Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions

Vernon G. Thomas

Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, Ontario N1G 2W1, Canada

Corresponding author email address: vthomas@uoguelph.ca

ABSTRACT

A complete transition to the use of lead-free ammunition in the UK is impeded mainly by concerns of the shooting community about availability, prices, and effectiveness of lead substitutes. This paper assesses those claims. Steel, Tungsten Matrix, and bismuth-tin shot cartridges are made in the UK and are readily available on-line. Lead–free rifle bullets are imported, and are also available on-line. Steel shot and lead shot cartridges are priced similarly. Tungsten Matrix and bismuth-tin shot cartridges, and lead-free rifle bullets cost more than their lead equivalents. However, those costs are small compared with the total costs of shooting game in the UK. Based upon the experiences of hunters in the USA, Denmark and Germany, it has been demonstrated that all UK game species can be hunted effectively with lead-free gunshot and rifle ammunition. Regulations and prices affect, directly, product availability and public consumption. Without broad government regulation, and in the face of low shooter compliance, little incentive exists to market lead ammunition substitutes. It is concluded that, for both shotgun and rifle game shooting in the UK, there is no limitation on availability or significant price barrier to adopting lead-free ammunition regulation. It is also concluded that any future regulatory considerations should relate to the poisoning of wildlife, lead exposure to humans from eating lead-shot game, and international obligations to reduce risks of lead exposure throughout migratory bird flyways.

Key words: *Lead-free ammunition, non-toxic ammunition, shotgun, rifle, commercial availability, effectiveness, regulatory comparisons*

INTRODUCTION

Wildlife in both coastal and inland wetlands and in terrestrial habitats of the UK are exposed to lead from several sources, principally from lost fishing weights, shot from game and target shooting, and spent bullets from game stalking. Wildlife, primarily birds, are exposed to these either through direct ingestion of shot from the environment, as with waterbirds and terrestrial gamebirds, or ingestion of ammunition or its fragments in the flesh of game animals or gralloch (gut pile), as with scavenging or predatory raptors. A large number of reports in the scientific press indicate that these forms of spent lead constitute an established risk to animals (Butler *et al.* 2005, Potts 2005, Thomas *et al.* 2009, Newth *et al.* 2013, Payne *et al.* 2013), and also humans who consume game meat killed with lead ammunition (Knott *et al.* 2010, Pain *et al.* 2010, Green and Pain 2012). The single problem of lead exposure in wildlife and humans is best resolved by replacing lead used in fishing weights and sporting ammunition (*i.e.* lead shotgun shot and lead-based rifle bullets) with non-toxic substitutes (Thomas and Guitart 2003, Thomas 2010).

The sport angling and ammunition making industries have already developed lead-free substitutes for use as sinkers, gunshot for waterfowl and upland game shooting (Thomas 2009), clay target shooting (Thomas and Guitart 2013), and game stalking with rifles (Thomas 2013). The progressive legislation of various countries has resulted in varying degrees of replacement of lead products (Mateo 2009). Most notably, Denmark has prohibited importation, sale, possession and use of lead shotgun ammunition and fishing gear since 1996. The state of California requires lead-free rifle ammunition to be used by hunters in Condor preservation zones under the Ridley-Tree Condor Preservation Act of 2007, and lead-free ammunition will be required throughout the entire state for all types of hunting from 2019 under California AB711[1]. It is interesting to note that no country has yet to ban the use of lead fishing weights, and rifle and shotgun ammunition for *both* hunting and target use. However, where non-toxic regulations have been introduced and *enforced*, the result is marked reduction of lead poisoning in wildlife, such as North American waterfowl (Anderson *et al.* 2000, Samuel and Bowers 2000, Stevenson *et al.* 2005). The UK countries introduced regulations between 1999 and 2009 to prohibit the use of lead gunshot over wetlands and/or for shooting wildfowl (Newth *et al.* 2012), as well as regulation to prohibit use of sinkers (<28.4 g) in coarse angling in 1986.

However, despite lowering of exposure to lead sinkers (Sears and Hunt 1991, Perrins *et al.* 2003), poor compliance with Regulations restricting the use of lead gunshot, at least in England where monitoring has taken place, has meant that significant exposure still remains for waterbirds exposed to lead shot (Newth *et al.* 2013, Cromie *et al.* 2010, 2015).

A "piece meal" approach to regulating the use of lead products reflects the enormous political strengths of the angling, hunting and shooting communities in many countries, rather than the angling and ammunition makers' abilities to make lead substitutes (Scheuhammer and Thomas 2011). The different sporting communities do not agree on the levels of exposure and risk presented by their members' activities, and frequently voice various concerns about lead substitutes (Miller *et al.* 2009, Haig *et al.* 2014, Epps 2014) regardless of their perceived validity. This paper deals with, and contests, two common concerns - the availability and effectiveness of lead-free ammunition for hunting game with shotguns and rifles in the UK.

METHOD

Definition of terms used in this paper

Availability: The term "availability" has several relevant components. Product availability refers to whether a given product is made and distributed. Retail availability refers to whether a given product is able to be purchased in a given location, whether online, or over-the-counter in a retail store. Economic availability refers to whether a given product is available to the public at a competitive price, in this case, relative to that of comparable lead ammunition.

Effectiveness: The term "effectiveness" refers to the ability of the gunshot or bullet to kill animals quickly when used competently. This assumes that the following considerations are met:

- The shooter is competent in judging distances and can present multiple shotgun shot or a bullet to the *vital regions* of animals.

- For shotgun shooting, a minimum of five shot should be delivered to the vital regions of the animal (see page 152-164 in Garwood 1994).

- The choice of cartridge gauge, mass of shot and size of shot is commensurate with delivering a minimum of five shot deep into the vital regions of the animal at the distance chosen for shooting.

- For rifle shooting, the calibre and mass of the bullet must be adequate to penetrate the vital regions (brain, anterior spinal column, heart, and anterior lung region) of the animal, allowing optimal expansion of the bullet and creation of a wide wound channel.

Toxicity: The term "non-toxic[2]" is used in reference to shotgun ammunition, as defined by the U.S. Fish and Wildlife Service, and is, here, used synonymously with the term "lead-free". The maximum allowable level of lead in gunshot under U.S. Fish and Wildlife Service criteria is 1% by mass (USFWS 1997).

[1] http://www.latimes.com/local/political/la-me-pc-california-jerry-brown-gun-control-20131011,0,6334949.story#axzztsZdb2Ga

[2] Non-toxic shot is defined as any shot type that does not cause sickness and death when ingested by migratory birds

Assessment of availability and effectiveness of shotgun and rifle ammunition

Reference to The Periodic Table of the Elements reveals that the metal substitutes for lead shotgun and rifle ammunition have already been identified and developed commercially, based on the criteria non-toxicity, density, ballistic suitability, availability, and price. Plastic-coating lead shot to resist dissolution is not a practical option. Such shot are abraded in the avian gizzard (Irby *et al.* 1967), and would not receive the unconditional approval of the U.S. Fish and Wildlife Service as non-toxic to waterfowl and the environment. There are three leading lead gunshot substitutes - iron, bismuth-tin alloy, and tungsten-based shot - that are made in the UK and are already used for hunting internationally. Lead-free rifle bullets may be made from pure copper, or gilding metal, an alloy of approximately 95% copper and 5% zinc.

Product availability of iron (steel) shot, bismuth-tin, shot, and tungsten-based shot was assessed through an online computer survey in autumn, 2014, using Google as the search engine. Retail availability and the relative economic availability was determined by an online survey of UK shotgun cartridge distributors in autumn, 2014, using the search engine Google.

The retail availability and relative costs of lead-based and lead-free rifle ammunition were based on an online computer survey, and the papers of Knott *et al.* (2009) and Thomas (2013). The assessment of the lethality of rifle ammunition was based on published scientific papers comprising Spicher (2008), Knott *et al.* (2009), Grund *et al.* (2010), Trinogga *et al.* (2013), Thomas (2013), and Gremse *et al.* (2014).

RESULTS AND DISCUSSION

Product availability of lead-free ammunition in the UK

LEAD-FREE SHOTGUN CARTRIDGES

Tungsten-based shot is made in two available types, Tungsten Matrix (a composite of 95% tungsten powder and 5% plastic polymer) and Hevi Shot (an alloy of tungsten, 1% iron, and up to 40% nickel). Tungsten Matrix shot cartridges are made and distributed in the UK by the company Gamebore[3]. Hevi Shot pellets are made in the USA and are imported, assembled into cartridges, and distributed in the UK. Bismuth-tin (approximately 95% bismuth, 5% tin) shot cartridges are made and distributed in the UK by the company Eleyhawk[4]. Steel (> 99.5% soft annealed iron) shot cartridges are made and distributed in the UK by all the major UK cartridge makers. Additionally, steel shot cartridges are imported and distributed throughout the UK from the leading cartridge makers of the USA, Belgium, Czech Republic, France, Germany, Italy, and Spain.

Although the three types of lead-free shot cartridges (tungsten-based, bismuth-tin and steel) are produced in the UK, their level of manufacture falls far below that of traditional lead shot. Thus the UK company Gamebore (a leading UK cartridge manufacturer) indicated that for the year ending October 31, 2014, lead shot cartridges accounted for 94.38% of the total volume of production (59.601 million cartridges) for the UK market. Steel shot cartridges were 5.61% of total production (3.54 million cartridges), while Tungsten Matrix cartridges were only 0.005% of total production (3,000 cartridges)[5]. Comparable data for bismuth-tin shot cartridges were not available, but one would expect their production of lead-free shot cartridges to be dwarfed by that of lead shot cartridges. The production of steel shot cartridges by non-UK makers is not known. Neither is the amount of steel shot cartridges imported for sale in the UK.

LEAD-FREE RIFLE AMMUNITION

Unlike shotgun ammunition, where lead-free shot is required for shooting over wetlands and/or for shooting wildfowl, there is no requirement that lead-free rifle bullets be used for hunting mammals in the UK. This greatly influences the availability of lead-free bullets. A search of online websites revealed very few companies selling lead-free rifle ammunition. Only one company, Midway UK[6], as of November 2014, advertises a very extensive line of lead-free bullets on its website. The company's products are from four USA makers (Barnes, Cutting Edge Bullets, Hornady, and Nosler), and one European maker (Lapua), and are listed in calibres and bullet weights corresponding to the rifle calibres presented in Table 1. The leading European makers of lead-free bullets and assembled rifle cartridges are: Brenneke, Lapua, Norma, RWS, Sako, and Sellier and Bellot. The volume of production of lead-free ammunition relative to traditional lead-core ammunition by these companies is not known. However, the lead-free products in different rifle calibres

[3] Gamebore website: http://www.gamebore.com [4] Eleyhawk website: http://www.eleyhawkltd.com
[5] Data provided by Mr. R. Cove, President and CEO of Kent Gamebore. [6] Midway UK http://www.midwayuk.com

Table 1: **Suitability of centre-fire lead-free rifle ammunition for hunting species of mammals in the UK.** The examples of cartridge calibres is not exhaustive, only representative of the commonly-used rifle calibres in the category.

Species	**Small size calibres,** *e.g.* **.222, .223**	**Small size calibres,** *e.g.***240, .243**	**Medium size calibres,** *e.g.* **.250, .270,**	**Medium size calibres,** *e.g.* **7 mm, .300, 8 mm**	**Large calibre,** *e.g.* **9.3 mm**
Red Deer *Cervus elaphus*	a †	a	+ ††	+	+
Fallow Deer *Dama dama*	a	+	+	+	+
Sika Deer *Cervus nippon*	a	+	+	+	+
Roe Deer *Capreolus capreolus*	+	+	+	b †††	b
Muntjac Deer *Muntiacus muntjak*	+	+	b	b	b
Chinese water Deer *Hydropotes inermis*	+	+	b	b	b
Badger *Meles meles*	+	+	b	b	b
Fox *Vulpes vulpes*	+	+	b	b	b

† Calibre is generally too small to ensure humane kills under field conditions. †† The + sign indicates that bullets of those calibres are suited for hunting that species. ††† Bullets of those calibres are generally too large for hunting those species.

and bullet weights feature prominently in these companies' websites. All of these companies export lead-free products to the USA, where a greater market exists, especially in California since 2007. Potentially, they could export to the UK, were the market to exist.

Retail and economic availability of lead-free ammunition

The retail market for shotgun ammunition in the UK is large and very competitive. In recent years, much of the retail availability has shifted to on-line bulk store warehouses that feature the UK and foreign cartridge companies' vast array of products for shooting both game and clay targets. For example, five leading on-line stores retail cartridges containing steel, tungsten-based, and bismuth-tin shot; Ammoshack, Clayshooting 'R'Us, Countryway Gunshop, Just Cartridges, and William Powell Cartridges[7]. All these cartridge types can be bought in boxes of 25, in cases of 250, and flats of 1000 cartridges. While the majority of cartridges offered for sale are mainly in 12 gauge, with various weights of shot loadings and shot sizes, sub-gauge cartridges (mainly 20 gauge) are also listed in the offerings.

There is an enormous disparity among the retail prices of the different shot types. The company Just Cartridges sells cartridges loaded with steel, Tungsten Matrix, Hevi-Shot, and bismuth-tin shot, and provides a good comparison. The comparative costs[8] for 12 gauge cartridges containing 32 g of shot of the same shot size are found in Table 2.

These prices explain why the production figures for Tungsten Matrix and steel shot by Gamebore are so disparate. Simply put, demand is determined in large part by retail prices, and industry manufactures at levels determined directly by

[7] Web site address: **Ammoshack** http://www.ammoshack.co.uk **Clayshooting'R'Us** http://www.clayshootingrus.co.uk **Countryway Gunshop** http://www.countrywaygunshop.co.uk **Just cartridges** http://www.justcartridges.com **William Powell cartridges** http://www.williampowellcartridges.com This list is not meant to be exhaustive, only representative of the current UK on-line retail availability. [8] Based on November, 2014, advertised prices.

Table 2: **Comparative prices for lead and non-toxic shotgun cartridges in 12 gauge** (as taken from a major cartridge selling website). Prices are those advertised in November, 2014.

Shot type	Manufacturer	Price per box of 25	Price per case of 250
Steel shot	3 different UK makers	£7.10-7.75	£64 – 69
Bismuth-tin shot	Eleyhawk	£ 36.25	£323
Hevi-Shot	loaded in the UK	£56	£497.50
Tungsten Matrix	Gamebore	£70	£626.25
Lead shot (across 4 UK makers):			
Lead	Gamebore	£6.80 – 6.95	£60.50 – 62.00
Lead	Eley	£6.95 – 7.05	£62.00 – 63.00
Lead	Hull	£9.25 – 9.50	£81.25 – 83.00
Lead	Lyalvale	£8.15 – 9.70	£72.75 – 86.75

demand. The comparison reveals that the retail prices for steel shot and lead shot cartridges overlap. Thus, there should be no economic impediment to shooters adopting steel shot cartridges. The lead-free type of shot most similar (ballistically) to lead shot is, however, the most expensive. These retail prices reflect most the world prices for the component metals, based on their rarity, strategic importance, costs of processing and assembly into shot. Furthermore, there is not going to be much change in these relative prices as a function of demand, although an increase in the economy of scale might lower the absolute costs of tungsten-based and bismuth-tin shot.

The company Midway UK provides on-line prices for an array of lead-free bullets of different calibres and different bullet weights and profiles per calibre. The bullets made by Barnes cost approximately £1 per bullet across a range of bullet diameter of 0.224 – 0.366 inch. These are much the same as the prices for similar lead-free bullets made by the companies Nosler and Hornady. Match-grade bullets made by the company Cutting Edge Bullets were more expensive, approximately £1.30 to £1.40 per bullet[9]. Lead-free bullets made by Lapua were the most expensive, at £2.62 per bullet, and sold in the smallest range of bullet calibres. The prices of equivalent lead-core bullets, are lower, by about half, than the commonly-used lead-free bullets made by Hornady, Nosler, and Speer[10]. However, many specialised lead-core bullets, such as "Match Grade" and "partition" bullets may cost more than the lead-free versions.

This paper does not have comparative data on the UK retail prices of assembled (*i.e.* ready to be fired) lead-free and lead-core rifle ammunition. However, Thomas (2013) indicated that in the USA there was no major difference between the prices of these two ammunition types, regardless of the maker, common calibre, and bullet weights. Knott *et al.* (2009) indicated that there was a difference in price for the two types of bullets used in their UK study, but suggested that this was an artefact of low demand, and that differences in price would decline with increase in hunter demand.

The economic costs of lead-free ammunition should be related to other costs incurred in game shooting. People in the UK pursue rough shooting as well as pest control, but precise figures of the costs of these activities are not readily available. Driven gamebird shooting and stalking in the UK are sports that are extremely expensive compared with rough shooting. An online survey of sporting estates' fees for different species of game yielded the following approximate costs. It is recognized that fees vary very much according to years, individual estates, and other mitigating factors:

- Red deer stags, from £395 to £495 per stag. Some estates then charge more on the basis of antler size; so 7-11 points cost £590, and stags with 12+ points cost an additional £195

[9] The price reflects these bullets' being made by CNC lathing, as opposed to die-swaging, to achieve a greater degree of concentricity.
[10] Prices as advertised in November, 2014.

per point.

- Red deer hinds, from £195 to £250 per hind.
- Fallow deer, from £450 per animal.
- Roe deer, from £350 per animal.
- Driven pheasants and partridges, £32 -36 per bird.
- Driven red grouse, £75-80 per bird.

These advertised prices are exclusive of taxes, and do not include other incidental costs of game shooting. For rifle-shot game, the costs of a single lead-free bullet are small in comparison to the totality of the costs of shooting an animal, possession of which still remains with the estate for subsequent sale to the retail game market. Similarly for gamebirds taken by shotgun, using Tungsten Matrix shot (bought by the case) rather than lead shot would add about £2 to the cost per bird. Use of bismuth-tin shot would cost about £1.50 more per bird, and use of steel shot would convey no extra cost. Collectively these approximate figures indicate that for both rifle and shotgun shooting, there is no large economic barrier to the adoption of lead-free ammunition in the UK. Similarly, for rough shooting and pest control conducted with shotguns, use of steel shot would pose no extra financial costs.

Use and effectiveness of lead-free shotgun and rifle ammunition

LEAD-FREE SHOTGUN AMMUNITION

All game species in the UK can be shot confidently with shot made of steel, Tungsten Matrix, Hevi Shot, or bismuth-tin alloy. These four shot types are produced in all the shotgun gauges used commonly by UK shooters, and in shot sizes designed for shooting common game animals of all sizes (Table 3). Steel shot is not loaded into cartridges of gauge smaller than 20 because of high pressure concerns. This same concern does not apply to shot made from bismuth–tin alloy and Tungsten Matrix

Table 3: **Suitability of three different types of US-approved, non-toxic, lead-free shot for shooting common species of birds and mammals in the UK.** The + sign indicates that the species in question should be hunted with the cartridge gauge, size, and shot size that is advised for that species within normal field shooting distances.

Species	**Steel shot.** In gauges 10, 12, 16, 20	**Bismuth-tin shot.** In gauges 10, 12 , 16, 20, 28, .410	**Tungsten-based shot** *e.g.* Tungsten-Matrix, Tunsten-iron, or Hevi Shot. In gauges 12, 16, 20
Geese species	+	+	+
Large-bodied ducks	+	+	+
Small-bodied ducks	+	+	+
Ring-necked pheasant *Phasianus colchicus*	+	+	+
Partridge species	+	+	+
Wood Pigeon *Columba palumbus*	+	+	+
Woodcock *Scolopax rusticola*	+	+	+
Snipe *Gallinago gallinago*	+	+	+
Red Grouse *Lagopus l. scoticus*	+	+	+
Ptarmigan *Lagopus mutus*	+	+	+
Golden plover *Pluvialis apricaria*	+	+	+
Rabbit *Oryctolagus cuniculus*	+	+	+
European hare *Lepus europaeus*	+	+	+
Mountain hare *Lepus timidus*	+	+	+

shot. These three shot types can be produced in different cartridge lengths for a given gauge. Thus 12 gauge cartridges can be made in 2.5", 2.75", and 3.0" lengths, depending upon the species of game being hunted. The production of 2.5" cartridges in 12 gauge allows older, British-made, guns chambered and proofed for 2.5" cartridges to continue to be used for hunting with these types of lead-free ammunition. Twenty gauge cartridges can also be made in 3.0" lengths. Tungsten-Matrix and bismuth-tin alloy shot can be loaded into cartridges using the same components (primers, powders, shot cups and wads) used for making lead shot cartridges. All four shot types can be loaded into cartridges with photo/biodegradable shot cups designed for use in locations where plastic shot cups are not permitted. Tungsten-based Hevi-Shot is produced for use in hunting both upland and wetland game, and the USA manufacturer makes cartridges loaded with this shot in a variety of gauges, though only 12 gauge cartridges appear to be offered for sale in the UK.

Steel shot has a density of 7.8 g/ml, less than that of lead shot (lead-antimony shot is approximately 11.0 g/ml). Hunters are advised to compensate for the lower density by using steel shot of two sizes larger than the traditional lead shot (*i.e.* #4 steel rather than #6 lead) to retain down-range energy. The effective range of steel shot cartridges is still about 40 yards, quite comparable to lead shot cartridges, when the criteria of shot pattern density and energy for penetrance are considered together (Garwod 1994, Pierce *et al.* 2014). Tungsten Matrix shot has a density of 10.8 g/ml, very close to that of most lead shot products, and it can be used interchangeably with lead shot cartridges, with respect to shooting distances, response to barrel choke, and ballistic efficiency. Bismuth-tin alloy shot has a maximum density of 9.2 g/ml, and it can also be used interchangeably with lead shot cartridges. Hunters are advised to use a shot one size larger than the lead shot equivalent to compensate for the lower density. Hevi-Shot is listed as having a density of 14 g/ml. Thus shooters could consider using shot one or two sizes smaller that the lead shot equivalent to realise similar shot pattern densities.

Concerns have arisen about the negative impacts of steel shot on shotgun barrels and need to be addressed in this paper. Barrels comprise three regions: the chamber, the barrel bore, and the terminal choke. Steel shot is much harder than lead shot and does not deform during the initial detonation in the cartridge chamber, unlike soft lead pellets. There is no damage to the chamber because the pellets are still inside the cartridge case. As steel pellets travel down the barrel, they are contained inside a protective cup that prevents the pellets contacting the walls of the barrel and causing damage. The only point along the barrel where some risk *might* arise is when the steel shot pass through the choke. The chokes of different makes of shotguns are not made in a consistent, uniform manner. Concerns pertain to abruptly-developed, as opposed to progressively-developed, chokes in barrels. It is *possible* that large steel shot (larger than #4 steel) passing through an abruptly developed, tightly-choked (full and extra-full), barrel could cause a small ring bulge to appear, simply because the steel shot do not deform when passing through the constriction. This does not occur if the barrels are more openly choked, such as "modified" or "improved cylinder"[11]. This is the essence of the concerns. For shooters with interchangeable, removable, chokes, the solution is to use a more open choke when shooting such steel shot, as when shooting waterfowl or "high" pheasants. For shooters with gun barrels having "fixed" chokes, the choke, if necessary, can be relieved readily by a gunsmith to a more open choke. The shooting of steel shot of diameter *smaller* than #4 does not cause concerns when fired through tight chokes. The same caveat about shooting large steel shot through fixed choke barrels also applies to large Hevi-Shot pellets, which are also much harder than lead shot.

It is interesting to note that lead shot is hardened deliberately by the addition of up to 6% antimony, and also by coating with nickel plate, to resist deformation during detonation and passage through tight chokes. This is to improve the proportion of pellets that arrive around the target, especially at ranges of 30-40 m. Steel shot is known to pattern well for this reason, and without the need of much barrel choking.

LEAD-FREE RIFLE AMMUNITION

This type of ammunition was made initially in the USA in order to produce bullets with superior ballistic properties and lethality than many lead-core counterparts, rather than to produce non-toxic ammunition (Thomas 2013). The leading US maker, Barnes Bullets Inc., sells lead-free ammunition under its own name, and sells lead-free bullets loaded into cartridges made and sold by Federal and other companies. These are available in the UK (Knott *et al.* 2009). All species of UK mammals can be hunted with lead-free centre-fire ammunition (Table 1). An array of lead-free rifle ammunition is made by European companies for those calibres commonly used in UK rifles, as listed in Table 1. Thomas (2013) provided a

[11] See the RWS website on this point. **http://www.rws-munition.de**

list of larger array of lead-free rifle calibres and bullet weights that were readily available to US consumers, and potentially, if demand warranted, to UK hunters.

The principal lead exposure and toxicity concern with lead-core ammunition is that the lead core would disintegrate on entering the animal and spread fragments into adjacent organs and tissues. This concern is associated, especially, with unbonded lead core bullets, in which the lead is not fused with the copper outer jacket. The many small fragments of lead in a shot animal then pose a toxic risk when either passed into the edible meat of human food (Pain *et al.* 2010), or become ingested by scavengers that eat the discarded remains of shot animals (Watson *et al.* 2009, Haig *et al.* 2014). The effectiveness and lethality of lead-free rifle bullets made of copper or gilding metal have been demonstrated by field shooting on UK species of deer (Knott *et al.* 2009) and on German species of deer and wild boar (*Sus scrofa*) by Spicher (2008). These results have been supported by the experimental shooting of euthanised sheep and wild white-tailed deer *Odocoileus virginianus* by Grund *et al.* (2010) at distances of 80-175 m. Further evidence of the effectiveness of lead-free rifle bullets is provided by detailed, controlled, ballistic experiments of Trinogga *et al.* (2013) and Gremse *et al.* (2014). Both studies concluded that lead-free bullets were equally as effective as lead-core counterparts in expanding, creating destructive wound channels, and retaining their initial mass after penetration. It is possible that some tiny copper bullet fragments could be ingested by scavengers (*e.g.* golden eagles *Aquila chrysaetos*) and humans. However, Franson *et al.* (2013) reported that American kestrels *Falco sparverius* experimentally-dosed with copper pellets did not exhibit any signs of toxicity.

Jurisdictions with lead-free ammunition hunting regulations

Regulation of lead ammunition began with controls over hunting in wetlands because that was where the most obvious signs of lead exposure in wildlife existed, from as long ago as the middle of the last century (Bellrose 1959). Lead poisoning in terrestrial birds, especially gamebirds, and in raptors has been reported for similarly long periods (Calvert 1876, Mulhern *et al.* 1970). The USA and Norway were the earliest nations to enact laws requiring use of lead-free shot over wetlands in 1991, and since that time, an increasing number of countries have enacted similar restrictions to the same conservation end (Avery and Watson 2009, Mateo 2009).

The African-Eurasian Migratory Waterbirds Agreement (AEWA) original Annex text when it came into force in 1999 (4.1.4) read that "Parties shall endeavour to phase out the use of lead shot for hunting in wetlands by the year 2000" and as a contribution to delivering the Aichi 2020 Biodiversity targets, it was agreed in 2012 that AEWA Parties should not only phase out the use of lead shot in wetlands but also evaluate the effectiveness of national measures already taken to this end, and understand and address barriers to implementation where measures are not effective (AEWA 2012; see also Stroud 2015, for policy commitments). Increased awareness of the extent and severity of lead exposure from spent ammunition to a range of wild bird taxa (Pain *et al.* 2009, Watson *et al.* 2009) has led to the realisation that greater regulation is also needed for hunting/shooting over terrestrial habitats. Most recently, published studies revealing elevated levels of lead in shot game used as human food have raised concerns about the need for new regulations to address this source of exposure (Guitart *et al.* 2002, Pain *et al.* 2010, Green and Pain 2012).

Internationally, the regulation of lead ammunition use over terrestrial habitats is very limited, whether in rifles or shotguns. California is the only state/country to have passed legislation requiring the use of lead-free rifle ammunition for hunting. The Ridley-Tree Condor Preservation Act of 2007 applies to hunting in the range of this species, and was passed to reduce lead exposure in condors to fragments of lead from spent ammunition. California has since passed law AB711 in 2013 that will require all hunting with shotgun or rifle to be conducted state-wide with lead-free ammunition by 2019, so extending the power of the Ridley-Tree Act. The passage of these laws is predicated on the known effectiveness of lead substitutes and their growing availability as makers increase their production towards 2019. The state of South Dakota also passed into law (1998) the requirement that all upland game hunting with shotguns use lead-free ammunition on both private and state-owned lands.

The most progressive legislation is provided by Denmark which, since 1996 has required lead-free ammunition to be used for all shotgun hunting and non-Olympic target shooting. Enforcement of the law, and thus hunter compliance, is enhanced by prohibiting the import, possession, and use of lead shot cartridges (Kanstrup 2006). Denmark still has to act on the use of lead-core rifle ammunition. The Netherlands also requires

that lead-free shotgun cartridges be used for hunting nation-wide in all habitats (Mateo 2009).

At the 11th Meeting of the Conference of the Parties to the UNEP Convention on Migratory Species (CMS) in November, 2014, Resolution 11.15 on Preventing Poisoning of Migratory Birds (UNEP-CMS 2014a) and its Guidelines (UNEP-CMS 2014b) were adopted by the Parties. The guidelines include the recommendation to phase out all lead ammunition (gunshot and bullets) in all habitats (wetlands and terrestrial) within three years. The Resolution agrees that "it is for each Party to determine whether or how to implement the recommended actions, considering the extent and type of poisoning risk, whilst having regard to their international obligations and commitments, including those under the Convention". The intention of this is clear, *i.e.* that countries that do not have particular risks, or have only trivial risks from one of the listed poisons within their territory (*e.g.* with respect to lead ammunition this may apply to countries where all hunting is forbidden) need not act. In contrast, the expectation is that countries that do have anything more than a trivial risk from one of the poisons within their territory should follow the recommendations in order meet their international commitments – including under the CMS.

Lead poisoning has been shown to be a significant problem for both welfare and survival in migratory birds in the UK (Pain *et al.* 2015). The Resolution, which is politically binding both at EU and individual signatory Member State levels, requires that the UK responds to the proposed timing and extent of the lead ammunition phase–out across the country, while considering the devolved jurisdictional powers of Wales, Scotland and Northern Ireland. Implementation of the Resolution requires extension of lead-use bans beyond what currently exist in the UK. The UK government has also to consider its relation to the European Union in this manner because of the sharing of the migratory bird flyways with different European Union partners, and because the EU *en bloc* is also a signatory to the CMS.

In addition to the requirements under the CMS, lead levels in marketed shot game, whether national or imported, raise concerns about national food standards and the need to regulate human lead exposure in this manner (Knott *et al.* 2010, Green and Pain 2012). It is both desirable and possible that constructive regulation to end the use of lead ammunition could serve the interests of both human consumers and wildlife, and ideally, be harmonised across regions of the UK, as well as adjacent European countries.

CONCLUSIONS

Issues of availability

SHOT: The product availability of lead-free shot is assured in the UK by two British companies (Gamebore and Eley) making two proprietary brands, and all of the major British cartridge makers producing steel shot cartridges. Additionally, foreign-made steel shot ammunition is imported into the UK and distributed through online and other retailers. This is to satisfy current regulations requiring use of lead-free cartridges for shooting waterfowl, but the same manufacturing, importing, and distribution system could be used to supply lead-free shot cartridges across all game shooting. The retail availability of steel, bismuth, and tungsten-based shot cartridges is large, especially from on-line dealers.

BULLETS: Lead-free rifle bullets are imported from either American or European makers, and a growing number of companies either make or produce assembled rifle cartridges with lead-free bullets (Thomas 2013). The retail availability of this type of ammunition is restricted for two reasons. The size of this UK rifle shooting community is smaller than the shotgun shooting community, and far fewer shots are used per shooting season. The other main reason is that game shooting with rifles and lead-core ammunition is still allowed in the UK.

The economic availability of lead-free rifle ammunition is not a barrier to a transition away from lead bullet use in this sport. Although lead-free bullets are approximately double the price of lead-core bullets, few rifle shots are used in a typical deer hunt, and then, their costs become a very small part of the total costs of the hunt. A transition to lead-free shotgun cartridges carries different economic costs. The cost is zero for steel shot, 5-6 times more for bismuth-tin shot, and 10-11 times more for Tungsten Matrix shot. However, relating these prices to the costs of game shooting indicates that the costs of the target animals and other related costs predominate, not the costs of the ammunition. There is no strong economic barrier to the regulated transition to lead-free shot for all game and pest shooting in the UK.

In considerations of availability, issues of regulation and prices predominate. If regulations mandating use of lead-free ammunition do not exist, there is little incentive for industry to

manufacture let alone distribute, and even less for shooters to use in the field. Industry must have the assurance of established markets (Thomas and Guitart 2010). Even then, the price of lead-free ammunition will determine the market share, as indicated by the relative prices for Tungsten Matrix and steel shot cartridges. Adoption of voluntary use policies in the UK is not a prudent approach. If there is no compunction on shooters to use lead-free ammunition, there is no reason for retailers to stock it, and no economic return to industry to make it (Thomas and Owen 1996).

The issue of compliance also impinges on availability. Cromie *et al.* (2002, 2010, 2015) reported that there was very low compliance (approximately 70% non-compliance) among shooters of waterfowl in England with the required use of lead-free cartridges, despite their availability and low cost. In the absence of enforcement in the UK, such behaviour continues, despite more than a decade of encouragement by shooting organisations to obey the law (Cromie *et al.* 2015). One can also envisage a situation in which regulations are introduced requiring lead-free shot for all game shooting in the UK, but compliance could still be low because legal lead cartridges produced for target shooting might still be used for other terrestrial and upland game shooting. The majority of cartridge manufacture in the UK is to satisfy the target shooting community. Thus Gamebore indicated that, for 2013-14, 75-80% of its cartridge production was for target shooting: less than 25% of production was for game shooting, including lead-free ammunition (R. Cove, *pers. comm.*)[12]. Thomas and Guitart (2013) showed that UK cartridge makers *already* produce steel shot cartridges suited to clay target shooting, and that their use could reduce the lead pollution footprint associated with this sport. The only practical way to achieve high compliance is to adopt the same regulatory approach as Denmark, and across all shooting sports.

EFFECTIVENESS OF LEAD-FREE SUBSTITUTES

Twenty-three years of steel shot use in the USA, combined with about a decade's use of bismuth-tin shot and tungsten-based shot, indicate that these substitutes are very effective in producing humane kills of upland game birds and waterfowl, when used responsibly (Pierce *et al.* 2014). A similar conclusion is reached from hunters' experiences in Denmark (Kanstrup 2006) where lead-free ammunition must be used for waterfowl and upland game hunting.

The use of lead-free rifle bullets is also increasing in popularity in the USA, not because they are lead-free, but because they are ballistically very effective. As evidence of this, the US National Rifle Association awarded Barnes Bullets Inc. of Utah the 2012 American Hunter Ammunition Product of the Year Golden Bullseye Award for its VOR-TX line of lead-free ammunition (Thomas 2013). Only one US jurisdiction (California) requires their use in one part of the state, but the availability of a wide range of bullet calibres, weight and types far exceeds what one might expect for this one state, alone (Thomas 2013). It is possible that different US and European makers are anticipating other states' making similar regulations as California, and want to be ready with their own brands of lead-free rifle ammunition. Concerns about the effectiveness of this type of ammunition have been dispelled by the field studies of Spicher (2008), Knott *et al.* (2009), and Grund *et al.* (2010), and the exhaustive ballistic work of Trinogga *et al.* (2013) and Gremse *et al.* (2014). The demonstrated effectiveness of this lead-free ammunition, coupled with its low costs of use, could enable government regulators to require its use across the UK and elsewhere.

THE INTERESTS OF LANDOWNERS

Clients who shoot lead shot cartridges over the estates of landowners leave a legacy of spent shot that is rarely recovered. This shot can be ingested by gamebirds resulting in lead exposure (Butler *et al.* 2005, Potts 2005, Thomas *et al.* 2009, reviewed in Pain *et al.* 2015). This is of greater concern to wild populations of birds as opposed to stocked birds because of the risk of sub-clinical poisoning and mortality across seasons. The use of lead-free shot on these estates would (other than from limited legacy exposure) remove this risk to surviving birds. Additionally, the gamebirds sold to the retail food market would now conform to a "lead-free" standard, and benefit consumers. Any costs are externalised to the paying clients, not the landowners, so it is in the interest of landowners to keep their estates lead-free.

A similar case can be presented for shooting large game with rifles. Many deer shot in the UK have their internal organs (known as 'gralloch') removed and left, exposed, in the field. Any lead bullet fragments remaining in the discarded organs could be consumed by scavengers that might then succumb to lead poisoning (Watson *et al.* 2009). A requirement that only lead-free rifle ammunition be used would negate any risks of lead exposure from ammunition sources to wild scavengers. Similarly, the carcass would be also 'lead-free', and satisfy human

[12] Mr. R. Cove, President and CEO, Kent Gamebore, November, 2014.

food health standards in this regard. Again, the client is paying for the lead-free bullet, and the estate benefits from the sale of uncontaminated venison.

CONSIDERATIONS RELATED TO EXTENDING LEAD-FREE AMMUNITION REQUIREMENTS

A decision by government to extend existing regulations would have significant implications for the cartridge makers of the UK, who would then need to increase their production of steel, bismuth–tin, and Tungsten Matrix shot ammunition. The same decision has fewer consequences for rifle ammunition because most is imported into the UK market. Any such changes would require that discussions should take place between policy makers and the UK ammunition makers, as to the length of a phase-in period. The following considerations apply to this issue. Virtually all steel shot is made in China, and is imported into the UK for assembly into steel shot cartridges[13]. Thus the Chinese production capacity would have to be increased, consistent with projected demand. The tungsten used to manufacture Tungsten Matrix shot is produced from Chinese-mined ores, refined in China, and imported into the UK. The Chinese production of this metal would also have to increase. The bismuth presently used in making shot is derived mainly from the refining of other metals, not the mining of bismuth ores. Any projected increase in the demand for bismuth-tin shot would have to be met by assurances of availability of this metal from whichever source. The making of bismuth-tin shot requires its own specialised technology, whose production capacity would have to increase to satisfy a projected increase in cartridge demand. Industry would require an adequate phase-in time to install such technology.

This paper has shown that the major UK ammunition makers already have the technology, manufacturing capacity, and marketing in place to satisfy the demands of existing UK regulations for lead-free shot use over wetlands. Given that cartridges for game shooting comprise a smaller segment of the annual production (at least for Gamebore, at about 20-25%), there is considerable room to expand this segment. However, to do so requires a firm commitment to ammunition makers that regulation can provide. The persistent and continuing low hunter compliance with regulation, at least in England, reduces the interests of makers to produce more lead-free cartridges. The use of lead shot cartridges in all types of shooting therefore needs to be examined in the interests of compliance and lead pollution reduction on a larger scale.

In November, 2009, a workshop was convened at the request of the International Council for Game and Wildlife Conservation (CIC) to evaluate the continued use of lead ammunition and their lead-free substitutes for hunting (Kanstrup 2010). Article 6 of the final Resolution stated

"We recommend that a Road Map be developed by the CIC in close collaboration with other stakeholders to implement the phase-in of non-toxic ammunition for all hunting and shooting as soon as practicable. This roadmap should include clear objectives with timelines."

Article 8 of the Resolution stated

"We find that voluntary or partial restrictions on the use of lead ammunition have been largely ineffective and that national and international legislation is required in order to ensure effective compliance and to create the assured market for non-toxic ammunition."
(Kanstrup 2010).

The collective evidence presented in the present paper indicates that Articles 6 and 8 of the above Resolution apply completely to hunting and shooting in the UK, and could be implemented forthwith.

[13] *Pers. comm.* with Mr. R.Cove, President and CEO of Kent Gamebore, November, 2014.

REFERENCES

AEWA (2012). Resolution 5.23 annex: AEWA's contribution to the strategic goals and Aichi targets of the strategic plan for biodiversity, 2012-2020. Available at: http://www.unep-aewa.org/sites/default/files/publication/mop5_proceedings_0.pdf. Accessed: August 2015.

ANDERSON WL, HAVERA SP, ZERCHER BW (2000). Ingestion of lead and non-toxic shotgun pellets by ducks in the Mississippi flyway. *The Journal of Wildlife Management* 64(3), 848-857.

AVERY D, WATSON RT (2009). Regulations of lead-based ammunition around the world. In: Watson RT, Fuller M, Pokras M, Hunt WG (eds). *Ingestion of lead from spent ammunition: implications for wildlife and humans.* The Peregrine Fund, Boise, Idaho, USA. pp 161-168. DOI:10.4080/ilsa.2009.0115.

BELLROSE FC (1959). Lead poisoning as a mortality factor in waterfowl populations. *Illinois Natural History Survey Bulletin* 27(3), 235-288.

BUTLER DA, SAGE RB, DRAYCOTT RAH, CARROLL JP, POTTS D (2005). Lead exposure in ring-necked pheasants on shooting estates in Great Britain. *Wildlife Society Bulletin* 33(2), 583-589.

CALVERT HS (1876). Pheasants poisoned by swallowing shot. *The Field* 47(189).

CROMIE R, LORAM A, HURST L, O'BRIEN M, NEWTH J, BROWN M, HARRADINE J (2010). Compliance with the environmental protection (Restrictions on Use of Lead Shot)(England) Regulations 1999. Defra, Bristol. Available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=16075. Accessed: August 2015.

CROMIE RL, BROWN MJ, HUGHES B, HOCCOM DG, WILLIAMS G (2002). Prevalence of shot-in pellets in mallard purchased from game dealers in England in winter 2001/2002. *Compliance with the Lead Shot Regulations (England) during winter 2001/02*. RSPB. Sandy, UK.

CROMIE RL, NEWTH JL, REEVES JP, O'BRIEN MF, BECKMANN KM, BROWN MJ (2015). The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium*. *Lead ammunition: understanding and minimising the risks to human and environmental health.* Edward Grey Institute, The University of Oxford. pp 104-124. Available at: http://oxfordleadsymposium.info. Accessed: October 2015.

EPPS CW (2014). Considering the switch: challenges of transitioning to non-lead hunting ammunition. *The Condor* 116(3), 429-434. DOI: 10.1650/CONDOR-14-78.1.

FRANSON JC, LAHNER LL, METEYER CU, RATTNER BA (2012). Copper pellets simulating oral exposure to copper ammunition: absence of toxicity in American kestrels (*Falco sparverius*). *Archives of Environmental Contamination and Toxicology* 62(1), 145-153. DOI:10.1007/s00244-011-9671-1.

GARWOOD GT (1994). *Gough Thomas's gun book: shotgun lore for the sportsman*. The Gunnerman Press: Auburn Hills, Michigan, USA.

GREEN R, PAIN D (2012). Potential health risks to adults and children in the UK from exposure to dietary lead in gamebirds shot with lead ammunition. *Food and Chemical Toxicology* 50(11), 4180-4190. DOI:10.1016/j.fct.2012.08.032.

GREMSE F, KRONE O, THAMM M, KIESSLING F, TOLBA RH, RIEGER S, GREMSE C (2014). Performance of lead-free versus lead-based hunting ammunition in ballistic soap. *PLoS ONE* 9(7), e102015. DOI: 10.1371/journal.pone.0102015.

GRUND MD, CORNICELLI L, CARLSON LT, BUTLER EA (2010). Bullet fragmentation and lead deposition in white-tailed deer and domestic sheep. *Human-Wildlife Interactions* 4(2), 257-265.

GUITART R, SERRATOSA J, THOMAS VG (2002). Lead-poisoned wildfowl in Spain: a significant threat for human consumers. *International Journal of Environmental Health Research* 12(4), 301-309. DOI:10.1080/0960312021000056410.

HAIG SM, D'ELIA J, EAGLES-SMITH C, FAIR JM, GERVAIS J, HERRING G, RIVERS JW, SCHULZ JH (2014). The persistent problem of lead poisoning in birds from ammunition and fishing tackle. *The Condor* 116(3), 408-428. DOI:10.1650/CONDOR-14-36.1.

IRBY HD, LOCKE LN, BAGLEY GE (1967). Relative toxicity of lead and selected substitute shot types to game farm mallards. *The Journal of Wildlife Management* 31(2), 253-257.

KANSTRUP N (2006). Non-toxic shot-Danish experiences. In: Boere G, Galbraith CA, Stroud DA (eds). *Waterbirds around the world.* The Stationery Office, Edinburgh. p 861.

KANSTRUP N (2010). Sustainable Hunting Ammunition. 5–7 November, 2009. *CIC Workshop Report*. 75pp. International Council for Game and Wildlife Conservation, Budapest, Hungary. Aarhus, Denmark.

KNOTT J, GILBERT J, GREEN RE, HOCCOM DG (2009). Comparison of the lethality of lead and copper bullets in deer control operations to reduce incidental lead poisoning; field trials in England and Scotland. *Conservation Evidence* 6, 71-78.

KNOTT J, GILBERT J, HOCCOM DG, GREEN RE (2010). Implications for wildlife and humans of dietary exposure to lead from fragments of lead rifle bullets in deer shot in the UK. *Science of the Total Environment* 409(1), 95-99. DOI:10:1016/j.scitotenv.2010.08.053.

MATEO R (2009). Lead poisoning in wild birds in Europe and the regulations adopted by different countries. In: Watson RT, Fuller M, Pokras M, Hunt WG (eds). *Ingestion of lead from spent ammunition: implications for wildlife and humans*. The Peregrine Fund, Boise, Idaho, USA. pp 71-98. DOI:10.4080/ilsa.2009.0091.

MILLER D, SMITH M, MILLER J (2009). Caution before action on lead. *The Wildlife Professional* 3(52), 52-66.

MULHERN BM, REICHEL WL, LOCKE LN, LAMONT TG, BELISLE A, CROMARTIE E, BAGLEY GT, PROUTY RM (1970). Organochlorine residues and autopsy data from bald eagles 1966-68. *Pesticides Monitoring Journal* 4(3), 141-144.

NEWTH JL, CROMIE RL, BROWN MJ, DELAHAY RJ, MEHARG AA, DEACON C, NORTON GJ, O'BRIEN MF, PAIN DJ (2012). Poisoning from lead gunshot: still a threat to wild waterbirds in Britain. *European Journal of Wildlife Research*. DOI: 10.1007/s10344-012-0666-7.

PAIN DJ, FISHER IJ, THOMAS VG (2009). A global update of lead poisoning in terrestrial birds from ammunition sources. In: Watson RT, Fuller M, Pokras M, Hunt WG (eds). *Ingestion of lead from spent ammunition: implications for wildlife and humans.* The Peregrine Fund, Boise, Idaho, USA. pp 99-118. DOI:10.4080/ilsa.2009.0108.

PAIN DJ, CROMIE RL, NEWTH J, BROWN MJ, CRUTCHER E, HARDMAN P, HURST L, MATEO R, MEHARG AA, MORAN AC (2010). Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. *PLoS ONE* 5(4), e10315. DOI:10.1371/journal.pone.0010315.

PAIN DJ, CROMIE RL, GREEN RE (2015). Poisoning of birds and other wildlife from ammunition-derived lead in the UK. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium*. *Lead ammunition: understanding and minimising the risks to human and environmental health.* Edward Grey Institute, The University of Oxford. pp 58-84. Available at: http://oxfordleadsymposium.info. Accessed: October 2015.

PAYNE JH, HOLMES JP, HOGG RA, VAN DER BURGT GM, JEWELL NJ, WELCHMAN D. DE B. (2013). Lead intoxication incidents associated with shot from clay pigeon shooting. *Veterinary Record* 173(22), 552. DOI: 10.1136/vr.102120.

PERRINS CM, COUSQUER G, WAINE J (2003). A survey of blood lead levels in mute swans *Cygnus olor*. *Avian Pathology* 32(2), 205-212. DOI:10.1080/0307946021000071597.

PIERCE BL, ROSTER TA, FRISBIE MC, MASON CD, ROBERSON JA (2014). A comparison of lead and steel shot loads for harvesting mourning doves. *Wildlife Society Bulletin*. DOI: 10.1002/wsb.504.

POTTS GR (2005). Incidence of ingested lead gunshot in wild grey partridges (*Perdix perdix*) from the UK. *European Journal of Wildlife Research* 51(1), 31-34. DOI: 10.1007/s10344-004-0071-y.

SAMUEL MD, BOWERS EF (2000). Lead exposure in American black ducks after implementation of non-toxic shot. *Journal of Wildlife Management* 64(4), 947-953. DOI:10.2307/3803203.

SCHEUHAMMER A, THOMAS VG (2011). Eliminating lead from recreational shooting and angling: relating wildlife science to environmental policy and regulation in North America. In: Elliott JE, Bishop CA, Morrissey CA (eds). *Wildlife ecotoxicology: forensic approaches.* Springer: New York, US. pp 359-382.

SEARS J, HUNT A (1991). Lead poisoning in mute swans, *Cygnus olor*, in England. *Wildfowl* (Suppl. 1), 383-388.

SPICHER V (2008). Experiences with lead-free rifle ammunition under field hunting conditions. In: Krone O (ed). *Lead poisoning of sea eagles: causes and approaches to solutions – the transition to lead-free rifle ammunition*. Leibniz-Institut für Zoo und Wildtierforschung: Berlin. pp 81-90.

STEVENSON AL, SCHEUHAMMER AM, CHAN HM (2005). Effects of nontoxic shot regulations on lead accumulation in ducks and American woodcock in Canada. *Archives of Environmental Contamination and Toxicology* 48(3), 405-413. DOI:10.1007/s00244-004-0044-x.

STROUD DA (2015). Regulation of some sources of lead poisoning: a brief review. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health.* Edward Grey Institute, The University of Oxford. pp 8-26. Available at: http://oxfordleadsymposium.info. Accessed: October 2015.

THOMAS V (2009). Nontoxic shot ammunition; types, availability, and use for upland game hunting. *The Wildlife Professional* 3(2), 50-51.

THOMAS VG, OWEN M (1996). Preventing lead toxicosis of European waterfowl by regulatory and non-regulatory means. *Environmental Conservation* 23(4), 358-364.

THOMAS VG, GUITART R (2003). Lead pollution from shooting and angling, and a common regulative approach. *Environmental Policy and Law* 33(3), 143-149.

THOMAS VG, SCHEUHAMMER AM, BOND DE (2009). Bone lead levels and lead isotope ratios in red grouse from Scottish and Yorkshire moors. *Science of the Total Environment* 407(11), 3494-3502. DOI: 10.1016/j.scitotenv.2009.02.003.

THOMAS VG (2010). Achieving uniform regulation of environmental lead exposure and poisoning in wildlife and humans. *The Environmentalist* 30(2), 206-210.

THOMAS VG, GUITART R (2010). Limitations of European Union policy and law for regulating use of lead shot and sinkers: comparisons with North American regulation. *Environmental Policy and Governance* 20(1), 57-72. DOI: 10.1002/eet.527.

THOMAS VG (2013). Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. *AMBIO* 42(6), 737-745. DOI: 10.1007/s13280-012-0361-7.

THOMAS VG, GUITART R (2013). Transition to non-toxic gunshot use in Olympic shooting: policy implications for IOC and UNEP in resolving an environmental problem. *AMBIO* 42(6), 746-754. DOI: 10.1007/s13280-013-0393-7.

TRINOGGA A, FRITSCH G, HOFER H, KRONE O (2013). Are lead-free hunting rifle bullets as effective at killing wildlife as conventional lead bullets? A comparison based on wound size and morphology. *Science of the Total Environment* 443, 226-232. DOI:10.1016/j.scitotenv.2012.10.084.

UNEP-CONVENTION ON MIGRATORY SPECIES (2014a). Resolution 11.15. Preventing poisoning of migratory birds. Adopted by the Conference of the Parties at its 11th meeting, 4-9 November 2014, Quito, Ecuador Available at: http://www.cms.int/sites/default/files/document/Res_11_15_Preventing_Bird_Poisoning_of_Birds_E_0.pdf. Accessed: August 2015.

UNEP-CONVENTION ON MIGRATORY SPECIES (2014b). Review and Guidelines to Prevent the Risk of Poisoning of Migratory Birds. *UNEP/CMS/COP11/Doc.23.1.2.* Bonn, Germany. Available at: http://www.cms.int/sites/default/files/document/COP11_Doc_23_1_2_Bird_Poisoning_Review_%26_Guidelines_E_0.pdf. Accessed: August 2015.

USFWS (1997). Migratory bird hunting: revised test protocol for nontoxic approval procedures for shot and shot coatings. 50CFR Part 20. Department of the Interior, U.S. Fish and Wildlife Service, Washington, D.C. Federal register 62(230): 63608-63615.

WATSON RT, FULLER M, POKRAS M, HUNT W (eds) (2009). *Proceedings of the conference ingestion of lead from spent ammunition: implications for wildlife and humans.* The Peregrine Fund, Boise, ID, USA.

Shotgun cartridges: a range of non-toxic alternatives are available. Steel shot represents the most widely used non-toxic alternative to lead and is comparably priced.

Photo Credit: A. Johnson