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Original Article

A Comparison of Lead and Steel Shot Loads for Harvesting Mourning Doves

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ABSTRACT With approximately 100 million shots fired at mourning doves (*Zenaida macroura*) annually, it is incumbent on managers to determine whether changes in ammunition will substantially alter harvest metrics or hunter satisfaction. We compared mourning dove harvest metrics for 1 lead (Pb 7½, 32 g) and 2 steel (Fe 7 and Fe 6, 28 g) 12-gauge ammunition types using a double-blind field test in central Texas, USA. There were no differences in the number of attempts, or number of shots fired among ammunition types. Hunters were unable to distinguish the ammunition type being used in the field, and we detected no relationship between ammunition type and level of hunter satisfaction. Field analyses detected no difference in doves bagged per shot, wounded per shot, bagged per hit, or wounded per hit among the 3 ammunition types. Necropsy analyses detected no difference in the proportion of birds with through-body strikes, mean penetration depth of through-body strikes, or mean embedded pellet depth among ammunition types. Ammunition and choke combinations that produced higher pattern densities yielded more hits per shot and produced more total strikes per bird, resulting in a higher percentage of birds with embedded pellets, more embedded pellets per bird, and a higher proportion of birds with broken legs. All 3 ammunition types retained sufficient lethality to harvest mourning doves under typical hunting conditions. Our results demonstrate that when the ammunition type used provides sufficient lethality for pellets to penetrate vital organs, pattern density becomes the primary factor influencing ammunition performance. © 2014 The Authors. The *Wildlife Society Bulletin* is published by The Wildlife Society

KEY WORDS ammunition, lethality research, mourning dove, nontoxic, shotgun, shotshell, Texas, toxic shot, wounding, *Zenaida macroura*.

Ingested lead (Pb) shot has been linked to acute toxicosis in wildlife (Bellrose 1951, Mudge 1981, Schwab and Daury 1989, Daury et al. 1993). As a result, regulations limiting or banning the use of Pb shot have been enacted by 29 countries including the United States (U.S. Department of the Interior 1976, Avery and Watson 2009). Recent research has focused attention on prevalence of Pb toxicosis in upland game birds (Keel et al. 2002, Butler et al. 2005, Stevenson et al. 2005, Strom et al. 2005, Thomas et al. 2009), and in species that scavenge on the Pb-contaminated remains of harvested animals (Clark and Scheuhammer 2003, Samour and Naldo 2005, Fisher et al. 2006, Hunt et al. 2006, Martin et al. 2008). Because of growing concern over use of Pb ammunition, several groups have called for regulations restricting Pb shot use (Nontoxic Shot Advisory Committee 2006, Avery and Watson 2009, The Wildlife Society 2009), while other organizations have called for total bans on all Pb-based ammunition (Keats and Wolf 2009, Pain et al. 2009, Center for Biological Diversity et al. 2010).

Historically, hunters in the United States have been skeptical about the effectiveness of nontoxic shot for hunting purposes (U.S. Department of the Interior 1976, Mikula et al. 1977, Smith and Townsend 1981, Humburg et al. 1982, Hebert et al. 1984). To address hunter concerns, research (i.e., lethality tests) has been completed comparing Pb and nontoxic ammunition harvest metrics for several species. This research included laboratory tests using tethered game farm mallards (*Anas platyrhynchos*; Bellrose 1953, Andrews and Longcore 1969, Kozicky and Madson 1973, Cochrane 1976) and controlled tests using flighted game farm mallards (Nicklaus 1976). Field tests conducted under actual hunting conditions have been completed for wild ducks (Kimball 1974, Mikula et al. 1977, Humburg et al. 1982, Hebert et al. 1984), large-sized wild geese (*Branta canadensis*; Anderson and Roetker 1978, Anderson and Sanderson 1979), medium-sized wild geese (*B. canadensis*; Smith and Roster 1979), and mixed wild waterfowl (Brownlee et al. 1985). To date,

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relatively few upland game bird tests have been conducted. These tests included a laboratory study using tethered domestic turkeys (*Meleagris gallopavo*; Roster 1990), a field study comparing steel (Fe) loads using released pheasants (*Phasianus colchicus*; Bihrle 1999, 2001), and a field test of limited sample size on mourning doves (*Zenaida macroura*; Anderson et al. 1980).

Mourning doves are the most abundant and widely hunted game species in North America (Aldrich and Duvall 1958, Grue et al. 1983, Baskett and Sayre 1993, Peterjohn et al. 1994). In 2011, an estimated 955,700 hunters spent 3.0 million days afield, and harvested 16.6 million mourning doves (Seamans et al. 2012). Texas (USA) alone hosts approximately 250,000 mourning dove hunters each year, and dove hunting contributes over US$300 million to the Texas economy annually (U.S. Department of the Interior et al. 2002, Johnson and Polk 2004, Southwick Associates 2007, Kruse 2011). Given the magnitude of the annual mourning dove harvest, and because dove hunters expend a relatively high volume of ammunition per dove bagged (approx. 4–8 shells/bird harvested; Nelson 1957, Lewis and Legler 1968, Haas 1977, Kendall et al. 1996), any regulations affecting dove hunting ammunition could have relatively large economic and environmental ramifications (Nontoxic Shot Advisory Committee 2006, Western Association of Fish and Wildlife Agencies 2010).

Previous lethality studies (controlled and field) have addressed concerns in waterfowl or larger upland game bird species, but relatively few have focused specifically on smaller game birds (i.e., <200 g), or have utilized smaller shot sizes (i.e., smaller than No. 4 shot or 3.30 mm). An unpublished Illinois (USA) mourning dove test (Anderson et al. 1980) was the only study focusing on small game birds. Similarly, only Anderson et al. (1980) and Hebert et al. (1984) tested ammunition containing pellets of a size suitable for mourning dove or other game birds of diminutive body size (i.e., ≤3.30 mm or No. 4 shot). As a result, wildlife managers cannot predict whether changes in ammunition use (imposed or voluntary) will alter harvest metrics (e.g., bagged per shot, wounded per shot) in mourning dove or other small upland game birds, and therefore require changes in harvest management (i.e., bag limits and/or season length).

Our objective was to determine whether changes in ammunition use could alter harvest metrics in mourning dove. We assessed the performance of the most popular Pb shot load currently being used by Texas dove hunters, with the most likely to be used nontoxic alternative, under field conditions. We compared ammunition characteristics (pattern count and pattern efficiency), hunter shot outcomes (harvest metrics), and terminal ballistics (necropsy metrics) among 1 Pb and 2 Fe ammunition types of comparable pellet weight, shot charge (payload) weight, and muzzle velocity. Using these data, we evaluated whether ammunition performance was governed primarily by pellet density, or if ancillary factors determined ammunition performance (e.g., load pellet count, pellet hardness, pellet size, pattern density, or choke selection).

STUDY AREA

Our study was conducted on private property in Brown, Coleman, and McCulloch counties, Texas (Latitude 31.467, Longitude −99.203). These 3 counties cover 8,577 km^2 consisting primarily of rural ranch land (<2% urbanized), with cropland limited to the deeper alluvial soils comprising 6% of the area (German et al. 2009, Wilkins et al. 2009). Dove hunting is an important recreational and economic activity in this part of Texas. Many local communities celebrate the opening of dove season with "Dove Festival" events, and there are numerous commercial dove-hunting operations in the area. The combined mourning dove harvest in Brown, Coleman, and McCulloch counties was estimated at >250,000 annually (R. V. Raftovich, U.S. Fish and Wildlife Service, unpublished data), with a mean hunter success rate of 90% (i.e., 90% of hunters harvested ≥1 dove; C. D. Mason, unpublished data).

METHODS

Study Design and Analyses

We compared differences in ammunition performance among 1 Pb and 2 Fe ammunition types under field conditions in Texas during 2008–2009. State (SPR-0309-028) and federal (MB190203-0) permits were obtained for the taking of migratory game birds, and transfer of game animals under federal and state guidelines. Study training areas, hunting areas, lodging, and logistics were obtained through the public bid process. Specifications for study ammunition were based on hunter responses to the 2002 Texas Parks and Wildlife Department Gun and Shot Survey (mail survey; Purvis et al. 2002), and ammunition was procured through the public bid process (only one manufacturer was willing to produce the test ammunition for the study). We used volunteer hunters to provide a cross-section of the Texas hunting public, and to avoid the obvious impropriety of using funding agency personnel as hunters. We used professional biologists employed by the Texas Parks and Wildlife Department, Oklahoma Department of Wildlife Conservation (OK, USA), and the Natural Resource Conservation Service as observers. All field data collection occurred in Texas, and all necropsy analyses were performed in Oregon, USA (laboratory of a coauthor).

Data were collected using a randomized block design with hunter × load as the experimental unit. Treatment factors included ammunition type (Pb 7½, Fe 7, and Fe 6), distance category (<28.3 m and ≥28.3 m; a median split of shot distances), and choke category (≤17.78 mm = "Full," 17.81–18.25 mm = "Modified," and ≥18.26 mm = "Improved Cylinder"). We used Levene's test (Levene 1960) to evaluate homoscedasticity among treatment groups, and the Lilliefors modification to the Kolmogorov–Smirnov test to assess normality (Lilliefors 1967). Parametric analyses (i.e., *t*-test, Analysis of Variance [ANOVA]) were used for many comparisons, but violations of assumptions that could not be addressed using either a stabilizing transformation, or a Brown–Forsythe modification to the *F*-statistic (Brown and Forsythe 1974), resulted in the use of nonparametric analogs (e.g., Kruskal–Wallis; Kruskal and Wallis 1952). When omnibus ANOVA tests revealed significant differences, multiple comparison procedures (Fisher's Least Significant Difference) were used to identify significant differences within factors (Zar 1996). When discussing ANOVA results, we report predicted mean responses for each factor, which are adjusted for all other variables in the model (least-square means or estimated marginal means; IBM Corp 2012, Field 2013).

We used the chi-square test of independence (hereafter, χ^2) for analysis of categorical data (Pearson 1900). When χ^2 tests were significant, we generated pairwise comparisons of column proportions (Z-tests) to determine which pairs of columns (for a given row) were significantly different (Sheskin 2011, IBM Corp 2012). All analyses were 2-tailed, and used an alpha level of 0.05.

Ammunition Specifications

We used the 2002 Texas Parks and Wildlife Department Gun and Shot Survey to identify the ammunition preferences of Texas dove hunters (Purvis et al. 2002; $n = 1{,}560$; response rate 53.03%). Most Texas dove hunters reported using a 12-gauge shotgun (73.04%), firing a 70 mm shell (2 3/4 inch; 92.01%), containing 32 g (1 1/8 oz; 40.29%) or 24.8 g (7/8 oz; 22.05%) of No. 7½ (64.17%) or No. 8 (27.22%) Pb (92.42%) shot.

Based on information from manufacturers and previous lethality studies, we selected Fe shot for our nontoxic test ammunition because 1) it was the least expensive of the available nontoxic ammunition types, and 2) Fe shot was available in a range of pellet sizes comparable to what is preferred by the majority of Texas dove hunters (Purvis et al. 2002). Further, a comparison between Fe shot (7.8 g/cc) and Pb shot (11.3 g/cc) represents the largest available disparity in density between Pb shot and other commercially available nontoxic alternatives (i.e., Bismuth, Tungsten, and the available alloys are closer in density to Pb than Fe; several alloys are actually higher in density than Pb). Therefore, if pellet density is the dominant factor influencing ammunition performance, then we were more likely to detect a significant difference using Fe shot than any other commercially available nontoxic pellet type.

We used this information to develop 3 70 mm (2 3/4 inch) 12-gauge loads for comparison: a 32 g (1 1/8 oz) load of No. 7½ (2.41 mm) Pb shot, a 28 g (1 oz) load of No. 7 (2.54 mm) Fe shot, and a 28 g (1 oz) load of No. 6 (2.79 mm) Fe shot. All 3 loads were produced to our specifications by the same manufacturer (Polywad, Macon, GA). The pellets in the Pb load were representative of high-quality Pb shot and contained 6% antimony (J. Menefee, Polywad, personal communication). The pellets in the 2 Fe loads were representative of high-quality steel shot used for bead blasting (aerospace surface preparation requiring high sphericity and uniformity of diameter), with a hardness of ≤95 on the diamond pyramid hardness scale (B. Rhodaberger, Ervin Industries, personal communication). The 2 Fe loads used a traditional one-piece, high-density polyethylene "steel shot" type wad. The Pb load used a European one-piece, low-density polyethylene "lead shot" type "stitched" wad, with 4 petals connected by a series of 3 tabs. All 3 loads were assembled in Fiocchi™ brand (Fiocchi Munizioni Company, Lecco, Italy) brown, opaque, 2-piece plastic hulls with 16 mm brass heights to preclude visual determination of load contents by participants (i.e., hunters and observers).

Hunter Selection

We used volunteer hunters to compare differences in ammunition performance. Hunters selected to participate in the study were required to have a Texas Hunting License, no history of game law violations, hunt with a 12-gauge shotgun, and be either Hunter Education certified or age exempt. In 2008, we selected 28 hunter participants from a pool of >60 pay-to-hunt customers at a commercial hunting operation. These hunters were invited to participate at the start of each field test during that year's collection (i.e., 3 hunts). In 2009, we used a random drawing to select 34 participants from the pool of >10,000 Texas Hunting License holders who were also 1) Harvest Information Program certified; 2) reported harvesting ≥1 dove in the 2007–2008 hunting season; and 3) had purchased an Annual Public Hunting Permit. Final participants in 2009 were selected only if they agreed to participate in all 6 field tests that year.

Observer Selection and Training

An observer accompanied each hunter into the field, distributed ammunition, and was responsible for all data collection during hunting activities. The volume of data collected for each shot fired in an attempt to harvest a mourning dove is large, must be collected and annotated properly in a short period of time, and accomplished while maintaining awareness of the safety issues present in a typical hunting environment. Accordingly, participation as a study observer required excellent observational skills, specialized safety training, in-depth field data training, and proficiency testing prior to data collection each year. Because of the substantial time investment required to train observers for this activity, all observers were professional biologists, and either currently or formerly employed by governmental agencies.

We conducted field and classroom training during the week prior to study data collection each year. Observer field training was conducted in the morning and evenings to coincide with maximum dove flight activity, with classroom training conducted during the middle of each day when dove flight activity was at a minimum. Field training focused primarily on 1) observer safety, 2) familiarization with wild dove flight, 3) identification of struck-bird reactions, 4) distance measurement and estimation techniques, 5) correct interpretation of post-shot bird behaviors, 6) proper field data entry, and 7) proper tagging of harvested birds. Classroom training focused on 1) field data recording methodologies; 2) bird tagging procedures; 3) choke measurement techniques; 4) pre- and post-hunt ammunition distribution and collection; 5) the hunter questionnaire; and 6) check-station procedures for turning in tagged doves, data sheets, ammunition, and equipment. All observer training techniques were developed by a coauthor (T. Roster) for previous lethality studies (Anderson and Sanderson 1979, Smith and Roster 1979, Humburg et al. 1982, Hebert et al. 1984, Bihrle 1999), training seminars (Cooperative North American Shotgun Education Program Seminar Series, Levels I and II), or as advisor to the British Association for Shooting and Conservation (unpublished wood pigeon [*Columba palumbus*] study; British Association for Shooting and Conservation 2000–2002).

Field training sites were selected to provide observers with the range of Texas dove-hunting environments, including feeding fields, water holes (tanks), and tree lines that result in overhead, crossing, quartering, and other typical shooting scenarios. Observers trained as a group, concealed within a hunting blind where the instructor (who served as surrogate hunter) fired on wild mourning doves using non-study ammunition (to avoid cross-contamination). Observers witnessed all shots fired as a group, but measured and recorded all required data independently. An assistant, working with the training instructor, recorded all shot outcomes and associated data on a master key. The master key consisted of data sheets and a set of bird tags (paper and metal) for uniquely identifying all shot outcomes and each dove harvested with a single shot. Observers were evaluated after each training session by comparing the observer data sheet and tags (paper and metal) with corresponding entries on the master data sheet and tags (each entry or cell on the data sheet and tags constituted one answer and one point). Observer scores (percentage correct) were posted in the classroom following each training session.

Observer proficiency in some techniques could only be obtained by repetitive training with a qualified instructor. For example, a large portion of field training time was devoted to distinguishing normal dove flight from the behavior exhibited following a miss or a hit. Similarly, observers were trained to use laser rangefinders (Nikon Monarch Laser 800$^{\mathrm{TM}}$, Melville, NY), strategically positioned camouflaged poles (measured from the hunter's position with the rangefinder), and trigonometric tables (angle and lateral distance), to accurately estimate the range to target for each shot fired. Likewise, observers were instructed in the proper use of digital calipers for measuring internal choke dimensions prior to the start of each field test, and following any change in choke by the hunter during the field test. Mastery of these skills was assessed by the instructor both in the field and by monitoring observer candidate test scores. We used descriptive statistics to report observer final test scores for 2008 and 2009 (mean percentage correct and SE).

Ammunition Testing and Analyses

We sampled each ammunition type ($n = 10$) to determine shot charge (payload) weight, number of pellets, and muzzle velocity, and conducted comparative pattern testing under no-wind conditions at a mean temperature of 15.6° C and 1,250-m elevation. Because shotshell patterns are influenced by firearm type, barrel length, choke, and distance (Compton 1996, Compton et al. 1997, Warlow 2005, Jones 2010), we standardized testing procedures by using one shotgun, choke set, and distances to isolate differences due solely to ammunition type. Patterns for each load were fired at 18.3 m, 27.4 m, 36.6 m, and 45.7 m from a Remington Model 332 with 76-cm barrel (0.185-cm diam bore) using improved cylinder (0.183-cm), modified (0.180-cm), and full (0.175-cm) Remington RemChoke$^{\mathrm{TM}}$ screw-in choke tubes (Remington Arms Company, Madson, NC). We calculated pattern count (i.e., pattern density) as the mean number of pellets registering inside a 76-cm-diameter circle centered over the densest portion of each pattern, using 10 shots for each load, choke, and distance combination. We determined pattern efficiency (pattern percentage) by dividing the mean number of pellet strikes by the average number of pellets found in 10 shells of each load (for example, 408/410 = 99.5%). We compared pattern counts (pattern density) using ANOVA, and used descriptive statistics to summarize ammunition characteristics.

Field Testing

During field testing, observers reported to the ammunition depot to receive gear and coded ammunition prior to each field test (i.e., hunt). We divided each ammunition type into lots of 100 rounds/lot, and assigned each lot an alphanumeric code. A random ink color ($n = 6$; red, yellow, purple, blue, black, and green) was applied to the brass head of all rounds in each lot to prevent accidental mixing of ammunition in the field. We limited the preparation and coding of ammunition to 2 researchers throughout the study. Neither the codes, nor the number of ammunition types being tested, were disclosed to any party. We randomly assigned observers to hunters, and ammunition lots were randomly assigned to observer–hunter pairs prior to each field test. Observers accompanied hunters to the field, dispensed ammunition, recorded data, tagged harvested birds taken with a single shot, retrieved spent shells, and completed post-hunt opinion surveys. Observers did not participate in field tests as hunters; retrieve birds; or discuss distances, ammunition, or shooting results with hunters. Upon returning from the field, observers checked in their gear, unused ammunition, spent ammunition, data sheets, tags, and birds. Observer equipment, coded ammunition, data sheets, and tags were then replenished by study personnel prior to subsequent field tests.

We used descriptive statistics to report field data-collection results, including hunts conducted, hunters participating, shots fired, shot outcomes, and average distance for shots fired. The result of each shot fired was put into 1 of 3 shot outcomes: bird bagged, bird wounded (i.e., not retrieved), or bird missed. The bagged category was further divided into 3 subcategories: bagged-undifferentiated, bagged-immobile (i.e., dead or immobile within 30 sec), and bagged-mobile (i.e., mobile for more than 30 sec). We compared the number of shots fired and the number of attempts, between hunters and ammunition types, using ANOVA. We used χ^2 to compare choke use among ammunition types for all shots fired, and all necropsied birds. Because previous studies have speculated whether hunter knowledge of shot type biased ammunition use (Szymczak 1978, Anderson and Sanderson 1979, Smith and Townsend 1981, Humburg et al. 1982), we asked hunters 2 questions after each hunt to assess knowledge of the shot type used (i.e., double-blind integrity of ammunition codes) and potential bias toward test ammunition: 1) if "The shooter felt he/she was shooting lead, steel, other, or don't know," and 2) if "The shooter felt the performance of the shells he/she was shooting was basically good, basically bad, or no opinion." We used χ^2 to compare hunter knowledge of ammunition type and bias versus actual ammunition used for each hunt. Similarly, previous studies found hunter reporting of shot outcomes (bagged, wounded, or missed) and distances to be biased relative to trained observers (Anderson and Sanderson 1979, Humburg et al. 1982, Nieman et al. 1987). We compared hunter perceptions of shot outcomes (Hit or Miss) with results recorded by trained observers using χ^2. Accuracy of hunter versus trained-observer distance estimates were compared using paired-sample *t*-tests, and the trend in estimation error was evaluated using linear regression.

Previous research has shown that distance influences pattern density, pellet velocity, and pellet energy (Mikula et al. 1977, Humburg et al. 1982, Hebert et al. 1984, Jones 2010). To assess the effect of distance on shot outcomes, we used χ^2 to compare shot outcomes (bagged, wounded, and missed) between distance categories within each ammunition type for all shots fired. Because differences in ammunition performance should produce disparate mean distances among ammunition types for various shot outcomes, we compared the mean distance for all shots fired, birds bagged, birds wounded, and birds hit (bagged + wounded) using ANOVA. To assess ammunition performance, we used χ^2 to compare shot outcomes (bagged, wounded, and missed) among ammunition types within distance categories for all shots fired. To evaluate so-called "hitting ability" (i.e., ability to hit the target), we used χ^2 to compare birds hit (bagged + wounded) and birds missed among ammunition types within distance categories for all shots fired. Finally, because previous authors have suggested the inclusion of misses may bias comparisons of ammunition performance, we used χ^2 to compare the number of birds bagged and wounded among ammunition types within distance categories for shots resulting in a hit (bagged + wounded). By removing "misses" from the analysis, any differences in performance are due solely to differences in terminal ballistics among ammunition types (Hayne 1982, Humburg et al. 1982, Bingham 1983, Hebert et al. 1984).

Necropsy Data Collection and Analyses

Tagged dove carcasses were frozen and shipped to the necropsy laboratory of our ballistician (T. A. Roster) in Klamath Falls, Oregon. Care was taken during transport, X-ray, and necropsy to preclude breaking delicate wing and leg bones. Necropsy technicians selected carcasses at random, thawed and X-rayed each specimen in 2 planes (anterior–posterior and left–lateral; 2 doves per 35.6-cm × 43.2-cm radiographic film) prior to necropsy. Wings and legs were extended, and offset, during X-rays to fully capture skeletal detail (anterior–posterior exposure for wings; left–lateral exposure for legs). Metal tags affixed to the right leg of all necropsy specimens served as the orientation marker for each radiograph. Radiographic exposures were considered acceptable if skeletal anatomy, especially the skull and cervical vertebrae, and pellet opacities (if any) could be clearly discerned. Radiographs were used to locate embedded and/or carried pellets, identify broken bones, and to verify penetration depths for those pellet strikes that had passed completely through the bird.

During necropsy, specimens were weighed, defeathered by hand, and oriented to match the radiographic image. A necropsy form containing 2 images of a defeathered specimen (left–lateral and anterior–posterior) was used for recording the location of all wounds, including broken bones, organs struck, entrance points, exit points, and wound angle for each pellet strike. All wound channels, organ strikes, broken bones, entrance points, exit points, and embedded pellets were annotated with unique symbols on the necropsy form, as closely as possible to the location evidenced on the radiograph. If an embedded pellet was evident on the radiograph, an attempt was made to find and remove the pellet. If removed, the pellet was taped to the necropsy form at the wound site using transparent archival tape. All thoracic and abdominal cavity wounds were probed to confirm the presence of wound channels, and to precisely determine the association between entrance and exit wounds. One 20-cm × 1.2-mm aluminum probe was inserted in each wound channel. If multiple wounds were observed, the probes were left in place until all wounds had been exhausted. Wound-channel depth and angle were annotated for each wound on the necropsy form. Wound channels $\leq$2 mm under the skin surface, or measuring <15 mm in length (tangential strikes), were not measured. All wound channels in the thoracic or abdominal areas that terminated in an embedded pellet were measured (regardless of length or depth). Finally, the heart and lungs were examined for penetrations, and any wounds annotated. All wounds were then totaled, and the difference between the number of entrance and exit wounds entered on the necropsy data form. Completed necropsy forms were filed with the associated radiographs at the close of each work day.

For quality control, random inspections of technicians were made during necropsy procedures to assess accuracy and adherence to necropsy protocol. Completed necropsy forms and radiographic images were inspected and checked for accuracy the following day by the ballistician. Any mistakes, omissions, or confusing data were returned to the original technician for correction and/or clarification.

We compared total pellet strikes, total through-body strikes, through-body strike depth (mean wound-channel length for through-body strikes), total embedded pellets, and embedded pellet depth (mean wound-channel depth for embedded pellets) among ammunition types using ANOVA. Because some necropsy metrics are counts of events within categories, we compared the distribution of leg breaks, wing breaks, through-body strikes, and embedded pellets among ammunition types using χ^2 categories of "zero" or "one or more" for each necropsy metric.

RESULTS

Observer Selection and Training

We used 22 observers in 2008 and 33 observers in 2009 (11 new and 22 returning observer participants). Observer final test scores averaged 95.3% ± 0.93% in 2008 (mean ± SE) and 98.9 ± 0.12% in 2009. Observers monitored the activities of 53 hunters during 9 field tests over the 2008–2009 field data collection period (i.e., 22 hunters in 2008, 31 hunters in 2009).

Ammunition Testing

We used descriptive statistics to report nominal versus actual shot charge (payload) weight, number of pellets, and muzzle velocity for each ammunition type (Table 1). Test results show the ammunition received was produced in accordance with the specifications provided to the manufacturer.

We standardized pattern testing (i.e., pellet strikes within a 76 cm circle using the same firearm, chokes, and distances) to isolate relative differences due solely to ammunition type. Pattern counts differed among ammunition types ($F_{2,324} = 1,179.153$, $P < 0.001$), choke categories ($F_{2,324} = 309.617$, $P < 0.001$), and between distance categories ($F_{3,324} = 3,845.816$, $P < 0.001$), with significant ammunition × choke ($F_{4,324} = 5.225$, $P < 0.001$), ammunition × distance ($F_{6,324} = 51.057$, $P < 0.001$), choke × distance ($F_{6,324} = 36.896$, $P < 0.001$) interactions, but no ammunition × distance × choke interaction ($F_{12,324} = 1.433$, $P = 0.149$; Table 2). Therefore differences in pattern density and pattern efficiency among ammunition types (Table 2) depended on distance, choke constriction, and the number of pellets in each load (Table 1). Multiple comparisons (Zar 1996) revealed that Pb 7½ and Fe 7 pattern counts were not significantly different for most combinations of choke and distance. However, Fe 7 produced greater pattern counts than Pb 7½ with full choke at 45.7 m, modified choke at 36.6 m, and improved cylinder at 45.7 m (Table 2). When using full or modified choke, pattern counts for Pb 7½ and Fe 7 were greater than those for Fe 6 for all distances. Conversely, Fe 6 using a full choke produced higher pattern counts than Pb 7½ and Fe 7 using improved cylinder choke at distances beyond 36.6 m (Table 2), despite the lower number of pellets within the Fe 6 load (Table 1).

There were general trends revealed by the pattern test (Table 2). For instance, pattern counts decreased as a function of distance within all chokes and loads, albeit at a lower rate for Fe 6. Within each ammunition type, pattern count increased as a function of choke (i.e., full > modified > improved cylinder) for all distances >18.3 m. Ammunition containing an equal number of pellets of similar size (Pb 7½ vs. Fe 7; Table 1), but with higher diamond hardness values (Fe > Pb), produced higher pattern efficiencies relative to softer pellets for each choke constriction and distance. Likewise, for pellets of similar hardness, pattern efficiency increased as a function of pellet size (i.e., Fe 7 vs. Fe 6). Generally, both test loads (Fe 7 and Fe 6) produced higher pattern efficiencies than the Pb 7½ control load (Table 2). However, because the Fe 6 test load contained 100 fewer pellets than either the Pb 7½ or the Fe 7 test load (Table 1), it is not surprising that it had substantially lower pattern densities for each choke and distance combination (Table 2).

Field Testing

Of the 53 hunters who participated in the study, 43 used all 3 ammunition types at least once during a season (meeting randomized block constraints). Observers recorded 5,094 shot outcomes, 1,146 birds bagged, 739 birds wounded, and 3,209 birds missed (Table 3). Of the 1,146 birds bagged, 1,110 (96.9%) were necropsied and used in subsequent analyses (birds were excluded if struck by >1 load, struck at >1 angle [indicative of a second strike], or missing body parts). The number of shots fired ($F_{42,121.790} = 2.005$, $P = 0.002$) and the number of attempts ($F_{42,127.663} = 1.511$, $P = 0.042$) differed among shooters. However, neither the number of shots fired ($F_{2,255} = 0.042$, $P = 0.959$) nor the number of attempts ($F_{2,255} = 0.179$, $P = 0.836$) differed among ammunition types. Choke use differed among ammunition types for shots fired ($\chi^2_4 = 66.494$, $P < 0.001$; Table 4) and for necropsy specimens ($\chi^2_4 = 11.055$, $P = 0.026$; Table 5). Improved cylinder was used less often, and modified choke was used more often, with the Fe 6 load relative to Pb 7½ (Tables 4 and 5). For the Fe 7 load, hunters used modified choke more often, and full choke less often, relative to Pb 7½ (Table 4).

Hunters were unable to discern ammunition type in the field ($n = 129$, $\chi^2_8 = 6.611$, $P = 0.579$), and guessed correctly less often than predicted by chance (18.6%, 7.0%, and 7.0%

Table 1. Mean (±SE) shot charge weight (g), number of pellets, pellet diameter (mm), velocity (m/sec), and peak pressure (MPa) for each 70 mm (2 3/4 inch) 12-gauge ammunition type tested during the 2008–2009 Texas (USA) mourning dove lethality study.

Criteria	Pb 7½	Fe 7	Fe 6
Nominal shot charge wt	32	28	28
Shot charge wt[a]	31.8 ± 0.07	28.6 ± 0.10	28.4 ± 0.08
No. of pellets in load[a]	410.4 ± 1.25	410.9 ± 1.43	310.6 ± 1.00
Pellet diameter[a]	2.39 ± 0.01	2.52 ± 0.01	2.78 ± 0.01
Nominal velocity	366	396	396
Velocity[b]	377.6 ± 0.84	404.3 ± 1.90	399.1 ± 1.20
Peak pressure[c]	70.9 ± 0.91	65.6 ± 1.38	65.4 ± 1.24

[a] Mean for 10 shells of each type.

[b] Mean for 10 shells of each type using 1.2-m screen spacing and 1.8-m instrumental distance, at 21° C, as reported by Polywad, Inc., Macon, GA, USA.

[c] Peak chamber pressure mean for 10 shells at 21° C, 50% relative humidity, 482 m elevation, as reported by Polywad, Inc., Macon, GA, USA.

Table 2. Mean pattern count (±SE) and pattern efficiency (%)[a] y choke and distance for each 70 mm (2 3/4 inch) 12-gauge ammunition type tested during the 2008–2009 Texas (USA) mourning dove lethality study[b].

	Pb 7½			Fe 7			Fe 6		
Distance	**I.C.**	**Mod.**	**Full**	**I.C.**	**Mod.**	**Full**	**I.C.**	**Mod.**	**Full**
18.3 m	408 ± 0.7	410 ± 0.1	410 ± 0.1	410 ± 0.5	411 ± 0.2	411 ± 0.1	311 ± 0.2	311 ± 0.0	311 ± 0.0
	99.5	100.0	100.0	99.7	100.0	100.0	100.0	100.0	100.0
27.4 m	346 ± 3.5	388 ± 2.2	398 ± 1.7	355 ± 3.2	385 ± 2.1	403 ± 1.5	280 ± 2.7	298 ± 2.5	305 ± 1.5
	84.3	94.5	97.0	86.5	93.7	98.1	90.1	95.8	98.1
36.6 m	254 ± 5.6	296 ± 5.0	322 ± 5.2	259 ± 9.0	310 ± 3.1	330 ± 4.3	203 ± 4.3	240 ± 3.5	261 ± 2.0
	62.0	72.2	78.5	63.1	75.4	80.1	65.2	77.2	83.8
45.7 m	158 ± 6.5	210 ± 7.4	217 ± 3.6	177 ± 5.3	209 ± 5.6	238 ± 7.4	144 ± 3.8	174 ± 6.2	185 ± 4.6
	38.5	51.3	52.8	43.0	50.8	57.8	47.1	56.0	59.6

[a] Mean for 10 replications of each ammunition type at each distance and choke. Pattern count determined by no. of pellets registering inside a 76-cm-diam circle drawn around densest portion of pattern. Pattern percentage (pattern efficiency) is the mean pattern, divided by the mean no. of pellets found in 10 shells of each type (410, 411, and 311, respectively).

[b] Pattern testing conducted in Klamath Falls, OR, USA, at a mean temp of 15.6° C, 1,250 m elevation, under no-wind conditions, through a Remington Model 332 with 30-inch barrel and 0.1854-cm-diam bore containing improved cylinder (I.C. = 1.83 cm), modified (Mod. = 1.80 cm), or full (Full = 1.75 cm) RemChoke screw-in choke tubes.

for Pb 7½, Fe 7, and Fe 6, respectively). Similarly, hunter perception of ammunition quality was unrelated to the shot type being used ($n = 129$, $\chi^2_6 = 3.649$, $P = 0.724$), because hunters rated all ammunition as "basically good" 72.9% of the time.

We found no difference between hunters and observers in their ability to recognize a hit ($t_{5069} = 0.954$, $P = 0.340$), but their ability to estimate distance differed ($t_{5030} = 6.884$, $P < 0.001$). Overall distance estimation error was small (hunter distance − observer distance, $\bar{x} = 0.9\,\text{m} \pm 9.3$ SD), but linear regression coefficients indicated hunters overestimated the range for closer targets and underestimated the range to more distant targets ($F_{1,5029} = 878.018$, $P < 0.001$, $b_0 = 10.94$, $b_1 = -0.314$).

Shot outcomes differed between distance categories overall ($n = 5{,}094$, $\chi^2_2 = 102.649$, $P < 0.001$), and within all 3 ammunition types (Pb 7½, $n = 1{,}683$, $\chi^2_2 = 27.505$, $P < 0.001$; Fe 7, $n = 1{,}727$, $\chi^2_2 = 28.424$, $P < 0.001$; Fe 6, $n = 1{,}684$, $\chi^2_2 = 52.473$, $P < 0.001$; Table 6). The frequency of birds bagged and missed differed between distance categories for all 3 ammunition types, but the proportion of birds wounded did not differ between distance categories for any ammunition type (Table 6).

Mean distance for all shots fired by hunters ($n = 5{,}094$) differed among ammunition types ($F_{2,5046} = 8.030$, $P < 0.001$) and between distance categories ($F_{1,5046} = 7{,}472.738$, $P < 0.001$), but there was no ammunition × distance interaction ($F_{2,5046} = 2.969$, $P = 0.051$; Table 7). Multiple comparisons showed differences between Pb 7½ and Fe 7 ($P < 0.001$), and between Fe 6 and Fe 7 ($P = 0.042$), but not between Pb 7½ and Fe 6 ($P = 0.051$). The estimated marginal means ranked Pb 7½ ≥ Fe 6 > Fe 7 for all shots fired, but differences among means were <1 m (i.e., Pb 7½ − Fe 7 = 0.922 m and Fe 6 − Fe 7 = 0.466 m) for all categories (Table 7).

We found no difference in mean distance for birds bagged ($n = 1{,}146$) among ammunition types ($F_{2,1098} = 1.238$, $P = 0.290$). There was a difference in birds bagged between distance categories ($F_{1,1098} = 1{,}809.770$), but no ammunition × distance interaction ($F_{2,1098} = 0.880$, $P = 0.415$).

We found no difference in mean distance for birds wounded ($n = 739$) among ammunition types ($F_{2,691} = 1.299$, $P = 0.274$). There was a difference in distance for birds wounded between distance categories ($F_{1,691} = 986.489$, $P < 0.001$), but no ammunition × distance interaction ($F_{2,691} = 1.255$, $P = 0.286$).

We found no difference in mean distance for birds hit (bagged + wounded; $n = 1{,}885$) among ammunition types ($F_{2,1837} = 1.901$, $P = 0.150$). There was a difference in birds hit between distance categories ($F_{1,1837} = 2{,}981.593$, $P < 0.001$), but no ammunition × distance interaction ($F_{2,1837} = 2.900$, $P = 0.055$).

Table 3. Summary of the number of attempts, shots, shot outcomes (categories B0–B4)[a], mean shot distances (m), number of birds bagged, and number of necropsy specimens collected using each 70 mm (2 3/4 inch) 12-gauge ammunition type tested during the 2008–2009 Texas (USA) mourning dove lethality study.

Load	Attempts	Shots	B0	B1	B2	B3	B4	Mean distance	Bagged[b]	Necropsy[c]
Pb 7½	1,269	1,683	8	295	49	237	1,094	29.57	352	340
Fe 7	1,303	1,727	3	343	69	268	1,044	28.71	415	404
Fe 6	1,227	1,684	1	315	63	234	1,071	29.31	379	366
Totals	3,799	5,094	12	953	181	739	3,209	29.19	1,146	1,110

[a] B0–B4 are shot outcome categories: B0, bagged-undifferentiated; B1, bagged-immobile (dead or immobile within 30 sec); B2, bagged-mobile (mobile for more than 30 sec); B3, wounded (not retrieved); and B4, missed.

[b] No. bagged = B0 + B1 + B2.

[c] Birds were excluded from necropsy if they retained >1 pellet type, were struck at >1 angle (indicative of a second strike), or were missing body parts.

Table 4. Frequency of choke use (count and percentage) for all shots fired by each 70 mm (2 3/4 inch) 12-gauge ammunition type tested during the 2008–2009 Texas (USA) mourning dove lethality study[a]. Percentages are in relation to column totals.

Choke[b]	Pb 7½	Fe 7	Fe 6	Total
Improved cylinder	544	590	419	1,553
	32.3% A[c]	34.2% A	24.9% B	30.5%
Modified	721	830	900	2,451
	42.8% A	48.1% B	53.4% C	48.1%
Full	418	307	365	1,090
	24.8% A	17.8% B	21.7% C	21.4%
Total	1,683	1,727	1,684	5,094

[a] Differences among table values detected by χ^2 test of independence ($P < 0.001$).

[b] Internal choke dimensions measured with digital calipers and assigned to 1 of 3 choke categories: ≤17.78 mm = full, 17.81–18.25 mm = modified, and ≥18.26 mm improved cylinder.

[c] Within a row, columns with the same letters are not different (Z-tests, $P > 0.050$).

Shot outcomes (bagged, wounded, and missed) differed between distance categories overall ($n = 5{,}094$, $\chi^2_2 = 102.649$, $P < 0.001$), and within each ammunition type ($n = 1{,}683$, $\chi^2_2 = 27.505$, $P < 0.001$ for Pb 7½; $n = 1{,}727$, $\chi^2_2 = 28.424$, $P < 0.001$ for Fe 7; and $n = 1{,}684$, $\chi^2_2 = 52.473$, $P < 0.001$ for Fe 6).

Shot outcomes (bagged, wounded, and missed) did not differ among ammunition types overall ($n = 5{,}094$, $\chi^2_4 = 8.485$, $P = 0.075$), nor within either distance category ($n = 2{,}538$, $\chi^2_4 = 8.625$, $P = 0.071$ for distances <28.3 m; $n = 2{,}556$, $\chi^2_4 = 5.786$, $P = 0.216$ for distances ≥28.3 m; Table 7).

Hitting ability (birds hit and birds missed) differed among ammunition types overall ($n = 5{,}094$, $\chi^2_2 = 7.966$, $P = 0.019$), and within 28.3 m ($n = 2{,}538$, $\chi^2_2 = 7.777$, $P = 0.020$), but did not differ beyond 28.3 m ($n = 2{,}556$, $\chi^2_2 = 4.652$, $P = 0.098$). Pairwise comparisons of column proportions showed that Pb 7½ had fewer hits and more misses per shot fired than Fe 7 overall ($P < 0.050$), as well as fewer hits and more misses per shot fired than either Fe 7 or Fe 6 within 28.3 m ($P < 0.050$; Table 7).

For shots resulting in a hit (bagged + wounded) we found no difference in the frequency of birds bagged or wounded among ammunition types overall ($n = 1{,}885$, $\chi^2_2 = 0.538$, $P = 0.764$), nor within either distance category ($n = 1{,}075$, $\chi^2_2 = 0.816$, $P = 0.665$ for distances <28.3 m; $n = 810$, $\chi^2_2 = 1.095$, $P = 0.578$ for distances ≥28.3 m; Table 7).

Necropsy Analyses

Total pellet strikes differed among ammunition types ($F_{2,1104} = 5.525$, $P = 0.004$; Table 8), with Fe 6 producing fewer strikes than either Pb 7½ ($P = 0.009$) or Fe 7 ($P = 0.001$). Total through-body strikes differed among ammunition types ($F_{2,1104} = 3.919$, $P = 0.020$; Table 8), with Fe 6 producing fewer total through-body strikes than Pb 7½ ($P = 0.022$), but not Fe 7 ($P = 0.085$). However, through-body strike mean penetration (weighted by the no. of through-body strikes) did not differ among ammunition types ($F_{2,1826} = 2.011$, $P = 0.134$). The number of embedded pellets differed among ammunition types ($F_{2,1104} = 25.058$, $P < 0.001$; Table 8), with Fe 7 producing more embedded pellets than either Pb 7½ ($P < 0.001$) or Fe 6 ($P < 0.001$). Because total embedded pellets could not be transformed to attain homoscedasticity, ANOVA results were verified using a Kruskal–Wallis test ($P < 0.001$). However, embedded pellet mean penetration (weighted by the no. of embedded pellets) did not differ among ammunition types ($F_{2,327} = 0.870$, $P = 0.420$; Table 8).

The number of leg breaks (zero, one, or more) differed among ammunition types overall ($n = 1{,}110$, $\chi^2_2 = 8.233$, $P = 0.016$), and within each distance category (distances

Table 5. Frequency of choke use (mean and percentage) for all necropsy specimens by each 70 mm (2 3/4 inch) 12-gauge ammunition type tested during the 2008–2009 Texas (USA) mourning dove lethality study[a]. Percentages are in relation to column totals.

Choke[b]	Pb 7½	Fe 7	Fe 6	Total
Improved cylinder	142	153	119	414
	41.8% A[c]	37.9% AB	32.5% B	37.3%
Modified	138	187	194	519
	40.6% A	46.3% AB	53.0% B	46.8%
Full	60	64	53	177
	17.6% A	15.8% A	14.5% A	15.9%
Total	340	404	366	1,110

[a] Differences among table values detected by χ^2 test of independence ($P = 0.026$).

[b] Internal choke dimensions measured with digital calipers and assigned to 1 of 3 choke categories: ≤17.78 mm = full, 17.81–18.25 mm = modified, and ≥18.26 mm improved cylinder.

[c] Within a row, columns with the same letters are not different (Z-tests, $P > 0.050$).

Table 6. Frequency of shot outcomes (counts and percentages) between distance categories, within each 70 mm (2 3/4 inch) 12-gauge ammunition type tested, using all shots fired during the 2008–2009 Texas (USA) mourning dove lethality study. Percentages are in relation to column totals.

Shell type	Shot outcome	<28.3 m	≥ 28.3 m	Total
Pb 7½[a]	Bagged	218 (26.1%[b]) A[c]	134 (15.8%) B	352 (20.9%)
	Wounded	104 (12.4%) A	133 (15.7%) A	237 (14.1%)
	Missed	514 (61.5%) A	580 (68.5%) B	1,094 (65.0%)
	Total	836 (100.0%)	847 (100.0%)	1,683 (100.0%)
Fe 7[a]	Bagged	255 (29.3%) A	160 (18.7%) B	415 (24.0%)
	Wounded	135 (15.5%) A	133 (15.5%) A	268 (15.5%)
	Missed	480 (55.2%) A	564 (65.8%) B	1,044 (60.5%)
	Total	870 (100.0%)	857 (100.0%)	1,727 (100.0%)
Fe 6[a]	Bagged	248 (29.8%) A	131 (15.4%) B	379 (22.5%)
	Wounded	115 (13.8%) A	119 (14.0%) A	234 (13.9%)
	Missed	469 (56.4%) A	602 (70.7%) B	1,071 (63.6%)
	Total	832 (100.0%)	852 (100.0%)	1,684 (100.0%)
Total[a]	Bagged	721 (28.4%) A	425 (16.6%) B	1,146 (22.5%)
	Wounded	354 (13.9%) A	385 (15.1%) A	739 (14.5%)
	Missed	1,463 (57.6%) A	1,746 (68.3%) B	3,209 (63.0%)
	Total	2,538 (100.0%)	2,556 (100.0%)	5,094 (100.0%)

[a] Differences between shot outcomes within table subsection (ammunition types) detected by χ^2 tests of independence ($P < 0.001$).

[b] No. in parentheses are proportions within that distance category and ammunition type.

[c] Within a row, columns with the same letters are not different (Z-tests, $P > 0.050$).

<28.3 m, $n = 704$, $\chi^2_2 = 11.518$, $P = 0.003$; distances ≥ 28.3 m, $n = 406$, $\chi^2_2 = 6.508$, $P = 0.039$; Table 8). Results indicate Fe 7 and Pb 7½ produced more leg breaks than Fe 6 within 28.3 m ($P < 0.050$), and Pb 7½ produced more leg breaks than Fe 7 ($P < 0.050$), but not Fe 6 ($P > 0.050$), beyond 28.3 m. Overall, Pb 7½ produced more leg breaks than Fe 6 ($P < 0.050$), but not Fe 7 ($P > 0.050$). Conversely, the number of wing breaks (zero, one, or more) did not differ among ammunition types overall ($n = 1{,}110$, $\chi^2_2 = 0.939$, $P = 0.625$), nor within either distance category (distances <28.3 m, $n = 704$, $\chi^2_2 = 3.488$, $P = 0.175$; distances ≥ 28.3 m, $n = 406$, $\chi^2_2 = 0.569$, $P = 0.752$).

DISCUSSION

Ammunition

Pattern test results were consistent with previous ballistic research findings, and indicated that differences in pattern

Table 7. Ammunition performance metric means (±SE) and percent differences[a] by distance category for each 70 mm (2 3/4 inch) 12-gauge ammunition type tested during the 2008–2009 Texas (USA) mourning dove lethality study. Metrics derived from all shots fired and analyzed using χ^2 or analysis of variance.

Distance category	Metric[b]	Pb 7½	Fe 7	Fe 6	Fe 7 vs. Pb 7½[c]	Fe 6 vs. Pb 7½[d]	Fe 7 vs. Fe 6[e]
<28.3 m	Shot distance (m)*	21.78 ± 0.23	21.07 ± 0.23	21.00 ± 0.23	−3.3%	−3.6%	0.3%
	Bagged per shot	0.261 ± 0.02	0.293 ± 0.02	0.298 ± 0.02	12.4%	14.3%	−1.7%
	Wounded per shot	0.124 ± 0.01	0.155 ± 0.01	0.138 ± 0.01	24.7%	11.1%	12.3%
	Hits per shot*	0.385 ± 0.02	0.448 ± 0.02	0.436 ± 0.02	16.4%	13.3%	2.7%
	Bagged per hit	0.677 ± 0.03	0.654 ± 0.02	0.683 ± 0.02	−3.4%	0.9%	−4.3%
	Wounded per hit	0.323 ± 0.03	0.346 ± 0.02	0.317 ± 0.02	7.2%	−1.9%	9.3%
≥ 28.3 m	Shot distance (m)*	37.58 ± 0.23	36.45 ± 0.23	37.46 ± 0.23	−3.0%	−0.3%	−2.7%
	Bagged per shot	0.158 ± 0.01	0.187 ± 0.01	0.154 ± 0.01	18.0%	−2.8%	21.4%
	Wounded per shot	0.157 ± 0.01	0.155 ± 0.01	0.140 ± 0.01	−1.2%	−11.1%	11.1%
	Hits per shot	0.315 ± 0.02	0.342 ± 0.02	0.293 ± 0.02	8.5%	−6.9%	16.5%
	Bagged per hit	0.502 ± 0.03	0.546 ± 0.03	0.524 ± 0.03	8.8%	4.4%	4.2%
	Wounded per hit	0.498 ± 0.03	0.454 ± 0.03	0.476 ± 0.03	−8.9%	−4.4%	−4.6%
All distances	Shot distance (m)*	29.68 ± 0.17	28.76 ± 0.16	29.23 ± 0.17	−3.1%	−1.5%	−1.6%
	Bagged per shot	0.209 ± 0.01	0.240 ± 0.01	0.225 ± 0.01	14.9%	7.6%	6.8%
	Wounded per shot	0.141 ± 0.01	0.155 ± 0.01	0.139 ± 0.01	10.2%	−1.3%	11.7%
	Hits per shot*	0.350 ± 0.01	0.395 ± 0.01	0.364 ± 0.01	13.0%	4.0%	8.6%
	Bagged per hit	0.598 ± 0.02	0.608 ± 0.02	0.618 ± 0.02	1.7%	3.5%	−1.7%
	Wounded per hit	0.402 ± 0.02	0.392 ± 0.02	0.382 ± 0.02	−2.5%	−5.1%	2.8%

[a] Percent difference provides for a dimensionless comparison of effect size among treatments (magnitude of effect).

[b] Shot distances are predicted mean responses for each factor, adjusted for all other variables in the ANOVA model (least-square means or estimated marginal means). All other metrics are proportions derived from frequencies tested by χ^2.

[c] Fe 7 vs. Pb 7½ is percent difference calculated as (Fe 7 – Pb 7½)/Pb 7½.

[d] Fe 6 vs. Pb 7½ is percent difference calculated as (Fe 6 – Pb 7½)/Pb 7½.

[e] Fe 7 vs. Fe 6 is percent difference calculated as (Fe 7 – Fe 6)/Fe 6.

* Denotes metrics where significant differences were detected among ammunition types (ANOVA or χ^2 test; $P < 0.050$).

Table 8. Necropsy metric means (±SE) and percent differences[a] by distance category for each 70 mm (2 3/4 inch) 12-gauge ammunition type tested during the 2008–2009 Texas (USA) mourning dove lethality study. Metrics derived from all shots fired and analyzed using χ^2 or analysis of variance.

Distance category	Metric[b]	Pb 7 ½	Fe 7	Fe 6	Fe 7 vs. Pb 7½[c]	Fe 6 vs. Pb 7½[d]	Fe 7 vs. Fe 6[e]
<28.3 m	Shot distance (m)	20.3 ± 0.38	20.1 ± 0.35	19.7 ± 0.36	−1.1%	−3.3%	2.2%
	Total strikes*	3.5 ± 1.05	3.6 ± 1.04	3.0 ± 1.04	2.8%	−11.9%	16.6%
	Through-body strikes*	1.7 ± 0.04	1.7 ± 0.04	1.5 ± 0.04	2.1%	−6.3%	9.0%
	Through-body strikes (%)	0.78 ± 0.03	0.80 ± 0.03	0.80 ± 0.03	1.7%	1.9%	−0.2%
	Through-body depth (mm)	31.8 ± 1.01	30.7 ± 1.01	31.3 ± 1.01	−1.0%	−0.5%	−0.5%
	Embedded pellets*	0.1 ± 0.02	0.3 ± 0.02	0.1 ± 0.02	269.0%	37.9%	167.5%
	Embedded pellets (%)*	0.09 ± 0.02	0.29 ± 0.03	0.12 ± 0.02	212.8%	28.7%	143.0%
	Embedded depth (mm)	28.6 ± 1.10	28.7 ± 1.05	28.1 ± 1.08	0.1%	−0.5%	0.6%
	Leg breaks (%)*	0.39 ± 0.03	0.41 ± 0.03	0.27 ± 0.03	5.2%	−30.4%	51.1%
	Wing breaks (%)	0.61 ± 0.03	0.57 ± 0.03	0.52 ± 0.03	−6.4%	−14.4%	9.2%
≥28.3 m	Shot distance (m)	35.4 ± 0.49	34.8 ± 0.45	35.4 ± 0.49	−1.8%	0.0%	−1.8%
	Total strikes*	2.6 ± 1.06	2.6 ± 1.06	2.3 ± 1.06	0.7%	−13.6%	16.6%
	Through-body strikes*	1.2 ± 0.06	1.0 ± 0.05	0.8 ± 0.06	−13.8%	−25.5%	15.8%
	Through-body strikes (%)	0.76 ± 0.04	0.66 ± 0.04	0.64 ± 0.04	−13.0%	−15.6%	3.2%
	Through-body depth (mm)	29.9 ± 1.02	29.5 ± 1.02	30.1 ± 1.02	−0.4%	0.2%	−0.6%
	Embedded pellets*	0.3 ± 0.03	0.5 ± 0.03	0.3 ± 0.03	65.0%	−2.0%	68.4%
	Embedded pellets (%)*	0.28 ± 0.04	0.45 ± 0.04	0.28 ± 0.04	58.0%	0.0%	58.0%
	Embedded depth (mm)	28.6 ± 1.07	26.2 ± 1.05	31.3 ± 1.07	−2.7%	2.6%	−5.2%
	Leg breaks (%)*	0.37 ± 0.04	0.23 ± 0.03	0.30 ± 0.04	−37.8%	−19.2%	−23.1%
	Wing breaks (%)	0.45 ± 0.04	0.47 ± 0.04	0.50 ± 0.04	5.6%	10.5%	−4.4%
All distances	Shot distance (m)	27.9 ± 0.31	27.4 ± 0.28	27.5 ± 0.30	−1.6%	−1.2%	−0.4%
	Total strikes*	3.0 ± 1.04	3.1 ± 1.04	2.6 ± 1.04	1.9%	−12.5%	16.5%
	Through-body strikes*	1.4 ± 0.04	1.3 ± 0.03	1.1 ± 0.04	−5.1%	−14.9%	11.5%
	Through-body strikes (%)	0.77 ± 0.02	0.75 ± 0.02	0.74 ± 0.02	−3.7%	−3.9%	0.2%
	Through-body depth (mm)	30.8 ± 1.01	30.1 ± 1.01	30.7 ± 1.01	−0.7%	−0.1%	−0.6%
	Embedded pellets*	0.2 ± 0.02	0.4 ± 0.02	0.2 ± 0.02	112.5%	7.8%	97.1%
	Embedded pellets (%)*	0.17 ± 0.02	0.35 ± 0.02	0.18 ± 0.02	112.7%	7.9%	97.2%
	Embedded depth (mm)	28.6 ± 1.06	27.4 ± 1.03	29.6 ± 1.05	−1.3%	1.0%	−2.3%
	Leg breaks (%)*	0.38 ± 0.03	0.34 ± 0.02	0.28 ± 0.02	−10.6%	−26.4%	21.5%
	Wing breaks (%)	0.55 ± 0.03	0.53 ± 0.02	0.51 ± 0.03	−2.7%	−6.6%	4.1%

[a] Percent difference allows for a dimensionless comparison of effect size among treatments (magnitude of effect).

[b] Shot distance, total strikes, through-body strikes, through-body depth, embedded pellet strikes, and embedded pellet depth are predicted mean responses for each factor, adjusted for all other variables in the ANOVA model (least-square means or estimated marginal means). All metrics listed as percentages (%) are proportions derived from frequencies tested by χ^2.

[c] Fe 7 vs. Pb 7½ is percent difference calculated as (Fe 7 – Pb 7½)/Pb 7½.

[d] Fe 6 vs. Pb 7½ is percent difference calculated as (Fe 6 – Pb 7½)/Pb 7½.

[e] Fe 7 vs. Fe 6 is percent difference calculated as (Fe 7 – Fe 6)/Fe 6.

* Denotes metrics where significant differences were detected among ammunition types (ANOVA or χ^2 test; $P < 0.050$).

efficiency and pattern density were a function of distance, choke constriction, pellet count, shot hardness, and pellet size (Brister 1976, Roster 1978, Jones 2010). Our results are also in agreement with previous lethality studies, because Humburg et al. (1982) reported Fe 4 (206 pellets/shell) and Fe 2 (151 pellets/shell) produced higher pattern efficiencies than Pb 4 (206 pellets/shell), but did not differ from buffered Pb 4 (203 pellets/shell; buffering prevents pellet deformation). As a result, the pattern densities for the Humburg et al. (1982) Fe 4 were higher than both the Pb 4 and buffered Pb 4 at all distances. Similarly, Anderson et al. (1980) conducted pattern tests using Pb 8 (459 pellets/shell), Fe 6 (354 pellets/shell), and Fe 4 (210 pellets/shell), and found Fe 4 > Fe 6 > Pb 8 in terms of patterning efficiency. However, because their Fe loads contained substantially fewer pellets per shell than their Pb 8 load, only the Fe 6 load (354 pellets/shell) was able to surpass the Pb 8 (459 pellets/shell) in pattern density, and only at distances ≥36.6 m (Anderson et al. 1980).

Harvest Metrics

Similar to Anderson et al. (1980), we detected differences in the frequency of shot outcomes between distance categories overall, and within each ammunition type. Anderson et al. (1980) used Pb 8, Fe 6, and Fe 4 ammunition on mourning dove, but used longer distance categories (≤36.6 m, >36.6 m). Hebert et al. (1984) found differences in the proportion of ducks hit per shot and bagged per shot between distance categories (<32 m, ≥32 m) with Fe 4 and Pb 6. Interestingly, Hebert et al. (1984) reported a difference in the proportion of ducks wounded per shot between distance categories with Fe 4 load, but not Pb 6; but their plot of the proportion of ducks wounded per shot by 4.6-m distance intervals remained relatively constant for both Fe 4 and Pb 6 (Hebert et al. 1984). Despite the differences in shot sizes and target species, our results are in agreement with the findings of both Anderson et al. (1980) and Hebert et al. (1984) and indicate hunter success (hitting and bagging rates) decreases with distance, regardless of the ammunition type being tested.

We detected no difference among ammunition types in the frequency of birds bagged per shot, wounded per shot, or missed per shot overall, or within either distance category. However, Fe 7 produced more hits (birds bagged + birds wounded) than Pb 7½ overall, and within each distance category. As such, our findings are similar to Anderson et al. (1980) where Fe 6 (558 pellets/shell) had more hits than the Pb 8 test load (602 pellets/shell) in both distance categories and overall, but differ from results reported by Hebert et al. (1984) where the Pb 6 (279 pellets/shell) obtained more hits per shot than the Fe 4 load (213 pellets/shell). In these studies (Anderson et al. 1980, Hebert et al. 1984), the number of pellets differed among loads, and thus may have influenced outcomes. Because the probability of obtaining a hit is proportional to pattern density (Brister 1976, Compton 1996, Jones 2010), we concluded that differences in our overall hitting ability were due to higher patterning efficiency and differential choke use among hunters, resulting in more hits per shot by Fe 7 and Fe 6, than by Pb 7½. Cochrane (1976) reached this same conclusion when analyzing birds from the Nilo controlled test (Kozicky and Madson 1973; tethered mallards shot at 6 distances using Pb 4, Fe 4, Cu 4, and Pb 6), stating "the number of pellets and distance at which a duck is shot determine the probability that a duck will be bagged, crippled, or survive" (Cochrane 1976:13).

Hayne (1982) and Bingham (1983) suggested that bagging and wounding rates should be compared on a "per hit," rather than "per shot," basis to provide a more direct comparison of ammunition terminal performance. Our results differ from those of Hebert et al. (1984) who found a significant difference between Pb 6 and Fe 4 in the number of birds wounded per hit (42% more for Fe 4), but not in the number of birds wounded per shot.

Necropsy Metrics

Necropsy metrics provide additional information on ammunition performance that cannot be obtained solely from pattern testing or harvest metrics. As such, necropsy variables quantify the interaction of penetration (pellet momentum and size; Fackler 1988, Warlow 2005, Coupland et al. 2011) and pattern efficiency (pellet hardness and size; Brister 1976, Compton 1996, Jones 2010) that enables us to characterize ammunition performance. For example, we detected no differences in penetrating ability among ammunition types (through-body strike mean penetration depth, embedded pellet mean depth). Yet, because of differences in pattern efficiency, Fe 7 produced a higher frequency of birds with embedded pellets, and more embedded pellets per bird, than Pb 7½. Conversely, although Pb 7½ and Fe 6 were similar in penetration and embedded pellet depth, Pb 7½ produced more leg breaks than Fe 6, due to differences in pellet count and pellet hardness (i.e., more hits and greater malleability created more leg breaks; von See et al. 2009). These differences would not have been detected without necropsy analyses, and are crucial to our understanding of ammunition performance (Caudell 2013).

Although previous lethality studies did not utilize the majority of necropsy metrics reported in our study, some comparisons are appropriate. Cochrane (1976) fluoroscoped 2,400 mallards from the Nilo controlled test (Kozicky and Madson 1973; tethered game farm mallards shot at 6 different distances using Pb 4, Fe 4, Cu 4, and Pb 6) and found the frequency of broken bones and the number of entrance wounds was correlated with shot distance. Overall Pb 4 caused more broken bones, had a higher bagging rate, and a lower wounding rate than Fe 4 over the distances tested (30, 40, 50, 60, 70, and 80 m; 100 replicates per load × distance). Further, Cochrane (1976) compared outcomes of the Nilo (Kozicky and Madson 1973) and Patuxent (Andrews and Longcore 1969) controlled tests using a common set of criteria (i.e., categories of bagged, wounded, and survived) and concluded that both Pb 4 loads performed better than either Fe 4 load in terms of bagged, crippled, or survived categories. However, the Patuxent Pb 6 shotshell outperformed all loads out to 60 m using the same criteria, due to the increased number of pellets in the Pb 6 load (i.e., higher pattern density).

Anderson et al. (1980) counted pellet holes (entrance and exit wounds) in mourning dove breasts harvested with Pb 8, Fe 6, and Fe 4, and found significant differences in the proportion of birds with $\geq$2 holes (78.7%, 88.2%, and 65.5%, respectively). They concluded that Fe 6 and Fe 4 were as effective as Pb 8 for harvesting mourning dove. Collectively, our study results agree with the findings of Cochrane (1976) and Anderson et al. (1980) and we suggest that while pellet size matters, you must have sufficient pattern density to ensure the probability of a pellet strike on the bird.

Our results indicated that pellet density is but one factor influencing ammunition performance. Further, the forensic evaluation of shotshell ammunition is a complicated subject, and will require more testing if we (i.e., the public, industry, state, and federal agencies) are to define the ballistic factors (internal, external, and terminal) responsible for differences in field performance among ammunition types (i.e., a large combination of different hulls, shot, wads, primers, and powders). Because necropsy metrics reveal subtle differences in terminal ballistic behavior that are unobtainable through other means, and provide an effective means for comparing ammunition performance, they should be included in all future lethality studies.

MANAGEMENT IMPLICATIONS

If the pellet size, velocity, and composition are of sufficient lethality (mass, velocity, shape, smoothness, etc.) to penetrate and disrupt the vital organs of the target species within the intended range of use, then our results suggest pattern density (i.e., choke selection, pellet count, and overall ammunition quality) is the most important factor influencing shotshell ammunition performance. However, we caution readers that our results may provide limited inference to other loads. Therefore managers and hunters should evaluate ammunition carefully, referencing creditable lethality tables for selecting shot size, minimum load weights, and choke constriction, in conjunction with pattern testing at applicable ranges. Based on our study results, changes in ammunition use (e.g., switch from Pb to Fe pellet types) should not alter population harvest, and therefore should not impact mourning dove bag limits or season lengths.

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