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Northern Bobwhite and Lead Shot Deposition in an Upland Habitat

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Abstract. We estimated total lead shotshell pellets expended, resultant pellet availability near soil surface, and the frequency of pellet ingestion by northern bobwhites (*Colinus virginianus*) attributable to nearly a quarter century of bobwhite hunting on a 202-ha upland habitat at Tall Timbers Research Station, Leon County, Florida. A total of 7,776 shots were fired, resulting in the expenditure of approximately 4.5 million pellets (~ 22,519/ha). Sixteen of 235 (6.8%) soil samples collected in 1989 and 1992 contained one or two pellets. Soil samples indicated that approximately 7,800 pellets/ha (about 35% of the projected 24-year deposition) were within 2.54 cm of the soil surface. Pellet ingestion by bobwhites was evaluated by examining 241 gizzards collected from 1989–92. Three bobwhites (1.3%) had ingested pellets ($\bar{x}$ = 1.3 pellets). No instances of suspected lead poisoning were noted in bobwhites over the 24-year period. Sport hunting of wild bobwhite populations on upland habitats appears to produce a low potential for lead poisoning compared to lead deposition in association with waterfowl and dove hunting.

The ingestion of lead shot as a source of lead toxicosis in waterfowl has been recognized for many years (Bowles 1908) and has been thoroughly documented in the more recent literature (Bellrose 1951, 1959; Trainer and Hunt 1965; Kendall and Driver 1982; Locke *et al.* 1982; Sanderson and Bellrose 1986). Estimates of mortality have ranged from 1.6–3.8 million waterfowl annually in North America (Feierabend 1983). Lead poisoning occurs to an unknown, but presumably lesser extent in other avian taxa that forage primarily in wetlands (Stendell *et al.* 1980; Windingstad *et al.* 1984; Snyder *et al.* 1991; Franson and Cliplef 1992; Pokras and Chafel 1992). In addition, secondary lead toxicosis produces mortality among raptors through the consumption of waterfowl with embedded or ingested lead shot (Custer *et al.* 1984; Wiemeyer *et al.* 1987). Various solutions to reduce wild bird mortality associated with the use of lead shot for waterfowl hunting have been recommended during the past half century; conversion to nontoxic shot shells (*i.e.*, steel shot) was implemented via federal and state regulations beginning in 1991 (Kraabel *et al.* 1996).

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Because lead shot also is deposited in upland habitats by sportsmen pursuing game other than waterfowl, concern has been expressed regarding the potential for lead poisoning of upland game (Lewis and Legler 1968; Best *et al.* 1992b; Lewis and Schweitzer 2000) and nongame species (Mörner and Petersson 1999). Instances of lead toxicosis in upland game birds, nongame birds, and various mammalian species are rare or infrequent but have been reported (Stowe *et al.* 1972; Diters and Nielson 1978; DeMent *et al.* 1987). Some of these cases of lead toxicosis were indicative of behavior patterns peculiar to individual animals and not the general population (Decker *et al.* 1979).

Compared with the amount of research on the distribution and persistence of lead pellets in wetlands, few studies have evaluated lead pellet deposition in upland habitats. Studies that have been conducted focused on localized areas with intensive shooting, such as shooting ranges, dove fields, and around stock-watering tanks (Lewis and Legler 1968; Castrale 1989; Best *et al.* 1992a, 1992b; Buck 1998). Before sound management decisions can be made regarding the ecological impacts of using lead shotshells for typical upland hunting scenarios, we must better understand the dynamics of lead shot deposition in upland habitats and lead toxicosis among wildlife species using these habitats.

A long-term population dynamics and disease investigation on northern bobwhites at Tall Timbers Research Station (Davidson *et al.* 1994), which included a rigidly controlled and monitored annual harvest of bobwhites, afforded a unique opportunity to examine factors important in assessing the risk of lead toxicosis under conditions characteristic of many upland hunting situations. Here, we estimate total lead pellets expended, resultant pellet availability near soil surface, and the frequency of pellet ingestion by bobwhites that are attributable to an annual 22–35% bobwhite hunting harvest over a period exceeding two decades.

Materials and Methods

The study was conducted at Tall Timbers Research Station (TTRS), a 1,120-ha area located in a limestone region of broken terrain in the northern part of Leon County, Florida. For more than 50 years previous to its establishment as a research station in 1958, TTRS was managed as a bobwhite hunting plantation under private ownership. During the period of this study, approximately 85% of TTRS was woodland consisting primarily of open stands of mature loblolly (*Pinus taeda*) and shortleaf pine (*Pinus echinata*) interspersed with live oak (*Quercus virginiana*). The remaining 15% of the area was agricultural fields. A history and general description of TTRS have been presented by Komarek (1975). Descriptions of the study site, land management practices, and bobwhite population characteristics at TTRS are available (Kellogg and Doster 1971; Kellogg *et al.* 1970, 1972; Dimmick *et al.* 1982; Doster *et al.* 1982; Smith *et al.* 1982; O'Brien *et al.* 1985; Pollock *et al.* 1989; Davidson *et al.* 1991).

The present research was conducted on the 202-ha area (study site 1) delineated by Kellogg *et al.* (1972). Most of this area was burned annually; however, a network of plowed firebreaks was maintained to protect fields and permanent fire research plots. During 1968–71, 1975–83, and 1988–91, all or most of 17 small fields averaging 1.9 ha in size were planted in corn. During 1972–74 and 1984–87, these fields were left fallow. Although a variety of minor habitat changes occurred during the study period (*e.g.*, hardwood succession on infrequently burned fire research plots, periodic mechanical removal of woody encroachment along field edges, or rotational protection of small patches of unburned nesting cover), the study area was continually comprised of relatively high-quality bobwhite habitat. During the early 1980s, TTRS also installed a 100-m grid system with permanent steel markers that encompassed the entire area of study site 1.

From 1968 through 1992, the Southeastern Cooperative Wildlife Disease Study (SCWDS) participated in a collaborative research effort on various facets of the ecology and management of northern bobwhites at TTRS. Many of the methods that form the underlying basis of the current study are contained in earlier publications; consequently, only brief descriptions of the key elements of this earlier work are given here.

Bobwhite Population Harvests

Bobwhites were live-trapped, banded, and released during a 2-week period in late January and early February annually from 1969 through 1992 for population estimates using mark-recapture. Throughout this period, the health of captured bobwhite was assessed by SCWDS personnel; this included basic physical examinations on live birds as well as necropsies. During these health evaluations any indication of ill health, including lesions and clinical signs of lead poisoning (*e.g.*, neurological difficulties, bile-stained vent and gizzard, impacted esophagus, etc.) were noted. Collection by shooting (recapture phase of mark-recapture) using shotguns and bird dogs began within 1 week following cessation of trapping and was completed within a 2-week period. Except for strict requirements regarding systematic coverage of the assigned hunting area and recordkeeping, hunting activities were similar to common practices used among sport hunters in the region (Doster *et al.* 1982; Kellogg *et al.* 1982). Although many volunteers assisted with hunting activities, each hunting party of two to four people included a lead individual who was experienced in all aspects of this activity and was responsible for ensuring proper conduct of this aspect of the work. Hunters were required to maintain contemporaneous records on the number of bobwhites found; the number of shots fired; the number of bobwhites killed; the age, gender, and band numbers of bobwhites killed; the number of bobwhites hit but not retrieved; the exact area hunted; and, from 1977 onward, the precise locations for birds killed. Further details on the methods employed for the population dynamics aspects of SCWDS/TTRS bobwhite research are presented elsewhere (Kellogg *et al.* 1972, 1982; Smith 1980; Smith *et al.* 1982; Dimmick *et al.* 1982; Doster *et al.* 1982; O'Brien *et al.* 1985; Pollock *et al.* 1989).

Estimation of Pellets Expended

Records of hunting activity were used to estimate the total number of lead pellets expended during the entire study period based on the following assumptions. At least 98% of all hunters used 12- or 20-gauge shotguns, and approximately half of the shots were fired from shotguns of each gauge. Although records were not kept on gauges of shotguns used, the preceding approximations were the consensus of SCWDS researchers (Kellogg, Doster, Davidson) who, individually or collectively, supervised research every year. Shells used were loaded with number 9 lead shot and were provided by SCWDS. The 20-gauge shells provided contained 7/8 ounces of shot, whereas 12-gauge shells contained 1 and 1/8 ounces of shot. Hence, we calculated an average of 1 ounce of number 9 shot was expended for every shot fired. The total number of pellets potentially deposited annually was then calculated by multiplying the total number of shots fired by 585 (the average number of number 9 pellets per ounce of shot) (Hercules 1990). Annual values were summed to obtain total pellets expended over the entire period.

Estimation of Pellet Availability

The methodology for collecting and processing soil samples were similar to other research (Lewis and Legler 1968; Castrale 1989; Best *et al.* 1992b; Buck 1998). Soil samples were taken in 1989 and 1992 along the permanent 100-m grid system during April after TTRS personnel completed prescribed burning activities. In 1989, a sample was taken within 1 m north of each grid marker. In 1992, sampling intensity was reduced to every third grid marker, and samples were obtained within 1 m south of markers. A 30-cm $\times$ 30-cm angle iron frame was used to delineate the sampling area to a depth of 2.54 cm. All soil and humus within the sampling area was collected after loose superficial forest floor litter had been removed. If the grid marker was in a fire break, an agricultural field, or a fire research plot, the sample for that marker was collected from the nearest woodland edge. This was done to eliminate bias caused by soil tillage and to avoid disturbing fire research plots.

Soil samples were stored in paper bags at room temperature, allowed to air-dry, and individually sifted through a series of three screens starting with a 0.635-cm mesh, progressing to a 0.168-cm mesh, and ending with a 0.098-cm mesh. When necessary, aggregates of soil or debris were macerated with a wooden block to facilitate the screening procedure. Residue retained in the 0.098-cm mesh screen was placed in plastic bags, labeled, spread within the confines of the bag to ≤ 3 cm thickness, and radiographed. Radiographs were examined for radio-opaque objects compatible with lead pellets. Samples suspected of containing pellets were placed in 0.098-cm screens, washed with a spray of water, and the retained residue was flushed into a pan. Residues were examined with aid of magnification (3–6$\times$), and the pellets were recovered and counted. To ensure the sensitivity of the radiographic technique, 22 samples that contained radio-opaque objects that did not appear to be pellets also were inspected in this manner. These samples were selected based on the size, shape, and relative radiographic opacity of the objects. A *G* test for independence with Yate's correction (Sokal and Rohlf 1981) was conducted to test for differences in the number of pellets per sample between the 2 years.

To assess the overall sensitivity of the pellet recovery and detection methods, a controlled test was conducted on an area of the University of Georgia (UGA) campus. Five 30-cm $\times$ 30-cm sample plots were selected, and 10 number 9 lead shot pellets were deposited in each sample area. Soil samples were taken and processed in the same manner as at TTRS.

Estimation of Pellet Ingestion by Bobwhites

The frequency of pellet ingestion by bobwhites was estimated by examining gizzards from bobwhites shot on the study site each February from 1989 through 1992. Gizzards were removed by cuts at the junctions of the proventriculus and small intestine and then frozen intact in individual bags within 24 h. Later, gizzards were placed in a matrix of individually identifiable 2.5-cm × 2.5-cm cells fabricated from cardboard and radiographed. All gizzards that appeared to contain pellets based on radiography were dissected, and the gizzard and its contents were inspected to determine if the pellets had been ingested or were embedded pellets resulting from gunshot. To be classified as ingested, pellets had to meet criteria of a two-step decision process. The criterion for first step was that the pellet had to be in gizzard contents within the lumen. At the second step, meeting either of two criteria could result in classification of a pellet as being ingested. One was pellet wear from the grinding action of the gizzard, and the other was absence of hemorrhages, rents in musculature, or other evidence of pellet penetration of the gizzard due to gunshot. Pellets that were lodged in gizzard tissues or pellets that were within the gizzard lumen but associated with penetrating wounds did not meet these criteria; these were classified as embedded pellets attributable to gunshot.

Results

Annual hunting harvest (including crippling loss) was targeted at 25% of the population on the 202-ha study site; actual harvest averaged 28% and ranged from 22% to 35%. To achieve these harvest levels from 1969 through 1992, 7,776 shots ($\bar{x}$ = 324 shots/year) were fired expending an estimated 4,548,960 pellets. By 1992, the estimated density of pellets expended on the study site was approximately 22,519/ha.

The sensitivity of the procedure to detect and recover pellets from the soil was high. Radiography detected all 50 pellets that had been placed in the five control plots at the UGA campus, and recovery of pellets from the processed residues was 100%. Further more, no pellets were recovered from any of the 22 field samples containing radio-opaque objects that did not conform to pellet shape or size.

During 1989, 171 soil samples were collected and examined for lead shot. Eight (4.7%) samples each contained a single pellet ($\bar{x}$ = 0.05, SE = 0.02). In 1992, 64 samples were collected and 8 (12.5%) were positive for lead pellets. Seven contained a single pellet and one contained 2 pellets ($\bar{x}$ = 0.14, SE = 0.05). The difference in means between the 2 years was insignificant (G = 3.02, p = 3.84). Thus, the 1989 and 1992 data sets were combined; the combined data set had a 6.8% prevalence ($\bar{x}$ = 0.07, SE = 0.02) of lead pellets per soil sample. Assuming the distribution of lead shot on the study area was similar to the distribution of pellets in the samples, the 1989 data indicated a density of 5,033 pellets/ha. Using these same assumptions, the predicted density of lead pellets in 1992 was 15,130 pellets/ha. A density of 7,783 pellets/ha was predicted based on the combined data sets.

From 1989–92, 241 gizzards were collected from bobwhites shot on the study site. Radiography disclosed that numerous gizzards (> 40) contained one or more pellets; however, on dissection most were found to be embedded rather than ingested pellets. Three of 241 (1.3%) gizzards contained a total of four pellets ($\bar{x}$ = 1.3) that were classified as ingested. In 1989 and 1990, none of 105 gizzards examined contained ingested pellets. Of the 20 gizzards collected in February 1991, 2 (10%) contained pellets classified as ingested. In 1992, 1 of 116 (0.8%) gizzards contained one pellet classified as ingested. All of the ingested pellets were classified as such based on the absence of penetrating lesions in the gizzard, and none met the criterion of being worn.

Fifty to 75% ($\bar{x}$ = 67%) of the annual bobwhite population were handled for either banding or necropsy from 1969–92, and no instances of suspected lead poisoning were noted.

Discussion

The combined 1989 and 1992 soil samples indicated a density of approximately 7,800 pellets/ha within the upper 2.54 cm of soil, which was 35% of the roughly 22,000 pellets/ha expended based on the number of shots fired. An unknown portion of this disparity can be attributed to factors that would preclude actual pellet deposition in the soil. These include pellets embedding in bobwhites, trees, or other objects and flight of pellets off the study site. Detectability of pellets actually deposited could have been limited, to an unknown extent, by factors affecting pellet mobility within soil, particularly infiltration of pellets deeper than 2.54 cm from the surface. Soil erosion processes also may cause redistribution and concentration of pellets under certain circumstances. For example, a soil sample purposefully selected (not part of the systematic survey) at the lower reaches of a shallowly eroded dirt road that ascended a hillside contained 17 pellets (Doster personal observation). However, the gentle topography and dense understory vegetation at TTRS should preclude significant pellet redistribution by erosion on the vast majority of the study site. Soil tillage also has been found to reduce available lead shot by 41–85% in other studies (Fredrickson *et al.* 1977; Esslinger and Klimstra 1983; Buck 1998). Because agricultural fields or firebreaks were not sampled, soil tillage is unimportant in interpreting pellet density data for our soil samples.

The quantities of lead pellets deposited at TTRS during the 24-year period, whether based on number of shots fired or pellets counted during soil sampling, seem trivial when compared with the pellet densities found in many wetland habitats hunted for waterfowl or upland sites with intensive dove hunting. Pellet densities reported on wetland sites include 99,025/ha in New Mexico (Schranck and Dollahon 1975), 303,415/ha in Missouri (Fredrickson *et al.* 1977), 109,833/ha in Illinois (Esslinger and Klimstra 1983), and 157,150/ha in Massachusetts (Windingstad and Hinds 1987). Research conducted on upland sites reported pellet densities of 108,900/ha in a Tennessee dove field (Lewis and Legler 1968), 172,222–348,750/ha on three dove fields in Illinois (Buck 1998), and 860,185/ha surrounding a New Mexico water tank (Best *et al.* 1992b). All were posthunting season levels.

The approximation that 7,800 pellets/ha were within the top 2.54 cm of soil probably overestimates the pellets actually available to foraging bobwhites. Although bobwhites are rasorial birds, they are weak scratchers (Stoddard 1931) and do not routinely forage as deep as 2.54 cm in the soil. Nevertheless, other species of birds and mammals forage within this zone, and thus the data are useful in this broader context. In addition, the commonly used measurement of the top 2.54 cm of soil allowed direct comparison with data from other soil lead deposition studies.

None of the pellets that were classified as ingested had any evidence of wear, which implies that all were recently ingested. Application of rates of wear described for lead pellets experimentally fed to bobwhites (McConnell 1967) predict that all of these pellets were acquired less than 10 days before the birds were killed; this scenario seems improbable. Alternatively, these pellets may not have been ingested but actually may have been embedded pellets that were misclassified. Misclassification could have occurred if the pellets lodged within the gizzard contents after they entered the gizzard by passing through precisely the gizzard's junction with either the proventriculus or duodenum. In such a case, detection of pellet-induced trauma would not have been possible by examining the gizzard alone but would have required careful examination of both the proventriculus and duodenum for lesions. Regardless, the estimated frequency of pellet ingestion (1.3%) by bobwhites was minor compared to the prevalences of ingested pellets and resultant lead poisoning in several species of waterfowl (Environmental Impact Statement 1986). This low (and even possibly inflated) ingestion rate also conforms with the absence of lead poisoning as a generally recognized mortality factor of wild bobwhites. Indeed, there are only four published reports of pellet ingestion or lead toxicosis in wild bobwhites, which collectively involve a total of five individuals (Stoddard 1931; Westemeier 1966; Best *et al.* 1992b; Lewis and Schweitzer 2000).

Fundamental differences exist between the hunting activities in this study, which we believe are reasonably representative of bobwhite hunting (Doster *et al.* 1982), and those that typify waterfowl and dove hunting activities. In our study, shooting was not concentrated around particular locations but occurred throughout the 202-ha study area. Further, the approximately 3 shots fired per bobwhite harvested (Kellogg and Doster 1971; Doster *et al.* 1982) is markedly lower than comparable values for waterfowl (3–15 shots/bird) (Environmental Impact Statement 1986) and doves (5–8 shots/bird) (Lewis and Legler 1968). Concentration of shooting around waterfowl blinds, small wetlands or impoundments, dove fields, or stock watering tanks combined with the number of shots fired are the primary determinants that produce the high lead pellet densities often associated with waterfowl and dove hunting. These differences in how hunting is done appear to be important risk factors that ultimately result in lower pellet densities in the environment, lower rates of pellet ingestion, and lower frequencies of lead toxicosis among bobwhites and other species in upland habitats where small game hunting occurs.

As far as we are aware, this is the first study to investigate the magnitude of environmental lead shot deposition attributable to known harvest levels of an upland gamebird (other than mourning doves) over a period of many years. Although our findings indicate that hunting wild bobwhite populations in natural settings appears to result in minimal lead toxicosis risks compared to those associated with waterfowl and dove hunting, it is a source of environmental lead deposition that could be addressed by implementing alternative shot regulations, as was done with waterfowl hunting. Further research will be necessary to determine the benefits and appropriate priority of any such regulatory changes within overall efforts to reduce environmental lead deposition.

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