Larsen, R. T., J. T. Flinders, D. L. Mitchell, and E. R. Perkins. 2007*b*. Grit size preferences and confirmation of ingested lead pellets in chukars (*Alectoris chukar*). Western North American Naturalist 67:152–155.

Lewis, J. C., and E. Legler. 1968. Lead shot ingestion by mourning doves and incidence in soil. Journal of Wildlife Management 32:476–482.

Lewis, L. A., and S. H. Schweitzer. 2000. Lead poisoning in a northern bobwhite in Georgia. Journal of Wildlife Diseases 36:180–183.

Locke, L. N., and G. E. Bagley. 1967. Lead poisoning in a sample of Maryland mourning doves. Journal of Wildlife Management 31:515–518.

Longcore, J. R., L. N. Locke, G. E. Bagley, and R. Andrews. 1974. Significance of lead residues in mallard tissues. U.S. Fish and Wildlife Service Special Scientific Report 182, Washington, D.C., USA.

Lowry, J. H. Jr., R. D. Ramsey, K. Boykin, D. Bradford, P. Comer, S. Falzarano, W. Kepner, J. Kirby, L. Langs, J. Prior-Magee, G. Manis, L. O'Brien, T. Sajwaj, K. A. Thomas, W. Rieth, S. Schrader, D. Schrupp, K. Schulz, B. Thompson, C. Velasquez, C. Wallace, E. Waller, and B. Wolk. 2005. Southwest Regional Gap Analysis Project: final report on land cover mapping methods. RS/GIS Laboratory, Logan, Utah, USA.

McConnell, C. A. 1968. Experimental lead poisoning of bobwhite quail and mourning doves. Proceedings Annual Conference Southeast Association of Game and Fish Commissioners 21:208–219.

Pain, D. J. 1996. Lead in waterfowl. Pages 251–264 *in* W. N. Beyer, G. H. Heinz, and A. W. Redmon-Norwood, editors. Environmental contaminants in wildlife: interpreting tissue concentrations. CRC Press Boca Raton, Florida, USA.

Pain, D. J., I. J. Fisher, and V. G. Thomas. 2009. A global update of lead poisoning in terrestrial birds from ammunition sources. Pages 99–118 *in* R. T. Watson, M. Fuller, M. Pokras, and G. Hunt, editors. Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, Idaho, USA.

Pokras, M. A., and M. R. Kneeland. 2009. Understanding lead uptake and effects across species lines: a conservation medicine based approach. Pages 7–22 *in* R. T. Watson, M. Fuller, M. Pokras, and G. Hunt, editors. Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, Idaho, USA.

Rattner, B. A., J. C. Franson, S. R. Sheffield, C. I. Goddard, N. J. Leonard, D. Stang, and P. J. Wingate. 2009. Technical review of the sources and implications of lead ammunition and fishing tackle and natural resources. Pages 68–70 *in* R. T. Watson, M. Fuller, M. Pokras, and G. Hunt, editors. Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, Idaho, USA.

Sanderson, G., and F. C. Bellrose. 1986. A review of the problem of lead poisoning in waterfowl. Illinois Natural History Survey Special Publication 4:1–34.

Scheuhammer, A. M., and S. L. Norris. 1996. The ecotoxicology of lead shot and lead fishing weights. Ecotoxicology 5:279–295.

Scheuhammer, A. M., J. A. Perrault, E. Routhier, B. M. Braune, and G. D. Campbell. 1998. Increased lead concentrations in edible portions of game birds harvested with lead shot. Environmental Pollution 102:251–257.

Schranck, B. W., and G. R. Dollahon. 1975. Lead shot incidence on a New Mexico public hunting area. Wildlife Society Bulletin 3:157–161.

Schulz, J. H., J. J. Millspaugh, A. J. Bermudez, X. Gao, T. W. Bonnot, L. G. Britt, and M. Paine. 2006. Acute lead toxicosis in mourning doves. Journal of Wildlife Management 70:413–421.

Schulz, J. H., J. J. Millspaugh, B. E. Washburn, G. R. Wester, J. T. Lanigan, and J. C. Franson. 2002. Spent-shot availability and ingestion on areas managed for mourning doves. Wildlife Society Bulletin 30: 112–120.

Trainer, D. O. 1982. Lead poisoning of waterfowl. Pages 24–30 *in* G. L. Hoff and J. W. Davis editors. Noninfectious diseases of wildlife. The Iowa State University Press, Ames, USA.

Tranel, M. A., and R. O. Kimmel. 2009. Impacts of lead ammunition on wildlife, the environment, and human health—a literature review and implications for Minnesota. Pages 318–337 *in* R. T. Watson, M. Fuller, M. Pokras, and G. Hunt, editors. Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, Idaho, USA.

U.S. Fish and Wildlife Service [USFWS]. 1986. Final supplemental environmental impact statement, use of lead shot for hunting migratory birds in the United States. U.S. Department of the Interior, Washington, D.C., USA.

Walter, H., and K. P. Reese. 2003. Fall diet of chukars (*Alectoris chukar*) in eastern Oregon and discovery of ingested lead pellets. Western North American Naturalist 63:402–405.

Westemeier, R. I. 1966. Apparent lead poisoning in a bobwhite. Wilson Bulletin 78:471–472.

Zembel, R. L. 1977. The feeding habits of the chukar partridge (*Alectoris chukar*) in the Argus and Coso Mountains of California. Thesis, California State University, Long Beach, USA.

Associate Editor: Dailey.