

Lead-Free Hunting Rifle Ammunition: Product Availability, Price, Effectiveness, and Role in Global Wildlife Conservation

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Abstract Proposals to end the use of lead hunting ammunition because of the established risks of lead exposure to wildlife and humans are impeded by concerns about the availability, price, and effectiveness of substitutes. The product availability and retail prices of different calibers of lead-free bullets and center-fire rifle ammunition were assessed for ammunition sold in the USA and Europe. Lead-free bullets are made in 35 calibers and 51 rifle cartridge designations. Thirty-seven companies distribute internationally ammunition made with lead-free bullets. There is no major difference in the retail price of equivalent lead-free and lead-core ammunition for most popular calibers. Lead-free ammunition has set benchmark standards for accuracy, lethality, and safety. Given the demonstrated wide product availability, comparable prices, and the effectiveness of high-quality lead-free ammunition, it is possible to phase out the use of lead hunting ammunition world-wide, based on progressive policy and enforceable legislation.

Keywords Lead-free ammunition · Toxicity · Hunting · Global conservation · Regulation

INTRODUCTION

Awareness of lead exposure and toxicity to wildlife from discharged lead ammunition has grown rapidly. What was believed, initially, to be a syndrome of wetland avian species that ingested shotgun pellets has widened to include upland species (Pain et al. 2009), and now species feeding on remains of mammals killed by lead rifle bullets. This latter form of lead exposure afflicts wildlife in North America, Germany, Japan, and Sweden (Hunt et al. 2006; Pauli and Buskirk 2007; Helander et al. 2009; Krone et al. 2009;

Saito 2009; Spicher 2011), and, presumably, elsewhere. Grund et al. (2010) mention over 200 000 deer being harvested, annually, in Minnesota. That is, presumably, the number of gut piles containing lead bullet fragments awaiting consumption by scavengers. Deer and other big game are hunted in many other US states. Shooters from three US states destroy over two million prairie dogs (*Cynomys ludovicianus*) annually (Reeve and Vosburgh 2006). Their remains augment the risks of lead exposure posed by gut piles derived from other species. In Europe, 2–3 million game animals are taken, annually, and the meat is marketed for human consumption. The roe deer (*Capreolus capreolus*) kill, alone, in 2005 for Germany, France, Austria, Poland and (former) Czechoslovakia was 2.086 million animals (Schaller 2007; Burbaite and Csányi 2009). Lead fragments in gut piles from these and other game animals present risks to scavengers (Krone 2011). The ingestion of lead fragments from rifle-killed meat by humans is the latest component of this growing awareness of serious lead exposure (Dobrowolska and Melosik 2008; Kosnett 2009; Iqbal et al. 2009; Knott et al. 2010; Pain et al. 2010), a risk that can be prevented by use of lead-free rifle ammunition.

Few examples of legislation requiring use of lead-free rifle ammunition for game hunting exist. They comprise Sweden and Mauritania (Avery and Watson 2009), the island of Hokkaido, Japan (Saito 2009), and some parts of Germany (Krone et al. 2009). Lead poisoning of California Condors (*Gymnogyps californianus*) led to passage of the Ridley-Tree Condor Preservation Act by the State of California in 2007, requiring use of non-toxic ammunition by hunters in the range of this species (Thomas 2009). Passage of that law was predicated on the existence of non-toxic rifle bullets and shotgun ammunition.

Conservation derives from changes in human behavior, as guided through enlightened public policy, and enforced

by progressive legislation (Thomas and Guitart 2010). Lead exposure and toxicity to wildlife and humans from lead ammunition is completely preventable. However, achieving the transition to lead-free ammunition requires that suitable alternatives exist, that hunters support their use, and that their use is enforced by law. Legislation is critical in this regard because it is the biggest determinant of assured markets for non-toxic alternatives and compliance with their use (Thomas and Owen 1996; Thomas and Guitart 2010). In 2009, an expert consultation, convened by the International Council for Game and Wildlife Conservation (CIC), and attended by representatives of the Federation of the Hunting Associations of the European Community (FACE), the British Association for Shooting and Conservation (BASC), and others, issued a resolution (Points No. 4 and 6) that urged an end to the use of lead ammunition in hunting. Point No. 5 stated:

It is now technically feasible to phase out the use of lead ammunition for all hunting and shooting. However, we recognize that while a wide range of non-toxic gunshot is currently available, it may take longer for other types of non-toxic ammunition to be developed, e.g. some rifle bullets. (Kanstrup 2010, p. 72)

Reluctance of the hunter community to support adoption of non-toxic rifle ammunition appears to be based, largely, on perceptions of availability, price, and effectiveness of substitutes, plus other concerns, that are never part of the scientific literature. This paper examines these perceptions and is addressed to policy makers to facilitate change. It deals with developments of lead-free rifle bullets, their current availability, ballistic effectiveness, and price. This topic was addressed, briefly, in Knott et al. (2009), but here, I address availability in the USA and Europe in terms of the manufactured availability of different categories and calibers of lead-free bullets and rifle ammunition, and their comparative prices. Possible regulatory changes for the European Union and other countries are also presented.

BULLET FRAGMENTATION AND THE DEVELOPMENT OF LEAD-FREE HUNTING BULLETS

This was driven by the need to produce expanding and solid hunting bullets with high ballistic efficiencies that retain their mass and produce quick, humane kills. Passage of the Ridley-Tree Condor Preservation Act by California effectively combined these concerns with the issue of toxicity of bullet components. Most types of expanding lead-core bullets will fragment during passage through the target animal, the extent of fragmentation depending on the bullet's terminal velocity, hardness of tissues encountered, and

bullet design. This has been investigated in detail by Grund et al. (2010). The extent of bullet expansion is determined carefully, depending on the type of game being hunted, and this has consequences for fragmentation. Large-caliber solid bullets (comprising a lead-core surrounded by a thick copper, or copper/steel, jacket) are designed not to expand or fragment, and are used for deep penetration of vital regions of elephants (*Loxodonta africana*) and Cape buffalo (*Syncerus caffer*). Such bullets pose little toxic risk to wildlife or humans. By contrast, highly frangible bullets of smaller caliber are designed for hunting small pests (e.g., prairie dogs), and fragment extensively on impact to destroy all vital tissues (see Fig 1 in Pauli and Buskirk 2007). Such animals are usually not buried after being destroyed, and their remains pose a considerable toxic risk to scavengers (Pauli and Buskirk 2007). Between these two extremes, are expanding hunting bullets of many different calibers and different characteristics of penetration and expansion designed to take edible game of different body sizes.

Copper, or copper–zinc alloy (gilding metal), has been selected for lead-free bullets. These bullets are designed to expand into four/six frontal petals that impart a large shock to the animal while creating a wide wound channel. These fired bullets retain over 99 % of their initial mass (Grund et al. 2010; Irschik et al. 2012), and should some small fragments pass into the offal or edible meat, they pose no toxic risk to scavengers, humans, and the wider environment (Thomas et al. 2007; Thomas and McGill 2008; Franson et al. 2012; Irschik et al. 2012). Sabots (slugs) designed to be fired from shotguns, are also made from copper, and are discharged inside a plastic sleeve. They can replace lead slugs used for hunting game at close range ($\ll 100$ m). Highly frangible lead-free bullets designed for destroying small-bodied pests have also been developed, using a thin jacket of copper and an inner core of non-toxic metals. Finally, large-caliber, solid, bullets made entirely of copper or gilding metal have been produced for hunting large African game.

MATERIALS AND METHODS

The term “availability” has different meanings. There is “market availability” in which market forces determine whether a given product can be purchased at the retail level, regardless of cost. “Product availability” refers to whether a specific product is made, and is the focus of this paper. This is an important consideration, given the many calibers and rifle cartridge case dimensions used by hunters in different regions of the world. If a transition to use of lead-free rifle bullets is to materialize, both product availability and market availability must exist. “Legal availability” refers to whether a given cartridge product can be imported, exported, sold or used in a given jurisdiction, and is not considered in this paper.

A computer web (Google) search was made of all the center-fire rifle cartridge makers in the USA, Australia, and Europe who listed lead-free bullets and shotgun sabots in their inventory, whether they made the bullets themselves, or made center-fire rifle cartridges using the lead-free bullets of other makers. The products of companies that made lead-free bullets were segregated by type, i.e., solid, expanding, or frangible, and finally by caliber of bullet. Within a given bullet caliber (or diameter), a range of bullet weights could be produced, and was recorded. Bullets of a given caliber are often loaded into cartridge cases of different dimensions (e.g., .300 H & H, .300 Winchester, or .300 Weatherby). I recorded those companies that produced rifle cartridges in different cartridge case dimensions per caliber for public sale. Companies that make lead-free shotgun sabots or slugs were recorded, together with the shotgun gauge for which intended. Lead-free bullets designed for use in muzzle-loading rifles have been developed recently. The companies making them were recorded, including the rifle calibers for which they were intended. This analysis did not include lead-free bullets designed for use in hand guns.

Reports of the effectiveness or lethality of lead-free bullets were obtained by searching the published scientific literature and on-line web-based sources using Google Scholar and Google, respectively, as the search engines. The comparative retail costs of traditional lead-core and lead-free, non-toxic ammunition were investigated using a single, large, US store's inventory. Cabela's Inc. (<http://www.cabelas.com/>) operates 34 retail stores in 23 US States, and is the largest store (in both North America and Europe) selling both types of ammunition produced by several major US ammunition makers. An on-line comparison of prices reflects instantaneous prices listings, and integrates pricing policy and competition across the entire nation. This comparison is based on the quoted retail prices of loaded ammunition made mainly by the US companies Barnes LLC, Federal, Hornady, Remington, and Winchester. These companies are the leading manufacturers of hunting ammunition in the USA. Confinement of the price comparison to US makers reflects products made under similar economic production costs, and obviates problems of costs reflecting import duties and tariffs. I compared the retail cost of the following rifle cartridges, .223 Remington, .243 Winchester, .270 Winchester, 7 mm Remington, .30-06, .300 Winchester, .300 H & H, .375 H & H, and .416 Rigby. This range covers the most commonly used cartridges used for hunting in North America. The last three rifle cartridges are used commonly in Africa for safari hunting. Where possible, I compared the prices of cartridges made by the same manufacturer with the same bullet weight made in both lead-core and lead-free bullet offerings. Only cartridges of comparable quality of components and manufacturing

precision were used in the price comparison. Thus the cheap lead-core ammunition made in Asia and former Eastern Bloc countries was excluded from the analysis because such ammunition may lack the component quality and consistent accuracy desired by hunters.

RESULTS

Manufactured Product Availability

A wide range of lead-free bullet calibers (35) is made and loaded into center-fire rifle cartridges of both US and European designations. Barnes Bullets LLC in the USA is the world's largest maker of lead-free bullets (Table 1). Lead-free bullets made by Barnes LLC and several other companies are loaded into a wide selection of hunting cartridges by 37 leading ammunition makers¹ in the USA, Australia, and Europe. Consequently, virtually all of the lead-core bullet calibers that are used for hunting in North America and Europe are available in lead-free form, as are the many hunting cartridge designations into which they are loaded. For example, one company, Corbon/Glaser, offers 44 center-fire rifle cartridges loaded with different weights of lead-free bullets designed for taking all species of North American game. The US company, Nosler, makes expanding bullets in five calibers (.243, .277, .284, .308, and .338) and three calibers of frangible bullets (.204, .224, .243). Woodleigh bullets, made in Australia, are available in 16 different calibers, and a variety of bullet weights in some calibers (Table 1). The Woodleigh solid bullets are made from copper-alloy, and are made as non-expanding solids in all calibers. They derive their lethality from hydrostatically generated shock to create large wound channels rather than expanding frontal petals. Lead-free bullets of varying weight and type now exist for hunting every game species. Such projectiles are available as slugs for use in shotguns, expanding bullets for muzzle-loading and center-fire rifles, solid (non-expanding) bullets for hunting large African species, and highly frangible bullets for destroying small animal pests (Table 1).

¹ These companies are listed alphabetically. Consult their web sites to see the range of loaded rifle ammunition produced. Ammo Bros., ASYM Precision Ammunition, Barnes Bullets, Black Hills Ammunition, LLC, Brenneke, Corbon-Glaser, Custom Cartridge, Inc., Cutting Edge Bullets, D Dupleks Ltd., Double Tap Ammo, Dynamic Research Technologies, Federal, GS Custom Bullets, LLC, International Cartridge Corporation, Lapua, Miwall Corporation, Monolithic Munitions, LLC, North Fork Bullets, Nosler, Norma, OPG Gun Ventures, LLC, P-Bar Co. LLC, Pierce Premium Rifle Ammunition, Remington Arms, RWS, Safari Arms, Sako, Sellier & Bellot Ammunition, Silver State Armory, Sinterfire, Inc., Snake River Ammunition, Stars & Stripes Ammunition, Styria Arms, Tombob Outdoors, LLC, Weatherby, Winchester, and Woodleigh.

Table 1 List of lead-free bullet calibers for center-fire and muzzle-loading rifles made by Barnes Bullets LLC, Woodleigh, Nosler, and Remington in different bullet weights, and copper shotgun slugs made by Remington and Federal

Bullet type	Caliber: inches and (metric) and available bullet weights
Center-fire rifle bullets	
Barnes TSX	.224 (5.56 mm) [6], .243 (6 mm) [1], .257 [2], .264 (6.5) [2], .277 (6.8 mm) [5], .284 (7 mm) [5], .308 [8], .310 (7.62) [1], .311 (7.65 mm) [1], .323 (8 mm) [2], .338 [5], .358 [2], .366 (9.3 mm) [2], .375 [4], .411 [1], .416 [3], .423 [1], .458 [6], .474 [1], .505 [1], .509 [1], .510 [1], .583 [1]
Barnes TSX Tipped	.224 (5.56 mm) [3], .243 (6 mm) [1], .257 [2], .264 (6.5 mm) [2], .277 (6.8 mm) [3], .284 (7 mm) [4], .308 [6], .323 (8 mm) [1], .338 [5], .358 [2], .366 (9.3 mm) [1], .375 [1], .416 [1], .458 [1].
Barnes Varmin-A-TOR	.204 [1], .224 (5.56 mm) [2], .243 (6 mm) [2]
Barnes Varmint Grade	.204 [1], .224 (5.56 mm) [3], .243 (6 mm) [1]
Barnes Solids	
Copper-Tin alloy construction	.224 (5.56 mm) [1], .243 (6 mm) [1], .257 [1], .264 (6.5 mm) [1], .277 (6.8 mm) [1], .284 (7 mm) [1], .308 [1], .338 [2], .366 (9.3 mm) [4], .375 [6], .410 [1], .416 [4], .422 [2], .458 [5], .474 [1], .504 [2], .509 [1], .510 [1], .583 [1], .618 [1]
Woodleigh Solid Bullets	
Copper-Alloy construction	.284 (7 mm) [1], .308 [2], .312 [1], .323 (8 mm) [2], .358 [1], .366 (9.3 mm) [2], .375 [2], .410 [1], .416 [1], .422 [1], .458 [4], .468 [1], .474 [1], .500 [2], .505 [1], .585 [1]
Nosler	
Ballistic Tip Varmint	.204 [1], .224 (5.56 mm) [2], .243 (6 mm) [1]
Nosler, E-Tip, Expanding	.243 (6 mm) [1], .257 [1], .277 [2], .284 (7 mm) [2], .308 [3], .323 (8 mm) [1], .338 [1]
Nosler Solids	.366 (9.3 mm) [1], .375 [2], .416 [1], .458 [1], .474 [1]
Remington	
Premier® Copper Solid	.30-06 [1]
Remington Disintegrator Varmint	.223 [1], .22-250 [1]
Barnes Muzzle-Loading Projectiles	
Expander MZ	.400 [1], .451 [2], .500 [2]
Spitfire MZ	.451 [2]
Spitfire Tipped MZ	.451 [2]
Spitfire TEZ(Sleeved sabot)	.451 [2]
Shotgun Slugs	
Remington Premier® Copper slugs	For: 12 ga Magnum 3 inch, 12 ga. 2 ^{3/4} inch; 20 ga 2 ^{3/4} inch Shotguns
Federal slugs	For: 12 ga Magnum 3 inch, 12 ga. 2 ^{3/4} inch; 20 ga 2 ^{3/4} inch Shotguns

The European metric for major calibers is given in parentheses and number of different bullet weights is in square brackets

The array of lead-free bullets available on retail markets covers all of the common and less-common rifle calibers (Table 1). Similarly, these bullets are loaded into a range of rifle cartridge designations that covers the vast majority of rifle cartridges used by hunters in North America, Europe, Africa, and elsewhere.

In Europe, the German company Brenneke makes a copper bullet (Pioneer brand) in four of the commonly used calibers and five major cartridge designations (.308 Win, .30-06, 8x57JS, 8x57JRS, and 9.3x62). Another German company, RWS, makes lead-free rifle ammunition in calibers .223 Remington (Copper Matrix brand), .30-06, and .308 (Bionic brand). In Finland, Lapua makes both lead-free bullets and loaded rifle cartridges (Naturalis brand) in seven

different calibers suitable for hunting small to large-bodied game. The European ammunition makers Norma, Sako, and Sellier & Bellot, manufacture lead-free ammunition using Barnes bullets in a range of commonly used center-fire cartridge designations for hunting all European game species. Barnes makes VOR-TX® lead-free rifle cartridges in three commonly used European calibers (7X64 Brenneke, 8x57 Mauser, and 9.3x62) destined for use mainly in Europe. Large US ammunition makers such as Federal, Winchester, and Remington, distribute their lead-free products internationally, so augmenting availability.

The array of lead-free ammunition available to the hunter is not limited by the array of rifle cartridge designations made by the leading manufacturers in the US,

Europe, and Australia. Hunters who hand-load their own rifle cartridges are able to purchase the lead-free bullets directly from the makers (especially Barnes Bullets LLC, Lapua, and Nosler) and fabricate their own ammunition. This applies particularly to hunters in North America, for whom this is a common practice.

Reported Effectiveness of Lead-Free Rifle Bullets

There has been little formal research published on the effectiveness of lead-free rifle bullets, and this may contribute to the reluctance of some hunters to embrace lead-free ammunition. However, Knott et al. (2009) using Barnes bullets of .243 and .270 caliber on red deer (*Cervus elaphus*), roe deer, and sika deer (*Cervus nippon*) found that there was no accuracy difference between copper and traditional lead bullets, nor difference in the killing power under field conditions. The lethality of copper bullets of different calibers has been measured on wild game animals in Germany. Spischer (2008) reported that 95 % of 247 animals (mainly deer and wild boar (*Sus scrofa*)) were killed cleanly with one shot. Trinogga et al. (2013) reported no significant difference in the lethality of lead-core and lead-free ammunition used on 65 wild ungulates under typical German hunting conditions. The comparative penetrance of large-caliber, lead-free, solid bullets (i.e., Barnes copper and Woodleigh gilded metal bullets) and conventional solid bullets was measured by Haley (2010). He found no difference in penetrance, and reported that the Barnes and Woodleigh bullets retained their integrity after firing through 80+ cm of a simulated elephant flesh and bone matrix. The resistance to fragmentation of Barnes copper bullets was measured by Grund et al. (2010), who fired 10 g (150 grain) .308 (7.62 mm) Winchester bullets into euthanized domestic sheep from 50 m, and live wild white-tailed deer (*Odocoileus virginianus*) from 80 to 175 m. These authors reported that, in both situations, the copper bullets retained almost 100 % of their initial mass upon recovery (Grund et al. 2010).

The term “effectiveness” integrates the terminal ballistic properties of bullets with the judgement and skill of hunters. A number of hunter magazine articles has been reprinted on the Barnes Bullets LLC web site (Barnes 2012) in which the effectiveness of Barnes copper bullets is endorsed from field experiences. This is, admittedly, not an objective, peer-reviewed, source of information, and may be subject to bias. Perhaps the best endorsement of the effectiveness of copper bullets comes from the US National Rifle Association, which gave Barnes Bullets LLC the 2012 American Hunter Ammunition Product of the Year Golden Bullseye Award for its VOR-TX[®] Ammunition, loaded with copper bullets (Barnes 2012).

There are some minor ballistic caveats on the use of copper bullets. The terminal velocity of expanding bullets

should exceed 2000 feet per second (610 m per second) for optimal expansion to occur inside animals. This is not an issue for animals shot at responsible hunting distances. Lead-free copper bullets have a lower density than lead-core bullets of similar mass, requiring that they be fired at a higher (150–200 feet per second: 46–61 m per second) initial velocity. This is not problematic for hunting rifles’ actions and barrels. Concerns about damage to barrels caused by using copper lead-free bullets are unfounded because lead-core bullets are also encased in a copper jacket that engages the barrel’s rifling. Copper bullets of the same caliber and mass as their lead-core equivalent are slightly longer to compensate for their lower density, and may require deeper seating in the cartridge case. This could impinge on the powder capacity of some cartridges with limited case volumes. However, this is not realized in the vast majority of hunting ammunition calibers.

Comparative Costs of Traditional Lead-Core and Lead-Free Ammunition

Data in Table 2 are from Cabela’s Inc. website on July 25, 2012, and present a snapshot of advertised prices. These prices may change because of market forces, changes in the manufacturers’ costs due to volatile global metal prices (especially copper), and changes in consumer preference. The list of advertised lead-free ammunition does not reflect all that is commercially available, only those specific hunting cartridges presently sold by Cabela’s Inc. Thus, other cartridge retailers may stock other lead-free ammunition not listed by Cabela’s Inc. The prices pertain to the USA, with its large, well-developed, market for rifle ammunition, but the price comparisons have broader application. The most realistic comparison is between the prices for Federal Premium TSX and Federal Premium lead-core ammunition, because the same company is using the same components, technology, and marketing to establish the price of the two product lines.

The prices of cartridges of given caliber and bullet mass vary among manufacturers, both for lead-core and lead-free offerings (Table 2). However, for calibers 7 mm Remington, .30-06, .300 Winchester, .375 H & H, and .416 Rigby the prices for lead-free and lead-core ammunition made by Federal were identical (Table 2). These are among the most commonly used cartridges for hunting deer, elk, moose, and bears in North America and Europe, and African plains game. For calibers .223 Remington, and .243 Winchester, the price differences were inconsistent across all brands of ammunition. In some cases the lead-core products were more expensive: for others, lead-free products were cheaper (Table 2). For the popular caliber .270 Winchester, lead-free cartridges were slightly more expensive, 1–2\$ per box over lead-core cartridges at 37.99\$ per box of 20.

Table 2 Comparison of listed retail prices for different brands of commonly used lead-free and lead-core rifle hunting ammunition

Cartridge	Bullet composition	Company product	Bullet mass, grains	Retail price, US\$ per box of 20 cartridges
.223 Remington	Lead-free	Federal Premium TSX ^a	55	29.99
		Federal TNT	43	24.99
		Winchester Lead-free	55	22.99
	Lead-core	Federal Premium	55	23.99–27.99 ^b
		Winchester Silvertip [®]	55	25.99
		Remington Power Lokt	55	28.99
.243 Winchester	Lead-free	Barnes VOR-TX [®]	80	32.99
		Federal Premium TSX	85	29.99
		Federal Premium	85	25.99
	Lead-core	Winchester Silvertip [®]	55 and 95	31.99
		Remington Core Lokt	80	36.99
		Barnes VOR-TX [®]	130	38.99
.270 Winchester	Lead-free	Federal Premium TSX	130	39.99
		Federal Premium	130	29.99–37.99 ^b
		Winchester Silvertip [®]	130	34.99
	Lead-core	Remington Core Lokt	130	19.99
		Barnes VOR-TX [®]	140 and 160	42.99
		Federal Premium TSX	160	45.99
7 mm Remington	Lead-free	Federal Premium TSX	110	37.88
		Federal Premium	160	45.99
		Winchester Silvertip [®]	140 and 150	42.99
	Lead-core	Remington Core Lokt	150 and 170	26.99
		Barnes VOR-TX [®]	150 and 180	39.99
		Federal Premium TSX	160 and 180	37.99
.30-06	Lead-free	Federal Premium TSX	110	39.88
		Federal Premium	180	35.99–38.99 ^b
		Federal Premium	150 and 165	29.99–37.99 ^b
	Lead-core	Winchester Silvertip [®]	150, 160, and 168	35.99
		Remington Core Lokt	150 and 180	19.99
		Barnes VOR-TX [®]	165 and 180	45.99
.300 Winchester	Lead-free	Federal Premium TSX	165 and 180	47.99
		Federal Premium	180	47.99
		Winchester Silvertip [®]	180	45.99
	Lead-core	Remington Core Lokt	150 and 180	27.99
		Federal Premium TSX	180	62.99
		Federal Premium	180	49.99–54.99 ^b
.300 H & H	Lead-free	Nosler Custom Trophy	180	59.99
		Federal Premium TSX	300	65.99
		Federal Premium	300	65.99
	Lead-core	Remington Core Lokt	270	54.99
		Nosler Custom Trophy	260	65.99
		Fusion Safari Rifle	300	64.99
.375 H & H	Lead-free	Federal Premium TSX	400	199.99
	Lead-core	Federal Premium	400	179.99–199.99 ^b

Prices were taken from the US company Cabela's Inc. web site on July 25, 2012

^a Federal Premium TSX cartridges are loaded with Barnes copper TSX bullets

^b The price differences reflect the different bullet shapes available for a given bullet weight

The largest price difference in this comparison was for the caliber .300 H & H. The price of Federal TSX was 8\$ higher than the lead-core equivalent at 55\$ per box of 20. This is now a comparatively rare hunting cartridge in the USA, but not for plains game in Africa. An important observation is that lead-core cartridges made by Remington, in calibers .270 Winchester, 7 mm Remington, .30-06, .300 Winchester, and .375 H & H were listed at much lower prices than other makers' lead-core and lead-free bullets (Table 2), and provide products for cost-conscious hunters.

DISCUSSION

A wide range of lead-free bullet and slug calibers now exists for hunting any species on any Continent, and they satisfy the caveat of Resolution 5 of the CIC expert consultation on Sustainable Hunting Ammunition (Kanstrup 2010). Their development has occurred mainly in the USA over the past 32 years, based on the need for more reliable and lethal hunting bullets. The US lead-free ammunition has set a bench-mark for the industry (Barnes 2012). The commercial availability of lead-free ammunition is also increasing, especially from on-line retailers. The websites of two US companies, Cabelas Inc. and Cheaper Than Dirt (<http://www.cheaperthandirt.com/>), indicate that 48 different hunting rifle cartridges are sold with lead-free bullets, covering the broad range of popularly used hunting rifle ammunition. Now, concerns over lead exposure in wildlife species and humans will drive the extension of these developments. The search for lead bullet substitutes uses the criteria non-toxicity, density, ballistic efficiency, availability, price, and ease of manufacture. The Periodic Table of the Elements reveals that all the possible, realistic, substitutes for lead bullets have already been identified and are being used, particularly elemental copper, whose non-toxicity to wildlife and humans has been established (Thomas et al. 2007; Thomas and McGill 2008; Franson et al. 2012; Irschik et al. 2012).

The published information on the accuracy and lethality of lead-free bullets on wild animals is limited, except for the studies of Spicher (2008), Knott et al. (2009), Grund et al. (2010), and Trinogga et al. (2013). However, were lead-free bullets less effective than equivalent lead-core bullets, it is unlikely that they would receive national product awards in 2012, especially in the USA, where intense competition exists among ammunition makers. The market availability of lead-free bullets and cartridges in the USA, as reflected in the 44 rifle cartridge listing of Corbon-Glaser and the listings of Cabela's Inc. and Cheaper Than Dirt, greatly exceeds that expected from the lead-free ammunition regulations of California, alone. This, again,

attests to their acceptance among American hunters. A survey of German hunters indicated a broad awareness of toxicosis in wildlife from spent lead bullets. Two-thirds of the respondents replied that they would adopt lead-free ammunition under certain conditions, and 86 % of those who had used lead-free ammunition intended to continue hunting with it (Schuck-Wersig 2011).

The present analysis indicates that the annual cost of high-quality lead-free ammunition is not a major impediment to its adoption for hunting, especially given the number of cartridges hunters use in practice and hunting. However, because some brands of lead-core ammunition are much cheaper than high-quality lead-free ammunition, there will be continuing opposition to a transition from hunters for whom price is a critical issue. Knott et al. (2009) indicated that copper bullets were 6.3 % less expensive than lead bullets when bought on-line in the UK, and those prices would decline further with increased economy of scale. Thus, the present wide product availability (37 independent companies), commercial availability, and absence of performance barriers could allow a phase out of lead-core rifle bullets for hunting world-wide, as was suggested for Germany by Krone et al. (2009). Increasing the product and market availability in Europe and elsewhere would be aided by more companies making lead-free bullets. Arguably, the number of European companies already making lead-free ammunition from their own and other companies' bullets may reduce the need for this suggestion. However, greater market availability needs the *assurance of demand* that only regulation can provide by requiring that all game be hunted with lead-free ammunition (see Thomas and Guitart 2010 on this point).

Awareness of lead exposure from spent ammunition has come mainly from North America and Europe, because that is where the problems have been most widely investigated and reported (Watson et al. 2009; Krone 2011). Safari hunting occurs widely across Africa (Booth 2010). The meat, a by-product of trophy hunting, is normally consumed by local people, who, including scavengers, are liable to be lead-exposed in the same way. There has been an especial development of lead-free expanding and solid bullets in the calibers .375 H & H and above by Barnes LLC, Nosler, and Woodleigh for taking African animals (Table 1). These bullets complement and extend the range of lead-free calibers from .243 to .375 H & H. Thus, all African species could be taken with lead-free ammunition, subject to regulation, and this risk of lead exposure could end.

Regulatory Options for Countries

Potential regulatory approaches to phasing out lead rifle ammunition would vary geographically. European Commission Regulation 1881/2006 sets maximum levels (MLs) for certain contaminants, including lead, in marketed food.

However, while a wide range of foodstuffs derived from domesticated and wild organisms are listed within 1881/2006 and have MLs set for lead, wild game, which is shot with lead ammunition in most European countries, is not included (EC1881 2006). Lead concentrations in game shot with bullets frequently exceed MLs set for other domestically raised meats, sometimes by more than an order of magnitude (Pain et al. 2010). Much European game meat is sold to defray the costs of maintaining species' habitats. In 2008, 38 024 tonnes of game meat, valued at 415.987 million \$US, were exported in the European Union (FAOSTAT 2011). Thus, adding game meat to the list of foods for which MLs are set within Regulation EC1881 (2006) would be a positive step because mechanisms exist for food inspection in EU countries, and could assist the transition to lead-free ammunition in hunting. However, as was noted by the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN 2012), establishing permissible levels of lead in game destined for sale would not, alone, be sufficient to reduce risks to human health. This is because lead concentrations vary considerably within a shot animal (since lead fragments can be distant from the wound channel), and inspection mechanisms could result in frequent false positive or false negative results. Also, in Spain and other countries, much game meat is consumed directly by hunters and their families, so not entering the usual regulated markets. The only regulatory solution to these problems is for the European Parliament to pass a Directive specifying that only lead-free, non-toxic, rifle and shotgun ammunition be allowed for game hunting, including the use of frangible bullets in killing pest animals not destined for food. This issue was addressed in detail by Thomas and Guitart (2010) for gunshot and fishing weights used in the European Union. The same policy process could be used to include lead-free rifle ammunition.

It is illegal to sell shot game in the USA and Canada, but it can be donated. In these countries hunting mammals is a state/provincial jurisdiction: it is federally regulated only in some national parks and wilderness areas. Accordingly, regulations would have to be developed by individual states/provinces. This could produce a mosaic of different approaches, as exists for use of lead-free gunshot in upland hunting (Thomas 2009). Even where state legislation is essential to assist recovery of endangered California Condors, only California has created law. Arizona has a voluntary use of lead-free rifle ammunition, and Utah has neither (Thomas 2009). However, where lead-free ammunition is required (since 2007) in parts of California, there has been a significant decline in the blood lead levels of golden eagles (*Aquila chrysaetos*) and turkey vultures (*Cathartes aura*) (Kelly et al. 2011), so the regulation is producing the desired effect.

African countries are not part of a single regulative body, so each has to set its own regulations on lead-free ammunition. This would be more about regulating use of lead-free ammunition by foreign hunters than by national hunters. Such regulation would not constrain safari hunting, given the parity of ammunition costs and ballistic effectiveness referred to in the present paper, and would benefit both human and environmental health.

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