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Lead-free, high-powered rifle bullets and their applicability in wildlife management

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Abstract: In recent years, concern over the use of lead-based ammunition for hunting has been growing, primarily due to consumption of discarded offal by scavengers and donated game meat for human consumption. While there are alternative bullet technologies on the market that are suitable for hunting, these alternatives have not been adequately researched and tested for use in professional wildlife damage management (WDM). Differences between hunting and WDM include an increased level of precision necessary for safe WDM work, potentially greater distances for shots fired at targets, a need for instant incapacitation, and overall cost-effectiveness. To determine the applicability of lead-free bullets for WDM, we reviewed current lead-free bullet technologies and examined their limitations and benefits based on ballistic theory and available research. We found that there has not been sufficient research or experience with lead-free ammunition in the unique shooting scenarios used in WDM. Some of the issues identified by our review include a reduced theoretical precision of lead-free bullets due to a mismatch between bullet length and twist rate of the rifle barrel, lower performance of lead-free ammunition at greater ranges compared with lead-based bullets, and greater chance of bullets passing through targets and striking a nontarget object or animal. While some of these deficiencies may be overcome with new equipment and decreased target ranges, there are still situations where lead-based ammunition may be the safest and most practical option.

***Key words*:** ballistics, firearms, human–wildlife conflicts, lead fragmentation, lead-free ammunition, lead poisoning, sharpshooting

For much of the past century, the standard type of bullet used for hunting with center-fired, high-powered rifles has been copper-jacketed lead-core (CJLC) bullets. Most of CJLC bullets are made by placing a lead core inside of a copper jacket. These CJLC bullets can be made in a variety of styles, including hollow points (where the lead does not completely fill the copper jacket), plastic or metal tipped (where a plastic or metal point is placed in the hollow cavity to increase aerodynamic performance and aid in expansion), lead tipped (where the lead extends past the copper jacket and is formed into a point), match or target bullets (where the lead almost completely fills the copper jacket, but the copper jacket forms the tip), and full-metal jacket (where the tip is made from the closed portion of the jacket and the base is exposed lead). Each of these bullet types will fragment, deform (i.e., mushroom), or retain their shape, based on the design. Recent research has shown that with bullets that are designed to fragment, lead particles from the core of the bullet can be found in areas of an animal's body up to 45 cm from the primary wound tract (Grund et al. 2010, Stewart and Veverka 2011). Concerns over lead contamination in the environment, consumption of lead by wildlife, and human consumption of lead fragments in the meat of game animals have led natural resource agencies in some areas of the country to require the use of lead-free bullets (Avery and Watson 2009).

Lead-free bullets are defined as bullets that use some metal, other than lead, as the core. Lead-free bullets are typically made with solid copper (or an alloy of copper), metal powder compressed in a copper jacket, or compressed metal powder that is sintered. Solid copper is the most common lead-free bullet used for hunting. Solid copper bullets may be formed on a lathe or through other processes. Sintered bullets are formed by placing metal powder in a mold and then heating it until the exterior forms a solid surface. These types of bullets can take the forms of most of the designs of solid copper bullets. Copper-jacketed, compressed metal powder (CJCMP) utilizes a similar manufacturing process as CJLC bullets. A copper jacket is filled with powder. The powder is then pressed into the copper jacket until it reaches a density near that of the solid metal. Sintered and CJCMP bullets can be made from a variety of metal alloys and are typically considered frangible or brittle and can break apart upon contact with an object. Sintered and CJCMP bullets are typically used for indoor ranges to reduce ricochet and to reduce aerosolization of lead particles, although some have been advertised for hunting or wildlife control. None of the lead-free bullets is considered toxic and are thought to be harmless to animals or humans who might accidently consume them or parts thereof, making them an alternative for CJLC bullets used for hunting wildlife.

Professional shooting for the management of wildlife differs from sport hunting in several ways, including: shooting in urban, airport, and other sensitive environments; increased level of precision; low or no tolerance for inconsistent ammunition; shot placement due to disease sampling or other considerations; low or no pass-through of the bullet; and a desire for instant incapacitation (measured in fractions of a second; MacPherson 2005) or near-instant incapacitation (1 to 30 seconds) to avoid loss of the animal and to maintain professional standards (Caudell et al. 2009). While many of the current lead-free bullets are designed for and are acceptable for sport hunting, there has been little research published on their applicability in professional wildlife control and management, especially in sensitive environments. Much of what we know about firearms has been developed over time, as professional opinion or consensus has developed about the type of ammunition to use on different species of wildlife (Caudell et al. 2009). However, because lead-free bullets have not been as widely used as lead-based bullets, a professional consensus concerning the use of lead-free bullets in professional wildlife shooting situations has not been fully developed. Our objective is to present technical information about the technologies available for lead-free bullets and to discuss their potential for use in professional wildlife shooting situations.

Matching the bullet to the rifle

One of the factors necessary for a fired bullet to achieve both precision and accuracy is that it reaches an optimal rate of spin to stabilize it in flight (McCoy 1999, Litz 2009). Bullet weight is one of the factors used when selecting bulles for hand-loading or when selecting factory-loaded ammunition. Each gun barrel is grooved on the inner wall of the barrel (i.e., rifling) with a particular twist that is designed to stabilize the bullet in flight. The rate of twist of the rifling is an indicator of the largest bullet of that caliber that could be fired and stabilized in flight. Bullets are stabilized by imparting enough twist so that gyroscopic stability is achieved (Litz, 2009). The length of the bullet determines the amount of twist needed to achieve gyroscopic stability. When bullets were made primarily with lead-cores and copper jackets, most bullets of a similar design (e.g., spitzer, round nose, ultra low drag) had a similar length-to-weight ratio. Because most bullets are sold by weight, one would select a bullet based upon weight. However, with the advent of newer bullet technologies, bullet weights and their subsequent lengths are no longer equivalent.

Shooters familiar with their firearms will typically have identified a bullet, groups of bullets, or bullet weights that work well in their rifles. Because solid copper or other lead-free bullets of the same weight are typically longer than a CJLC bullet of equal weight, the minimum twist rate required to stabilize different bullets in flight will not be the same. The traditional method for determining the rifle barrel twist rate needed to stabilize a bullet was the Greenhill formula (Miller 2006). This formula was originally designed with football-shaped projectiles at subsonic speeds (Litz 2009). The Miller Stability Formula (Miller 2006, Litz 2009) is a more recently developed formula and takes into account modern projectiles. To determine if a particular projectile will be stabilized when shot from a specific rifle, the following formula can be applied:

$$SG = 30m / t^2d^3l(1+l^2),$$

where SG = gyroscopic stability factor, m = bullet mass in grains, t = rifle's twist in calibers per turn, d = diameter (caliber) of the bullet in inches, and l = length of the bullet in calibers.

An SG value of 1.4 or higher is needed to adequately stabilize a projectile in flight (Litz 2009). Based on the formula, a .308 caliber rifle with a 1:12 twist rate will stabilize a 168 grain, 1.2-inch-long lead-core bullet (SG = 1.80). However, that same rifle will not stabilize a 168 grain, 1.42-inch-long, solid copper bullet (SG = 1.11). A 1:10 twist rate is required to bring this same copper bullet to gyroscopic stability (SG = 1.59). For a more precise measurement of the twist rate needed, Litz (2009) provided the velocity and atmospheric corrections for this formula.

Heavier bullets are generally chosen in long-range shooting applications because heavier bullets retain more downrange energy, retain speed, and are less affected by wind than their lighter equivalents. The greater energy and speed contribute to the functioning of the bullet (i.e., expansion or fragmentation), its depth of penetration, and the terminal effects on the animal. In suboptimal conditions (i.e., wind and rain), heavier bullet allow for increased precision at longer ranges. To utilize heavier lead-free bullets, new equipment with the twist rate matched for the desired bullet would need to be purchased, or new barrels would need to be fitted to existing rifles.

Effects on range to target

In general, lead-free bullets are less dense than an equivalent lead-core bullet. Therefore, lead-free bullets will lose velocity quicker than lead-core bullets. Because solid copper bullets are harder than CJLC bullets, they will typically need a higher velocity to completely expand or will need additional features, such as plastic tips, scoring, or other alterations to enhance expansion. A nonscientific experiment conducted by a firearms writer (<*http://chuckhawks.com/hornady_GMX_bullets.htm*>) showed that Hornady .30 caliber, solid copper bullets fired into ballistic gelatin completely "mushroomed" at 3,200 feet per second (fps), had reduced expansion at 2,700 fps, and opened the bullet tip only at 2,000 fps. This type of information, derived from rigorous, scientific methodology, is an important step for determining the theoretically effective range of lead-free bullets. Once the shooter has a theoretical idea of the terminal ballistics of the ammunition, decisions can be made about the ethical range of an ammunition-rifle-shooting scenario (Caudell et al. 2009), and field trials then can be conducted. If the maximum and optimal effective range of a bullet is not known, the number of wounded and lost animals may increase. Much of this information with lead-based bullets has been generated over decades of experience and discussion among hunters, biologists, ballisticians, and other shooters, but because lead-free bullets are a relatively recent development, a consensus or professional opinion has not been fully developed.

Bullet fragmentation and shot placement

An important aspect of solid copper bullets for the end-user to understand is that they are nonfragmenting and retain most of their weight, a fact often used as a selling point for these products. When new hunters are taught about shot placement, they are typically told that a good area to aim for on the animal is the heart and lungs. This is because a near miss to the heart would still hit the lungs and would typically result in widespread damage to both the lungs and the heart, primarily due to the bullet fragmenting in the body. Bullet fragmentation is considered to be one of the primary methods of increasing the permanent damage of the wound cavity and increasing the chance of near-instantaneous incapacitation when the central nervous system (CNS) is not hit (DeMuth 1966, Fackler et al. 1984). However, because solid copper bullets are not designed or expected to fragment, shot placement becomes a critical factor if instant or near instant incapacitation is desired. A near miss to the heart may cause the heart to be temporarily displaced (due to the temporary cavity caused by the passage of the bullet) likely resulting in a longer, unpredictable period to incapacitation (MacPhearson 2005, Maiden 2009).

Discussion

Most bullets, including lead-free ones, will cause instantaneous incapacitation to an animal if the CNS is hit. This is the ideal bullet placement for lead-free bullets. However, when animals are past the distance where a shooter can consistently hit the brain or spinal cord, other, less optimal, shot placements may have to be used. Our remaining discussion will be limited to situations where a direct hit to the CNS is not achieved or desired. We believe the most significant limitation of current lead-free bullet technologies is the inability of bullets to

Figure 1: Copper-jacketed compressed, metal powder bullets (140 grain Barnes MPG bullets) after being fired into the head and spinal cord of tuberculosis-infected captive elk (*Cervus elaphus*) at ~1000 fps terminal velocity. While instant incapacitation was achieved, many of the recovered bullets did not break apart, even after striking the ground, because of the low velocity.

fragment in a similar fashion to ballistic tip, soft point, hollow point, and other lead-core bullets, resulting in less permanent damage of the wound track.

To offset the lack of fragmentation, additional focus on shot placement, based on extensive knowledge of the anatomy, should be emphasized. Shots that result in instant or near-instant incapacitation should be used. If a bullet penetrates deeply enough to hit the heart or the aorta, incapacitation will be near instantaneous. A head shot is ideal if pass-through by the bullet is not a concern. Most of the available lead-free bullets can pass through the head of a white-tailed deer (*Odocoileus virginianus*) and potentially retain sufficient energy to cause damage to another animal or property (A. J. DeNicola, White Buffalo Inc., personal communication). A shot to the spinal cord and or vertebral column also will cause instant incapacitation and will slow bullets more than a head shot. Anatomy, shot placement from different angles, time-until-death, and the distance the animal runs after being shot should be studied using a variety of lead-free ammunition. Shooters should be intimately familiar with both the size and location of the targets that result in instant and near-instant incapacitation (i.e., spinal cord, heart, brain) and the expected accuracy of their firearm and ammunition combination.

Sintered and CJCMP bullets will break apart or disintegrate when they encounter enough resistance; however, both of these types of bullets must have sufficient speed to accomplish this. If speeds are too high, these bullets will disintegrate too soon after penetrating the skin to cause sufficient trauma to incapacitate quickly. These bullets can still disintegrate at lower speed if they strike an object hard enough, but do not do so consistently. Even when fired at the speed for which the CJCMP were designed, we have had reports and made observations of the bullet performing inconsistently. D. Sinnett (U.S. Department of Agriculture, Animal and Plant Health Inspection Service [USDA-APHIS] Wildlife Services, personal communication) observed several instances where factory-loaded .308 CJCMP ammunition did not disintegrate after it struck a bighorn sheep (*Ovis canadensis*). The authors observed 2 bullets fired into a post-mortem deer carcass with a terminal velocity of approximately 2,500 fps passed through thigh muscle and pelvic bone without fragmenting. At low speeds (<1000 fps), the authors have also observed that these bullets will retain their shape, bend, or otherwise deform, but will not consistently disintegrate (Figure 1).

C. Ruth (South Carolina Department of Natural Resources, unpublished report, <*http://www.dnr.sc.gov/wildlife/deer/articlegad.html*>) conducted an experiment that examined the distance white-tailed deer ran after being shot. One of the aspects he examined was the difference in effectiveness between traditional lead-core bullets (classified as "soft" bullets) and newer, lead-free bullets (classified as "hard" bullets). Ruth found that there was a significant difference between bullet types. Deer that were hit with a rapidly expanding soft bullet ran less often, ran shorter distances, and provided better blood trails than those hit with hard bullets. Studies similar to this one on the effectiveness of these lead-free bullets should be expanded upon. Our own anecdotal experience using lead-free bullets in several operational disease control projects showed that, at best, solid copper and CJCMP bullets' effectiveness on long-range (i.e., >300 m) was variable when the CNS or heart-aortic complex was missed. For short-range shooting (50 to 150 m) of deer, bighorn sheep, and other medium to large game species, we have observed both accuracy and near-instant incapacitation with some lead-free ammunition, but the results have been variable. Data from both field and controlled studies need to be compiled and analyzed on the specific situations where using lead-free ammunition results in instant or near-instant incapacitation.

In some shooting situations, solid copper bullets are not desirable. Stewart and Veverka (2011) described a personal communication with sharpshooter T. DeNicola (White Buffalo Inc.) who stated that soft-tipped, highly frangible ammunition is desirable because bullets can be selected that do not pass through the head of the animal and that result in instant incapacitation when the CNS is struck. While lead-free, frangible bullets, such as CJCMP and sintered bullets, are available, they may not function properly with a typical body shot used by hunters. Some CJCMP contain a copper jacket where the metal is compressed enough to be near the hardness of solid metals. While these can break apart upon striking an object, they may still penetrate the materials used to build a typical house, skin of an airplane, or other objects commonly found in sensitive environments. Tests would have to be conducted to determine under what situations (e.g., distance, target on the animal, caliber) it would be acceptable to expect near-instantaneous incapacitation.

A major concern about lead-based ammunition is the ingestion of lead from hunted animals by avian scavengers and humans (Avery and Watson 2009). However, there are differences between how large-game animals are handled in hunting situations and professional wildlife damage management. Hunters typically gut their animals in the field and leave the offal for scavengers to eat. While it is still unclear how much of a threat such offal is to the long-term survival of species such as bald eagles (*Haliaeetus leucocephalus*), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), and other scavengers that eat it, there is evidence that ingested lead fragments have an impact on individual raptors (Kramer and Redig 1997, Hunt et al. 2006., Watson et al. 2009). Mitigation, such as removing offal and carcasses from the environment during wildlife control or other projects, may reduce lead exposure to scavengers. Donated meat from large-game species could be restricted to parts of the carcass taken from pre-determined distances from the wound tract, based on the type of ammunition used. Additional studies, similar to those by Grund et al. (2010) and Stewart and Veverka (2011) would need to be conducted using the most common types of lead-based bullets to determine at what distances from the wound tract is the farthest a lead fragment will typically travel.

Establishing an ethical range

As part of training, shooters should establish their ethical range for each of the lead-free bullets they will use, not just the accuracy of the rifle. Caudell et al. (2009) defined an ethical range as the longest shot that can be taken that will humanely kill the target, with low chance of missing it, and not compromise safety. We further refine ethical range to include instantaneous to near-instantaneous incapacitation of the target and quantified "low chance of missing the target." Ethical range that is site- and situation-specific should take into account the limitations of the bullets being used, distance to target, specific shooting scenario, size of area that must be hit, and limitations of the equipment being used. Shooters may need to reduce their ethical range for lead-free bullets (compared to bullets they have more experience with and whose terminal ballistics are understood) to achieve accurate shot placement and to allow lighter, lead-free bullets to maintain sufficient velocity to achieve full expansion.

Common expectations of shooters engaged in professional wildlife management included shooting equipment capable of sub-minuteof-angle accuracy, minimal pass-through of bullets, ammunition that will produce replicable results in comparable shooting situations, and instantaneous to near-instantaneous incapacitation. This is a level of performance needed that is often beyond typical hunting equipment and ammunition. While much of the lead-free ammunition will probably perform adequately in a hunting situation, current lead-free bullet technologies may not meet the expectations of the professional wildlife biologist in certain WDM scenarios until the limitations of lead-free ammunition have been properly evaluated through research and the limitations are known before it is applied in the field.

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