Proceedings of the

Oxford Lead Symposium

Lead Ammunition:
understanding and minimising the risks to human and environmental health

10th December 2014

Edward Grey Institute,
The University of Oxford, UK

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Editors

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FOREWORD

In 1983, Professor Richard Southwood chaired the Royal Commission on Environmental Pollution's report on Lead in the Environment (RCEP 1983). This report resulted from concern being progressively extended to the possible effects on humans of lead at ever-decreasing blood concentrations, and the high level of associated public debate. The report was seminal, and most of its recommendations have been implemented by successive governments.

Recommendations included that lead should be phased out of petrol additives and progressively reduced in paint, that research should continue into the effects of lead at low concentrations, particularly on children, and that the anthropogenic dispersal of lead and man's exposure to it should be reduced further. These have all now happened. Among other recommendations were that urgent efforts should be made to develop alternatives to lead shot and lead fishing weights (to protect wildlife from unnecessary poisoning), and that as soon as these alternatives are available, the Government should legislate to ban any further use of lead shot and fishing weights in circumstances where they are irretrievably dispersed in the environment. Lead fishing weights were banned in 1986, and alternatives to lead gunshot were developed some decades ago. However, only limited regulations requiring the use of non-toxic shot have been introduced in the UK, compliance with these remains poor (at least in England)(Cromie *et al.* 2015), and thousands of tonnes of lead shot continue to be deposited in the environment annually. Thus, the use of lead ammunition is the remaining significant source of unregulated dispersal of lead into our environment; one that presents risks to the health of wildlife and humans today, and one that builds an ever increasing toxic legacy.

I was delighted to chair the Oxford Lead Symposium in December 2014 and learn more about this important and topical issue.

It is notable that in addition to the extensive evidence reviewed and presented at this symposium, some 60 experts from both wildlife and human health disciplines have recently signed consensus statements on the strength of the science surrounding risks and impacts of lead from ammunition, and the need to move to the use of non-toxic alternatives (Group of Scientists 2013, 2014; Appendix 2). This level of scientific agreement is impressive, although perhaps not surprising given the long history of research into the subject.

Several international political imperatives exist for the UK Government to move towards the use of non-toxic ammunition (Stroud 2015). These include the African-Eurasian Migratory Waterbirds Agreement, which required the use of non-toxic shot in all wetlands by the year 2000 (AEWA 1999), and more recently the Convention on Migratory Species (CMS)(UNEP-CMS 2014). In November 2014 Contracting Parties to the CMS adopted a resolution, the guidelines of which recommend the phase out of all lead ammunition, in all habitats, within three years. Such Multilateral Environmental Agreements are politically binding to signatory countries, of which the UK is one, and give a clear indication of the necessary direction of travel.

The Symposium heard that alternatives to lead ammunition are technically possible, not prohibitively costly, and many are already available (Gremse and Reiger 2015, Thomas 2015). Alternatives to lead shot are in use in parts or all of many countries; Denmark for example required the use of non-toxic gunshot for all shooting almost 20 years ago (Kanstrup 2015). Alternative bullet types are already in use in some places, and others, such as California State, are phasing in their use (Thomas 2015). Several major landowners and managers in the UK have already taken steps to phase out lead bullets on their landholdings.

The decisions to be made now are political. The organisations represented at this symposium stressed that they are not progressing an anti-shooting agenda, but rather advocating that shooting sports must act in a sustainable way that does not put wildlife and human health at risk, especially when such risks are avoidable. Those with an interest in this topic may wish to consider the analogies in the protracted debate surrounding the removal of lead from petrol presented in the European Environment Agency report 'Late Lessons from Early Warnings' (Needleman and Gee 2013).

Although estimates of numbers of birds killed by consuming lead from ammunition in the UK cannot readily be made with precision, at least tens and possibly hundreds of thousands of birds are estimated to die annually from this cause; many more suffer welfare impacts (Pain *et al.* 2015). More recent information, including that from the European Food Safety Authority (EFSA 2010) and the agencies responsible for food safety of a number of EU countries (including the UK)(Knutsen *et al.* 2015) have already highlighted the risks that frequent game consumption presents to human health, particularly that of young children. It is estimated that at least thousands and possibly tens of thousands of young children are currently consuming sufficient game to potentially risk health effects in the UK (Green and Pain 2015).

Lead ammunition may be traditional (Cromie *et al.* 2015) but it is doubtful whether future generations would perpetuate a tradition of knowingly adding lead to food or exposing wildlife to poisoning. It will be for politicians to decide whether these wildlife and human health risks and impacts combined are sufficient to require sports shooters in the UK to use the non-toxic ammunition available, and to set a timetable for implementing the recommendation, made in 1983, of the Royal Commission on Environmental Pollution.

The Lord Krebs Kt, MA, DPhil, FRS, FMedSci, Hon DSc.

Wild shot game is increasing in popularity: lead levels in game are currently unregulated.

Photo Credit: Denis Vermenko/Shutterstock.com

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INTRODUCTION

I hosted this symposium with its diverse audience, all with an interest in lead ammunition, with a certain feeling of déjà-vu. It is now some 30 years since I was heavily involved in the issues of lead poisoning; on that occasion the victims were primarily mute swans *Cygnus olor* and the source of the lead was fishing weights. Eventually – and it took several years of research and debate – the sale and use of the most commonly used sizes of fishing leads were forbidden. The result was dramatic, nationally the mute swan population doubled in the next ten years; on the lowland, most heavily-fished rivers such as the Thames, the increases were even greater.

Then, as now, the stakeholders involved appeared to have some sort of blind-spot when it came to seeing lead as a poison. "Surely this little pellet isn't dangerous?", "It doesn't really dissolve does it?" I do not believe that in the 1980s we would ever have made any real progress on the issue of lead poisoning from fishing weights in mute swans had it not been for the newspapers of the time being filled with news of lead in petrol. Nowadays, no one can be oblivious to the issues of lead because of the damage to human health, particularly children's health due to impacts on their developing brains. Eating food with lead purposefully shot into it, of course, now seems like a bad idea.

The Royal Commission on Environmental Pollution report on Lead in the Environment (RCEP, 1983), made clear the potential dangers of lead, recommending that its use for ammunition and for fishing weights should be withdrawn. Successive Governments have dragged their heels over the issue of lead ammunition, none seeing it as a serious enough concern compared with other issues with which they are dealing. This is strange in view of the growing awareness by the Medical Profession who have steadily lowered the permitted levels of lead, especially in food and drink. For wildlife there are some regulations on the use of lead gunshot but these are clearly not working. It seems to me that more than 30 years is more than enough time to decide to take action to stop it from being distributed into the environment. This has gone on for over a century or two contaminating soils, poisoning wildlife and resulting in a gradual build-up that can only make the situation worse; it is certainly easier to spread it around than to collect it!

I hope the opportunity given by this Oxford Lead Symposium and its proceedings, to learn about the progress made with so many aspects of the problems that the use of lead poses, as well as solutions to the problem, will help make the UK a healthier and safer place.

Professor Chris Perrins, LVO, FRS.

ACKNOWLEDGEMENTS

There are a number of people to whom I am particularly grateful for making the symposium and the proceedings valuable contributions to both the science and the discourse of the lead ammunition issue in the UK: the symposium was expertly chaired by Lord Krebs and Prof. Colin Galbraith; and Prof. Ian Newton provided wisdom in the summing up of the day's events. I am grateful to Profs. Richard Delahay and Chris Spray for their independent peer review and editing of the papers in the proceedings. The speakers provided insightful presentations which are captured well in the papers contained herein. Thank you to Tim Jones for capturing the day's events and to Ruth Cromie and Jonathan Reeves for providing valuable administrative support.

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Lead poisoned whooper swan *Cynus cygnus* close to death found in Scotland, 10 years after introduction of regulations to reduce lead in wetlands. Eroded lead gunshot was subsequently found in the bird's gizzard.

Photo Credit: WWT

Regulation of some sources of lead poisoning: a brief review

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ABSTRACT

The history of environmental pollution by lead is as long as its history of use by human society. However, although there has been nearly three centuries of regulation related to lead in industrial or domestic settings, use of leaded paint and leaded petrol remains legal in some countries and there are other widespread sources. Population exposure especially in developing countries continues to be significant not least as a consequence of the movement of 'dirty', high risk industries to poor countries with less developed regulatory regimes. Accordingly lead is a subject of global public health targets.

International recognition of lead as a source of wildlife mortality or morbidity has developed over recent decades, although implementation of clearly set international objectives is hindered by the 'invisible' nature of such poisoning – with poisoned animals seldom being seen by the public. This facilitates denial of the issue since lead impacts are not a 'spectacular' cause of wildlife deaths.

The history of initiatives to reduce population exposure to lead through better regulation is one in which vested interests have fought to maintain the *status quo* - seeing regulation as a threat to their economic interests. Indeed, very similar types of justification have been made by those arguing against better regulation of lead emissions into the environment - whether as a fuel additive, or in relation to ammunition and other sources that poison wildlife. Thus, understanding the difficulties faced by past advocates for better regulation informs contemporary initiatives to reduce harm from lead discharges.

Significant, albeit slow, progress has been made in one arena, with the African-Eurasian Migratory Waterbirds Agreement providing an important international driver for national policy change amongst its 75 Contracting Parties. The call by the 120 Parties to the Convention on Migratory Species in 2014 to ***"Phase-out the use of lead ammunition across all habitats (wetland and terrestrial) with non-toxic alternatives within the next three years…"*** provided important global recognition of the issue. It will be important to make rapid progress to this end to avoid prolonging unnecessary poisoning of wildlife at risk.

Key words: *Lead, legislation, petrol, paint, fishing weights, gunshot, ammunition, waterbirds, poisoning, wetlands, UK, AEWA, CMS*

NARRATIVE

Lead toxicology

Lead is a highly toxic poison that affects most body systems, resulting in death at high exposures, and a range of adverse physiological and behavioural impacts at lower exposures. There is no safe threshold of exposure. Unlike many other trace metals it has no physiological function. It acts as a neurotoxin, affecting multiple aspects of animal (and thus human) behaviour and causing brain damage at low levels of exposure in the absence of other symptoms. Developing individuals (children) are particularly at risk (Flora *et al.* 2012).

Its physical properties *i.e.* density, malleability, low melting point, tensile strength and resistance to corrosion in particular – together with availability and relative cheapness, has meant that the metal has long been of value to human society. Indeed, our word 'plumbing' derives from the lead's Latin name *plumbus* owing to its use in Roman water supply systems.

Lead in antiquity

The history of environmental pollution by lead is as long as its history of use by human society (Settle and Patterson 1980, Hong *et al.* 1994, Hernberg 2000). Both the Egyptians and Hebrews used lead and the Phoenicians mined the ore in Spain *c.* 2,000 BCE. Hernberg (2000) notes the earliest written account (on an Egyptian papyrus scroll) as a record of homicidal use of lead compounds. Two thousand years ago, lead was in wide and regular use by the Greeks and Romans given its ready accessibility as a by-product of silver production, and the practical consequences of its physical properties. Significant lead production commenced *c.* 5,000 years ago with the discovery of smelting techniques for lead sulphide ores (galena). Its geological co-occurrence with silver (of significance for coinage) resulted in an increasing extent of lead production over the next 2,000 years, with mining and smelting in Spain representing c. 40% of worldwide lead production during Roman times (Hong *et al.* 1994). Roman production has been estimated at 60,000 tonnes per annum for 400 years (Hernberg 2000). The environmental emission of air-borne lead particles from these early Roman mining and smelting activities have given a record of changing deposits not only within the Greenland ice-cap (the first evidence of anthropogenic hemispheric-scale lead pollution (Hong *et al.* 1994)), but also in wetlands across the whole of Europe (Shotyk *et al.* 1998, Renberg 2001). The source has been isotopically distinguished from naturally occurring emissions sources such as sea spray and volcanic eruptions.

Archaeological evidence exists to demonstrate both the significant contamination of local environments with lead (*e.g.* Delile *et al.* 2014), and the toxicity resulting from production and some aspects of use (Waldron 1973, Retief and Cilliers 2005 and references therein). Indeed, the risk of acute poisoning had been recognised by Pliny the Elder in the first century CE: ***"While it is being melted, all the apertures in the vessel should be closed, otherwise a noxious vapour is discharged from the furnace, of a deadly nature, to dogs in particular."*** Pliny noted that lead poisoning was common among shipbuilders, whilst Dioscerides – a physician in Nero's army in the same period – observed that "Lead makes the mind give way."

The main uses of lead at this time were for plumbing; for domestic utensils made from lead and pewter (an alloy of lead and tin) or use of pottery with lead glazes; and as a sweetener used in the production and storage of wine. Lead plates were dipped in wine during fermentation to counter-act the acidity of grape juice, and lead acetate ("sugar of lead") added to sweeten the taste. Use of lead-lined storage vats also resulted in significant concentrations within wine (Waldron 1973, Needleman and Gee 2013).

There is no doubt that there was significant exposure to lead from multiple sources in Roman society. However, the extent to which chronic exposure to lead was significant in the collapse of the Roman civilisation remains academically contested and has been reviewed by Gilfillan (1965), Nriagu (1983) and Retief and Cilliers (2005) among others.

Global lead production fell with exhaustion of Roman lead mines around 2,000 years ago leading to parallel declines in lead concentrations in Greenland ice and European wetlands, presumably related to reduced smelting activity (Settle and Patterson 1980, Hong *et al.* 1994, Shotyk *et al.* 1998, Renberg 2001).

The onset of industrial exposure to lead

Hernberg (2000) and Needleman and Gee (2013) summarise the rise of human exposure to lead over the last millennium. Lead continued to be used in alcohol production, with one of the earliest public health laws in 1498 prescribing the death penalty in some German states for those adding lead sugar to wine. Later US legislation banned the use of lead condensing coils for rum distillation in 1723.

Needleman and Gee (2013) recount the case of the physician Sir George Baker who, in 1768, correctly diagnosed the cause of annual epidemics of colic (with a high case fatality rate), each autumn in Devon, as arising from acute poisoning derived from lead keys within the millstones used to press acidic cider juice (Baker 1772). Yet,

***"Rather than receiving praise for his incisive work, Baker was condemned by the clergy, the mill owners and by fellow physicians: cider was Devon's main export. Baker suffered the fate of many 'early warning' scientists whose inconvenient truths are not welcomed by supporters of the* status quo."**

(Needleman and Gee 2013).

Whilst Ambassador to France (1776-1785), Benjamin Franklin correctly diagnosed different routes of lead exposure amongst different trades and their medical consequences. He concluded:

"This mischievous effect from lead is at least 60 years old; and you will observe with concern how long a useful truth may be known and exist, before it is generally received and practiced on."

(Franklin 1818).

An epidemic of acute population exposure to lead came with the Industrial Revolution not least owing to the ubiquity of lead use in diverse manufacturing processes. Indeed Hernberg (2000) noted that ***"a comprehensive list of exposed jobs would be too extensive"*** to develop.

The nineteenth century saw growing clinical understanding of the causes and consequences of acute lead poisoning, and the wide extent of acute, often fatal, poisoning lent urgency to the need for regulation (Legge and Goadby 1912, Hernberg 2000). Recognising poisoning risks from use of lead glazes, Josiah Wedgewood pressed government for legislative controls through extension of the 1833 Factories Act from textile industries to the potteries. However, opposition from other pottery manufacturers led to a 30 year delay until statutory controls on lead were eventually included within the 1867 Potteries Regulations (Needleman and Gee 2013).

The need to reduce levels of lead poisoning was central to the development of early occupational and public health initiatives from the second half of the nineteenth century as documented by Hernberg (2000).

The histories of regulation to remove lead from paint and from petrol are typical of initiatives to reduce lead exposure from other sources.

Lead in paint

The risks from exposure to paint containing white lead carbonate, or yellow lead chromate additives was first recognised in 1892 and the death of a child from consumption of flakes of leaded paint was diagnosed and reported in 1914 (Thomas and Blackfan 1914). Leaded paint was widely withdrawn in Europe and Australia between 1909 and the 1930s, although with a motivation to prevent occupational exposure to decorators rather than home owners and their children (Needleman and Gee 2013). Many such national initiatives were driven by the national implementation of White Lead (Painting) Convention adopted by the International Labour Organisation in 1921 (Hernberg 2000). This prohibited the use of white lead in indoor painting.

In the UK, Sir Thomas Legge became the first Medical Inspector of Factories in 1898 and did much to focus attention on, and reduce the extent of, industrial lead poisoning (Legge and Goadby 1912). However, he resigned in protest at the British government's refusal to ratify the Convention in 1926. In the USA, the Lead Industries Association managed to block the US government from signing the Convention, such that federal legislation prohibiting indoor uses of leaded paint only came into force in 1972 (Jacobs 1995, Needleman and Gee 2013, Kessler 2014):

"The consequences of this delay have been disastrous"

(Hernberg 2000).

Lead in paint continues to be manufactured, sold and used in many countries. A recent analysis by Kessler (2014) showed use of leaded paints to be legal in 40 countries, many being developing countries, although also including the major emerging economies of Brazil, Russia, India, China, South Africa

STOP PRESS: A global review of the status of phasing out of lead paint was published by SAICM in September 2015: **http://tinyurl.com/nd8svek** and Mexico. Thus, 123 years after recognition of this issue, a significant proportion of the world's population still remains at risk to exposure from lead in paint both in industrial and domestic settings (ICCM 2009).

The Plan of Implementation of the World Summit on Sustainable Development (WSSD) in 2002 called to:

"57. Phase out lead in lead-based paints and in other sources of human exposure, work to prevent, in particular, children's exposure to lead and strengthen monitoring and surveillance efforts and the treatment of lead poisoning."

(WSSD 2002).

Subsequently, in its Resolution II/4 B (May 2009), UNEP's International Conference on Chemicals Management (ICCM) endorsed the establishment of a global partnership (the Global Alliance to Eliminate Lead Paint[1]) to promote the phase out of use of lead in paints as an important contribution to the implementation of paragraph 57.

Lead paint has been identified as a major emerging policy issue by UNEP's Strategic Approach to International Chemicals Management[2] (SAICM), a global policy framework to foster sound management of chemicals (ICCM 2009, 2012). ICCM (2012) noted:

"that lead paint remains widely available in both developing and developed countries. ... although the economic and social costs of eliminating lead paints are minimal and non-lead paints with similar colours, performance characteristics and costs are available. It is of serious concern that the use of lead paint appears to be increasing with economic development and that exposures to lead may continue over many years as paintwork deteriorates or is removed during repainting and demolition."

Lead in petrol

A very significant literature exists on the multiple initiatives to initially reduce levels of, and ultimately remove lead as an additive from petrol (Wilson 1983, Rutter and Jones 1983, Nriagu 1990, Needleman 2000, Tong *et al.* 2000, Landrigan 2002, Wilson and Horrocks 2008, Needleman and Gee 2013). The recent detailed history by Needleman and Gee (2013) gives a detailed and perceptive account especially of the development of the case for regulation in the USA and based on Needleman's personal involvement (also Needleman 2000).

REGULATION OF LEAD IN PETROL IN THE USA

In summary, in 1921 tetra-ethyl lead (TEL) was discovered to be a suppressant of premature ignition of petrol in high compression engines. Its use as a fuel additive eliminated engine 'knock', thus significantly increasing engine performance. However, from the outset it was recognised that the word 'lead' had negative connotations with the public – being associated with poisoning in the public mind – such that TEL was produced and branded as "ethyl" (Needleman and Gee 2013): an early example of brand 'spin'.

Over 300 cases of acute poisoning (including several fatalities) in TEL production factories, and public health concerns as to the implications of use of TEL as a fuel additive, resulted in the early involvement of the US Surgeon General who ultimately organised a high level conference in 1925 between public health officials and industry. Needleman and Gee (2013) give a detailed account of the events leading up to this conference and its conclusions. The immediate outcome was a temporary ban on the sale of leaded petrol whilst an independent committee assessed risks.

After a time-and-data-limited investigation, the Surgeon General's Committee concluded in 1926 that

"at present there are no good grounds for prohibiting the use of ethyl gasoline … provided that its distribution and use are controlled by proper regulations"

(Needleman and Gee 2013).

Important caveats however, highlighted the incompleteness of available data, the poorly-understood risks of long-term exposure to low levels of lead, and the need for continued research to better understand these issues: ***"this investigation must not be allowed to lapse."*** However, the US Public Health Service never undertook further investigations and for the next 40 years substantially all studies into the health impacts of TEL were conducted and funded by the industry *i.e.* Ethyl Corporation, E.I. DuPont and General Motors (Needleman and Gee 2013).

Much of the debate within the Committee and the earlier Conference had centred around the nature of risk and where the burden of proof lay – with manufacturers to demonstrate that their product (TEL) was safe, or with the health sector to demonstrate that their product was unsafe. These issues were to be repeatedly revisited in future debates.

[1] Global alliance to eliminate lead paint http://www.unep.org/chemicalsandwaste/hazardoussubstances/LeadCadmium/PrioritiesforAction/GAELP/tabid/6176/Default.aspx [2] Strategic Approach to International Chemicals Management http://www.saicm.org/

Better understanding of exposure levels came with the pioneering research of Clair Patterson in the 1960s who showed that contemporary lead body burdens were then 600 times higher than in pre-industrial humans (Patterson 1965, Settle and Patterson 1980) and that nearly all modern environments were widely contaminated with lead – at levels which were far from 'normal'.

Through the late 1960s and into the 1970s, medical studies were starting to focus in detail on the effects of chronic exposure to low levels of lead, especially on children, although the TEL industry were quick to dismiss early research owing to methodological deficiencies (Wilson 1983). However, the meticulous investigation of Needleman *et al.* (1979) was undertaken to the highest methodological standards, and convincingly demonstrated significant statistical correlations between lead exposure (as measured by dentine lead levels) and a range of educational and psychological deficits in schoolchildren. Multiple further studies followed confirming and elaborating these findings of low-level effects on human development (*e.g.* Rutter and Jones 1983, Needleman and Gatsonis 1990).

In response to this growing medical evidence, 'safe' levels of lead in the USA (as determined by the Centers for Disease Control and Prevention (CDC)) were lowered progressively from a concentration in whole blood of 60 μg/dl in 1960, to 40 μg/dl and then 30 μg/dl in the 1970s, to 25 μg/dl in the 1980s, 10 μg/dl in the early 1990s, and most recently to 5 μg/dl in 2012 (CDC 2012).

The main political driver to address the issue of TEL in petrol in the USA came, not primarily from health impacts, but from the need to install catalytic converters to comply with the 1970 Clean Air Act. Since lead 'poisons' the platinum catalyst, there was a need to eliminate it from petrol. However, health impacts had also been recognised and the Environmental Protection Agency (EPA) feared that technological developments might develop non-platinum catalytic converters in the future. Accordingly, EPA released Regulations requiring the phased reduction of lead in petrol on health grounds also. Industrial interests challenged these all the way to the Supreme Court, where ultimately they lost, strengthening the EPA's regulatory position. Issues of risk, cumulative exposure and proportionality of regulatory responses were central to these cases (Needleman 2000, Needleman and Gee 2013).

REGULATION OF LEAD IN PETROL IN THE UK

Both research and regulation addressing lead in petrol in the UK lagged behind that in the USA and Japan (the first country to regulate against TEL) and is described by Millstone (2013). In essence, governmental policy development was strongly influenced by industrial pressure and justified on the basis of scientific uncertainty, despite growing research evidence from UK studies as well as the significant body of research from the USA.

In the UK, progress towards lead-free petrol started to develop momentum with the launch in January 1981 of the pressure group, the Campaign for Lead-free Air (CLEAR). This influentially brought together a very wide range of social interests including mothers groups, five political parties, trade unions, environmental health officers, schools, environmentalists and many others (including 60% of General Practitioners and 90% of the public both determined by polls (Wilson 1983)) to lobby for the elimination of lead from petrol. From the outset, CLEAR's position was to argue from the basis of best science, both presenting syntheses of that knowledge to the public (*e.g.* Wilson 1983) and bringing together key scientists to share new data and information (Rutter and Jones 1983).

Although other national reviews (*e.g.* Jaworski 1978) had reached quite different conclusions, up until then, UK Government reviews had down-played the significance of the issue:

"We have not been able to come to clear conclusions concerning the effects of small amounts of lead on the intelligence, behaviour and performance of children."
(Lawther 1980).

However, three years later, the substantial and independent review of evidence by the Royal Commission on Environmental Pollution came to quite different conclusions:

"We are not aware of any other toxin which is so widely distributed in human and animal populations and which is also so universally present at levels that exceed one tenth of that at which clinical signs and symptoms occur."
(RCEP 1983).

The Commission made 29 recommendations including the need to urgently phase out lead in petrol, the need to change European Directive 78/611/EEC (which set a minimum level of lead in petrol), and the banning of lead shot and lead fishing weights (below). Given the major pressure from civil society (as documented by Wilson 1983) the UK Government rapidly

"accepted the Royal Commission's recommendation that, as a further logical step [to ongoing reduction of levels of TEL], the remaining lead in petrol should be phased out as soon as practicable throughout the European Community. … The Government believe that the Royal Commission's target date of 1990 for the introduction of unleaded petrol throughout the EC is a reasonable one to aim at – and improve upon if possible."
(Department of the Environment 1983).

However, despite that, it actually took 17 more years before leaded petrol was withdrawn from UK forecourts in 2000 (Lean 1999).

Change away from leaded petrol only commenced in 1987 with the introduction of preferential tax rates for unleaded fuel. At this point

"UK was one of the last industrialised countries to embrace unleaded petrol"
(Millstone 2013).

Millstone also notes the cessation of systematic official monitoring of lead levels in British children at the time of this policy change such that

"the beneficial effects of phasing out leaded petrol in the UK have been only fragmentarily documented."

GLOBAL ELIMINATION OF LEAD IN PETROL

Whilst most industrialised countries have followed in regulating against lead in petrol, it continued to be sold in many developing or other countries. In view of its continuing use, the 2002 World Summit on Sustainable Development (WSSD) urged the need to:

"56. Reduce respiratory diseases and other health impacts resulting from air pollution, with particular attention to women and children, by:
… (b) Supporting the phasing out of lead in gasoline; …"

The UNEP-led Partnership for Clean Fuels and Vehicles[3] was launched after the WSSD and has continued to promote global change to unleaded petrol and reduce or eliminate other vehicular pollutants such as sulphur, developing a regulatory tool kit[4] and other support tools for national use. As at January 2015, only Algeria, Yemen and Iraq still have leaded fuel available alongside unleaded petrol, with Afghanistan, North Korea and Myanmar removing it from sale in 2014.

Contemporary human exposure to lead

Whilst great progress has been made to eliminate population exposure to lead in developed countries through comprehensive regulations aimed at public and occupational health, very large numbers remain exposed to significant levels of lead in developing countries. In 2004, WHO (2010) estimated that 16% of children worldwide have blood lead levels above 10 µg/dl. Hernberg (2000) notes that these facts are linked:

"Unfortunately, part of the improved situation in the developed countries is due to the fact that dangerous industries, such as ship breaking, secondary lead smelting, [electronic wastes – Huo et al. *2007] and manufacturing of storage batteries, have been relocated to developing countries."*

How rapidly progress will be made will depend on the extent of high level political support for public health objectives and the transposition of this into national policies and regulations. The history of initiatives to reduce population exposure to lead through better regulation is one in which vested interests have fought to maintain the *status quo*, including sometimes through use of corrupt practices, seeing regulation and change as a threat to their economic interests (Wilson 1983, Nriagu 1990, Hernberg 2000, Needleman 2000, EEA 2001, 2013, Michaels 2008, Wilson and Horrocks 2008, Leigh *et al.* 2010, Millstone 2013, Needleman and Gee 2013).

"We must not let history repeat itself by neglecting effective prevention where it is most needed. It is a shame if action is not taken when all the ingredients for successful prevention exist."
Hernberg (2000).

Lead poisoning of wildlife: regulation of lead fishing weights in the UK

At the same time as the debate on lead in petrol was occurring in the UK (late 1970s), significant acute and chronic poisoning of mute swans *Cygnus olor* was demonstrated following ingestion of discarded lead fishing weights, especially on English lowland rivers (NCC 1981, Sears and Hunt 1991). In some instances, this was contributing to population-scale declines (Hardman and Cooper 1980). Following a request from Ministers in March

[3] UNEP Partnership for Clean Fuels and Vehicles http://www.unep.org/transport/new/pcfv/
[4] UNEP PCFV regulatory tool kit http://www.unep.org/Transport/new/PCFV/RegulatoryToolKit/index.html

1979, the Nature Conservancy Council (NCC) established a Working Group with a wide membership of interested parties to review the evidence.

The Working Group's report was published in December 1981 (NCC 1981) and its recommendations were particularly aimed at raising awareness within the angling community, and sought to eliminate poisoning by voluntary approaches. A priority recommendation however, was that:

"The Working Group would like to see the phasing out of split-lead shot within five years" and that ***"We further recommend that the Nature Conservancy Council should review the position in 1984 to establish how far this programme [of voluntary phase-out] has met with success. Should lead be found at that time to be still widely in use then further consideration should be given to securing the phasing-out of lead in angling."***

As subsequently for lead gunshot (below), a voluntary approach proved ineffective, with continuing waterbird poisoning occurring through the early 1980s. In April 1983, the Royal Commission for Environmental Pollution recommended that:

"22. Urgent efforts should be made to develop alternatives to lead shot and lead fishing weights.
23. As soon as these alternatives are available, the Government should legislate to ban any further use of lead shot and fishing weights in circumstances where they are irretrievably dispersed in the environment."
(RCEP 1983).

The government response to the Royal Commission was to support these recommendations:

"The Government hope that a withdrawal of lead can be achieved by voluntary means, but legislation will be considered if necessary."
(Department of the Environment 1983).

Continuing public concern resulted in Parliamentary debate (Hansard 1984). The NCC undertook a further review in January 1985 and estimated that up to 4,000 mute swans were still dying annually from lead fishing weight ingestion (NCC 1985). Given this further assessment, the UK government announced in July 1985

"that it would be prepared to introduce regulations to control the sale and import of lead shot for fishing from January 1987 if voluntary measures failed."
(NCC 1985)

In due course, The Control of Pollution (Anglers' Lead Weights) Regulations 1986 (HMSO 1986) came into force on 1 January 1987 banning the import and supply of lead fishing weights except dust shot (weighing <0.06 g) and large weights (>28.35 g). This, and the introduction of Regional Water Authority byelaws the following year, greatly reduced waterbird exposure to lead fishing weights and led to recovery of mute swan populations (Rowell and Spray 2004). However, post-ban monitoring between the mid 1990s and 2001 showed significant levels of blood lead levels in mute swans in England attributed to possible continued ingestion of long-discarded lead weights, illegal use of lead weights or legally used dust shot (Perrins *et al.* 2003).

Regulation of lead in ammunition

The history of the recognition of poisoning of wild birds through the ingestion of spent lead shot is summarised by Pain *et al.* (2015). Earliest regulatory steps to eliminate this risk were undertaken in the USA, with progressive regulation from 1971 until 1991/92 when a nationwide non-toxic shot requirement for waterfowl hunting became effective (Morehouse 1992). Legal challenges to these restrictions (six lawsuits and four appeals) ultimately strengthened the federal government's case to regulate on this issue (Anderson 1992).

The convening of an international workshop by the International Waterfowl and Wetlands Research Bureau (IWRB) in June 1991, which brought together over 100 participants from 21 countries, was fundamental to giving focus to the issue and initiating new policy initiatives within European countries. The detailed recommendations from that meeting (Pain 1992) charted a clear course to replace lead gunshot with non-toxic alternatives, but also addressed the problematic issues of implementation of such a policy, stressing the need to work with, and through, interested stakeholders.

UK REGULATIONS CONCERNING USE OF LEAD GUNSHOT IN WETLANDS

The UK response to the IWRB initiative was to convene a meeting of interested parties in September 1991 chaired by the Joint Nature Conservation Committee. This became the Lead Shot in Wetland Areas Steering Group which met annually for the next seven years. A Lead in Waterfowl Working Group, chaired by Department of the Environment (DoE), was established and met up to four times a year until 1997 to advise the Steering Group and government (Table 1). It members formally represented different sectors (footnote 2 to Table 1). With 46 organisations contributing to the Steering Group's deliberations (footnote 1 to Table 1), the advisory process was fully inclusive.

Following recommendations from the Working Group, at first a voluntary approach to phasing out use of lead shot in wetlands was promoted. When it became clear that this approach was of limited effectiveness, government announced that it would legislate to ban lead shot use in wetlands in order to comply with obligations under the African-Eurasian Migratory Waterbirds Agreement (AEWA) which, by this time, the UK had ratified (see below; Table 1).

Different legislative approaches were adopted in the constituent countries of the UK (Table 1). England and Wales banned the use of lead shot over all foreshore, over specified Sites of Special Scientific Interest (SSSIs), and for the shooting of all ducks and geese, coot *Fulica atra* and moorhen *Gallinula chloropus*, wherever they occur. In Scotland and Northern Ireland, lead shot was prohibited from use on or over any area of wetland for any shooting activity, with wetlands defined according to the Ramsar Convention's definition.

Table 1: **UK timetable relating to the voluntary phasing out and subsequent statutory regulation of lead gunshot in wetlands.**

Year	Lead Shot in Wetland Areas Steering Group †	Lead in Waterfowl Working Group ††	Statutory responses
1991	June: IWRB workshop on *'Lead Poisoning in Waterfowl',* Brussels (Pain 1992). September: first meeting of interested parties convened by Department of the Environment (DoE). Establishment of Working Group (WG) as a sub-group of the Steering Group.	October: Meeting of WG.	
1992	October: second meeting receives annual report from WG. Agrees five year programme of work – three years to develop suitable lead-free alternatives followed by a two year voluntary ban on the use of lead shot in 12-bore guns in wetlands.	January, May, September & December: WG meetings.	
1993	October: third meeting receives annual report from WG.	February, September & December: WG meetings DoE fund establishment of experimental ballistics research facility at University College London (UCL) to assist evaluation of non-toxic cartridges.	February: DoE issue press notice reporting WG advice – *"Lead shot should not be allowed to fall into coastal and inland wetlands where it might cause lead poisoning of waterfowl.* *Accordingly, wildfowl and wader shooting with lead shot should not take place over estuaries, salt marshes, foreshore, lakes, reservoirs, gravel pits, ponds, rivers, marshes and seasonally flooded land (river flood plains, water meadows, and grazing marshes).* *Since shot gun pellets can travel up to 300 m, such shooting should not take place within 300 m of the edge of the wetland concerned if it would result in the deposition of lead shot within it."*
1994	October: fourth meeting receives annual report from WG. Issues formal message: *"The gun and ammunition industry has indicated that safe, effective alternatives for 12-bore shooting are likely to be available in reasonable quantities by September 1995. After this time people are encouraged not to use lead in 12-bores where it would pose a threat to waterfowl. After September 1997, an effective ban on the use of lead in wetland areas is sought."*	March, June, September & December: WG meetings.	English Nature (EN) agree policy to ban use of lead 12-bore cartridges on National Nature Reserves (NNRs) where EN control the shooting from September 1997, with a ban on other gauges from September 1998. On other NNRs or adjacent land EN will encourage use of non-toxic shot from September 1997.

Year	Lead Shot in Wetland Areas Steering Group †	Lead in Waterfowl Working Group ††	Statutory responses
1995	October: fifth meeting receives annual report from WG.	March, June, August & December: WG meetings February, March & July: meetings of Public Relations sub-group to develop outreach materials for voluntary phase-out.	Scottish Natural Heritage and Countryside Council for Wales (CCW) agree • To encourage use of non-toxic shot during the two year voluntary phase-out period, but require from September 1997 the use of non-toxic shot as a condition of permits to shoot on all wetland NNRs. • Staff requirement to use non-toxic shot from September 1995. • Restriction of lead-shot use on SSSI *via* Potentially Damaging Operation lists for all wetland SSSIs notified or re-notified after September 1997. Start of two year voluntary phase-out (1995/6 & 1996/7 shooting seasons): *"After September 1995 shooters are encouraged not to use lead in 12-bores where it would pose a threat to waterfowl."*
1996	October: sixth meeting receives annual report from WG.	February, July & December: WG meetings. UCL reports on ballistics facility (Giblin & Compton 1996) January & April: meetings of Public Relations sub-group to develop outreach materials for voluntary phase-out.	Second year of voluntary phase-out period.
1997	June: seventh meeting. Proposes that voluntary phase-out should continue for a further year (1997/8 shooting season).	February & June: WG meetings.	*"After September 1997, an effective ban on the use of lead in wetland areas is sought."* Following consultation with interested parties (March-April), in August Ministers determine that voluntary phase-out will be extended for a further (third) year July: EN issue guidance note to staff on phasing out lead shot cartridges August: CCW require lead-free cartridges for shooting on NNRs December: UK government *"are considering the best legislative options to prohibit the use of lead shot over wetlands in the United Kingdom."* (Lords Hansard, 18 December, col. WA 109)[5].
1998	March: eight meeting cancelled in light of active work by government to prepare draft legislation (DETR 1999); annual meetings suspended.	March: WG suspended by DETR.	Exploration of options within government.

[5]Lords Hansard, 18 December, col. WA 109 http://www.publications.parliament.uk/pa/ld199798/ldhansrd/vo971218/text/71218w03.htm

Year	Lead Shot in Wetland Areas Steering Group †	Lead in Waterfowl Working Group ††	Statutory responses
1999			April-May: Public consultation on potential legislation in Great Britain (DETR 1999). **England:** The Environmental Protection (Restriction on Use of Lead Shot) (England) Regulations 1999 (from 1 September 1999) (HMSO 1999). The Environmental Protection (Restriction on Use of Lead Shot) (England) (Amendment) Regulations 2002 (from 1 September 2002) (HMSO 2002a). Environment Protection (Restrictions on Use of Lead Shot) (England) (Amendment) Regulations 2003 (from 31 October 2003) (HMSO 2003).
2002			**Wales:** Public consultation followed by The Environmental Protection (Restriction on Use of Lead Shot) (Wales) Regulations 2002 (from 1 September 2002)(HMSO 2002b).
2004			**Scotland:** Public consultation followed by The Environmental Protection (Restriction on Use of Lead Shot) (Scotland) Regulations 2004 (never came into force) (HMSO 2004a). The Environmental Protection (Restriction on Use of Lead Shot) (Scotland) (No.2) Regulations 2004 (from 31 March 2005) (HMSO 2004b). The Environmental Protection (Restriction on Use of Lead Shot) (Scotland) Amendment Regulations 2013 (from 31 January 2014) (HMSO 2013) .
2009			**Northern Ireland:** Public consultation followed by The Environmental Protection (Restriction on Use of Lead Shot) Regulations (Northern Ireland) 2009 (from 1 September 2009) (HMSO 2009).

† **The Lead Shot in Wetland Areas Steering Group involved:** Joint Nature Conservation Committee (JNCC: Chair and Joint Secretariat); Department of the Environment (DoE)/Department of the Environment, Transport and the Regions (Joint Secretariat); Agricultural Development and Advisory Service; AFEMS (European Sporting Ammunition Manufacturers Association); British Proof Authority; British Association for Shooting and Conservation (BASC); British Field Sports Society; Central Science Laboratories, Clay Pigeon Shooters Association; Country Landowners Association; DEVA; Eley Hawk Ltd.; English Nature; Environment and Heritage Service of the Department of the Environment Northern Ireland; Environment Agency; FACE (Federation of Hunting Associations of the EEC); Game Conservancy Trust; Gamebore Cartridge Co.; Gunmark Ltd.; Gun Trade Association; Kent Cartridge Co.; Home Grown Timber Growers Advisory Committee; Home Office Forensic Laboratory; Hull Cartridge Co.; IWRB; London Proof House; Ministry of Defence; Ministry of Agriculture, Fisheries and Food; National Farmers Union; National Rivers Authority; National Trust; Royal Military College of Science; Royal Society for the Protection of Birds; Royal Society for the Prevention of Cruelty to Animals; Scottish Association for Country Sports; Scottish Natural Heritage; Scottish Office Environment Department; Shooting Sports Trust (SST); Taylored Shot; The Proof Houses; Timber Growers Association; Tour du Valet; UK Loaders Association; University College London; Welsh Office; Wildfowl & Wetlands Trust (WWT).

†† **The Lead in Waterfowl Working Group comprised:** DoE (Chair and Joint Secretariat); JNCC (Joint Secretariat); BASC (representing shooting interests; Gamebore Cartridge Co. (representing cartridge manufacturers); Gun Trade Association (representing the gun trade); London Proof House (the British Proof Authority); SST (representing gun manufacturing interests); WWT (representing conservation interests). Other joined as invited participants according to the agenda.

INTERNATIONAL RESPONSES

The Standing Committee of the Convention on the conservation of European wildlife and natural habitats (Berne Convention) was the first multi-lateral environmental agreement to respond to the outcome of the 1991 IWRB workshop. Meeting in December that year it ***"Recommended"*** Contracting Parties to ***"take steps to phase out the use of lead gunshot in wetlands or waterfowl hunting as soon as possible"*** as well as undertake a range of supporting activities (Table 2). It has periodically revisited the issue, stimulating an important review of evidence in 2004 (Bana 2004).

The need to address lead shot poisoning was seen as a central issue during the negotiation of AEWA in the early 1990s. The final Agreement text agreed in 1995 called on Parties to ***"... endeavour to phase out the use of lead shot for hunting in wetlands by the year 2000."*** Since then, the exact nature of the target has changed as each target has passed (Table 2), but the goal has remained, that use of lead gunshot in wetlands should be eliminated. Indeed, the issue was central to the fourth Meeting of Parties in 2008, with a range of technical and advocacy materials being used at, produced for and following, that meeting (*e.g.* Beintema 2004, AEWA 2009). AEWA has further supported a range of training workshops in those regions where there has been little move towards use of non-toxic shot.

The agreement of the EU Sustainable Hunting Initiative[6], an initiative of the European Commission and a formal partnership between it, BirdLife International (BLI) and FACE (the European Federation of Hunting Associations) in 2004, has been helpfully supportive of AEWA objectives:

"Both organisations [BLI and FACE] ask for the phasing out of the use of lead shot for hunting in wetlands throughout the EU as soon as possible, and in any case by the year 2009 at the latest."

Most recently, the 11th Conference of the Parties to the Convention on Migratory Species (in Resolution 11.15) called on Parties to ***"Phase-out the use of lead ammunition across all habitats (wetland and terrestrial) with non-toxic alternatives within the next three years with Parties reporting to CMS COP12 in 2017, working with stakeholders on implementation."*** This is a more comprehensive target than AEWA, reflecting: the wider taxonomic scope of CMS; the need to eliminate poisoning risk to large raptors arising from use of lead bullets; and acknowledging that lead ammunition poses a risk to birds in both wetland and terrestrial habitats.

Table 2: **International decisions concerning lead poisoning and wildlife.**

Decision	Content	Comment
Convention on the conservation of European wildlife and natural habitats		
1991 – Standing Committee Recommendation No. 28 (Convention on the conservation of European wildlife and natural habitats 1991)	*"Take steps to phase out the use of lead gunshot in wetlands or waterfowl hunting as soon as possible."* *"Establish and adhere to a schedule for the replacement of lead shot by non-toxic alternatives, so that manufacturers and dealers may plan their programmes accordingly."*	
African-Eurasian Migratory Waterbirds Agreement		
1995 – Text of AEWA's Action Plan	*"Parties shall endeavour to phase out the use of lead shot for hunting in wetlands by the year 2000."*	
1999 – First Meeting of Parties – Resolution 1.14 (AEWA 1999)	*"Parties shall endeavour to phase out the use of lead shot for hunting in wetlands by the year 2000."* Call for elaborated guidance to phase out lead gunshot in wetlands.	

[6] EU Sustainable Hunting Initiative http://ec.europa.eu/environment/nature/conservation/wildbirds/hunting/charter_en.htm

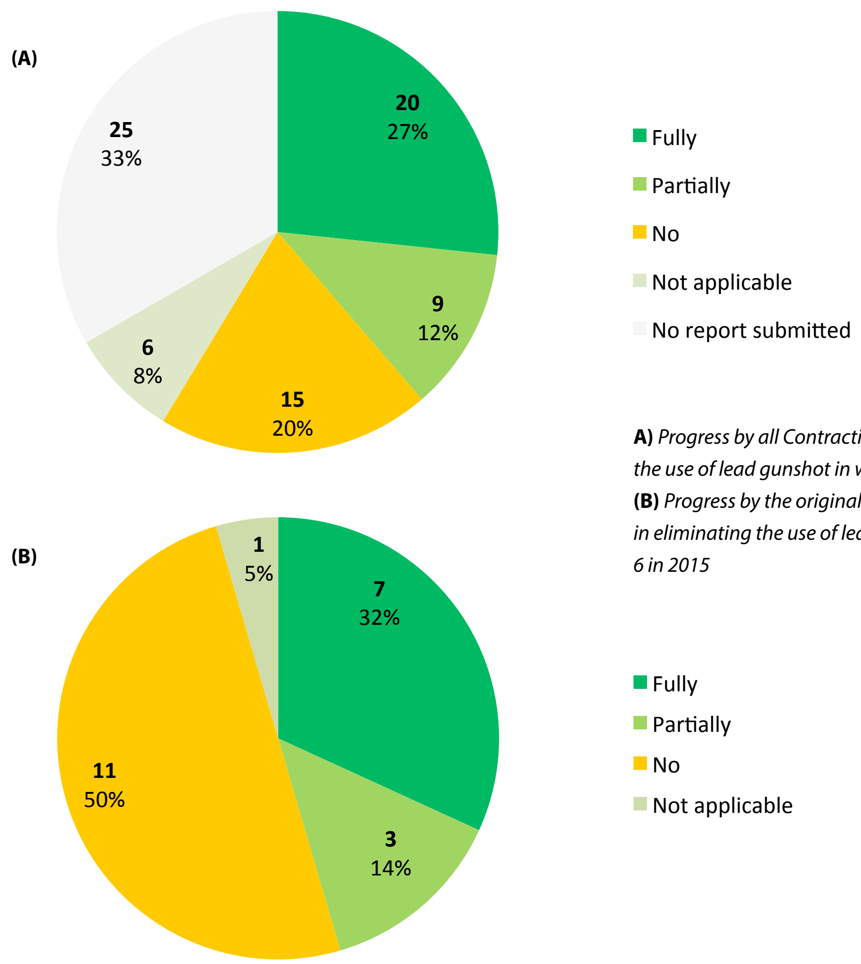
Decision	Content	Comment
African-Eurasian Migratory Waterbirds Agreement		
2002 – Second Meeting of Parties – Resolution 2.2 (AEWA 2002)	*"implementation of … still highly insufficient in the majority of Range States"* *"report to each MoP on progress … in accordance with self-imposed and published timetables"* .	Target changed from 2000 (by then already passed) to 'self-imposed timescales' in each Party.
2008 – Fourth Meeting of Parties - AEWA Strategic Plan 2009-2017 (AEWA 2008)	By 2017 the use of lead shot for hunting in wetlands is phased out by all Contracting Parties.	Target year re-instated – now 2017
2012 – Fifth Meeting of Parties – Resolution 5.23 (AEWA 2012)		Implement Targets for Strategic Plan Objective 2: 2.1 By 2017 the use of lead shot for hunting in wetlands is phased out by all Contracting Parties, Parties should: • Evaluate the effectiveness of national measures already taken to phase out the use of lead shot and to phase in non-toxic alternatives in wetlands; and • Engage with all relevant stakeholders, *inter alia* hunters and the manufacturing industry, to understand and address barriers to implementation; and to establish and implement joint communication strategies, ...
European Union Directive on the conservation of wild birds		
2004 – 25th anniversary conference of the Birds Directive (Council of the European Union 2004)	*"Aim to phase of the use of lead shot in wetlands as soon as possible and ultimately by 2009."*	Subsequent debates in the Directive's 'Ornis Committee'
Convention on Migratory Species		
2014 – Eleventh Conference of the Parties – Resolution 11.15 (UNEP-CMS 2014a, 2014b)	*"Phase-out the use of lead ammunition across all habitats (wetland and terrestrial) with non-toxic alternatives within the next three years with Parties reporting to CMS COP12 in 2017, working with stakeholders on implementation."* *"Phase-out the use of lead fishing weights in areas [high risk areas and replace] with non-toxic alternatives, within the next three years with Parties reporting to CMS COP12 in 2017, …"*	

Progress towards phasing out lead gunshot in wetlands

Triennial national reporting on the implementation of AEWA allows assessment of progress towards the objective of phasing out the use of lead gunshot in wetlands. Figure 1a presents the situation as at 2015 with information drawn from an analysis of national reports for the sixth Meeting of Parties (MOP 6) (AEWA 2015).

Simple proportions of all Parties are potentially misleading since, Range States (countries within the Agreement area) have progressively joined the Agreement over time. Whilst there were 22 Contracting Parties at MOP 1 in 1999, at MOP 6 (2015) there were 75. Thus it is perhaps unsurprising that recently acceding Parties have yet to phase out use of lead shot in wetlands. Yet, of the original 22 Parties of MOP 1, 11 (50%) have yet to legislate against lead gunshot in wetlands (Figure 1b). However, of those with no progress since 1999, 9 are African states with likely little recreational use of shotguns in wetlands, whilst Romania and Senegal both indicated to AEWA in 2012 that bans were under consideration.

Analysis of the best available information shows steady but (very) slow progress towards the goal of eliminating lead gunshot from wetlands around the world (Figure 2). By 2015, 23 countries are known to have prohibited the use of lead gunshot in wetlands, with a further 10 having partial bans (such as bans related just to Ramsar Sites or within one or more entities of a federal state). Further countries are in the process of introducing legislation or are formally considering the issue. The call to Convention on Migratory Species Parties from COP 11 (Table 2) adds further pressure for action.



A) *Progress by all Contracting Parties to AEWA in eliminating the use of lead gunshot in wetlands as at 2015;*
(B) *Progress by the original 22 Contracting Parties at MoP 1 in eliminating the use of lead gunshot in wetlands by MOP 6 in 2015*

Figure 1: **Progress made by Contracting Parties to AEWA in eliminating lead gunshot in wetlands.** *See legend for details.*

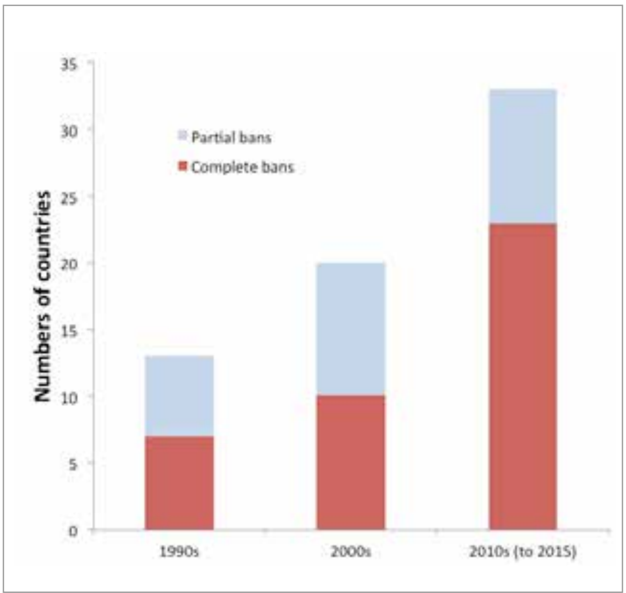


Figure 2: **Progress towards eliminating the use of lead gunshot in wetlands world-wide.** *Partial bans include situations where some progress has been made but a complete national ban has yet to be achieved. Data from Fawcett and van Vessem (1995), Kuivenhoven and Van Vessem (1997), Beintema (2004), and AEWA (2015).*

CONCLUSIONS

As with many other pollutants, the regulation of lead in the environment has typically lagged (many) decades after the recognition of its impacts, whether to the health of humans or wildlife. Indeed, leaded paint and leaded petrol remains in use in some countries over a century after the recognition of the toxicity of the former and *c.* 80 years after the appreciation of TEL toxicity. Exposure to lead from multiple sources continues despite recognition of the problem at the highest levels. The Governing Council of the United Nations Environment Programme adopted a decision in 2003 in which it:

"6. Appeals to Governments, intergovernmental organizations, non-governmental organizations and civil society to participate actively in assisting national Governments in their efforts to prevent and phase out sources of human exposure to lead, in particular the use of lead in gasoline, and to strengthen monitoring and surveillance efforts as well as treatment of lead poisoning, by making available information, technical assistance, capacity-building, and funding to developing countries and countries with economies in transition."

(UNEP 2003)

The development of regulations to address pollution that has health or environmental impacts, especially when industrially-derived, has always been problematic. This has typically led to 'late lessons from early warnings' as explored in detail by EEA (2001, 2013).

Development and acceptance of better, risk-reducing, regulations typically face two impediments to change: the opposition of vested interests (typically economic and/or political, as described by Michaels (2008) and Oreskes and Conway (2010)), and a reluctance to accept the need for change by stakeholders or wider society – often resulting in the failure of voluntary approaches to encourage change.

The role of economic interests in slowing the development and implementation of better regulation has been documented in many of the sources given in this paper but, perhaps typically, Wilson and Horrocks (2008) gives a detailed assessment of the multiple factors which long-delayed the removal of lead from New Zealand's petrol.

In some situations, public can readily embrace the need for better regulation. Thus Wilson (1983) documents the campaign to remove lead from petrol in the UK which, in 1983, had a massive cross-section of British civil society aligned against the government, the petroleum and lead industries, and car manufacturers. Yet in other situations, such as the encouraged voluntary phase-outs of lead fishing weights in the 1980s and of lead gunshot over wetlands in the 1990s, stakeholders have resisted change. Such response has an extensive sociological literature, especially in the context of climate change denialism (*e.g.* McCright and Dunlap 2011, Washington and Cook 2011). Cromie *et al.* (2015) reviews the issue further in the context of the continuing high levels of non-compliance with UK lead gunshot regulations.

Several common themes emerge from the history of removal of lead in petrol (Table 3). Many types of argument used by industrial advocates of leaded petrol in the 1960s and 1970s are not dissimilar to those currently adopted today against the change away from toxic lead ammunition.

Table 3: **Common issues faced by advocates of better regulation to reduce lead poisoning.**

	Examples from lead in petrol debates
1. Denial of the issue – *'There isn't an issue that needs to be addressed.'*	*"Potential health hazards in the use of leaded gasoline ... while well worth investigating, were hypothetical in character."* Kehoe cited by Nickerson (1954) in Nriagu 1990. *"Lead was described as "a naturally occurring toxin, as are alcohol, sugar and salt."* Associated Octel 1995 cited by Wilson and Horrocks 2008. *"There is no evidence, however, that airborne lead from petrol has been the cause of ill health in any group of the general population, even in towns with heavy traffic..."* Turner 1981, Associated Octel. *"In 1986 The Minister of Energy went even further in claiming that there was no proven link between lead in gasoline and lead in people in New Zealand. In stark contrast, a review in the same year (by a New Zealand scientist) concluded that a third of blood lead came from lead additives."* Wilson and Horrocks 2008.
2. Challenging the science – *'There may be a theoretical issue but the science shows there isn't a problem.'*	*"The search for a solid, factual scientific basis for claims against lead has produced nothing of substance ... Normally attacks on lead have focussed on changes that lead emissions from auto exhausts are a health hazard to the public, or that lead-free gasoline is necessary to meet automobile emission requirements of the US Clean Air Act of 1970. Neither charge is founded fact. Scientific evidence does not support the premise that lead in gasoline poses a health hazard to the public, either now or in the foreseeable future."* Cole *et al.* 1975 cited by Nriagu 1990. *"**[Senator] Muskie:** Does medical opinion agree that there are no harmful effects and results from lead ingestion below the level of lead poisoning?* ***Kehoe:*** *I don't think that many people would be as certain as I am at this point.* ***Muskie:*** *But are you certain?* ***Kehoe:*** *... It so happens that I have more experience in this field than anyone else alive. ... The fact is, however, that no other hygienic problem in the field of air pollution has been investigated so intensively, over such a prolonged period of time, and with such definitive results."* Dialogue from Senate Subcommittee on Air and Water Pollution hearings on the US Clean Air Act, 1966 quoted by Needleman 2000.
3. Studies have not been undertaken in this country – *'Research from other countries is not relevant.'*	*"New Zealand [NZ] authorities discounted the relevance of international research by their continued insistence that NZ was relatively free of air pollution, or well "ventilated" as one put it. In 1987, the Chief Air Pollution Control Officer for the Health Department asserted that the density of motor cars per square kilometre was low in NZ, thereby implying that motor vehicle pollution was of limited significance. This view completely ignored the high urban density of vehicles."* Wilson and Horrocks 2008.

	Examples from lead in petrol debates
4. Ultimately accepting the science but denying its implications for the issue – *'Even if the science demonstrates measurable effects, it's not actually causing any damage.'*	*"It was misleading at best and fraudulent at worst to talk about the symptoms and horrors of lead poisoning. That is just like talking about the horrors of gassing World War I soldiers with chlorine at a hearing as to whether we should chlorinate to purify drinking water."* Blanchard cited by Stein 1982 in Needleman 2000.
5. Resisting change on the basis of no alternatives, cost *etc.* – *'Even if there is demonstrated damage, then we just have to live with it because there are no alternatives; it's too difficult/expensive to change* etc.'	*"Even when there was subsequently evidence for adverse impacts on children from a longitudinal study in New Zealand, this appeared to have little or no impact on the policy process."* Wilson and Horrocks 2008. *"The amount of extra lead we get from pollution by exhaust gases is comparatively very small. I accept that we should be better without it, but if we do without it we have to use a lower octane petrol; we therefore have to have lower compression engines. These factors bring other problems in their wake. It is a matter of economics and sense."* Lord Mowbray and Stoughton 1971.
6. Once change is inevitable, rapid acceptance by interest groups and denial that there was any problem – *'Not sure what all the fuss was about as it's quite possible to produce cars than run on unleaded petrol; guns that use non-toxic shot; angling tackle that use non-toxic weights* etc.'	*"On January 1 [1976] the legal limit of lead in petrol in Germany was reduced to 0.15 grams per litre, well below that which the DoE accept British industry cannot reasonably be asked to go. ... Oil companies throughout the world have been unanimous on the perils of what Germany has done. These are:* ... *(5)* ***Excessive wear and tear. Unlikely.*** *German petrol companies are now fervent in their assurances to motorists that the new petrol will not harm their engines as they once were in their threat that it would."* Ottaway and Terry 1976.

It is clear that making faster progress to eliminate the risk to wildlife from lead would benefit from more insight into behavioural change theories and the use of more sophisticated ways of 'selling' the need for change to stakeholders. This will help move the understanding and behaviour of people (including both the public and those with influence in decision/policy making processes).

In this regard, the 'invisible' nature of lead poisoning of wildlife, with affected animals seldom being seen by the public, unfortunately reinforces resistance to what is seen as unnecessary change. Lead is not a 'spectacular' cause of death in the way that acute episodes of oil pollution are, even though lead poisoning has likely killed orders of magnitudes more waterbirds than have marine oil spills.

As noted above, a wide range of international multi-lateral environmental agreements have now formally recognised the need to ban the use of lead gunshot in wetlands. Whilst, until recent years, this international recognition has been largely restricted to the African-Eurasian region, the acknowledgement by 120 Parties to CMS of the global nature of the issue in 2014 was a major step forward. The call by CMS COP 11 to Parties to ***"Phase-out the use of lead ammunition across all habitats (wetland and terrestrial) with non-toxic alternatives within the next three years…"*** is ambitious indeed. It will be important to make rapid progress to this end to avoid prolonging the unnecessary poisoning of wildlife.

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Lead gunshot pellets in different states of erosion removed at *post mortem* examination from the gizzard of a lead poisoned swan found in England 15 years after introduction of regulations aimed at reducing lead poisoning.

Photo Credit: WWT

Risks of health effects to humans in the UK from ammunition-derived lead

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ABSTRACT

Lead is a toxic metal to which humans in the UK were formerly exposed through a wide range of pathways such as occupational exposure, lead plumbing, paints, petrol additives and foods. Controls on most of these sources have left dietary lead as the main pathway of lead exposure in the UK. This paper shows that ammunition-derived lead, especially from gamebird meat, is the predominant and significant cause of exposure to dietary lead in the small proportion of the UK population who eat gamebird meat frequently. Using information from surveys of gamebird meat consumption by the general population and of high-level game consumers who eat game at least once per week, we estimate minimum and maximum numbers of people who eat game and numbers of these potentially at risk of a set of adverse health outcomes. In the UK, at least one million people eat gamebird meat at least once per year and at least tens of thousands of people from the shooting community are high-level consumers of wild-shot game. Children are likely to be the most numerous group vulnerable to significant negative effects. We estimate that thousands of children in the UK per year (probably in the range 4,000 - 48,000) could be at potential risk of incurring a one point reduction in IQ or more as a result of current levels of exposure to ammunition-derived dietary lead. Numbers of adults at potential risk of incurring critical health effects appear to be smaller.

Key words: *human health, lead, game meat, gamebird meat, high-level consumer, diet survey, children, blood lead, IQ*

INTRODUCTION

Lead is a toxic metal that has a wide range of effects on the health and functioning of humans. There is no known biochemical requirement for lead in humans and other animals. Information on the adverse effects of lead on human health has accumulated over time and indicates that there are effects on most body systems, some of which are detectable at low levels of blood lead (EFSA 2010). In this paper, we first assess the degree to which humans in the UK are exposed to dietary lead derived from spent ammunition. We then consider the potential magnitude of effects of exposure to ammunition-derived lead on health and functioning. Finally, we make approximate estimates of the numbers of people in the UK who may be at risk of negative health effects from the ingestion of ammunition-derived lead.

Routes by which lead is absorbed by humans and its fate in the body

Inorganic lead can, to some extent, be absorbed through the skin, but primarily enters the bloodstream following ingestion of contaminated dust, paint fragments, food and water or inhalation of dust. The primary route of exposure to lead in Europe is in the diet (EFSA 2010). The amount and rate of absorption of ingested lead depends on the individual (age, nutritional status *etc.*) and the physical and chemical characteristics of the material ingested. Children absorb proportionately more ingested lead than adults. Once absorbed, lead is transported around the body in the bloodstream. It is excreted primarily in faeces and urine, but is also incorporated into hair and lost when hair is shed. Lead is also transferred from the blood to soft tissues such as the liver and kidneys and to bone where it accumulates. The half-life of lead in blood is about 30 days, but in bone it is several decades, although a labile compartment exists (USASTDR 2007). Hence, lead is accumulated in the body over the lifetime of an individual, primarily in bone, and lost only slowly. About 94% of the total lead body burden in adults is in the bone, compared with about 73% in children. Lead may be mobilised from bone in times of physiological stress, resulting in elevated blood lead concentrations (USATSDR 2007).

Quantity of gamebird meat consumed annually and minimum number of consumers in the UK

We used data from the UK National Diet and Nutrition Survey (NDNS) programme to estimate the mean quantity of gamebird meat eaten per year by people in the UK (NatCen Social Research 2014). NDNS provides detailed quantitative information on food intake and diet composition based on surveys of a representative sample of UK citizens. We used data from the core survey based on 4-day diet diary results collected in the four survey years 2008/09-2011/12 (NatCen Social Research 2014). We used data from the 4,071 subjects for whom the diet was reported on all four diary survey days. For each subject, we extracted the variable GameBirdsg, which is the mean quantity in grams of gamebird meat consumed per day. This is the only measure of game meat consumption included in the NDNS. This variable was non-zero for 87 subjects. We coded the age of each subject as the midpoint of the age class. For example, the midpoint of the age class coded as 15 years was 15.5. The exception to this was the age class 1 year. The survey only covers children older than 1.5 years, so this class midpoint was coded as 1.75 years.

To relate the proportion of subjects for which consumption of gamebird meat was reported in the 4-day diary period to subject age and sex, we fitted three asymptotic non-linear models:

$\mathbf{P_g = exp(A)}$ **Model 1,**

$\mathbf{P_g = exp(A - B\ exp(-C\ Age))}$ **Model 2,**

$\mathbf{P_g = exp(A_s - B\ exp(-C\ Age))}$ **Model 3,**

where $\mathbf{P_g}$ is the proportion of subjects for whom gamebird consumption is reported, **A** is a constant representing the logarithm of the asymptotic proportion of subjects who eat gamebird meat, **B** and **C** are constants and **Age** is the age class midpoint in years. The parameter **A** was assumed not to differ between males and females in Model 2, but to take different values for the two sexes in Model 3. We calculated the binomial probability of observing the recorded numbers of subjects of each age and sex who did and did not consume gamebird meat under each of the three models. For each model, we used a quasi-Newton algorithm to obtain the parameter values at which the log-likelihood of the data was maximised. We used bootstrap resampling, with replacement, of the 4,071 subjects to obtain confidence intervals of parameter estimates and derived values. We performed 1,000 bootstrap replicates and took the bounds defined by the central 950 bootstrap estimates to represent the 95% confidence limits.

Model 2, which assumes that the proportion of people who consumed gamebird meat changed with age, but did not differ by sex, had the lowest value of the Akaike Information Criterion (AIC) (Model 1 AIC = 843.29, Model 2 AIC = 832.64, Model 3 AIC = 833.95). Likelihood-ratio tests indicated a highly statistically significant effect of age on the proportion consuming gamebird meat (Model 2 vs Model 1, $\chi^2_{(2)} = 14.65$, $P = 0.0007$), but no indication of a significant effect of sex (Model 3 vs Model 2, $\chi^2_{(1)} = 0.69$, $P = 0.405$). We therefore selected Model 2 as providing an adequate description of the data. The proportion of subjects consuming gamebird meat increased most rapidly with advancing age over about the first 20 years, being less than 1% for the youngest infants and about 3% for adults (see Figure 1).

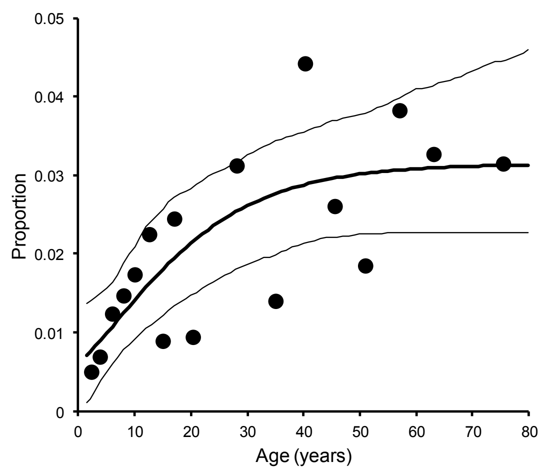

Figure 1: **Proportion of individuals who consumed gamebird meat during a 4-day diet diary survey conducted as part of the UK National Diet and Nutrition Survey in the years 2008/09 - 2011/12 in relation to age.** *Each symbol represents the proportion for a group of individuals in an age class that included at least 200 subjects. The thick curve shows the asymptotic relationship $P_g =$ exp(-3.459-1.668 exp(-0.073 Age)) fitted to the disaggregated data by a maximum-likelihood method. The thin curves show bootstrap 95% confidence limits. Results are shown for both sexes combined because there was no indication of a significant difference between the sexes.*

We next multiplied the number of people estimated to be in each year class of age in the UK (in mid-2013, from Office of National Statistics 2014) by the estimated proportion of people consuming gamebird meat for that age class from the analysis reported above. Uncertainty in these estimates of proportions was taken into account by the bootstrap method, but UK population totals were taken to have been estimated without error. The total number of people estimated to consume gamebird meat in a typical 4-day period was 1,613,341 (95% C.L. 1,293,414 – 1,931,975), which represents 2.52% of the UK population (95% C.L. 2.02 – 3.01). Equivalent estimates were made for sub-groups based on age. The estimated number of children up to the age of 8.0 years that ate gamebird meat is 49,576 (95% C.L. 29,083 – 87,870). The estimated number of children between 8.0 and 18.0 years that ate gamebird meat is 119,780 (95% C.L. 77,530 – 178,574). The estimated number of adults that ate gamebird meat is 1,443,984 (95% C.L. 1,091,320 – 1,741,397). It should be noted that these are estimates of numbers of people eating gamebird meat in a typical four day period. They are likely to be representative of the situation for any time of year because proportions of people eating gamebird meat have previously been found to be similar within and outside the shooting season (Taylor *et al.* 2014). However, the numbers of people eating gamebird meat over a longer period, such as a year, would be larger than this unless people are completely consistent from one 4-day period to another in whether they eat game or not. Hence, these estimates are minimum numbers of consumers of gamebird meat.

We analysed the NDNS data on the mean quantity of gamebird meat eaten per day using polynomial ordinary least squares regression of log-transformed values. This analysis included data only from the 87 subjects who consumed gamebird meat. We fitted the first-, second-, third-, fourth- and fifth order polynomial regressions on the age class midpoint in years. In none of these regression models did the effect of age on daily gamebird meat consumption rate approach statistical significance (P always > 0.50). Similarly, the effect of sex did not approach statistical significance in any model (P always ≈ 0.50). Visual inspection of the data (Figure 2) similarly confirmed no sign of consistent effects of age or sex. We therefore used a single log-normal distribution with no effects of age or sex to describe the distribution of values. We used bootstrap resampling of the 87 subjects, with replacement, to obtain confidence intervals of parameter estimates. We performed 1,000 bootstrap replicates and took the bounds defined by the central 950 bootstrap estimates to represent the 95% confidence limits. The mean of the $\log_e$-transformed daily consumption rate in g/d was 2.511 (95% C.L. 2.294 - 2.725), which is equivalent to a geometric mean of 12.3 g/d (95% C.L. 9.9 – 15.3). The standard deviation of the log-normal distribution was 1.044 (95% C.L. 0.896 – 1.160). The arithmetic mean daily consumption rate was 19.1 g/d (95% C.L. 15.5 – 22.6). Although these data derive from 4-day diet diary periods, the arithmetic mean daily consumption rates for those who eat gamebird meat are likely to apply to the whole year, because sampling was representative of the whole year.

We estimated the total mass of gamebird meat eaten per year by the whole UK population by multiplying the estimated numbers of consumers by the arithmetic mean amount eaten per day and the number of days in a year, with uncertainty in numbers of people and consumption rates accounted for using the bootstrap method. The total mass of gamebird meat eaten per year by the whole UK population was estimated to be 11,232 tonnes (95% C.L. 9,162 – 16,251).

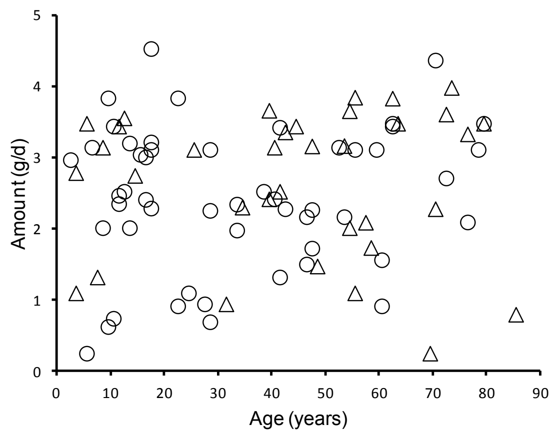

Figure 2: **Mean amount (g) of gamebird meat eaten per individual per day averaged over a 4-day diet diary survey period for those individuals who ate some gamebird meat during the diary period.** *Data are from surveys conducted as part of the UK National Diet and Nutrition Survey in the years 2008/09 -2011/12. Amounts eaten per day are* $\log_e$ *-transformed and shown in relation to age. Each symbol represents the datum from one individual. Results for males are shown by triangles and those for females by circles.*

An independent check on the quantity of gamebird meat consumed annually in the UK

Numbers of wild gamebirds and waterfowl shot in the UK in 2004 are given in PACEC (2006) as just under 19 million, of which about 79% were pheasants *Phasianus colchicus*. This total excludes woodpigeons *Columba palumbus*, which PACEC (2006) treats as pests, rather than game. Results from game bag records collected by the Game and Wildlife Conservation Trust and presented by Aebischer (2013), show that numbers of pheasant, red-legged partridge *Alectoris rufa*, grey partridge *Perdix perdix* and mallard *Anas platyrhynchos* shot in 2011 were 12 – 23% higher than they were in 2004, with the scale of increase varying among the four species. Because of the preponderance of pheasants in the national bag of gamebirds and waterfowl, we took the value for the 2004 – 2011 increase in bag of this species (12%) to represent the recent increase in bag for all gamebirds and waterfowl combined. Multiplying by the 2004 total of 19 million gives an estimated UK total for 2011 of 21.3 million gamebirds and waterfowl shot, excluding woodpigeons. PACEC (2006) reports that 3.6 million pigeons were shot, 'not as part of a job', in 2004 and that 53% of the total number of pigeons shot were killed not as part of a job. Hence, the estimated total number of pigeons shot is 6.8 million. Adding these to the total of other birds shot and assuming that the 2004 pigeon total also applies to 2011, gives a total of 28.1 million birds shot in 2011. This is a conservative estimate because we used the lowest of the four species estimates of the 2004 – 2011 increase in bag. Multiplying the species totals by mean body weights (from Snow and Perrins 1998) gives a total of 25,400 tonnes for the total annual weight of the bag of these quarry bird species. PACEC (2006) reported that 99% of the gamebirds and waterfowl and 90% of the pigeons were intended for human consumption. Using these proportions we estimated that the total annual unprocessed intact weight of gamebirds, waterfowl and pigeons intended for human consumption was 24,700 tonnes, derived from 27.3 million individual wild-shot birds. It seems probable that some of these birds were not used as food in the UK because their carcasses were rejected or because they were exported. The proportions of birds rejected and exported are unknown, as is the extent to which exports were compensated for by imports.

We estimated the mean weight of unprocessed gamebird carcasses required for a serving of a main course game meal using recipes published on the internet by the British Broadcasting Corporation (BBC n.d.). We used the number of birds required by the recipe and converted this into the weight of unprocessed bird carcasses required using body weights from Snow and Perrins (1998). In doing this, we took into account whether male or female birds were specified. We divided the total unprocessed weight of game required by the recipe by the number of portions this was said to provide. We avoided recipes which did not use the whole bird. We found ten eligible recipes for galliform gamebird meals (four pheasant, three partridge, three grouse *Lagopus lagopus*). The mean weight of unprocessed carcass per served portion was 499 g (1 SE = 56 g). Assumed values for the mass of a typical gamebird meal for an adult vary widely. EFSA (2010) assumed that an adult portion of game meat was 200 g, whereas FSA (2002) gives a value of 100 g. This suggests that between 20% and 40% of the unprocessed weight of a gamebird used for food is present in the resulting meal. Hence, based upon estimates of the numbers of wild-shot birds, we calculate that between 0.2 x 24,700 = 4,940 tonnes and 0.4 x 24,700 = 9,880 tonnes of gamebird meat has been eaten by UK consumers annually in recent years. This range overlaps the confidence interval of the value of 11,232 tonnes per year (95% C.L. 9,162 – 16,251) obtained from the gamebird meat consumption reported in the diet diary surveys from the NDNS.

Average *per capita* quantity of game meat consumed annually by high-level consumers of game in Scotland

We made an estimate of the mean number of meals including game meat consumed per week and per year by high-level consumers of game using a survey conducted by the Food Standards Agency in Scotland (FSAS 2012). This study reported a survey of game consumption rates derived from quantitative questionnaires administered to respondents during semi-structured interviews conducted in Scotland in 2011. People involved in the management and use of wild game were contacted and asked to participate in the study. These contacts included butchers, game dealers, members of shooting clubs, farmers, gamekeepers, beaters and gun shop proprietors. Respondents identified others known to them, who were not necessarily working in the same types of enterprises as the initial contacts, who ate wild game frequently and who were then also asked to participate. In total, 311 subjects were asked about their level of consumption of wild game and the interviews showed that 200 of these reported consuming wild game at least once per week during the shooting season. This level of consumption was taken by FSAS (2012) to represent the definition of a high-level consumer of wild game and our further calculations are only performed on the results from the 200 high-level consumers defined in this way.

Of the high-level consumers of wild game, 79% reported eating wild game once or twice per week during the shooting season and 21% ate wild game more frequently (three or more times per week) during the shooting season. All but two of the 200 high-level consumers also reported on their consumption of wild game outside the shooting season. Thirty-two percent of these high-level consumers reported eating wild game once or twice per week outside the shooting season and 9% ate wild game more frequently (three or more times per week) outside the shooting season. Raw data from the survey kindly provided to us by FSAS, show that 41% of high-level consumers reported eating wild game at least once per week throughout the year (both within and outside the shooting season) and 9% ate wild game at least three times per week throughout the year.

We used the raw data from the FSAS (2012) survey to make an estimate of the mean number of wild game meals consumed per week throughout the year by high-level consumers. To do this, it was first necessary to estimate the proportion of high-level consumers eating wild game during the shooting season on average 1.0 – 2.0 times per week, 2.0 – 3.0 times per week, and so on up to 6.0 – 7.0 times per week. We assumed that wild game was not eaten on more than seven occasions per week. Since the proportion of high-level consumers eating wild game on 1.0 – 3.0 occasions per week is much higher (79%) than the proportion eating game on 3.0 – 7.0 occasions per week (21%, see above), it seems plausible that the proportion of consumers eating game at each progressively higher number of occasions per week diminishes exponentially (*i.e.* by the same proportion) for each stepwise increase in consumption rate of one game meal per week. If this is the case, the proportions of high-level consumers eating wild game during the shooting season 1.0 – 2.0 times per week, 2.0 – 3.0 times per week, and so on up to 6.0 – 7.0 times would be 54%, 25%, 12%, 5%, 3% and 1% respectively. These proportions were obtained by calculating numerically the rate of exponential decline per occasion in the proportion of consumers in each one occasion per day category which would result in 79% being in the 1.0 – 3.0 occasions per week category and 21% being in the 3.0 – 7.0 occasions per week category. Outside the shooting season, the proportions of high-level consumers reporting wild game consumption in the categories never, less often than once a month, at least once a month, at least once a fortnight, at least once per week and three or four times per week or more are 20%, 6%, 26%, 16%, 31% and 1% respectively for consumers who ate wild game once or twice per week during the shooting season. The equivalent proportions of out-of-season consumption for consumers who ate wild game three or more times per week during the shooting season are 7%, 0%, 5%, 10%, 37% and 41% respectively. These results for consumption within and outside the shooting season were combined by converting them to mean daily consumption rates (game meals per day) for the two periods and multiplying by the number of days in the shooting season and outside it. For this purpose, the duration of the shooting season was taken to be 124 days, which is the season for pheasant shooting. Had the shooting seasons for all game animals been merged, their combined duration would have been larger than this. However, because pheasants comprise the majority of wild-shot birds eaten by people in the UK (PACEC 2006), adopting their season alone seems reasonable. Based upon these assumptions, the estimate of the mean consumption rate of wild game averaged over the whole year for the FSAS sample of high-level consumers was 1.64 game meals per week or 86 game meals per year. Confidence limits for this estimate were obtained by bootstrap resampling from the raw data provided by FSAS. We drew 10,000 bootstrap samples of 200 at random from the 200 real data and performed the same set of calculations upon each of the bootstrap sets as described above. We then took the values bounding the central 9,500 of these bootstrap estimates as the 95% confidence interval. The bootstrap 95% confidence interval for the estimated number of game meals eaten per week, year-round, is 1.49 – 1.84 meals per week. Hence, subject to the assumptions made about the duration of the shooting season and other issues, this survey provides reasonably precise estimates of the rate of consumption of game meals by this sample of high-level consumers in Scotland. If it is assumed that a typical game meal includes 200 g of meat (EFSA 2010), these per capita rates of consumption are equivalent to 17.1 kg per person per year (95% C.L. 15.5 – 19.2 kg) or 8.6 kg per person per year (95% C.L. 7.7 – 9.6 kg) if a game meal contains an average of 100 g of meat (FSA 2002). This compares with a *per capita* consumption rate of gamebird meat averaged across the whole UK population of 0.175 kg per person year, based upon the NDNS (see above). Hence, the amount of game meat eaten by high-level consumers is much higher, perhaps by two orders of magnitude, than the UK average. Had those NDNS subjects who ate gamebird meat during the 4-day diet diary period continued to eat it at the rate reported in the diary throughout the year, the annual *per capita* amount consumed by that subset of people would have been 7.0 kg per person per year (95% C.L. 5.7 – 8.2 kg).

Quantity of ammunition-derived lead in food eaten by humans in the UK

Previously it seems to have been supposed that exposure to elevated levels of dietary lead due to ingestion of meat from game shot with lead bullets and lead shot posed a minimal hazard to human health. This route of exposure is not mentioned in the Codex Alimentarius Code of Practice on reducing exposure to lead in food (Codex Alimentarius 2004). Ammunition-derived lead might not be eaten by consumers of game meat if nearly all of the mass of the projectiles striking the game animal remained in large pieces, which either passed through the carcass or were removed during food preparation or at the table. However, X-radiographic studies show that mammals and gamebirds shot with lead bullets and gunshot often contained lead fragments which were small, numerous and widely dispersed in edible tissues away from the wound canals. Results for large mammals killed using lead bullets come from X-ray studies of red deer *Cervus elaphus* (Knott *et al.* 2010), roe deer *Capreolus capreolus* (Knott *et al.* 2010) and white-tailed deer *Odocoileus virginianus* (Hunt *et al.* 2009, Grund *et al.* 2010). They indicate the presence of many small bullet fragments in the edible tissues of the carcass at distances up to 24 cm from the wound canal. Small fragments, which form a substantial proportion of fragment mass (Knott *et al.* 2010), were not removed by standard butchery practices on deer and fragments were found in both minced meat and steaks prepared for human consumption (Hunt *et al.* 2009).

Substantial fragmentation of lead shot also occurs when gamebirds and waterfowl are killed using gunshot. A UK study (Pain *et al.* 2010) found small fragments on X-rays in 76% of 121 gamebirds of six species examined. In this study wild-shot gamebirds obtained in the UK from selected supermarkets, game dealers or game shoots were X-rayed to determine the number of shot and shot fragments present. Most fragments were less than about a tenth of a shot in size. The small radio-dense particles sometimes appeared to follow the track taken by a shotgun pellet during passage through a bird, were sometimes clustered around bone, but sometimes appeared to be scattered throughout the bird. It was estimated that approximately 0.3% of the mass of lead in the gunshot considered to have struck gamebirds in their study would need to have fragmented into small particles to account for the concentrations of lead subsequently found in meals cooked using the gamebird meat. This reflects the lead remaining after all of the large fragments visible to the naked eye had been removed.

Studies of concentrations of lead in game meat also indicate that ammunition-derived lead is present in meat eaten by humans. Dobrowolska and Melosik (2008) measured lead concentrations in samples of muscle tissue from ten wild boar *Sus scrofa* and ten red deer shot with lead bullets. Lead concentrations in muscle tissue were elevated above the background level at up to 30 cm from the bullet track. Butchering and food preparation procedures on these boar and deer would require that a substantial proportion of muscle would have to be discarded if all tissue retained for human consumption was to have lead concentration within the limit set by the EU of 0.1 mg/kg for non-game meat (excluding offal). Lindboe *et al.* (2012) found that the mean concentration of lead in random samples of ground meat from moose *Alces alces* killed in Norway with lead-based bullets was 5.6 mg/kg.

Johansen *et al.* (2004) found that lead contamination of the meat of seabirds killed using lead shot occurred even though shot was removed after cooking. Pain *et al.* (2010) found a mean lead concentration of 1.181 mg/kg in meals prepared from 121 wild-shot gamebirds of six species, with no significant variation among species. Lead concentrations in the meals were statistically related to both the number of shotgun pellets and large fragments of lead removed before chemical analysis, and the number of small radio-dense fragments, detected by X-radiography of the gamebirds, which could not readily be removed. High concentrations of lead occurred in some meals prepared from birds in which no whole pellets or large fragments were apparent on X-rays. The only plausible mechanism for this is that lead particles remain in the meat after the removal of whole shot and large fragments.

An arithmetic mean concentration of 0.414 mg/kg (414 ppb) was found in twelve samples of pheasant meat purchased in the UK and reported in FSA (2007).

Many other data on concentrations of lead in game meat are summarised in EFSA (2010), but it is not clear whether or not visible shot and bullet fragments had been removed prior to analysis.

To protect human health, the European Commission sets maximum levels (MLs) for contaminants, including lead, in many foods (Commission Regulation 1881/2006)(EC 2006). The ML for lead in non-game meat (excluding offal) is 0.1 mg/kg, but no ML has been set for game meat. The results presented above show that lead concentrations in the meat of wild game animals shot with lead ammunition and eaten by humans are often one or two orders of magnitude higher than the non-game meat ML.

Bioavailability of ammunition-derived lead present in game meat and the effect of its ingestion on blood lead concentration

As described above, both lead shot and lead bullets fragment when fired into quarry animals and produce pieces of lead of a wide range of sizes which are embedded in the tissues. Some of these are at a considerable distance from the wound and remain after butchery and food preparation. Several studies indicate elevation in the concentration of lead in the blood (B-Pb) of people who eat game animals killed using lead ammunition, which indicates that some ingested ammunition-derived lead is absorbed (Bjerregaard *et al.* 2004, Johansen *et al.* 2006, Iqbal 2009, Dewailly *et al.* 2001, Bjermo *et al.* 2013, Meltzer *et al.* 2013, Knutsen *et al.* 2015). Analysis of stable isotope ratios of lead in blood samples indicates that exposure to ammunition-derived lead is the main cause of elevated blood lead (B-Pb) in indigenous people in Canada (Tsuji *et al.* 2008).

Hunt *et al.* (2009) performed an experiment on pigs to assess whether their B-Pb increased when they were fed on minced meat from deer shot with lead-based bullets. Statistically significant increases in their B-Pb were observed compared with controls fed on meat that contained no fragments. Mean blood lead concentrations in pigs peaked at 2.29 µg/dl two days following first ingestion of fragment-containing venison, which was 3.6 times higher than that of controls (0.63 µg/dl). Isotope ratios of lead in the meat matched those of the lead in the bullets used to shoot the deer, supporting the contention that the absorption by the pigs was of dietary lead derived from the ammunition.

These findings indicate that B-Pb of humans tends to increase in association with consumption of game meat containing ammunition-derived lead due to absorption of ammunition-derived lead from the alimentary canal. However, without further analysis, they do not indicate what proportion of the ammunition-derived lead ingested is absorbed or how much B-Pb is increased per unit of dietary lead ingested. Such estimates require either *in vitro* gastrointestinal simulation experiments which attempt to simulate conditions in the human alimentary canal or empirical studies in which both the intake of lead and the elevation of B-Pb are measured.

The absolute bioavailability of dietary lead derived from ammunition (the proportion of the ingested amount which is absorbed and enters the blood) might be expected to be lower than that of lead in the general diet because some of the ingested ammunition lead may remain as metallic fragments after cooking and processing in the alimentary canal. Metallic lead, especially that remaining in large fragments, may not be totally dissolved nor be absorbed in the intestine as readily as more soluble lead salts and complexes (Barltrop and Meek 1975, Oomen *et al.* 2003).

Mateo *et al.* (2011) used cooked meat from partridges killed with lead shot for *in vitro* gastrointestinal simulation experiments. They found that far more lead in the cooked gamebird meat was bioaccessible (soluble and available for absorption) in the simulated intestine phase when a recipe containing vinegar was used (6.75%) than when wine was used (4.51%) or than in uncooked partridge meat (0.7%). However, the reliability of estimates from *in vitro* gastrointestinal simulation experiments depends upon the uncertain degree to which the experiment mimics human digestion and absorption (Zia *et al.* 2011), and frequently-used cooking methods may vary between countries.

Because of these potential problems with *in vitro* estimates, Green and Pain (2012) used observations from two studies of Greenland adults (Bjerregaard *et al.* 2004, Johansen *et al.* 2006) to derive a quantitative empirical relationship between the mean daily intake of dietary lead from the meat of birds killed using lead shot and the mean concentration of B-Pb. There was a strong relationship in the data from both Greenland studies between mean B-Pb and the estimated mean rate of intake of dietary lead from meals of cooked wild bird meat. The regression models of Green and Pain (2012) indicated that the effect of ingested ammunition-derived lead on B-Pb was 39% lower than that expected for lead not derived from ammunition (Carlisle and Wade 1992). However, it should be noted that this regression method is subject to a known bias. Least squares regression assumes that the independent variable (in this case the dietary lead intake rate) is known without error. This is not the case because the intake rate means used were determined from sample estimates with attached errors which cannot be fully quantified and adjusted for. The direction of this bias on the slope of the fitted regression is negative, meaning that the true absolute bioavailability of lead may be larger than that estimated by this method.

There appear to be no published studies in which B-Pb was related to ingestion rates of ammunition-derived lead in children. The bioavailability of lead in the ordinary diet is considerably higher in children than in adults (Mushak 1998, IEUBK 2010).

Green and Pain (2012) assumed that the ratio of the absolute bioavailability of dietary lead from cooked wild bird meat to that of lead from the ordinary diet, calculated for adults (above), would be the same in children. As there is a widely-used value for the absolute bioavailability to children of lead from the ordinary diet (0.5, from Mushak 1998, IEUBK 2010), they estimated a value for absolute bioavailability in children of dietary lead derived from the cooked meat of wild birds of 0.3060. The same caveat about probable negative bias in this estimate applies as that described above for adults.

Effects of lead on human health and functioning

The consequences of exposure to lead for human health have been considered in great detail by the appropriate authorities of several countries. Lead affects the nervous, urinary, cardiovascular, immune, reproductive and other body systems and a range of organs, including the brain (USATSDR 2007, EFSA 2010). Experiments show that high doses of lead can induce tumours in rodents, and possibly humans, and the International Agency for Research on Cancer classified inorganic lead as 'probably carcinogenic to humans' (Group 2A) in 2006 (IARC 2006). Body systems particularly sensitive to low levels of exposure to lead include the haematopoietic, nervous, cardiovascular and renal systems (EFSA 2010).

Once lead has been absorbed into the body, its effects on health and functioning are largely independent of its original source. Hence, correlations between health outcomes and concentration of lead in tissues are an important source of information on effects of lead on health. The concentration of lead in whole blood is the most widely used measure of recent exposure, because of the short half-life of lead in the blood. Although measurements of lead concentrations in other tissues, such as bone, might be more informative about long-term exposure and chronic effects on health, sampling them is impractical and seldom possible. Hence, much of what is known about the health effects of lead is based upon correlations between health outcomes and B-Pb.

As evidence about the health effects of lead has accumulated and the sensitivity of analyses has increased, B-Pb concentrations shown to be associated with human health effects have correspondingly decreased. In addition, as human health concerns have resulted in regulations that have reduced human exposure from several previously important sources, such as occupational exposure, plumbing, paint and petrol additives, it has become possible to detect significant associations between health outcomes and B-Pb at much lower concentrations than would previously have been possible. Consequently, there has been a progressive decrease in the B-Pb concentrations proposed as thresholds for action and these are now one sixth or less of those considered as protective of human health in the

1960s (CDC 2005, 2012, Green and Pain 2012).

The removal of lead additives from vehicle fuel across Europe has resulted in a substantial decrease in lead absorbed through the lungs from the atmosphere. Today, the majority of lead exposure in the general population across the EU, including the UK, is from the diet (EFSA 2010). For decades, the principal approach of public health authorities to assessing health impacts of lead in the diet has been to identify a tolerable rate of dietary intake. This sought to maintain exposure below a no-observed-adverse-effect-level (NOAEL) that was assumed to exist. In 1982, the Joint Food and Agriculture Organisation/World Health Organisation Expert Committee on Food Additives (JECFA) set a Provisional Tolerable Weekly Intake (PTWI) of dietary lead of 25 µg/kg bw for infants and children This was extended to all age groups in 1993 and confirmed by JECFA in 1999. The PTWI was endorsed in 1992 by the European Commission's Scientific Committee for Food (SCF 1994). The European Commission carried out an updated lead exposure assessment in 2004 (SCOOP 2004) and together with the SCF opinion this formed the basis of setting Maximum Levels of lead in foodstuffs in the EU (Regulation (EC) No 1881/2006). However, today it is considered that there is no blood lead concentration below which negative physiological effects of lead are known to be absent (EFSA 2010, ACCLPP 2012). Hence, the concept of a tolerable intake level has been called into question. In 2007, the European Commission requested the European Food Safety Authority (EFSA) to produce a scientific opinion on the risks to human health related to the presence of lead in foodstuffs. In particular, EFSA was asked to consider new developments regarding the toxicity of lead, and to consider whether the PTWI of 25 µg/kg bw was still appropriate.

Following a detailed analysis of the toxicological information, the EFSA CONTAM Panel based their dose-response modelling on chronic effects in humans, and identified developmental neurotoxicity in young children and cardiovascular effects and nephrotoxicity in adults as the critical effects for the risk assessment. Several key findings are briefly summarised below with numerous individual studies fully referenced in EFSA (2010).

NEUROTOXICITY

A large number of studies have examined the relationship between B-Pb and measures of nervous system function in children and adults. Toxic effects of lead upon the nervous system in adults include impairment of central information processing, especially for visuospatial organisation and short-term verbal memory, psychiatric symptoms and impaired manual dexterity. There is also evidence that the developing brains of children are especially susceptible to the effects of lead exposure, even at low concentrations of lead.

A meta-analysis of the results of seven studies published between 1989 and 2003 of the IQ of 1,333 children in relation to B-Pb (Lanphear *et al.* 2005), and a refinement/reanalysis of the same data (Budtz-Jørgensen 2010) found marked decreases in IQ with increasing B-Pb, even at low B-Pb values. The effects of lead on the developing nervous system appear to persist, at least until late teenage years.

CARDIOVASCULAR EFFECTS

Long-term low-level exposure to lead is associated with increased blood pressure in humans. Meta-analyses support a relatively weak, but statistically significant, association between B-Pb levels and systolic blood pressure, amounting to an increase in systolic blood pressure of approximately 1 mm Hg with each doubling of B-Pb (Nawrot *et al.* 2002, Staessen *et al.* 1994), without any clearly identifiable B-Pb threshold for this effect.

NEPHROTOXICITY

A range of cross-sectional and prospective longitudinal studies have been conducted to examine the relationship between serum creatinine levels, which rise when kidney filtration is deficient, and B-Pb. Studies suggest an increased likelihood of chronic kidney disease as B-Pb levels rise, and the EFSA CONTAM Panel concluded that nephrotoxic effects are real, that they may be greater in men than women and that they are exacerbated by concurrent diabetes or hypertension.

The EFSA CONTAM Panel's analysis led to the conclusion that there is no evidence for a minimum B-Pb threshold below which effects on IQ, systolic blood pressure and chronic kidney disease do not occur. Hence, the NOAEL and PTWI approaches were not supported by evidence. Instead, the EFSA CONTAM Panel proposed the use of the Benchmark Dose (BMD) approach. The BMD is the B-Pb concentration associated with a pre-specified change in response (*i.e.* a specified loss of IQ, increase in systolic blood pressure, increased incidence of chronic kidney disease), the Benchmark Response (BMR).

The EFSA CONTAM Panel proposed BMRs that could have significant consequences for human health on a population basis (Table 1). These were: a 1% reduction in IQ (a one point reduction in

IQ) as the BMR for IQ, a 1% increase in systolic blood pressure (SBP) (equivalent to a 1.2 mm Hg change) as the BMR for cardiovascular effects; and a 10% increase in expected incidence of chronic kidney disease as the BMR for nephrotoxicity (EFSA 2010, Table 1). The JECFA PTWI was subsequently withdrawn in 2010/2011 (WHO 2007, JECFA 2010, WHO 2011).

Table 1: **Critical effects of lead, associated blood lead levels and corresponding dietary lead intake values** identified by the EFSA Panel on Contaminants in the Food Chain (CONTAM – EFSA 2010)

Benchmark Response (BMR)	BMDL (95th percentile lower confidence limit of the benchmark dose – BMD of extra risk) derived from blood lead levels (µg/L)	Corresponding dietary lead intake value (µg/kg bw per day)	Population level effects of BMR
A 1% (1 point) reduction in IQ in young children	$BMDL_{01}$ = 12	0.50	The BMR for IQ could impact the socioeconomic status of a population and its productivity. Studies in the USA have related a 1 point reduction in IQ to a 4.5% increased risk of failure to graduate from high school and a 2% decrease in productivity in later life (Schwartz 1994, Grosse *et al.* 2002).
A 1% increase in systolic blood pressure (SBP) in adults (equivalent to a 1.2 mm Hg change)	$BMDL_{01}$ = 36	1.50	A 1% increase in SBP has been related to an increase in the percentage of the population treated for hypertension by 3.1%, and a 2.6% or 2.4% increase in expected annual mortality from cerebral stroke or myocardial infarction respectively (Selmer *et al.* 2000).
A 10% increase in expected incidence of chronic kidney disease in adults	$BMDL_{10}$ = 15	0.63	

EFSA findings on the hazards to human health from dietary lead in Europe

The EFSA CONTAM Panel used the Integrated Exposure Uptake Biokinetic (IEUBK 2010) Model for lead in children (IEUBKwin version 1.1) and an equation from Carlisle and Wade (1992) for lead in adults to estimate the dietary intake of lead (BMD) required to produce the elevations in B-Pb associated with the BMR and also the BMDL, the lower one-sided 95% confidence bound of the BMDs (Table 1). This modification of the BMD allows for uncertainty in the dose-response relationship. They also assessed data on lead concentrations in foods in the European Union, including lead directly derived from ammunition in game meat. EFSA used information on lead concentrations in food and amounts of food eaten by individuals in participating countries to calculate mean ('average base diet') and 95th percentile ('high base diet') lead dietary exposures separately for each country. These exposure data were then used to produce corresponding B-Pb concentrations, and these were compared with the BMDLs to evaluate risk. In some assessments, groups of people frequently consuming game meat (defined as one 200 g meal per week of game) were considered separately. In calculating the effects upon B-Pb of game meat consumption the EFSA CONTAM Panel assumed that the bioavailability of dietary lead directly derived from ammunition was the same as for other sources of dietary lead. They obtained the ratio of dietary exposure, assuming various diets, to the BMDLs. The risk of

Benchmark Responses occurring was considered to be of particular concern if this ratio exceeded one.

The EFSA CONTAM Panel concluded that there was a potential risk[1] that some children in groups with average and high base diets could incur reductions of one IQ point as a result of exposure to dietary lead. Exposure to additional lead from frequent consumption of game, while not specifically evaluated, would further increase this risk in those exposed. The EFSA CONTAM Panel concluded that risk of cardiovascular effects as a result of exposure to lead was very low for adult average consumers across European countries. However, if exposure to dietary lead was closer to the upper end of the range in adult high consumers, the potential exists for some consumers to have increased systolic blood pressure as a result of exposure to lead. For nephrotoxicity, the EFSA CONTAM Panel concluded that it is possible some consumers at the high and low end of the exposure ranges could potentially incur chronic kidney disease as a result of exposure to dietary lead.

For consumers of an average base-diet, but also with frequent consumption of game meat, the CONTAM Panel concluded that there was a potential risk that some people could incur cardiovascular and nephrotoxic effects as a result of exposure to lead. This risk is increased over people not frequently consuming game due to the relatively high lead levels in game.

In their summary conclusions, the EFSA CONTAM Panel considered that [for the population in general] at current levels of lead exposure there is only a low to negligible risk of clinically important effects on either the cardiovascular system or kidneys of adult consumers. However, in infants, children and pregnant women, there is potential concern at current levels of exposure to lead for effects on neurodevelopment.

Frequent consumption by these most vulnerable groups of game shot with lead ammunition would obviously increase exposure.

Effects of lead on human health not assessed by EFSA

Green and Pain (2012) also assessed studies of effects of lead on Standard Assessment Test (SAT) scores of UK schoolchildren and in rates of spontaneous abortion in pregnant women in Mexico, which were not evaluated by EFSA. The SAT score study (Chandramouli *et al.* 2009) was not published in time to be evaluated by EFSA, whilst the spontaneous abortion study by Borja-Aburto *et al.* (1999) was available but not mentioned in EFSA (2010).

Chandramouli *et al.* (2009) reported a negative association of academic test results of UK schoolchildren at Key Stage 1 (SATs) with B-Pb measured at 30 months of age. Green and Pain (2012) used the relationship between the mean outcome of the SATs writing test and blood lead to estimate the reduction in the test score expected from a specified increase in B-Pb. EFSA (2010) did not calculate a BMR for SATs scores. However, EFSA (2010) defined the BMR for IQ as 1 IQ point, which is one-fifteenth of the population standard deviation for IQ. To calculate an equivalent change in SATs KS1 writing score to that identified as the BMR for IQ, we obtained the maximum-likelihood mean and standard deviation of SATs scores for children in England in 2010 (Department for Education 2013). The calculated values were 1.90 SATs grade points for the mean and 0.60 SATs grade points for the standard deviation, where the SATs grades run from 0 (working towards Level 1) to 4 (Level 4). Hence, we took the equivalent BMR for the SATs KS1 writing grade score to that used by EFSA (2010) for IQ to be 0.60/15 = 0.04 SATs grade points.

Green and Pain (2012) used a statistical model fitted by Borja-Aburto *et al.* (1999) to describe the relationship between B-Pb and the proportion of pregnant women in Mexico City who incurred spontaneous abortion. The model adjusted for the effect of a previous history of spontaneous abortion. EFSA (2010) did not evaluate this study or calculate a Benchmark Response (BMR) for spontaneous abortion.

Potential risks to humans in the UK from ammunition-derived lead

Green and Pain (2012) used data on lead concentrations in UK gamebirds, from which gunshot had been removed following cooking to simulate human exposure to lead (Pain *et al.* 2010). They combined this with UK food consumption and lead concentration data to evaluate the number of gamebird meals (of 200 g for adults; 118 g for a 6.9 year old and 100 g for a 2.5 year old child) consumed weekly that would be expected, based upon published studies, to result in specified changes, over and above those resulting from exposure to lead in the base

[1] Where we have described groups potentially at risk of incurring critical effects the specific terminology used by EFSA is generally that 'the possibility of an effect cannot be excluded' (EFSA 2010).

diet, in IQ, systolic blood pressure and chronic kidney disease. As described above, these health effects were considered in the opinion of the EFSA CONTAM Panel (EFSA 2010) to be significant at a population level. Green and Pain (2012) also used the same approach to evaluate potential effects of consumption of gamebird meat on SAT scores and in rates of spontaneous abortion, which were not assigned BMRs by EFSA.

The results indicated the potential for the consumption of 40 - 70 g of gamebird meat per week to be associated with a 1 point decrease in the IQ of children, the BMR identified by EFSA (2010), with the two values being for Green and Pain's regression estimate of bioavailability and the standard bioavailability values as used in IUEBKwin.

For the present study, we estimated a potential risk of change in children's SATs writing tests scores equivalent to the EFSA BMR for IQ in children (see above) for those that consume 12.7 to 20.4 g of gamebird meals per week. Amounts of game that adults would need to consume to be at potential risk from an arbitrary 1% increased risk of spontaneous abortion (women), and from the EFSA BMRs for chronic kidney disease and systolic blood pressure are presented in Table 2.

Table 2: **Numbers of people in the UK calculated to be at potential risk of incurring threshold health or function effects of ammunition-derived lead from gamebirds** assuming two values of the bioavailability of lead from ammunition and consistent rates of consumption of gamebird meals throughout the year.

			High bioavailability			**Low bioavailability**		
Health/function outcome	**Critical response**	**Age class**	**Threshold intake rate g/week**	**No. affected**	**95% C.L.**	**Threshold intake rate g/week**	**No. affected**	**95% C.L.**
IQ	Deficit of 1 IQ point*	Children < 8 years	40	38126	16704 - 63012	70	28710	12684 - 47846
SATs writing score	Deficit of 0.04 score point	Children < 8 years	12.7	47926	20072 - 79495	20.4	45427	19346 - 75507
Spontaneous abortion rate	Increase in risk by 1%	Women 18-45 years	560	10977	5432 - 17157	920	3505	1333 - 6259
Chronic kidney disease Model 1	Increase in risk by 10%*	Adults > 18 years	240	235898	151954 - 319277	380	112158	64637 - 162612
Chronic kidney disease Model 2	Increase in risk by 10%*	Adults > 18 years	800	23713	9920 - 40652	1300	6749	2045 - 13965
Systolic blood pressure	Increase by 1.2 mmHg*	Adults > 18 years	640	39584	18369 - 64640	1040	12320	4342 - 23273

Critical responses marked * are Bench Mark Responses (BMR) defined by EFSA (2010). Two models for calculating the BMR for kidney disease were used: Model 1 is that used by EFSA(2010) and Model 2 is that proposed by Green and Pain (2012) to allow for confounding variables.

A limitation of this study is that Green and Pain (2012) estimated BMDs but did not estimate BMDLs, as was done by EFSA (2010). This is because of the difficulties associated with including uncertainties in the additional elements used in their calculations, such as bioavailability. Had BMDLs been calculated they would have indicated that consumption of smaller quantities of gamebird-derived meals would result in BMDL doses than those resulting in the BMD doses.

We used the results of analyses of national diet data from the NDNS (as described earlier) and UK population data for 2013 to estimate maximum numbers of individuals in the UK exceeding the threshold intake rates of gamebird meat required to be at potential risk from incurring critical responses (see Table 2). We used the number of children less than 8.0 years old as the group at potential risk from incurring IQ and SATs effects. We used the number of women in the age range 18.0 to 45.0 years old as the group at potential risk from incurring the spontaneous abortion effect and did not attempt to allow for the proportion that were pregnant. The estimates are maxima because we assumed that the proportion of people consuming gamebird meals and the distribution of amounts consumed per four-day period were constant throughout the year and as specified by analyses of the data shown in Figures 1 and 2. Although there may be some consistency over time in game consumption, its magnitude is unknown. If consumers did not eat game consistently through the year at the rates indicated by the NDNS survey, the number of consumers would be larger than our estimates but the average amount eaten per consumer would be smaller. The net result would be a reduction in the numbers of people with gamebird meal intakes exceeding those required to be at potential risk of the critical responses.

The maximum numbers shown in Table 2 indicate the potential for tens of thousands of UK children to have gamebird meal intakes exceeding those required to be at potential risk from incurring the critical responses for IQ and SATs scores. Maximum numbers of adults exceeding threshold intake rates for potential risk of incurring cardiovascular, nephrotoxicity and spontaneous abortion critical responses tended to be smaller, being hundreds or thousands. The exception was for the chronic kidney disease critical response as defined by the dose-response model used by ESFA (2010). This model indicated that over one hundred thousand people might exceed the threshold intake rate. However, as noted by Green and Pain (2012), this dose-response model did not allow for potential confounding variables and may overestimate effects. The alternative model proposed by Green and Pain (2012) allows for confounding variables and gives smaller maximum numbers (Table 2).

Recognising that the results shown in Table 2 are maxima, we also calculated equivalent minimum values using independent data. We used the results of an unpublished survey of the shooting community in the UK conducted by the British Association for Shooting and Conservation (BASC) and the Countryside Alliance (CA), which is cited in LAG (2014). The survey estimated that about 9,000 (midpoint of range 5,500-12,500) children under 8 years old and about 44,500 adults (midpoint of range 27,000 - 62,000) from the shooting community consume at least one game meal per week averaged over the year. This estimate refers to all types of game, but, as most game in the UK is shot using lead ammunition, it is likely that the vast majority of the game meals reported by members of the shooting community were made using wild gamebirds killed using lead ammunition.

We used the estimates of the threshold intake rates of gamebird meat required to be at potential risk of incurring the critical responses from Table 2 in combination with the LAG (2014) estimates of numbers of high-level consumers analyses of game in the UK and the results of the FSAS (2012) survey of the distribution of numbers of game meals eaten per week by high-level game consumers in Scotland to estimate minimum numbers of individuals in the UK potentially exceeding the thresholds (Table 3). We used the number of children less than 8.0 years old as the group at potential risk from incurring IQ and SATs effects because this is the age group used in the survey results cited in LAG (2014). We assumed that the proportion of adult high-level consumers who were women in the age range 18.0 to 45.0 years old was the same as for all UK adults in 2013. Because the rates of consumption of game in the FSAS (2012) and LAG (2014) surveys were in meals per week rather than weights of meat, it was necessary to assume an average meal size. We used the values used by Green and Pain (2012), based upon the 200 g game meal size for adults used by EFSA (2010) and also the lower values (30 g for children, 100 g for adults) for gamebird meals from FSA (2002). We used bootstrap resampling of the FSAS (2012) survey data, as described previously, to estimate uncertainty in the numbers. From each bootstrap replicate, a non-parametric cumulative distribution of numbers of game meals per year was constructed and proportions of subjects exceeding a specified threshold were obtained by linear interpolation.

Table 3: **Numbers of UK high-level consumers of game from the shooting community calculated to be at potential risk** of incurring threshold health or function effects from ingestion of ammunition-derived lead from gamebirds under various assumptions about game meal size and bioavailability of lead from ammunition**.**

				Small meal size					Large meal size				
					High bioavailability		Low bioavailability			High bioavailability		Low bioavailability	
Health/function outcome	Critical response	Age class	No. high-level consumers	Meal size (g)	No. affected	95% C.L.	No. affected	95% C.L.	Meal size (g)	No. affected	95% C.L.	No. affected	95% C.L.
IQ	Deficit of 1 IQ point*	Children <8 years	9000	30	5124	4382 - 5602	3800	3053 - 4374	118	>9000	>9000 - >9000	>9000	>9000 - >9000
SATs writing score	Deficit of 0.04 score point	Children <8 years	9000	30	>9000	>9000 ->9000	8040	7668 - 8328	100	>9000	>9000 - >9000	>9000	>9000 - >9000
Spontaneous abortion rate	Increase in risk by 1%	Women 18-45 years	10154	100	886	312 - 1245	0	0 - 0	200	2267	1601 - 2800	926	476 - 1313
Chronic kidney disease Model 1	Increase in risk by 10%*	Adults >18 years	44500	100	18052	14498 - 2085	4561	2634 - 6434	200	28361	24739 - 30825	19402	15671 - 22091
Chronic kidney disease Model 2	Increase in risk by 10%*	Adults >18 years	44500	100	0	0 - 0	0	0 - 0	200	4314	2381 - 6110	438	185 - 744
Systolic blood pressure	Increase by 1.2 mmHg*	Adults >18 years	44500	100	578	248 - 969	0	0 - 0	200	6479	4139 - 8589	3962	1716 - 5601

Critical responses marked * are Bench Mark Responses (BMR) defined by EFSA (2010). Two models for calculating the BMR for kidney disease were used: Model 1 is that used by EFSA (2010) and Model 2 is that proposed by Green and Pain (2012) to allow for confounding variables. Numbers of high-level consumers are the mid-points of the ranges for children and adults from the shooting community estimated by a BASC/CA survey (LAG 2014) to eat at least one game meal per day throughout the year. The number of women at potential risk of spontaneous abortion is the number of child-bearing age obtained by multiplying the BASC/CA adult total by the proportion of adults in the 2013 UK population who are women in the age range 18-45 years. Small meal sizes are from FSA (2007) and large meal sizes from Green and Pain (2012) (children) and EFSA (2010) (adults).

The minimum numbers shown in Table 3 indicate that thousands of UK children from the shooting community may have gamebird meal intakes exceeding those required to be at potential risk from incurring the critical responses for IQ and SATs scores. Maximum numbers of adults from the shooting community estimated to exceed threshold intake rates for potential risk from incurring cardiovascular, nephrotoxicity and spontaneous abortion critical responses tended to be much smaller, ranging between zero and hundreds or thousands. As was the case for the maxima in Table 2, the exception was for the chronic kidney disease critical response from the dose-response model used by EFSA (2010). The same comment applies to this result as was made for the maxima.

CONCLUSIONS

People in the UK can be exposed to lead from ammunition principally by ingestion of dietary lead derived from small fragments of lead shot or bullets in game meat and the absorption of lead in the alimentary tract. Mean lead concentrations in meat from both large and small game animals shot with lead ammunition are often elevated, and frequently considerably elevated above the levels considered acceptable for meat derived from the muscle tissue of non-game animals. Some ammunition-derived dietary lead from the tissues of game animals ingested by humans is absorbed in the alimentary tract and enters the bloodstream. The absolute bioavailability of ammunition-derived lead may be lower than that of lead in the general diet, but the extent to which this is the case is unclear. However, the minimum plausible value of absolute bioavailability of ammunition-derived lead is substantial and capable of causing elevation of blood lead concentrations thorough absorption of ammunition-derived dietary lead.

At least one million people in the UK consume wild game at least once per year and surveys indicate that at least tens of thousands of people from the shooting community are high-level consumers of wild-shot game. The mean frequency of consumption of game meat by these high-level consumers may exceed one game meat meal per week, averaged over a whole year. There may be some high-level consumers outside the shooting community who are not included in these estimates. Many more people consume game less frequently.

There is no known requirement for lead by humans and no evidence for a threshold of exposure such as dietary intake rate or of blood lead level below which lead-induced negative health effects, such as increased systolic blood pressure, risk of chronic kidney disease and reduction in IQ score, can be considered to be completely absent.

Our calculations of minimum and maximum numbers of people in the UK exceeding threshold intake rates of gamebird meat required to be at potential risk of incurring the critical health effects identified by EFSA (2010) and Green and Pain (2012) indicate that children are likely to be the most numerous group vulnerable to negative effects on cognitive development from exposure to ammunition-derived lead. It is estimated that thousands of children in the UK (calculated to be in the range 4,000 - 48,000) could be at potential risk of incurring a one point or more reduction in IQ as a result of current levels of exposure to ammunition-derived dietary lead. Numbers of adults potentially vulnerable to critical health effects appear to be smaller, but the available data are too sparse to be certain.

In accord with these conclusions, the UK Food Standards Agency (FSA 2012) have advised that frequent consumers of game shot with lead ammunition should eat less of this type of meat, and that this is especially important in the case of toddlers and children, pregnant women and women trying for a baby, because of the harm that lead can cause to the brain and developing nervous system. This is consistent with recent advice given following risk assessments by equivalent agencies in a range of other European countries who consider that these most vulnerable groups should eat little or no game shot with lead ammunition (Germany, Spain, Sweden and Norway, see Knutsen *et al.* 2015).

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X-ray of a wood pigeon *Columba palumbus* sold by a game dealer: note the tiny radio-dense lead particles which would go unnoticed by the consumer.

Photo Credit: WWT

Associations between consumption of large game animals and blood lead levels in humans in Europe: the Norwegian experience

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ABSTRACT

Lead toxicity was re-assessed by international risk assessment bodies in 2010 and 2011 and was seen as more toxic than in previous risk assessments. No tolerable intakes of lead have been identified. High lead levels in minced meat from moose *Alces alces* hunted using expanding lead-based ammunition has previously been reported in Norway. In 2012, the Norwegian Scientific Committee for Food Safety (VKM) assessed the risk of lead exposure from cervid meat to the Norwegian population. In conjunction with that, the Norwegian Institute of Public Health investigated associations between cervid meat consumption and concentrations of lead in blood in Norwegians (the Norwegian Game and Lead study). The results showed that cervid game meat consumption once a month or more was associated with approximately 31% increase in blood lead concentrations. The increase seemed to be mostly associated with consumption of minced cervid meat. VKM concluded that the blood lead concentrations measured in participants in the Norwegian population studies were in the range of, and partly exceeding, the reference values for increased risk of high blood pressure and increased prevalence of chronic kidney disease in adults, and for neurodevelopmental effects in children. The additional lead exposure from cervid meat in frequent (monthly or more often) consumers of such meat is therefore of concern. For these reasons, continued efforts are needed to reduce lead exposure in the population.

Key words: *human health, blood lead, cervid meat, risk assessment, dietary study, Norway*

INTRODUCTION

Lead is a naturally occurring heavy metal found in small amounts in the earth's crust and is additionally an environmental contaminant due to human activities. Humans and animals are exposed to lead through food, drinking water, air and dust. This exposure and its subsequent accumulation in the body is known to be harmful both to humans and animals.

In 2010 and 2011, respectively, both the European Food Safety Authority (EFSA) and the Joint Food and Agriculture Organisation/World Health Organisation Expert Committee on Food Additives (EFSA 2010, JECFA 2011) concluded, based on dose-response analyses, that there were no obvious thresholds for critical endpoints of lead exposure, *i.e.* there is not a level under which there is no increased risk of adverse health effects. Neurodevelopmental effects in children and increased blood pressure in adults are critical effects of lead exposure identified by both EFSA and JECFA (EFSA 2010, JECFA 2011). Children are more sensitive than adults to the effects of lead because their brain is under development. Increased blood pressure due to lead exposure is not an adverse outcome by itself, but is associated with increased risk of cardiovascular mortality. The EFSA Panel on Contaminants in the Food Chain (CONTAM) (EFSA 2010) identified Benchmark Dose Lower-confidence Limits (BMDL) for reduction in IQ, increased blood pressure and prevalence of chronic kidney disease (Table 1).

Table 1: **Overview of reference values for blood lead concentrations** (from VKM 2013, based on EFSA 2010)

Blood lead concentration (µg/l)	Explanation
$BMDL_{01}$: 12	1% reduction in full scale IQ in children (= 1 point reduction in IQ)
$BMDL_{01}$: 36	1% increase in systolic blood pressure in adults (1.2 mmHg given a blood pressure of 120 mmHg)
$BMDL_{10}$: 15	10% increased prevalence of chronic kidney disease in adults

Throughout Europe lead is commonly used in rifle ammunition for cervid hunting. The use of lead shot for smaller animals including wild birds was prohibited in Norway in 2005. However, on February 3rd 2015, the Norwegian parliament voted to permit the use of lead shot for hunting outside wetlands and outside shooting ranges. This political decision was made against recommendations from the environmental and health advisory bodies in Norway. Norwegian researchers have reported findings of high lead levels (mean 5.6 mg/kg, max 110 mg/kg) in minced meat from moose *Alces alces* hunted using expanding lead-based ammunition (Lindboe *et al.* 2012). Maximum levels of lead (0.1 mg/kg) have been set by the European Commission (under Commission Regulation 1881/2006 [EC 1881/2006]) for meat from livestock animals, but no maximum levels have been set for game meat. In 2012, the Norwegian Food Safety Authority requested the Norwegian Scientific Committee for Food Safety (VKM) to assess the risk of lead exposure from cervid meat to the Norwegian population. Further, VKM was asked to describe the distribution of lead from ammunition in the carcass and to estimate the tissue area associated with the wound channel that has to be removed in order to reduce the risk. VKM was also asked to present, if any, other appropriate measures, in addition to removing tissue, in order to limit the content of lead residues from ammunition in cervid meat. Finally, VKM was asked to assess the significance of lead exposure to the health of dogs if they were fed with trimmings from the wound channel. The risk assessment was published in June 2013 (VKM 2013). The results of the human health risk assessment and the conclusions regarding possible measures to reduce exposure are presented here.

To improve the scientific basis for the VKM risk assessment the Norwegian Institute of Public Health initiated The Norwegian Game and Lead study. The aim of the study was to investigate associations between cervid meat consumption and concentrations of lead in blood in Norwegians. The outcome from this study was published in 2013 (Meltzer *et al.* 2013) and was used in the VKM risk assessment. In addition, associations between cervid meat consumption and blood lead concentrations in other available studies from Norway were explored by the Norwegian Institute of Public Health.

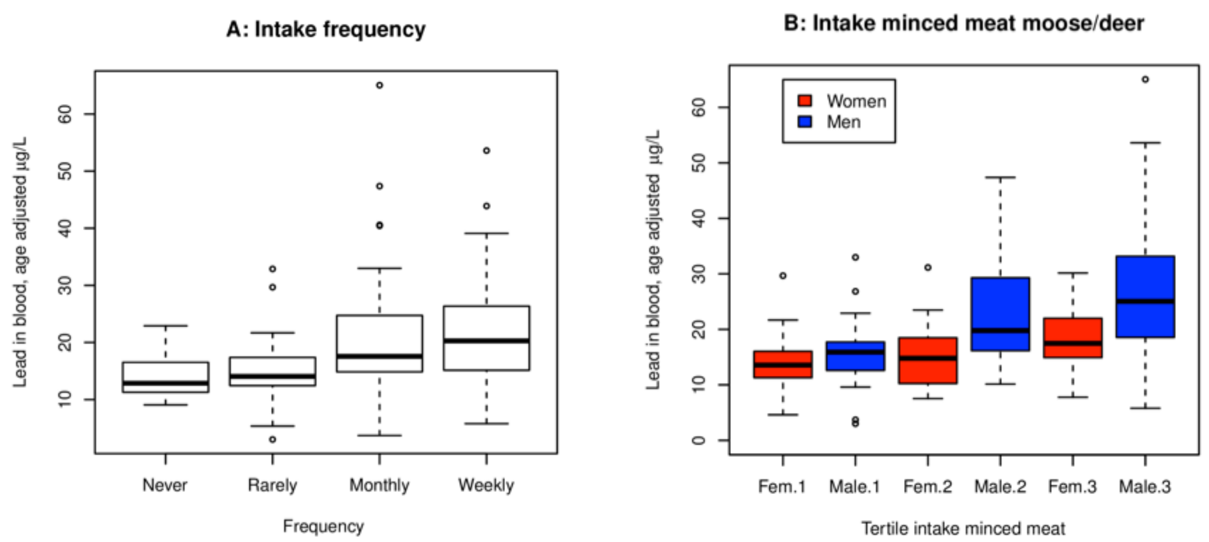
METHOD

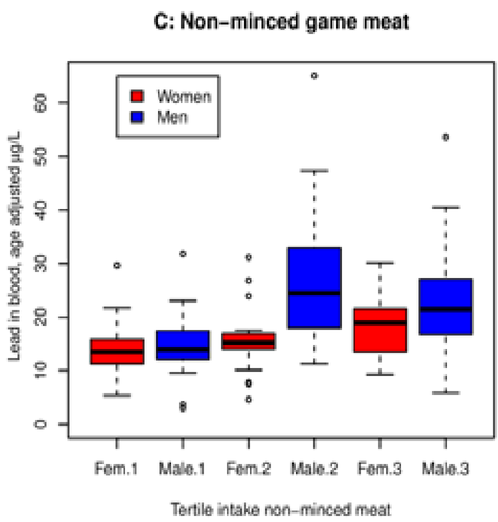
FOR THE NORWEGIAN GAME AND LEAD STUDY

The Norwegian Game and Lead study (Meltzer *et al.* 2013) was conducted in 2012 in adults (n = 147) with a wide range of cervid game meat consumption. The main aim was to assess whether high consumption of lead-shot cervid meat is associated with increased concentration of lead in blood. A second aim was to investigate to what extent factors apart from game meat consumption explain observed variability in blood lead levels. Participants were asked about the frequency of cervid game meat consumption (never, rarely during a year, one to three times per month and one or several times per week) and data were collected on their background (age, height, occupation, residence), hunting habits (number of years hunting, assembling own ammunition, number of shots fired, type of hunting, *etc.*), on modifying factors (dietary supplements, alcohol consumption, smoking, *etc.*) and consumption of game (moose, red deer *Cervus elaphus*, roe deer *Capreolus capreolus*, reindeer *Rangifer tarandus*, and small game). Detailed information on game consumption included whether the game was whole meat, minced meat or offal, whether the meat was from their own hunting or purchased, and consumption within both the last month and the last year.

RESULTS

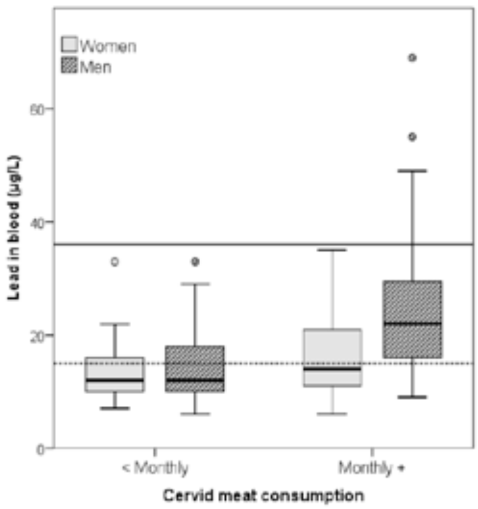
Median (5 and 95 percentile) blood lead concentration in the participants was 16.6 µg/l (7.5 and 39 µg/l). An optimal multivariate linear regression model for log-transformed blood lead indicated that cervid game meat consumption once a month or more was associated with approximately 31% increase in blood lead concentrations. The increase seemed to be mostly associated with consumption of minced cervid meat, particularly purchased minced meat (Figure 1). However, many participants with high game meat intake over a long period of time had low blood lead concentrations. Cervid meat together with the number of bullets shot per year, years of game consumption, self-assembly of bullets, wine consumption and smoking jointly accounted for approximately 25% of the variation in blood lead concentrations, while age and sex accounted for 27% of the variance. Blood lead concentrations increased approximately 18% per decade of age, and men had on average 30% higher blood lead concentrations than women. Hunters who assembled their own ammunition had 52% higher blood lead concentrations than persons not making ammunition. In conjunction with minced cervid meat, wine intake was significantly associated with increased blood lead. The proportion of participants with blood lead levels exceeding the EFSA BMDLs (Table 1) is illustrated in Figure 2.





(A) *Age-adjusted blood lead by frequency of game consumption.*
(B) *Age-adjusted blood lead by tertiles of intake of minced meat from moose or deer, separately for men and women. Blood lead means in the three men tertiles were 15.5, 23.0 and 26.7 µg/l, while the corresponding means for women were 13.7, 15.7 and 18.4 µg/l, respectively. Minced cervid meat intake was associated with total game intake at low and moderate game intakes, but not at the highest intakes.*
(C) *Age - adjusted blood lead by tertiles of intake of meat from game, except for minced meat from moose or deer, for men and women. No corrections have been made for intake of minced meat. Men in the highest tertile had slightly lower blood lead levels than those in the middle tertile, 26.7 vs.24.7 µg/l, but the difference was not significant (0.1<P<0.2). From Meltzer et al. (2013).*

Figure 1: **Age-adjusted blood lead by frequency of consumption**



Box plot details: the horizontal lines indicate the median blood lead concentration; the box indicates the interquartile range (IQR); the vertical bars represent observations within 1.5-times the IQR; and the circles indicate observations more than 1.5 times the IQR away from the box, considered outliers. The dashed horizontal line indicates the BMDL10 of 15µg/l for increased prevalence of chronic kidney disease and the solid horizontal line indicates the BMDL01 for increased systolic blood pressure. From VKM (2013), adapted from results in Meltzer et al. (2013).

Figure 2: **Proportion of participants with blood lead above BMDLs**

DISCUSSION

The results indicate that hunting practices such as use of lead-based ammunition, self-assembly of lead-containing bullets and use of lead-contaminated meat for mincing to a large extent determine human exposure to lead from cervid game consumption.

Lead exposure from cervid meat can be seen as additional to exposure from other foods, of which the main food groups contributing in the general population are grains and grain products, milk and other dairy products, non-alcoholic beverages and vegetables (EFSA 2012). According to the most recent (2012) representative national dietary survey in Norway, mean game (including cervid) meat consumption was low, at approximately 5-7 meals per year (VKM 2013). However, in several surveys in Norway, a large proportion (40 to 70%) of the participants consumed cervid meat at least once a month or more often (Birgisdottir *et al.* 2013, VKM 2013).

The mean or median concentrations of lead in blood in various Norwegian studies varied from 11 to 27 µg/l, which is in the same range as studies in most European countries from the last 10 years (Birgisdottir *et al.* 2013, VKM 2013). Blood lead concentrations were lower in pregnant women than in other adult population groups in Norway (VKM 2013). No information on blood lead levels in Norwegian children is available (VKM 2013). Recent data show that the geometric mean lead level in children of Swedish hunters was 11.7 µg/l (Forsell *et al.* 2014).

Associations between game meat consumption and blood lead concentration have been investigated in four population studies in Norway that were conducted prior to the Norwegian Game and Lead study (Birgisdottir *et al.* 2013, VKM 2013). In the three studies performed in the years 2003-2005, a significant association between game meat consumption and higher blood lead concentration was only seen in the subgroup of male participants in one of the studies (the Norwegian Fish and Game study). Furthermore, associations have been observed in two recent Swedish studies (Bjermo *et al.* 2013, Forsell *et al.* 2014) and a study from North Dakota, USA (Iqbal *et al.* 2009). None of the Norwegian studies could fully investigate the potential association between small game consumption and blood lead levels, because of infrequent consumption of small game among the participants. However, such associations have been observed in two studies in Greenland (Bjerregaard *et al.* 2004, Johansen *et al.* 2006). It is notable that lead concentrations in small game species, such as gamebirds, tend to be higher than in larger game, like deer (Pain *et al.* 2010) and therefore the relationship between blood lead and game consumption is logically likely to be present in frequent consumers of small game as well. Results from studies on associations between game meat consumption and blood lead concentration are summarised in Table 2.

Table 2: **Studies of association between game consumption and lead in blood**

Study, country	Sampling year (n)	Association between blood lead and frequency of game consumption?	Reference
Greenland	1993-1994 (162 adult men and women)	Yes	Bjerregaard *et al.* 2004
Greenland	2003-2004 (50 adult men)	Yes	Johansen *et al.* 2006
Fish and Game study, Norway	2003-2004 (184 adults)	Yes, but only in men	Birgisdottir *et al.* 2013
MoBa validation study, Norway	2003-2004 (119 pregnant women)	No	VKM 2013
Lake Mjøsa study, Norway	2004-2005 (64 adults)	No	VKM 2013
North Dakota, USA	2008 (736 adults and children)	Yes	Iqbal *et al.* 2009
Riksmaten, Sweden	2010-2011 (273 adults)	Yes	Bjermo *et al.* 2013
Lead and Game study, Norway	2012 (147 adults)	Yes	Meltzer *et al.* 2013
Swedish hunters and families	2013 (113 adults)	Yes	Forsell *et al.* 2014 (report in Swedish)

The distribution of fragmented lead ammunition within game meat is dependent on several variables. Available studies on lead concentrations in meat at different distances from the wound channel were summarised in the VKM report from 2013. Based on these data, it was concluded that removal of meat around the wound channel reduces lead exposure from cervid meat consumption. One study indicated that lead concentrations above 0.1 mg/kg can be found at a distance of 25 cm from the wound channel in red deer and wild boar *Sus scrofa* shot with various unknown ammunition (Dobrowolska and Melosik 2008). However, there were no available studies in moose, and the data did not allow a firm conclusion on the amount of meat needed to be trimmed around the wound channel in order to remove lead originating from the ammunition. Other possible measures identified by VKM to reduce lead exposure from cervid meat would be to use lead based ammunition with low fragmentation or ammunition without lead.

CONCLUSIONS AND RECOMMENDATIONS

Based on the data available in 2013, VKM concluded that the blood lead concentrations measured in participants in the Norwegian population studies were in the range of, and partly exceeding, the reference values for increased risk of high blood pressure and increased prevalence of chronic kidney disease in adults, and for neurodevelopmental effects in children.

The additional lead exposure from cervid meat in frequent (monthly or more often) consumers of such meat is therefore of concern. For these reasons, continued efforts are needed to reduce lead exposure in the population.

Based on the risk assessment from VKM, the Norwegian Food Safety Authority recommends that:

- Children, pregnant women, women of reproductive age and people with high blood pressure should not eat lead-shot cervid meat more often than once a month.
- The use of non-lead bullets removes the risk of lead contamination of game meat.
- If lead ammunition is used, one should use bullets that only fragment to a small extent on impact.
- Meat removal in a radius of 30 cm (*i.e.* a 60 cm diameter) along the bullet channel is necessary. The effect of this is however not fully known.

These recommendations are in line with those produced by food safety and risk assessment agencies of several other European countries in recent years (Table 3).

Table 3: **Advice by national food safety and risk assessment agencies regarding the consumption of game meat shot using lead ammunition**

Institute	Date	Advice
Federal Institute for Risk Assessment, Germany (BfR 2011)	September 2011	BfR recommends that children, pregnant women, and women planning to have children should not eat meat from game animals killed by hunters. The consumption of game meat contaminated by lead bullets should definitely be avoided. Cutting out large sections of meat around the bullet hole is not always enough to guarantee removal of lead.
Scientific Committee of the Spanish Agency for Food Safety and Nutrition Safety (AESAN 2012)	February 2012	AESAN recommends that children under 6 years of age, pregnant women and women who plan on getting pregnant should avoid eating the meat of game that has been shot with lead ammunition. This is because the lead fragments cannot be removed from the meat completely. Wherever possible, limiting the use of lead ammunition in favour of other available alternatives should be promoted.
National Food Agency, Sweden (SNFA 2014)	June 2012	Pregnant women and children 0-7 yrs. should avoid eating meat shot with lead ammunition. Using lead-free ammunition eliminates the problem of elevated lead levels in game meat and products made from game meat.
	June 2014	Meat from the bullet channel and the affected meat next to the bullet channel and another 10 cm seemingly unaffected meat should not be used for food, but discarded.
Food Standards Agency, UK (FSA 2012)	October 2012	The Food Standards Agency is advising people that eating lead-shot game on a frequent basis can expose them to potentially harmful levels of lead. The FSA's advice is that frequent consumers of lead-shot game should eat less of this type of meat. This advice is especially important for vulnerable groups such as toddlers and children, pregnant women and women trying for a baby, as exposure to lead can harm the developing brain and nervous system.
The Norwegian Food Safety Authority (VKM 2013)	October 2013	Children, pregnant women, women in fertile age and people with high blood pressure should not eat lead-shot cervid meat more often than once a month. The use of non-lead bullets removes the risk of lead contamination of game meat. If lead ammunition is used, one should use bullets that fragment to a small extent upon impact. Meat removal in a radius of 30 cm along the bullet channel is necessary. The effect of this is however not fully known.

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X-ray of a roe deer *Capreolus capreolus* shot with a conventional lead-based (semi-jacketed) bullet: note the extent of fragmentation of the lead projectile and distance from the wound canal to which the consumer is then exposed.

Photo Credit: Oliver Krone/Leibniz Institute for Zoo and Wildlife Research, Berlin

Lead from hunting ammunition in wild game meat: research initiatives and current legislation in Germany and the EU

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ABSTRACT

Lead exposure from hunting bullets used in regular hunting practices for cloven-hoofed game in Germany is a major cause of death in raptors, especially white-tailed sea eagles *Haliaeetus albicilla* and attracts considerable political attention in Germany. We give an overview of related research projects since 2006. We focused on the use of hunting bullets of both lead and non-lead construction in hunting for cloven-hoofed game from an animal welfare perspective, on the rebound characteristics of lead and non-lead bullets and on bullet residues in marketable game meat from a consumer protection point of view. A timeline of research and policy-related responses from the various relevant organisations and agencies is presented. An overview of the current legislation in Germany for the use of lead and non-lead ammunition for rifle and shotgun hunting is given with pending legislative changes. There is a definite trend within state and federal governments to end the use of lead in hunting as a result of the scientific evidence on the risks to human and wildlife health. We summarise an European Union process concerning "lead in consumer articles", that excluded ammunition specifically by declassifying it as a "consumer article" and thus omitted addressing the issue of ammunition also being used in food production of game meat.

Key words: *lead, hunting, rifle, bullets, animal welfare, consumer protection, legislation, game meat, Germany, research initiatives*

NARRATIVE

Lead exposure has been found to be a major cause of death for raptors, especially white-tailed sea eagles *Haliaeetus albicilla* in Germany (Kenntner *et al.* 2001, Krone *et al.* 2003). Rifle bullets containing lead have been identified as a main source of lead exposure (Krone and Hofer 2005). This evidence prompted extensive political activity and research into the avoidance of lead as a bullet material in hunting. In 2006 the German Federal State of Brandenburg launched investigations into the suitability of alternative materials for rifle bullets to be used in hunting in state forests. In 2007, hunters from the states of Schleswig-Holstein and Bavaria joined the project (Gremse and Rieger 2007). In 2008, the State of Brandenburg halted the field research involving the use of non-lead bullets (State of Brandenburg 2008) due to safety concerns about the rebound characteristics of lead-free bullets. In 2010, the Federal German Government commissioned research into the rebound characteristics of rifle bullets, shotgun slugs[1] and shot of both

[1] A single, heavy shotgun projectile as opposed to "shot", where many individual, small spheres make up the charge of one cartridge.

lead and non-lead composition and continued research into the terminal ballistics of hunting bullets (Gremse *et al.* 2014a).

In 2010, the European Food Safety Authority Panel on Contaminants in the Food Chain published a Scientific Opinion on Lead in Food (EFSA 2010), concluding, "that the current PTWI [provisional tolerable weekly intake] of 25 µg/kg bw[2] is no longer appropriate as there is no evidence for a threshold for critical lead-induced effects." Shortly after, the Federal German Institute for Risk Assessment (BfR) released a statement regarding lead contamination of game meat from hunting ammunition (BfR 2010). In 2011, the results of the tests of bullet rebound characteristics (DEVA e. V. 2011) and an expert consultation on this report (Kneubuehl 2011a) were published, showing no increased risks associated with rebounds in the use of non-lead projectiles (Kneubuehl 2011b). A conference at BfR held in 2011 summed up the research progress, the state of political decision making and stakeholder dialogue (BfR 2011). In 2012, a Public-Private-Partnership-Project (LEMISI) was started by the federal and state governments in cooperation with private sectors (game meat processors, vendors, ammunition manufacturers, federal and state non-governmental hunting organisations) to monitor the lead, copper and zinc content of marketable game meat and to distinguish between hunting bullets and environmental sources (BfR 2013, Gremse *et al.* 2014b).

A first report was published (Gremse and Rieger 2012), linking observations of animal reactions to being shot, especially focusing on the animals' flight distance and situation specific, terminal ballistic performance data for the bullets used (n=2,881). The study showed a correlation between hunter satisfaction and animal escape distances after the shot. Animal escape distances were found to be dependent on bullet material only if terminal ballistic performance parameters were not included. In other words, when comparing equal terminal ballistic performance levels, escape distances do not differ between lead and non-lead bullets. A different study found wound size and morphology, and bullet material (lead/non-lead) to be independent (Trinogga *et al.* 2013). Test results and consultations on the rebound characteristics of shotgun slugs and shot were published in 2013 (DEVA e. V. 2013a, 2013b). For shotgun slugs, the rebound risks and areas do not differ between lead and non-lead projectiles. For shot, the evidence was reported to be inconclusive, as variation for factors like "mass retention" and "energy retention" in each material category was too highly influenced by characteristics individual to a specific product (Kneubuehl 2013). The status of research in this area was recently reported at a BfR conference (BfR 2013).

Research into the properties of lead and other bullet material was continued until spring 2014. Further analysis was carried out on the 2012 data linking field observations on the use of bullets to hunt roe deer *Capreolus capreolus*, red deer *Cervus elaphus*, fallow deer *Dama dama* and wild boar *Sus scrofa*, and terminal ballistic testing data (Gremse and Rieger 2014). At the 2014 BfR conference the status of research in this area was again presented, focusing especially on the methods and results of the now completed LEMISI Study.

A total of 2,201 animals consisting of roe deer, red deer and wild boar were shot with both lead and non-lead bullets during routine hunting in three states of Germany, and then sampled at the game processor by trained and licensed professionals. Three samples were obtained from each carcass (haunch, saddle and chest) after the carcass was judged fit for human consumption. Samples were analysed at independent laboratories for lead, copper and zinc content (Gremse *et al.* 2014b).

The use of lead bullets was shown to increase lead content in marketable game meat above the levels attributable to other environmental sources. The use of non-lead bullets was shown to significantly reduce meat lead content. Lead content was shown to be highest closest to the shot channel, progressively declining with distance from it (BfR 2014).

A new method of terminal ballistic analysis using computed tomography scanning of ballistic testing material was used and validated against conventional methodology (Gremse *et al.* 2014a). This approach not only allows a comparison of bullets and their ballistic properties, but also assesses bullet fragmentation into adjacent tissues. The study showed a dramatic reduction in bullet material deposition for non-lead bullets compared with lead bullets. The study showed equal terminal performance of one type of tested non-lead bullet with the lead control. Further research is in progress and will be reported in time.

State of Legislation

The use of ammunition for hunting in Germany is legislated through federal and state laws following the principle of "competing legislation". In practice, a third venue of rule has been

[2] PTWI: Provisional Tolerable Weekly Intake, expressed as amount of intake per kilogram body weight (bw) per week.

established – the rule of "ownership" (Heider 2013)(see below).

FEDERAL LEGISLATION

The German Federal Hunting Act (CGerLI 2008), as amended in 2013, does not give specific parameters for the use of shot for hunting, but rather prohibits its use for cloven-hoofed game and seals, both for shooting healthy and previously wounded game. The use of rifle ammunition is legislated by a minimum bullet diameter (calibre) of 6.5 mm (0.257") and minimum impact energy at 100 m for all cloven-hoofed game, except roe deer, of 2000 joules (~1.475 foot pounds). For roe deer, no minimum calibre is specified and a minimum impact energy of 1000 joules (~738 foot pounds) applies. No specifications are given for bullet or shot material composition. The Federal German Ministry for Food and Agriculture announced plans to change the Act to provide a standard national solution for the utilisation of hunting rifle ammunition. "The new act aims to minimize the lead contamination of game and environment through hunting ammunition and to ensure the utility of projectiles for hunting" (BMEL 2014). During the legislative process, this draft for a 'first law to change the Federal German Hunting Law' was commented on by the Federal Assembly (Bundesrat) on 27th March, 2015. The Federal Assembly moved to include a ruling in the draft with the objective to 1) ban lead ammunition for hunting and 2) ensure reliable terminal ballistic performance (German Federal Assembly 2015).

FEDERAL STATES LEGISLATION

The 16 German Federal States pass state hunting legislation, in which rulings of the federal act can be extended.

1. USE OF LEAD SHOT

Some 14 of 16 German Federal States implemented rulings against the use of lead shot over and around wetlands and waterbodies for hunting waterbirds (BMU 2011), in accordance with the "Agreement on the Conservation of African-Eurasian Migratory Waterbirds" (AEWA 2012). The Free State of Saxony, extended the ruling to include all game hunted with shot, not only waterfowl, starting 1st April, 2014 (Free State of Saxony 2012).

2. USE OF LEAD BULLETS

Some three of 16 German Federal States (Schleswig Holstein (LTSH 2014), Baden-Wuerttemberg (MLRV 2014) and Saarland (CdS Saarland 2014)) have moved to regulate the use of lead bullets for hunting. In Schleswig Holstein the use of lead bullets and shotgun slugs for hunting has been banned since 1st April, 2015. This action was based on the results of Gremse and Rieger (2012, 2014)(LTSH 2014). In Baden-Württemberg, the use of lead bullets will be banned for hunting cloven-hoofed game with effect from 2016. At Saarland, state-wide restrictions of bullets containing lead are in place, effective from 1st April, 2014, with a grace period granted to phase out their use by 2017. At time of writing the Federal State of North Rhine Westphalia is in the process of passing hunting legislation, which will restrict the use of lead bullets and shotgun slugs in hunting (MKULNV 2014).

3. OWNERSHIP RULINGS

In Germany hunting rights are tied to land ownership. There is a differentiation between the 'hunting right' and the 'right to hunt'. The former is the inalienable right of the landowner to gain from hunting of the owned land, whereas the 'right to hunt' "denotes the exclusive entitlement to care for and protect, to hunt and appropriate those animals living in the wild state which are subject to the right to hunt (game), on a specified area of land" (CGerLI 2008). Land is mostly owned by private, municipal, conventual, state and federal entities. Ten of the 16 forestry services of the Federal States, the Federal Forest Service and the 14 National Park Offices have rulings in place banning the use of lead rifle bullets on their land (DJV 2014). The City of Rostock municipal forest (City of Rostock 2011), the German Federal Environmental Foundation (DBU 2011), the City of Greifswald (Greifswald 2011) and the City of Fuerstenwalde (City of Fuerstenwalde 2014), restricted the use of lead bullets in 2008, 2012 (both DBU and Greifswald), and 2013 respectively. A summary of current federal, state and ownership rulings restricting the use of lead bullets, shot and slugs for hunting is given in Table 1.

EUROPEAN UNION INITIATIVE "LEAD IN CONSUMER ARTICLES"

In 2012 Sweden submitted a 'Proposal for a Restriction of Lead and its Compounds in Articles intended for Consumer Use' (ECHA 2013a) under REACH-Regulation. REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry[3]. It also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals. The goal of the Proposal

[3] http://echa.europa.eu/regulations/reach

Table 1: **Legislation relating to bans on lead ammunition in German regions and legislature**

Entity	Rifle non-lead only	Shotgun non-lead only
Federal Hunting Act	in progress*	
Baden-Württemberg	State Forests since 2014, state-wide by 2016	In line with AEWA
Bavaria	no provisions	In line with AEWA
Berlin	State Forests since 2013	In line with AEWA
Brandenburg	State Forests since 2013	In line with AEWA + State Forests
Bremen	no provisions	no provisions
Hamburg	no provisions	no provisions
Hesse	State Forests by 2015	In line with AEWA
Lower Saxony	State Forests since 2013	In line with AEWA
Mecklenburg-Vorpommem	State Forests since 2014	In line with AEWA
North Rhine- Westphalia	State Forests since 2013	In line with AEWA
Rhineland-Palatinate	State Forests since 2013	In line with AEWA
Saarland	State Forests since 2011, state-wide since 2014†	In line with AEWA
Saxony	provisions in place, not executed	All game species
Saxony-Anhalt	no provisions	In line with AEWA
Schleswig-Holstein	State Forests since 2013, state-wide by 2015	In line with AEWA
Thuringia	no provisions	In line with AEWA
Federal Forest Service	Since 2013	
German Federal Environmental Foundation	Since 2012	
City of Greifswald	Since 2011	
Zity of Rostock	Since 2008	
City of Furstenwalde	Since 2013††	

* Legislative action by Federal Government to change the Federal Hunting Act
† With a grace-period until 2017 excluding state forests
†† With exclusion of game drives

is stated as "Lead and its compounds shall not be placed on the market or used in articles or individual parts of articles, which are supplied to the general public and can be placed in the mouth by children, if the concentration of lead (expressed as metal) is equal or greater than 0.05% by weight" (ECHA 2013a). "Shot and ammunition" were identified as a "world end use of lead", identifying end consumer products (SCA 2012). During the first public consultation arguments were submitted by an anonymous, 'international, non-governmental organisation' from Belgium 'as to why ammunition should be out of the scope from the proposed Restriction' and confirmation was received "that ammunition will formally be excluded from the final text of the proposed restriction" (ECHA 2014a). The Association of European Manufacturers of Sporting Ammunition (AFEMS) refers to this process on their website[4] and states to be "involved with other European Associations in providing the necessary information and support concerning the use of metallic lead in ammunition." In the European Chemicals Agency (ECHA) Committee for Risk Assessment (RAC) "Opinion on the Swedish Proposal", it is "assumed that ammunition is kept out of reach for children due to member states implementation of existing EU legislation related to the safe-keeping of such articles. Normal and reasonably foreseeable conditions of use would not occur as the other hazards of ammunition would necessitate such articles being securely stored away from children" (ECHA 2013b). The ECHA Committee of Socio-economic Analysis (SEAC) follows this assumption in their opinion (ECHA 2013c).

Later documentation (compiled opinion by RAC and SEAC) (ECHA 2014b), the final background document to RAC and SEAC Opinions on "lead and its compounds in articles" repeat this opinion and fail to introduce differing views (ECHA 2014c). Alternate views to the RAC (Mullooly 2013) and SEAC (Knoflach 2014) opinions have been documented, touching on, only amongst other things, the topics of cultural, traditional and/or religious handcraft figurines and similar objects (objets d'art), writing instruments, keys, locks and musical instruments. However, the use of lead ammunition in sourcing food for human consumption has not been considered to date. The process does not therefore address the introduction of lead into food for human consumption from ammunition used in the production of game meat. Whether or how this will be addressed in time by this particular process remains to be seen.

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[4] http://www.afems.org

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Moribund white-tailed eagle *Haliaeetus albicilla* in final stages of lead poisoning: found due to satellite transmitter.

Photo Credit: Oliver Krone/Leibniz Institute for Zoo and Wildlife Research, Berlin

Poisoning of birds and other wildlife from ammunition-derived lead in the UK

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ABSTRACT

Lead is toxic to animals and thousands of tonnes of lead ammunition, primarily gunshot, are deposited and accumulate in the UK environment annually. Lead derived from ammunition now appears to be the most significant geographically widespread and common source of unregulated environmental lead contamination in the UK to which wildlife is exposed. The effects of lead from ammunition have primarily been studied in birds, with the two main exposure pathways being direct ingestion of spent gunshot (*e.g.* by wildfowl and terrestrial gamebirds, that mistake it for grit or food), and ingestion by predators and scavengers of lead gunshot, bullets, or fragments from these, in the flesh of their prey. Numerous studies conducted in the UK and overseas over the last 65 years have shown that lead poisoning from ammunition sources is geographically widespread and causes substantial suffering and mortality in many avian taxa. While relatively few studies have focussed on non-avian taxa in the UK, this does not imply that risks do not exist.

Broad estimates indicate that in the UK in the order of 50,000-100,000 wildfowl (c. 1.5-3.0% of the wintering population) are likely to die each winter (*i.e.* during the shooting season) as a direct result of lead poisoning. For migratory swans, this represents a quarter of all recorded deaths. Wildfowl that die outside of the shooting season will be additional, as will those that die of causes exacerbated by lead poisoning. Several hundred thousand wildfowl a year may suffer welfare effects. Estimates of mortality for terrestrial gamebirds in the UK are less accurate and precise, but indicate that in the order of hundreds of thousands of birds may die from lead poisoning annually. Studies in North America show that lead poisoning kills a substantial proportion of certain species of predatory and scavenging birds, but equivalent studies have not yet been conducted in the UK. A few studies from the UK have reported lead poisoning in certain raptor species, and the source and pathways exist for a wider range of species to be affected.

Key words: *Lead, ammunition, wildlife, birds, poisoning, mortality, UK, welfare*

INTRODUCTION

Lead is a naturally occurring toxic metal that has been used by humans for centuries, and is consequently widely distributed in the environment. Increasing knowledge of the negative effects of even low levels of exposure to lead on human health has resulted in society taking many actions to reduce emissions of, and exposure to, lead such as its removal from petrol and paint. For example, atmospheric lead emissions were estimated to have declined by 98% between 1990 and 2011 in England largely due to the phasing out of the use of lead additives in petrol (Thistlethwaite *et al.* 2013).

Current legislative controls and monitoring of industrial, municipal and agricultural lead emissions in the UK are such that cases of clinical lead poisoning from these sources in wildlife are likely to be rare. High concentrations of lead derived from sources other than ammunition and fishing weights exist in some soils in urban areas and near centres of current and historical industrial activity, especially mining and smelting.

Some lead derived from anglers' lead weights used before restrictions on their sale and use were introduced in 1987 is present in some wetlands and rivers, but additional lead from this source has probably been added at a low rate since then through a small amount of permitted use, and any illegal use that may have occurred. The mute swan *Cygnus olor* is the species reported to have been significantly affected by the ingestion of anglers' lead weights in the UK (Birkhead 1982, Birkhead and Perrins 1986) probably because of their habit of frequenting urban rivers and lakes where fishing activity is high. The recorded decrease in the incidence of lead poisoning in mute swans (Sears and Hunt 1990) and corresponding increase in their populations following the 1987 restrictions (Kirby *et al.* 1994) suggests that restrictions were largely successful. Newth *et al.* (2012) similarly found that the proportion of deaths attributable to lead poisoning in a sample of mute swans decreased significantly over time after restrictions, *i.e.* from 25% between 1971 and 1987 (pre-restrictions) to 4.6% between 1988 and 1999 and 2% between 2000 and 2010.

Beyond these sources, lead derived from ammunition now appears to be the only significant, geographically widespread and common source of unregulated environmental lead contamination to which wildlife is exposed.

This paper aims to bring together a broad range of evidence to illustrate the pathways by which wildlife is exposed to ammunition-derived lead and review the extent and impact of the problem in the UK.

PHYSIOLOGICAL EFFECTS OF LEAD

Lead is a non-essential metal that has no biological benefit to living organisms and is toxic to all vertebrates. Lead is also toxic to invertebrates but sensitivities appear to vary considerably (Eisler 1988). It is an accumulative metabolic poison that is non-specific, affecting a wide range of physiological and biochemical systems. These include the haematopoietic, vascular, nervous, renal and reproductive systems (Eisler 1988, USATSDR 2007, EFSA 2010, Franson and Pain 2011). Lead occurs primarily in inorganic form in the environment and lead in ammunition is in its elemental metallic form. In this paper, the term "lead" refers to inorganic lead. Following absorption, the effects of lead upon an animal's body systems are independent of source.

The toxic effects of lead are broadly similar in all vertebrates. In wild animals these effects are well known from numerous experimental and field studies. These have been reviewed many times (*e.g.* Eisler 1988, Pattee and Pain 2003, Franson and Pain 2011, Ma 2011). Although the present paper deals with wildlife in general, we have focussed upon birds because they are by far the most significantly studied taxon and are significantly affected. Clinical signs of poisoning are often associated with chronic exposure to lead in birds. Chronic exposure is extended exposure at a level that is not necessarily likely to cause immediate failure of biological functioning or death, although death may eventually result. Signs include anaemia, lethargy, muscle wasting and loss of fat reserves, green diarrhoea staining the vent, wing droop, lack of balance and coordination and other neurological signs such as leg paralysis or convulsions (*e.g.* Locke and Thomas 1996, Wobeser 1997, Friend and Franson 1999, Eisler 2000, Pattee and Pain 2003). In cases where birds die rapidly following acute exposure to high levels of lead, many of these signs may be absent.

Numerous experiments have been conducted where captive birds from many taxa, including wildfowl and raptors, have been dosed with lead gunshot and blood lead concentrations and physiological responses reported relative to controls (*e.g.* Pattee *et al.* 2006, Hoffman *et al.* 1981, 1985, reviews in Eisler 1988, see also Pattee and Pain 2003, and Franson and Pain 2011). In some instances, lead ammunition or ammunition fragments are eliminated rapidly from a bird's alimentary canal with little lead absorption, but they are also often retained until completely eroded, with the lead becoming soluble salts and much of it being absorbed by the bird. The acidic conditions in birds' stomachs and the strong mechanically grinding action in the gizzards of certain bird species facilitate erosion and solubilisation of lead ammunition, and blood lead concentrations can rapidly become elevated after ingestion of gunshot (*e.g.* see Hoffman *et al.* 1981, 1985, Pain and Rattner 1988, Pattee *et al.* 2006). Absorbed lead is transported in the bloodstream and deposited rapidly into soft tissues, primarily the liver and kidney, into bone, and the growing feathers of birds. Lead in bone is retained for long periods and bone lead concentrations increase over an animal's lifetime, whereas lead in soft tissues has a much shorter half-life (often weeks to months). Consequently, highest lead concentrations are generally found in bone, followed by kidney and liver, with intermediate concentrations in brain and blood, and lowest concentrations in muscle (Longcore *et al.* 1974a, Johnson *et al.* 1982, Custer *et al.* 1984, Garcia Fernandez *et al.* 1995). However, in cases of acute lead poisoning, concentrations in soft tissues may be very elevated relative to those in bone. Blood lead is a good indicator of recent exposure and usually remains elevated for weeks or months after exposure. The degree and duration of elevation of blood lead depends largely upon the amount absorbed and the duration of exposure. While lead in bone is less mobile than in other tissues, it can be mobilised under certain conditions. For example, lead may be mobilised from medullary bone together with calcium, when calcium is required for eggshell formation (Finley and Dieter 1978).

The first measurable biochemical effect of lead, occurring at very low blood lead levels, is inhibition of the activity of the blood enzyme delta-aminolevulinic acid dehydratase (δ-ALAD), necessary for haem synthesis in erythrocytes (Hernberg *et al.* 1970, Tola *et al.* 1973, Pain 1987, 1989, Martinez-Lopez *et al.* 2004). While some reduction in ALAD activity appears to be tolerated in birds, protracted inhibition in ALAD activity can be associated with haemolytic anaemia (Pain and Rattner 1988, Mateo *et al.* 2003). As in other animals, lead can affect a wide range of body systems influencing reproduction, productivity, behaviour and the immune system (for a selection of specific studies on a range of bird species see Longcore *et al.* 1974a, 1974b, Clemens *et al.* 1975, Finley *et al.* 1976, Finley and Dieter 1978, Dieter and Finley 1978, 1979, Kendall *et al.* 1981, Veit *et al.* 1983, Kendall and Scanlon 1982, 1984, Chasko *et al.* 1984, Fimreite 1984, Buerger *et al.* 1986, Pain and Rattner 1988, Trust *et al.* 1990, Redig *et al.* 1991, Franson and Smith 1999, Fair and Myers 2002, and for reviews see Scheuhammer 1987, Eisler 1988, Burger and Gochfeld 2000, Franson and Pain 2011).

Many factors may affect an individual bird's susceptibility to lead poisoning including its sex and breeding condition, the physical and chemical constituents of its diet and environmental factors such as temperature and food stress. For example, in some experimental studies, ingestion of just one lead gunshot has been sufficient to cause ill health or death in birds (*e.g.* Holladay *et al.* 2012, Pain and Rattner 1988), while in others, birds have survived higher doses. It is therefore difficult to generalise about the magnitude of impact on an individual bird of ingesting a set amount of lead from ammunition (unless this is large). However, it is currently considered that there are no identified "no observed adverse effect levels" (NOAEL) or "predicted no effect concentrations" (PNEC) for lead in humans (EFSA 2010) and thus likely for other vertebrates.

While the dose-response relationship can vary among individuals and species, the health impacts of exposure to lead show great consistency across experimental studies. When the large numbers of studies conducted are considered together, particularly those studies that have examined large numbers of birds over time, generalisations can be made. The diagnosis of large scale and geographically extensive wildfowl mortality from lead poisoning following gunshot ingestion was first reported in the USA in the 1950s (*e.g.* Bellrose 1959), supported by extensive *post mortem* data. These findings were subsequently further supported by numerous experimental studies where captive wildfowl were fed lead gunshot (see above). Studies of survival of birds in relation to exposure to lead gunshot have also been conducted. Tavecchia *et al.* (2001) analysed recoveries between 1960 and 1971 of adult mallard *Anas platyrhynchos* ringed in the Camargue, France, for which the amount and type of lead exposure (ingested or embedded gunshot) had been determined by X-radiography. Ingested gunshot was present in the gizzard of 11% of birds and embedded gunshot was present in 23% of birds. Annual survival of mallards containing more than one gunshot in the gizzard was 19% lower than in unaffected birds. Survival was also lower by 19% for birds with any embedded gunshot and the effects of gizzard and embedded gunshot together were additive. Based upon the proportion of birds with gunshot in the gizzard and the estimated effect of gunshot on survival, these authors estimated that 1.5% of wintering mallards may die from lead poisoning due to ingested gunshot every year in the Camargue. Mortality from embedded gunshot and wounding would be additional to this. Guillemain *et al.* (2007), analysed recovery data from 40,000 teal *Anas crecca* that had been trapped and X-rayed in the Camargue, France (1957–1978), and also found reduced survival from one or more ingested pellets.

In addition to the direct impacts of lead on welfare and survival, indirect effects are likely to occur. These may include: increased susceptibility to infectious disease *via* lead's immunosuppressive effects (Grasman and Scanlon 1995, Trust *et al.* 1990); and increased susceptibility to death from a range of other causes, such as collision with power lines (Kelly and Kelly 2005 – *via* its effects on muscular strength and coordination) and being shot (*e.g.* shown by Bellrose 1959, Heitmeyer *et al.* 1993, Demendi and Petrie 2006 and others).

EXPOSURE ROUTES

There are four main routes by which birds and other wild animals (vertebrates and invertebrates) can be exposed to ammunition-derived lead:

1. Direct ingestion of spent lead gunshot deposited in the environment. This affects mainly wildfowl, other waterbirds and terrestrial gamebirds.
2. Ingestion of lead gunshot or bullets, or fragments from these, in the flesh of either dead or living animals that have been shot but remain unretrieved. This affects mainly predatory or scavenging birds, primarily raptors, and potentially some carnivorous mammals.
3. Ingestion of soil, water, or lower organisms contaminated with lead that has degraded from lead ammunition and entered the environment.
4. Absorption of lead mobilised from pellets shot into the tissues of animals that have been wounded but survived.

The first two of these appear to be the most significant exposure routes. We do not deal with the last exposure route in this paper because, while there is strong evidence that embedding of lead ammunition occurs (*e.g.* see Table 1), there is uncertainty about whether this causes increases in tissue lead levels. While there is evidence that ducks with embedded lead gunshot survive less well (Tavecchia *et al.* 2001), this might be due to wounding, irrespective of gunshot type, rather than the toxic effects of absorption of lead from embedded gunshot.

The exposure routes plus the outcomes are illustrated and summarised in Figure 1.

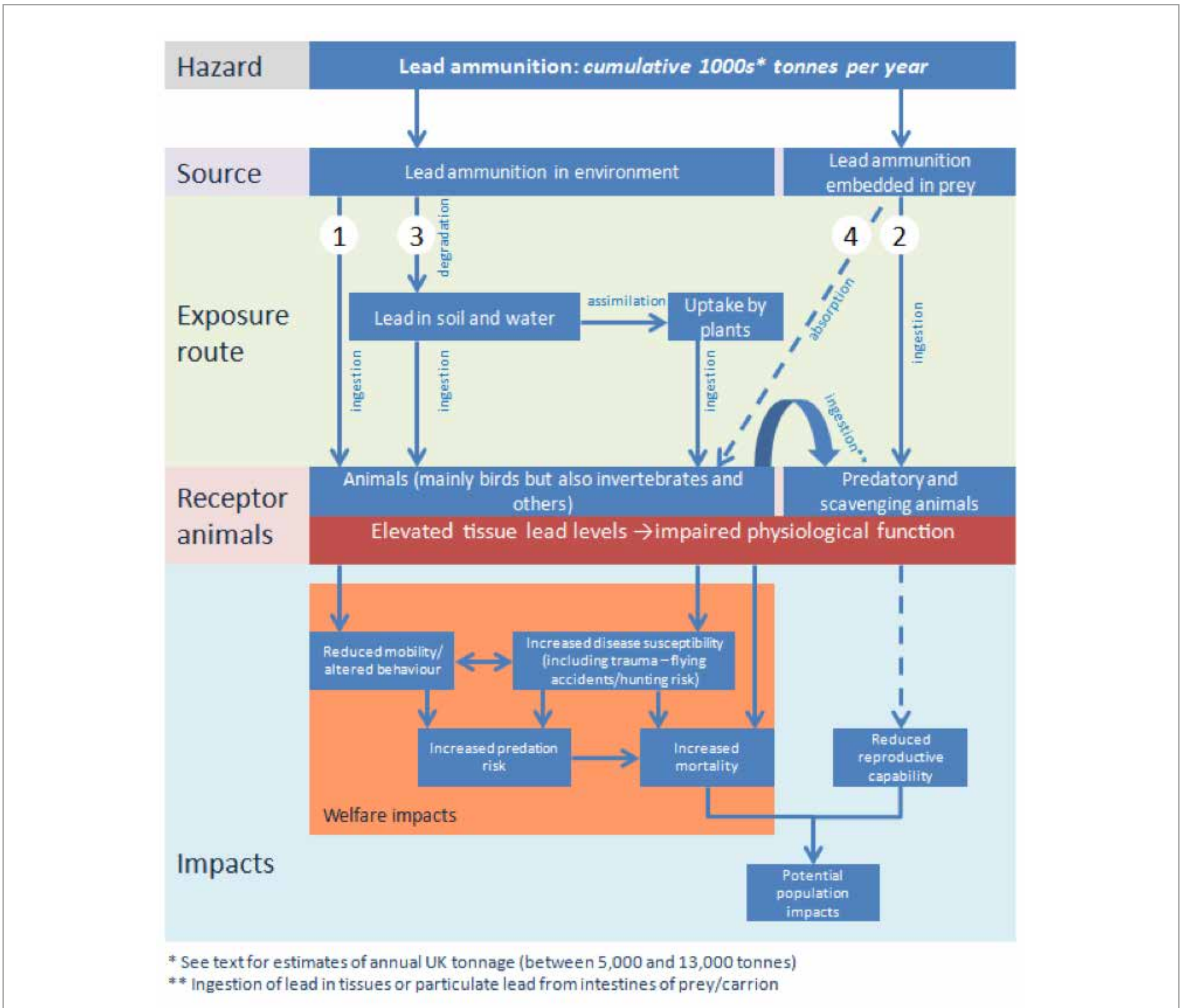

Figure 1: **Schematic illustrating and summarising the 4 exposure routes (see text) and range of impacts on wildlife of poisoning from lead ammunition sources.**

Amounts of lead from ammunition in the environment and its availability to wildlife

AMMUNITION DEPOSITED INTO THE ENVIRONMENT (*i.e.* OF RELEVANCE TO EXPOSURE ROUTES 1 AND 3)

The sport shooting of live quarry, clays and other targets is popular in the UK and most of the ammunition used is lead. Two thirds of the rural land in the UK is reportedly managed by shooting providers for a combination of reasons including shooting; active shoot management is undertaken on 2 million hectares of this (12% of the UK's rural land) (PACEC 2006). Many areas not managed specifically for shooting activities, including farmland and the foreshore, are also shot over for sport shooting, subsistence hunting and/or the control of pest animals (*e.g.* pigeons and corvids).

Each lead shotgun cartridge may contain between 100 and 600 lead gunshot depending on gunshot size, with a typical 30 g load containing approximately 300 individual number 6 gunshot. As gunshot leave the barrel of the gun they spread out thus even if the target is hit, most gunshot will miss. Only a small proportion of the gunshot from a single shotgun cartridge may be retrieved within a killed animal (see *e.g.* Cromie *et al.* 2010, Pain *et al.* 2010). Most lead gunshot fired from shotguns falls into the environment.

The tonnage of lead ammunition deposited annually into the UK environment is not precisely known. There are no official estimates of numbers of shooting participants, numbers of birds or other animals shot, or cartridges fired. However, broad estimates can be made using some published (*e.g.* PACEC 2006) and unpublished (*e.g.* shooting media, web articles and social media) sources. An estimated 28 million birds (gamebirds, wildfowl and pigeons) are shot annually in the UK (based upon PACEC 2006 and Aebischer 2013). The majority of gunshot used to kill these birds is composed of lead. Although there are restrictions on the use of lead for shooting wildfowl and/or over wetlands in the UK countries there is poor compliance with the legislation, at least in England (Cromie *et al.* 2002, 2010, 2015). In addition, wildfowl form only a small proportion of gamebirds shot. Assuming an average of 3-8 shots per bird (based on shooting web articles and social media) and 30 g gunshot per cartridge this represents about 2,500 to 6,700 tonnes of lead gunshot fired at gamebirds annually, most of which will fall into the environment. This excludes the gunshot used on the hundreds of thousands of rabbits and hares (combined), and numerous animals shot as part of pest control activities.

For target shooting, including clay pigeon shooting, the vast majority of the ammunition used is likely to be lead, probably to conform with International Shooting Sports Federation (ISSF) rules (Thomas and Guitart 2013). In 1991, it was reported that 220 million clay pigeons were used in the UK with at least one shot fired at each (B Carter, Clay Pigeon Shooting Association, *pers. comm.*; cited in Mellor and McCartney 1994). With a 28 g load commonly used to shoot clays and a number 8 cartridge (containing approximately 400 gunshot) this represented a minimum annual release of 6,160 tonnes of lead gunshot (approximately 88 billion individual gunshot) at the time, with a predicted rise in the popularity of clay shooting.

This suggests that approximately 8,000-13,000 tonnes of lead gunshot are used in the UK each year. This estimate is not precise and depends upon the accuracy of the assumptions in the estimate. It has been suggested by knowledgeable sources from the shooting community that approximately 5,000 tonnes a year of gunshot is used for all shooting combined although we have been unable to source any published data to substantiate this. These two figures are broadly similar and irrespective of the precise figure, thousands of tonnes of lead gunshot are deposited, and accumulate, in the UK environment annually, representing tens of billions of individual pellets. Ammunition used for target shotgun shooting is concentrated in and around target shooting clubs. Ammunition used for live quarry shooting is distributed, to variable degrees, across large tracts of the countryside.

The tonnage of bullets used annually (excluding those used by the police and/or the military) is considerably smaller, probably in the range of a few hundred tonnes a year. In areas of intensive lead bullet usage (*e.g.* firing ranges), bullets or fragments thereof are found deposited within the environment (*e.g.* Vantelon *et al.* 2005, Lewis *et al.* 2001). The authors are not aware of UK studies investigating the density of bullets in the environment in areas of lower intensity of usage such as places in which other more "typical" UK live quarry shooting activities occurs. However, it is probable that bullets that either miss their targets or travel through their targets are deposited within the environment, most likely penetrating whatever substrate by a distance dependent on the density of the substrate they hit, and the velocity and mass of the projectile.

A large amount of lead gunshot, bullets, and fragments thereof, is deposited in the environment annually and accumulates over time. Much of this may be available for animals to ingest directly, probably mistakenly for food, for grit, or inadvertently along with soil or foodstuffs.

Gunshot densities in the environment tend to be highest in areas of intense and/or regular hunting/shooting pressure. They typically range from just a few to hundreds per square metre (*e.g.* Mudge 1984, Spray and Milne 1988, Mellor and McCartney 1994 for the UK, and Mateo 2009 for Europe) but thousands can be found per square metre in some situations. For example, O'Halloran *et al.* (1988) reported gunshot density in the vicinity of a clay pigeon shooting range in Lough Neagh, County Antrim, of 2,400 gunshot/m^2 in the upper 5 cm of shoreline in front of the range and with gunshot being retrieved on the lake bed up to 60 m from the shore.

Lead is a relatively stable metal under most conditions and remains as pellets of gunshot for considerable periods of time. It has been used in the UK for over two centuries and, indeed, the potential for a "historical legacy" of gunshot remaining available to wildlife is an important aspect of the epidemiology of lead poisoning in wildlife. Complete decomposition of particulate lead probably takes tens or hundreds of years under most conditions (Scheuhammer and Norris 1996, Rooney *et al.* 2007). Gunshot degradation is caused by a combination of physical erosion/abrasion, which is accelerated in coarse and gritty soils and/or those with marked levels of movement and chemical activity.

Densities of lead gunshot in the soil tend to increase over time if lead gunshot continues to be used. However, gunshot will generally sink slowly through the soil and new soil accumulates above the gunshot with rates of sinking affected by soil density and other characteristics. Hartikainen and Kerko (2009) found that on the coarse stony soil of a shooting range in southern Finland, lead gunshot migrated downwards relative to the surface at a rate of some 2-3 mm per year. Flint (1998) found in various wetland types to which gunshot was added experimentally that most gunshot was still within the top 4 cm of sediment three years after deposition. In the Camargue marshes (southern France), assuming a constant settlement rate, Tavecchia *et al.* (2001) estimated a half-life of gunshot in the first 0-6 cm, thus available to waterfowl, for 46 years, with complete settlement beyond this depth after 66 years. Flint and Schamber (2010) found that 10 years after seeding experimental plots on tundra wetlands with number 4 gunshot, about 10% remained in the top 6 cm and >50% in the top 10 cm. These authors predicted that it would probably require >25 years for spent lead pellets to exceed depths at which waterfowl forage. However, one would expect the proportion of pellets available to feeding waterfowl to decrease with time over this period. Lead gunshot may become less available when redistributed by cultivation (*e.g.* Thomas *et al.* 2001), and some farming practices could hypothetically make lead gunshot deposited decades ago more available (Chrastny *et al.* 2010, Rooney and McLaren 2000, Stansley *et al.* 1992, White Young Green Environmental 2006), as can the lowering of water levels (Spray and Milne 1988).

While a historical legacy of deposited gunshot exists, there is good evidence that the majority of gunshot ingested by wildfowl is that most recently deposited. Anderson *et al.* (2000) found that in the fifth and sixth years after a nationwide ban on the use of lead gunshot for shooting waterfowl in the USA, 75.5% of 3,175 gunshot ingested by a sample of 15,147 mallard on the Mississippi flyway were non-toxic.

LEAD AMMUNITION IN THE TISSUES OF GAME SPECIES THAT CAN BE CONSUMED BY PREDATORS AND SCAVENGERS (*i.e.* OF RELEVANCE TO EXPOSURE ROUTE 2)

Of the tens of millions of animals shot in the UK each year using lead ammunition, an unknown proportion of the carcasses is not recovered and hence is potentially available to scavengers. For many of the tens of thousands of red deer *Cervus elaphus* shot per year, the viscera are discarded in the field and they, and any remnants of lead ammunition within them, are potentially available to scavengers. A further additional set of animals are wounded by gunshot and bullets but survive and may carry remnants of lead ammunition in their bodies. These animals may be eaten by predators, perhaps selected as prey because of their weakened condition, or die later and be eaten by scavengers.

The tissues of game animals killed using shotgun cartridges usually contain some of the gunshot that struck the animal and killed it. Pain *et al.* (2010) performed X-radiography on 121 entire carcasses of wild red grouse *Lagopus lagopus*, red-legged partridge *Alectoris rufa*, pheasant *Phasianus colchicus*, mallard, woodpigeon *Columba palumbus* and woodcock *Scolopax rusticola* killed by shooting and obtained from retailers and shoots in the UK (16 – 26 individuals per species). Eighty seven percent of all birds examined had whole gunshot, large fragments, small fragments or some combination of the three types detectable by X-radiography.

Substantial fragmentation of lead gunshot occurs when gamebirds and waterfowl are killed using gunshot. X-radiographic studies show that gamebirds and mammals shot either with lead gunshot or lead bullets often contained lead fragments which were small, numerous and widely dispersed in edible tissues away from the wound canals (*e.g.* Pain *et al.* 2007, 2010, Knott *et al.* 2010 for UK studies, and Dobrowolska and Hunt *et al.* 2006, 2009, Melosik 2008, Krone *et al.* 2009, Grund *et al.* 2010, for relevant studies elsewhere).

In addition to studies of lead ammunition and fragments in dead animals and animal parts, numerous studies have used X-radiography to investigate proportions of live birds, predominantly wildfowl, carrying embedded gunshot in their tissues. The proportion of animals, or parts thereof, shot using lead ammunition which are potentially available to predators and scavengers is unknown for some species, but may be high for quarry species such as ducks and geese (see Table 1 for live wildfowl), and must represent hundreds of thousands of animals potentially contaminated with ammunition-derived lead per year entering the food supply of wild predators and scavengers.

Even in some protected species, such as swans, that cannot be legally shot, a high proportion may contain embedded gunshot (Newth *et al.* 2011, see Table 1).

Sales of non-lead ammunition in the UK are low. Use of lead ammunition is permitted throughout the UK for the majority of shooting. Restrictions on the use of lead gunshot apply to the shooting of wildfowl and coot *Fulica atra* and moorhen *Gallinula chloropus* anywhere in England and Wales, and also for any species over certain listed wetland areas in these countries. In Scotland and Northern Ireland restrictions apply to all shooting with gunshot of any animal over wetlands, although all species including wildfowl may be shot with lead ammunition away from wetland areas in these countries. Wildfowl comprise a small proportion of birds shot, and ammunition composed primarily of lead is used for the vast majority of shooting of game in non-wetland habitats. The use of lead ammunition to shoot wildfowl has not been lawful in England since 1999, but recent compliance studies (see Cromie *et al.* 2010, 2015) found between 68 - 77% of wild duck carcasses bought from game dealers in England had been shot using lead ammunition. Hence, it is clear that the vast majority of game animals shot in the UK are killed using lead ammunition.

AMMUNITION-DERIVED LEAD IN SOILS AND WATER (HAVING ORIGINATED FROM INTACT GUNSHOT OR BULLETS DEPOSITED IN THE ENVIRONMENT) (*i.e.* OF RELEVANCE TO EXPOSURE ROUTE 3)

Wildlife may be exposed, primarily *via* ingestion, to lead of ammunition origin that has moved from deposited lead ammunition into the soil and water. While elemental lead is very stable under neutral pH conditions, the surface of ammunition will be chemically transformed in the environment, and the lead compounds formed, which will vary with soil conditions, will play an important part in determining the mobility of lead. In water the solubility of different compounds is related to pH, amount of calcium, salinity and the presence of humic material.

Soils and sediments act as an environmental sink for lead. Lead in soil may occur in a variety of chemical forms (*e.g.* as carbonates, sulphides *etc.*) and fractions, *e.g.* including exchangeable, adsorbed and organic complexes. Lead is strongly adsorbed to soil organic matter, silicate clays, peat and iron oxides. Consequently, under most conditions the majority of lead that enters soils and is transformed into lead compounds is likely to be retained in the upper layers and not leach to any great extent into the subsoil and groundwater. However, although this is a general rule, the mobility of lead in soils is nonetheless highly variable in relation to environmental conditions and is thus site specific. Research into the degradation/transformation of metallic lead from gunshot or bullets, (*e.g.* see Cao *et al.* 2003, McLaren *et al.* 2009, Sanderson *et al.* 2012, Sullivan *et al.* 2012) illustrates the varied impacts temperature, moisture and soil chemistry have on the rate of degeneration/transformation of metallic lead gunshot or bullets, the transformation products, and the rate of passage of lead and its transformation products through the soil profile.

Under most environmental conditions gunshot degrades only slowly and in addition to the chemical processes described above, degradation may be influenced by physical erosion/abrasion, which is accelerated in coarse and gritty soils and/or those with considerable soil movement. Movement of lead through the soil may also be influenced by other factors, such as precipitation and snow melt.

The National Sports Shooting Foundation (the trade association for America's firearms industry) has produced a report on 'Lead Mobility at Shooting Ranges', a synthesis of which is given in its

Table 1: **Summary table of prevalence of embedded gunshot in live trapped wildfowl species.**

Species	Country	Embedded shot (%)	Reference
Bewick's swan *Cygnus columbianus bewickii*	UK	31.2	Newth *et al.* (2011)
Whooper swan *Cygnus cygnus*	UK	13.6	Newth *et al.* (2011)
Migratory wild geese	Germany	21	Krone *et al.* (2009)
Pink-footed goose *Anser brachyrhynchus*	Denmark (1990-92)	24.6 (juvs)-36.0 (adults)	Noer and Madsen (1996)
	Denmark (1998-2005)	9.2-22.2	Noer *et al.* (2007)
Greylag goose *Anser anser*	Spain, Doñana	44.4	Mateo *et al.* (2007)
Canada goose *Branta canadensis*	Canada (Maritimes)	32	CWS, unpublished data
	USA	42	Funk (1951)
Small Canada goose *Branta canadensis parvipes*	Canada	≥25	Macinnes *et al.* (1974)
Brant goose *Branta bernicla*	USA	20	Kirby *et al.* (1983)
Barnacle geese *Branta leucopsis*	Denmark	13	Holm and Madsen (2013)
Mallard *Anas platyrhynchos*	UK	17.6	WWT unpublished (1980s)
	France, Camargue	23.4	Tavecchia *et al.* (2001)
	Netherlands	1.4-3.4 †	Lumeij and Scholten (1989)
	Netherlands	22-68 ††	Lumeij and Scholten (1989)
	Canada	28	Elder (1950)
	USA	13	Funk (1951)
	USA	27	Murdy (1952)
Northern pintail *Anas acuta*	UK	27.1	WWT unpublished (1980s)
	USA	13	Funk (1951)
Northern shoveler *Anas clypeata*	UK	25.8	WWT unpublished (1980s)
Gadwall *Anas strepera*	UK	26.3	WWT unpublished (1980s)
American black duck *Anas rubripes*	Canada (Maritimes)	12–18	CWS, unpublished data
Common teal *Anas crecca*	France, Camargue	4.4-9.6	Guillemain *et al.* 2007
Pochard *Aythya ferina*	UK	25.0	WWT unpublished (1980s)
Tufted duck *Aythya fuligula*	UK	14.9	WWT unpublished (1980s)
Canvasback *Aythya valisineria*	USA	29	Perry and Geissler (1980)
Lesser scaup *Aythya affinis*	USA	10	Perry and Geissler (1980)
Redhead *Aythya americana*	USA	15	Perry and Geissler (1980)
Ring-necked duck *Aythya collaris*	USA	21	Perry and Geissler (1980)
Common eider *Somateria mollissima*	Canada (Maritimes)	20-35	CWS, unpublished data

†Gizzard wall ††Whole body and an estimate.

Table 2: **Soil lead concentrations in shooting and control areas in the UK**

Gunshot source	Soil lead (mg/kg) (average of 72 mg/kg in principal English topsoil)		Reference
	Shooting Site	Control Site	
Game shooting wood and pheasant rearing area	160 (wood) 68 (field)	60 (wood) 44 (field)	Sneddon *et al.* (2009)
Clay pigeon shoot (100-175 m from stands)	Mean of 3,038 Max. of 8,172	72	Clements (1997)
Clay pigeon fall out zone on acid peat bog	Mean of 306 Max. of 15,700	67	White Young Green Environmental (2006)
Clay pigeon shoot for 20 years (80-100 m from stands)	5,000 to 10,600	-	Mellor and McCartney (1994)

executive summary[1]. Adriano (1986) provides comprehensive information on the biogeochemistry and bioavailability of lead in the terrestrial environment.

In areas of lead ammunition deposition, soil lead concentrations can be extremely elevated, *e.g.* from a few to hundreds of times higher than in control soils; some examples from the UK are given in Table 2. The figures here can be compared with average soil lead concentration of 72 mg/kg in principal English topsoil (with English soils in the principal domain, covering 94% of the area of England, having 'Normal Background Concentrations' of up to 180 mg/kg - British Geological Survey, see Ander *et al.* 2013). A limited number of studies is available either measuring lead in water from sites contaminated with lead, or lead in biota exposed to water contaminated by lead from ammunition (*e.g.* Heier *et al.* 2009, Stromseng *et al.* 2009). These provide evidence that in some areas where shooting occurs regularly and/or at high intensity, and in and possibly close to the gunshot fallout areas, water lead concentrations can be elevated above those at control sites. The extent to which such contamination is likely to affect sites downstream of shooting areas is unknown, but the likelihood of broader watershed contamination appears low, and it seems likely that the majority of the water contamination will be relatively local.

PATHWAYS OF EXPOSURE TO LEAD FROM AMMUNITION

DIRECT INGESTION OF AMMUNITION-DERIVED LEAD BY WILD BIRDS (EXPOSURE ROUTE 1)

The first published record of a bird poisoned following lead gunshot ingestion in the UK was for a pheasant, 139 years ago (Calvert 1876). Recognition of the direct ingestion of spent gunshot and subsequent mortality from lead poisoning in wildfowl and a range of other birds, primarily other waterbirds and terrestrial birds such as Galliformes, grew throughout the last century. This pathway of ingestion of lead gunshot has been extensively documented and reviewed (*e.g.* for global studies see Bellrose 1959, Franson and Pain 2011, and papers in Pain 1992 and Watson *et al.* 2009; for the UK see Olney 1960, 1968, Owen and Cadbury 1975, Thomas 1975, Thomas 1982, Brown *et al.* 1992, Thomas *et al.* 2009, Parslow *et al.* 1982, Mudge 1983, Street 1983, Spray and Milne 1988, Butler 2005, Butler *et al.* 2005, Potts 2005, O'Connell *et al.* 2008, Newth *et al.* 2012). Gunshot ingestion levels by wildfowl from UK studies and terrestrial birds from the UK and elsewhere are summarised in Tables 3 and 4 respectively.

Mateo (2009) provided a summary of historic prevalence of lead gunshot ingestion in 19 species of wildfowl from Europe including the UK (15 of which are species of swans, geese and ducks from northern Europe). Levels of gunshot ingestion varied among sites and species with an overall combined level

[1]Available online (see http://www.nssf.org/ranges/rangeresources/library/detail.cfm?filename=facility_mngmnt/environment/executive_summary.htm&CAT=Facility%20Management)

Table 3: **Summary of proportions of wildfowl with ingested gunshot from UK studies of hunter-shot birds and birds found dead.**

Species	**Birds found dead** All data from Newth *et al.* (2012) and WWT *post mortem* database.			**Birds shot by hunters**			**References** (birds shot by hunters only)
	N (sample size)	**Number with ingested gunshot**	**% with ingested gunshot**	**N (sample size)**	**Number with ingested gunshot**	**% with ingested gunshot**	
Mallard *Anas platyrhynchos*	479	15	3.1	2016	91	4.5	Olney (1960), Thomas (1975), Mudge (1983), Street (1983)
European wigeon *Anas penelope*	24	0	0	862	0	0	Olney (1960), Thomas (1975), Mudge (1983)
Common teal *Anas crecca*	68	1	1.5	1188	12	1	Olney (1960), Thomas (1975), Mudge (1983)
Northern shoveler *Anas clypeata*	16	0	0	133	3	2.3	Olney (1960), Thomas (1975), Mudge (1983)
Pochard *Aythya ferina*	72	12	16.7	130	11	8.5	Olney (1968), Thomas (1975), Mudge (1983)
Northern pintail *Anas acuta*	60	5	8.3	162	21	13	Thomas (1975), Mudge (1983)
Tufted duck *Aythya fuligula*	79	2	2.5	103	9	8.7	Thomas (1975), Mudge (1983)
Gadwall *Anas strepera*	65	0	0	42	2	4.8	Thomas (1975), Mudge (1983)
Goldeneye *Bucephala clangula*	1	0	0	15	1	6.7	Mudge (1983)
Pink-footed goose *Anser brachyrhynchus*	25	2	8	73	2	2.7	Mudge (1983)
White-fronted goose *Anser albifrons*	8	0	0	30	0	0	Mudge (1983)
Greylag goose *Anser anser*	133	9	6.8	42	3	7.1	Mudge (1983)
Barnacle goose *Branta leucopsis*	99	13	13.1	61	0	0	Mudge (1983)
Total	**1129**	**59**	**5.2**	**4857**	**155**	**3.2**	
Mute swan *Cygnus olor*	548	27	4.9	548*	16*	3.0*	*Swans are protected and numbers of 'shot' swans containing ingested lead are estimated from the ratio of gunshot in found dead to hunter-shot birds in the other species.
Whooper swan *Cygnus cygnus*	414	98	23.7	414*	60*	14.6*	
Bewick's swan *Cygnus columbianus bewickii*	99	13	13.1	99*	8*	8.1*	

Totals combined from all studies cited. The study of Olney (1960) did not cite the origin of the birds but wildfowlers were thanked in the acknowledgements for provision of birds and the text indicated that a small number of birds sent in for *post mortem* examination had been found to suffer from lead poisoning (although it did not state whether these were included). We have assumed that the birds in Olney's study were hunter shot. For the study of Thomas (1975) we have subtracted six mallard with gunshot in the gizzard as six birds had 'shot in' gunshot and it was unclear whether these had already been excluded from the results.

for mallard of 3.6%, pintail *Anas acuta* 5.4%, and pochard *Aythya ferina* 9.3% in northern European wetlands. The majority of studies summarised by Mateo (2009) appear to be of birds shot by hunters, though in some cases trapped birds were included. Studies conducted in the UK reported broadly similar levels of gunshot ingestion to those elsewhere in Europe, although they vary among sites and species (Table 3).

More recently, Newth *et al.* (2012) reported lead poisoning in wildfowl (between 1971 and 2010) in the UK where the majority of cases of birds dying of lead poisoning (75% of 251) still had lead gunshot in various stages of dissolution in their gizzards. The *post mortem* data used for this study revealed a small number (13) of lead poisoned birds with >40 pellets within the gizzard, three of which contained more than 100 pellets, including a Canada goose *Branta canadensis* whose gizzard contained 438 pellets, while Spray and Milne (1988) reported a mute swan with 844 pellets. Species suffering lead poisoning from ingested gunshot included those feeding in water and wetlands, as well as grazing species including geese and swans where a large proportion of time is spent feeding on agricultural land (Newth *et al.* 2012). Gunshot ingestion levels in birds found dead from this paper and WWT's database are given in Table 3. Of a subset of 104 whooper swans diagnosed as having died of lead poisoning, 86% contained shotgun pellets in the gizzard.

More studies on lead poisoning have been conducted on wildfowl than other taxa. However, where lead ingestion has been investigated in other taxa that feed in areas shot-over using lead gunshot it has generally been found. Table 4 summarises some of the studies that illustrate gunshot ingestion in a range of non-wildfowl waterbirds and in terrestrial birds. This is not comprehensive but illustrative of the range of different birds that can be affected.

Several methods have been used to estimate the proportion of wild birds with ingested gunshot in the gizzard or digestive tract and various biases may be associated with them. Hunter-shot birds will be subject to the biases involved in hunting, *e.g.* young birds are often over-represented in hunting bags. Also ingestion of lead may remove many poisoned individuals from a population (*via* lead-related morbidity and mortality) or conversely lead ingestion may disable birds sufficiently to make them more likely to be harvested (*e.g.* Bellrose 1959, Heitmeyer *et al.* 1993, Demendi and Petrie 2006). In field experiments Bellrose (1959) found that mallard dosed with lead gunshot were more vulnerable to being shot than undosed controls – by 1.5 times, 1.9 times and 2.1 times for birds dosed with one, two and four No. 6 gunshot respectively. Trapping may potentially introduce biases, but little information exists. Ingestion levels in birds found dead may also be subject to confounding factors. Firstly, "found dead" studies are biased towards those species most likely to be visible to humans *e.g.* large, white or close to human habitation. The nature of lead poisoning as a debilitating condition may make affected individuals more prone to disappearing into vegetation and to scavenging and predation (Sanderson and Bellrose 1986, Pain 1991). Moreover, gunshot may be ground down or dissolved in the bird's alimentary canal and thus not be apparent on radiographs or at *post mortem* examination. While proportions of birds found dead with ingested gunshot in the gizzard may not accurately reflect the situation in the wild population, finding gunshot in found dead birds obviously illustrates the pathway of ingestion.

Despite these biases and confounding factors, any one or all of these methods can be used to compare the prevalence of ingestion across space and time. Studies from across the world have shown that levels of gunshot ingestion are influenced by factors including species' feeding habits, gunshot density and availability (influenced by substrate type and shooting intensity, duration and season) and grit availability (*e.g.* Bellrose 1959, Flint 1998, Mudge 1983, Thomas *et al.* 2001, Demendi and Petrie 2006 – see also reviews cited above).

Several means can be used to establish or infer the provenance of elevated tissue lead concentrations in birds. Ratios of stable lead isotopes in materials vary according to the geological origin of the lead. Lead isotope ratios can therefore be compared between animal tissue samples, lead from ammunition and the other potential sources that exist in the area where the animal lived and this can help to identify or exclude some potential sources of the lead. Lead isotope studies have linked gunshot ingestion with elevated tissue lead concentrations in a range of wild birds in a number of studies from around the world. These studies support ammunition-derived lead as the major contributor to widespread elevated tissue lead concentrations in wild birds (*e.g.* Scheuhammer and Templeton 1998, Scheuhammer *et al.* 2003, Svanberg *et al.* 2006, Martinez-Haro *et al.* 2011).

Temporal or spatial correlations between elevated tissue lead levels in birds and hunting activities can also help establish the primary source(s) of lead exposure. Studies have compared

Table 4: **A selection of non-wildfowl avian species reported as ingesting lead gunshot from the environment.**

Species	Countries	References
Galliformes (largely terrestrial habitats)		
Chukar *Alectoris chukar*	USA	Hanspeter and Kerry (2003)
Grey partridge *Perdix perdix*	Denmark, UK	Clausen and Wolstrup (1979), Keymer and Stebbings (1987), Potts (2005)
Red-legged partridge *Alectoris rufa*	UK	Butler (2005)
Common pheasant *Phasianus colchicus*	Denmark, UK, USA	Calvert (1876), Elder (1955), Clausen and Wolstrup (1979), NWHL (1985), Dutton and Bolen (2000), Butler *et al.* (2005)
Wild turkey *Meleagris gallopavo*	USA	Stone and Butkas (1978)
Scaled quail *Callipepla squamata*	USA	Campbell (1950)
Northern bobwhite quail *Colinus virginianus*	USA	Stoddard (1931), Keel *et al.* (2002)
Ruffed grouse *Bonasa umbellus*	Canada	Rodrigue *et al.* (2005)
Helmeted guineafowl *Numida meleagris*	Canada	Hunter and Haigh. (1978)
Columbiformes (largely terrestrial habitats)		
Rock pigeon *Columba livia*	USA , Belgium	DeMent *et al.* (1987), Tavernier *et al.* (2004).
Mourning dove *Zenaida macroura*	USA	Locke and Bagley (1967), Lewis and Legler (1968), Best *et al.* (1992), Schulz *et al.* (2002).
Gruiformes (largely wetland habitats)		
Sandhill crane *Grus canadensis*	USA	Windingstad *et al.* (1984), NWHL (1985)
Clapper rail *Rallus longirostris*	USA	Jones (1939)
King rail *R. elegans*	USA	Jones (1939)
Virginia rail *R. limicola*	USA	Jones (1939)
Common moorhen *Gallinula chloropus*	Europe, UK, USA	Jones (1939), Locke and Friend (1992), Thomas (1975)
Common coot *Fulica atra*	France	Pain (1990)
American coot *F. americana*	USA	Jones (1939)
Charadriiformes (largely wetland habitats)		
American woodcock *Scolopax minor*	Canada	Scheuhammer *et al.* (1999, 2003)
Black-necked stilt *Himantopus mexicanus*	USA	Hall and Fisher (1985)
Long-billed dowitcher *Limnodromus scolopaceus*	USA	Hall and Fisher (1985)
Common snipe *Gallinago gallinago*	France, UK	Beck and Granval (1997), Thomas 1975
Jack snipe *Lymnocryptes minimus*	France	Beck and Granval (1997)
Dunlin *Calidris alpina*	Canada	Kaiser *et al.* (1980)
Ciconiiformes (largely wetland habitats)		
White-faced ibis *Plegadis chihi*	USA	Hall and Fisher (1985)
Ciconiiformes (largely wetland habitats)		
Caribbean flamingo *Phoenicopeterus ruber ruber*	Mexico	Schmitz *et al.* (1990)

See also Kimmel and Tranel (2007) for examples.

tissue lead levels in wildfowl before and after bans on the use of lead gunshot for wildfowl hunting (*e.g.* Samuel and Bowers 2000, Stevenson *et al.* 2005), or in areas where lead gunshot may be used *vs* areas where only non-toxic gunshot may be used (*e.g.* Franson *et al.* 2009). Scheuhammer and Dickson (1996) investigated the geographical pattern of elevated lead concentrations in several thousand wing bones from young-of-the-year ducks collected in Canada to investigate their relationship with activities known to cause environmental lead contamination, *i.e.* waterfowl hunting, non-ferrous metal mining/smelting, and urban/industrial development. Ingestion of spent-lead gunshot was the likely primary source of elevated lead exposure for wild ducks in Canada. In areas of significant waterfowl hunting, a widespread pattern of elevated bone-lead was found, rather than few small local sites of high lead exposure. However, lead contamination of bones of young ducks was significantly correlated with proximity to metal mining sites; this accounted for about a quarter of the total area characterised by a high incidence of elevated lead exposure.

These studies support ammunition-derived lead as the major source of widespread lead exposure.

INGESTION OF AMMUNITION DERIVED LEAD IN THE TISSUES OF DEAD OR LIVE GAME SPECIES (EXPOSURE ROUTE 2)

Many bird species worldwide, including New and Old World vultures, eagles, kites, buzzards, caracaras, gulls and corvids, frequently scavenge tissue from carcasses of dead vertebrates and parts of their bodies discarded by hunters. Predatory birds that may consume, and perhaps select, wounded animals carrying ammunition include species from the same taxonomic groups, but also include owls, falcons and a wider range of accipitrid raptors. In the UK, red kite *Milvus milvus*, golden eagle *Aquila chrysaetos*, white-tailed eagle *Haliaeetus albicilla*, buzzard *Buteo buteo*, raven *Corvus corax*, carrion crow *C. corone*, hooded crow *C. cornix* and magpie *Pica pica* are the bird species most likely to scavenge from carcasses or discarded viscera of game animals. All species of raptors and owls could potentially kill and feed upon a game animal with fragments of lead ammunition shot into its tissues. Because they frequently prey upon waterfowl which may be contaminated with embedded lead gunshot (Table 1), western marsh harriers *Circus aeruginosus* and peregrine falcons *Falco peregrinus* (which prey upon a wide range of medium sized birds) are the raptor species which might be expected to be most exposed to ammunition-derived lead *via* this route.

Ingestion of lead ammunition or ammunition fragments by predatory and scavenging birds has been reported for decades. Some of the earliest studies involved the poisoning of bald eagles *Haliaeetus leucocephalus*, which frequently feed on wildfowl in the USA (Kaiser *et al.* 1979, Feierabend and Myers 1984, Reichel *et al.* 1984), golden eagles (Craig *et al.* 1990) and the California condor *Gymnogyps californianus*, a Critically Endangered species whose remaining small population in the wild was almost driven to extinction by lead poisoning caused by scavenging upon discarded viscera and carcasses of unretrieved large game animals such as deer (Rideout *et al.* 2012). Numerous studies have reported ingested ammunition-derived lead in white-tailed eagles (*e.g.* Kenntner *et al.* 2001 in Germany and Austria, Helander *et al.* 2009 in Sweden), and in a proportion of the carcasses of both this species and of Steller's sea eagles *Haliaeetus pelagicus* and mountain hawk eagles *Spizaetus nipalensis* in Hokkaido, Japan (Saito 2009).

Examination of regurgitated birds' food pellets provides additional information on the frequency of ingestion of remnants of lead ammunition. X-radiographs of regurgitated food pellets from a roost site of red kites in the English Midlands found that a minimum of 2% contained lead gunshot (Pain *et al.* 2007). Since the study area included estates on which partridges and pheasants were shot with lead gunshot, scavenging of unrecovered shot birds or of wounded birds that died later could have been a route by which the red kites obtained the lead gunshot. Other studies have found that the frequency of occurrence of gunshot in regurgitated pellets is higher during than outside the hunting season. These include studies of western marsh harriers in France (Pain *et al.* 1997), eastern marsh harriers *Circus spilonotus* in Japan (Hirano *et al.* 2004) and white-tailed eagles in Sweden (Helander 1983).

Mateo *et al.* (2013) reviewed information on lead gunshot ingestion and lead poisoning in Spain, and reported the presence of lead gunshot in regurgitated pellets from red kites (in central Spain and Doñana), Egyptian vultures (in the Canary Islands), western marsh harriers (from the Ebro delta and Doñana), Spanish imperial eagles *Aquila adalberti* (from central Spain, Castilla-La Mancha and Doñana) and peregrine falcons (in Doñana). These authors reported that the incidence of ingestion of lead gunshot by the Spanish imperial eagle in Doñana varied between years in relation to goose hunting pressure, which in turn varies with water levels in the protected areas. For additional information on lead gunshot ingestion and poisoning of raptors in Spain see Mateo *et al.* (2007), and also Cerradelo *et al.* (1992), Mateo *et al.* (2001), González and Hiraldo (1988), Castaño López (2005), Mateo *et al.* (1999), Gonzalez (1991), Garcia and Viñuela 1999, Donázar *et al.* (2002).

Krone *et al.* (2009) performed experiments on white-tailed eagles in which iron nuts of various sizes were inserted into carcasses or discarded viscera form which they fed. The eagles always avoided ingesting nuts of 7.7 mm diameter or larger, but ingested some of the nuts smaller than this (2.7 – 6.0 mm). For the smallest size of nuts used in the experiment (2.7 mm), 80% of the nuts presented were eaten. These nuts were considerably larger than most of the fragments of ammunition-derived metal seen in X-radiographs of deer carcasses and discarded viscera. Knott *et al.* (2010) found that 83% by weight of the radio-dense fragments they found in deer viscera had a diameter less than 1 mm and the largest fragment seen on the radiographs was only slightly larger than the smallest nuts used in the experiment. Hence, this experiment suggests that in a similar situation in the wild, were fragments from lead ammunition to be present in a carcass, many of these could be readily ingested whilst scavenging on the remains of game animals.

Several methods exist to infer the origin of elevated tissue lead concentrations and lead poisoning in predatory and scavenging birds. The most detailed isotopic studies have been conducted on California condors and they indicate that elevated lead exposure in free-living condors is mostly consistent with lead from ammunition rather than other sources (Church *et al.* 2006, Finkelstein *et al*. 2010, 2012, Rideout *et al*. 2012). Departure of blood lead isotope signature from the background pattern in free-living birds increased progressively as the total blood lead concentration increased, moving towards the isotopic signature of lead ammunition and bullet fragments retrieved from lead poisoned condors (Church *et al.* 2006, Finkelstein *et al.* 2012). Isotopic analysis also illustrates that ammunition-derived lead is the likely provenance of elevated tissue lead concentrations in a number of Steller's sea eagles and white-tailed eagles in Hokkaido, Japan (Saito 2009 – with rifle ammunition implicated). Legagneux *et al.* (2014) found that blood lead concentrations in the raven, a scavenging species, increased over the moose *Alces alces* hunting season in eastern Quebec, Canada, and that birds with elevated blood lead levels had isotopic signatures that tended towards those of ammunition. Several other studies, including on red kites in England (Pain *et al.* 2007) and white-tailed eagles in Sweden (Helander *et al.* 2009) show isotopic signals consistent with ammunition sources in birds with elevated tissue lead, although they do not exclude all possible non-ammunition sources of lead. Lead concentrations in the livers of a sample of red kites and sparrowhawks *Accipiter nisus* found dead in Britain were not elevated and lead isotope signatures were distinct from that of leaded petrol, marginally overlapped with that for coal, and overlapped more with those for lead ammunition (Walker *et al.* 2012). The isotopic signatures in this study may reflect the fact that liver concentrations were low and could have resulted from multiple diffuse sources.

A number of studies of scavenging and predatory birds have investigated the relationship between tissue (generally blood) lead levels and spatial and temporal variation in exposure to food contaminated with ammunition-derived lead. Green *et al.* (2008) showed that blood lead concentrations in California condors tended to rise rapidly when satellite-tagged condors spent time during the autumn deer-hunting season in areas with high levels of deer hunting, but that visits to these same areas outside the hunting season, and visits to other areas with low levels of deer hunting at any time of year were not associated with rises in blood lead levels. Craighead and Bedrosian (2008) found that 47% of blood samples in ravens in the USA collected during the large game (mainly deer) hunting season had elevated blood lead (>10 µg/dl), compared with 2% outside the hunting season; these results were consistent with those of Legagneux *et al.* (2014) cited above. Kelly *et al.* (2011) compared blood lead concentrations in golden eagles and turkey vultures *Cathartes aura* prior to and one year following implementation of a ban (in 2008) on the use of lead ammunition for most hunting activities in the range of the California condor in California; lead exposure in both species declined significantly after the ban. Similarly, Pain *et al.* (1997) found that geometric mean blood lead levels were 3-4 times higher in free-flying live-trapped western marsh harriers during the hunting season in France than outside the hunting season. Kelly and Johnson (2011) found that the blood lead concentrations of turkey vultures in California were significantly higher during the large game hunting season than outside it. Gangoso *et al.* (2009) found that the geometric mean concentration of lead in the blood of Egyptian vultures in the Canary Islands was about four times higher during the hunting season than outside it. While these studies show consistent results, it is nonetheless worth noting that most studies which contrast the blood lead concentration of birds within and outside the hunting season underestimate the underlying difference in exposure to lead. This arises because blood lead remains high for some time, often several weeks, after the ingestion of lead has ceased. Consequently, some blood samples obtained in the early part of the non-hunting season will still contain appreciable amounts of lead acquired during the hunting season.

Widely available reference works summarise observations of the principal food sources of mammals and it is apparent that many mammal species worldwide frequently scavenge tissue from carcasses of dead vertebrates and parts of their bodies discarded by hunters (*e.g.* see Legagneux *et al.* 2014). Badger *Meles meles*, red fox *Vulpes vulpes* and pine marten *Martes martes* are the mammal species in the UK most likely to scavenge from these sources. We are not aware of direct observations of ingestion of ammunition-derived lead fragments by scavenging or predatory mammals in the UK. However, it seems probable from the feeding behaviour of many species, in which large chunks of meat and some bone fragments are swallowed, that some ingestion of remnants of ammunition occurs.

INGESTION OF CONTAMINATED SOIL, WATER OR BIOTA (EXPOSURE ROUTE 3)

Field studies provide evidence that where lead levels of soil, water and/or biota are elevated as a result of the degradation of lead from ammunition, there is likely to be uptake of lead by certain invertebrate and vertebrate animals, with higher tissue lead concentrations in animals from contaminated than control sites (Ma 1989, Stansley and Roscoe 1996, Vyas *et al.* 2000, Hui 2002, Migliorini *et al.* 2004, Labare *et al.* 2004, Heier *et al.* 2009, Bianchi *et al.* 2011). Few studies have been conducted in the UK, but Sneddon *et al.* (2009) found that tissues of earthworms (washed and retained until their bowel was empty before assaying) from a shooting woodland in Cheshire were significantly higher in lead (111.79 mg/kg) than in those from the control woodland (5.49 mg/kg). Mixed washed and unwashed small mammal hair showed no significant variations in lead levels between these sites.

ESTIMATED IMPACTS OF LEAD FROM AMMUNITION ON WILD BIRDS AND OTHER WILDLIFE IN THE UK

ESTIMATED ANNUAL MORTALITY IN WILDFOWL AND TERRESTRIAL GAMEBIRDS IN THE UK FOLLOWING DIRECT GUNSHOT INGESTION (EXPOSURE ROUTE 1)

The physiological effects of lead in wild birds and pathways by which ammunition-derived lead reaches them are described in foregoing sections. Here we estimate, broadly, the numbers of wildfowl and terrestrial gamebirds in the UK likely to suffer morbidity and welfare effects and to die from poisoning by ammunition-derived lead.

WILDFOWL

Data are sufficient to allow us to make rough estimates of annual mortality in wintering wildfowl in the UK, although with relatively low precision.

To do this, we used the average proportions of birds with ingested gunshot provided in Table 3 for the UK, and only estimated mortality for the species with data presented in this Table. The incidence of gunshot ingestion in swans cannot be estimated from hunter-shot birds because they are protected species, but data do exist for found-dead swans. To estimate an expected value for hunter-shot swans, we used data for all of the non-swan species (Table 3), and calculated the average percentages of hunter-shot and found-dead birds with ingested gunshot. For hunter shot birds this was 3.2% (155 of 4,857 birds) and for found-dead birds was 5.2% (59 of 1,129 birds). We then used the ratio of these (3.2/5.2; 0.62) to estimate what might reasonably be expected as the incidence of ingested gunshot in swans, had they been 'hunter-shot' (this was 3% for mute swan, 8.1% for Bewick's swan and 14.6% for whooper swan – Table 3).

British wintering population estimates for the species in Table 3 were taken from Musgrove *et al.* (2011), *i.e.* 2,356,100 birds. By multiplying the incidence of ingestion by species population sizes we estimate that 82,313 birds (3.5%) would have ingested gunshot at any one time, assuming that proportions are similar to those given for hunter-shot birds in Table 3. We used the method of Bellrose (1959) to estimate mortality from the incidence of ingested gunshot. We assumed the proportions of birds with different numbers of ingested gunshot (*i.e.*, 1, 2, 3 *etc.*) to be similar to that reported by Mudge (1983) in the UK. Mudge reported numbers of gunshot ingested by 12 of the 16 species in Table 3, and we have averaged these for our calculation, *i.e.* 54% of those birds with ingested gunshot had just one gunshot, 15% had 2 gunshot and so on (Table 5). We adjusted the proportions of birds with each number of ingested gunshot using Bellrose's estimates of hunting bias, because birds that have ingested lead gunshot are more likely to be shot by hunters, presumably due to their weakened state. We used the same hunting bias corrections as Bellrose, based upon his experimental work on mallard (Table 5). We also used Bellrose's method to correct for the effects of turnover. Bellrose

Table 5: Estimate of numbers of 16 species of wildfowl listed in Table 3 dying of lead gunshot ingestion annually during winter.

Number of gunshot ingested	**% hunter-shot birds with ingested gunshot**[1]	**Hunting bias correction**[2]	**% with ingested gunshot after correction for hunting bias**	**% with ingested gunshot corrected for turnover**[3]	**Additional mortality rate (annual probability of death)**[4]	**% of the population estimated as dying of lead poisoning**[5]	**Number of birds estimated as dying**[6]
1	1.89	1.5	1.26	9.45	0.09	0.85	20,039
2	0.525	1.9	0.276	2.07	0.23	0.48	11,230
3	0.081	2	0.041	0.30	0.3	0.09	2,147
4	0.207	2.1	0.098	0.74	0.36	0.27	6,255
5	0.207	2.2	0.094	0.70	0.43	0.30	7,132
6 or more	0.578	2.35	0.246	1.84	0.62	1.14	26,947
Totals	**3.487**		**2.015**	**15.11**		**3.13**	**73,750**

[1] Assuming incidences from Mudge (1983) for 12 of the 16 species in Table 3; [2] Correction factor based upon the increased likelihood of hunters to shoot wildfowl that have ingested lead gunshot (Bellrose 1959); [3] Assuming a 150 day hunting season (Britain) and an average 20 day residence time of gunshot in the gizzard – turnover of 150/20 = 7.5 (see Bellrose 1959); [4] Mortality level is the increase in mortality in mallard caused by ingestion of set numbers of lead gunshot (see Bellrose 1959) – we assume that the mortality level would be similar in all species; [5] % with ingested gunshot corrected for hunting bias and turnover multiplied by mortality level; [6] Using wintering wildfowl estimates from Musgrove *et al.* (2011).

took the average retention time of gunshot in the gizzards of mallard from experimental studies to be 20 days. He then divided the length of the hunting season by this 20 day period to give a turnover correction factor to account for the numbers of birds ingesting gunshot throughout the season. In the UK the wildfowl hunting season is at least 153 days (1 Sept until end of January inland – longer below the high water mark in all but Northern Ireland). We therefore used a correction factor of 7.5 (150/20) to account for turnover. By analysing ring recoveries, Bellrose calculated the absolute difference in the annual mortality rate of wild mallards in the USA between ringed ducks dosed experimentally with various numbers of gunshot and control ducks that were ringed but not given gunshot. This difference was for the year immediately following ringing and dosing (detailed in Bellrose 1959, Table 27 and pages 274-276). We assumed that these additional annual mortality rates would be broadly similar for all wildfowl. From these calculations, presented in Table 5, we estimate that 73,750 birds of the 16 species presented in Table 3 might die every winter in Britain from lead poisoning following gunshot ingestion (this figure would be slightly higher for the UK at c. 75,000, using data from Musgrove *et al.* 2013).

This may underestimate mortality for several reasons. It does not include species of wildfowl for which UK data on the incidence of gunshot ingestion is not available (*e.g.* some of the goose species), and does not include mortality caused by gunshot ingested in the UK outside of the hunting season (which will occur but likely with a reduced incidence). It also excludes the sub-lethal effects of lead which can also influence mortality. These three factors would result in our estimate of mortality being too low. A few factors could potentially result in our estimate being too high. We assume that mortality levels given ingestion of a specific number of gunshot will be similar in all species to those used by Bellrose (1959) for mallard, while these may be higher in some species and lower in others. It is possible that mortality levels could be lower in the geese and swans ingesting small numbers of gunshot (as they have larger body size), although they can ingest very large numbers of gunshot (Newth *et al.* 2012). As lead poisoning was the diagnosed cause of death in a quarter of migratory swans found dead (Newth *et al.* 2012), overestimation in these species seems unlikely. Had there been widespread compliance with regulations banning the use of lead gunshot for shooting wildfowl (and over certain wetlands) in England, this estimate, based upon data from before the ban, might overestimate the numbers affected currently. However, compliance with English regulations banning the use of lead gunshot for shooting wildfowl has been shown to be low (Cromie *et al.* 2010, 2015) with some 70% or more of ducks shot in England and purchased through game outlets being illegally shot with lead ammunition. Hence, legal and illegal deposition of lead gunshot in wetland and terrestrial wildfowl feeding habitats is likely to have continued at broadly similar levels to the period before the ban. Similarly, Newth *et al.* (2012) found that the proportion of birds dying from lead poisoning in England did not change significantly after the introduction of legislation. For this reason the estimate of number affected is likely to be approximately correct.

While there are various assumptions and uncertainties in this calculation for wildfowl, we suggest that the true value is likely to be in the high tens of thousands and probably lie within the range 50,000-100,000 individuals. More precise estimates cannot readily be made at this time.

Many more birds are likely to suffer welfare effects from lead ingestion than die. If all wildfowl predicted to ingest gunshot suffer welfare effects, this would result in about 15% (Table 5) of birds, *i.e.* c. 353,000 suffering welfare effects every winter (and more throughout the year). We therefore estimate that 74,000 – 353,000 individual wildfowl suffer welfare effects every winter.

While it is possible to broadly estimate mortality from lead poisoning, determining impacts at a population level is not straightforward. This is especially the case for wildfowl in the UK, as the majority are migratory and thus subject to pressures across their ranges. The only reasonably robust way of doing this is to model and compare alternative population trajectories for a species based upon demographic rates estimated when effects of ammunition-derived lead are present and absent. The long-term and complicated nature of collecting such information means that for most species, an accurate assessment of the extent of mortality, and possible population level effects from lead ingestion, whatever the source, is currently not possible for most species.

When detailed information on demographic rates is not available, it is legitimate to adopt a comparative approach to the detection of effects of external drivers on population trends (Green 1995). This involves comparing population trends across species or populations with differing levels of exposure to ammunition-derived lead. A negative correlation between population trend and exposure may be suggestive of population-level effects. At a European level, Mateo (2009) correlated population trends in a set of 15 taxonomically similar European wildfowl species with broadly comparable life-history characteristics with reported prevalence levels of shot ingestion. There was a statistically significant tendency for species with high levels of shot ingestion to have more negative population trends than species with low shot ingestion levels. As was pointed out by Mateo, correlation is not causation and effects of some unidentified factor might have led to a spurious correlation. Nonetheless, this analysis is suggestive of an effect of lead contamination on population trend and indicates that it is worth looking further at the effects of lead, especially for species with high shot ingestion levels.

TERRESTRIAL GAMEBIRDS

Less information is available for the UK on levels of gunshot ingestion by terrestrial birds than by wildfowl and it would not be appropriate to extrapolate levels of mortality in terrestrial gamebirds from the studies on wildfowl.

However, data on the proportion of terrestrial birds with ingested gunshot are available for several species in the UK, *i.e.* hunter-shot red-legged partridge (1.4%, Butler 2005[2]), hunter-shot pheasant (3%, Butler *et al.* 2005) and grey partridge found dead (4.5% average for adults and juveniles, Potts 2005), so order of magnitude estimates of mortality can be made. To do this we took breeding population estimates (from Musgrove *et al.* 2013) of these species and the other most numerous gamebirds (red grouse) potentially susceptible to gunshot ingestion and added the numbers of pheasant and partridge raised in captivity which are subsequently released for shooting each year (*i.e.* 35 million pheasants and 6.5 million partridges – released in 2004 (PACEC 2006)). To obtain numbers of individuals from Musgrove *et al.*'s (2013) estimates, we doubled the numbers of territories of red-legged and grey partridges. For pheasant, we assumed that the ratio of males to females was 1:4.6 (after the shooting season (Cramp and Simmons 1980)). We ignored the many young wild-bred birds hatched in the previous breeding season that are present during the shooting season because good estimates of the immature population were not readily available. Our estimate of numbers of terrestrial gamebirds birds that may potentially ingest gunshot is therefore an underestimate. We also omitted other potentially susceptible game species. We assumed that hunter-shot grey and red-legged partridges would have similar levels of gunshot ingestion (1.4%) because grey partridges found dead would be expected to have higher levels of gunshot ingestion if some had died of lead poisoning, and we assumed a low 1% level of gunshot ingestion in red grouse and used the 3% reported for pheasant. We then assumed that shooters are twice as likely to kill birds that have ingested lead gunshot (due to their weakened state) than to kill birds that had not ingested gunshot, and corrected for this (this is the correction factor for mallards that have ingested 3 shot - see Table 5 and Bellrose 1959). We then calculated the number of birds in the population likely to have ingested gunshot at any one time (c. 615,000). Given that we only have estimates for the proportion of gamebirds with ingested gunshot at the time they were killed, and gunshot has a residence time in the alimentary tract that rarely exceeds 30 days (on average about 20 in wildfowl (Bellrose 1959)), the number of birds likely to ingest gunshot at some time during the winter shooting season will be several times higher than this. All birds that ingest lead gunshot may suffer some welfare effect, and a proportion of them, perhaps of the order of hundreds of thousands, are likely to die from lead poisoning. We do not think that it is valid to give more precise estimates for terrestrial birds as studies of hunting bias and shot residence times in the intestine have not been conducted, and fewer studies are available on levels of shot ingestion.

EFFECTS ON PREDATORY AND SCAVENGING BIRDS AND OTHER WILDLIFE FOLLOWING INGESTION OF AMMUNITION-DERIVED LEAD IN THE TISSUES OF DEAD OR LIVE GAME SPECIES (EXPOSURE ROUTE 2)

Measurements of lead concentrations in tissue samples from carcasses of dead predatory and scavenging birds have been used, together with *post mortem* examinations, to assign the cause of death to lead poisoning and other causes. Such studies in the USA, Canada and Europe reported proportions of deaths caused by lead in species likely to be at risk of ingesting ammunition-derived lead ranging from 3% of deaths to 35% of deaths (Elliott *et al.* 1992, Wayland and Bollinger 1999, Wayland *et al.* 1999, Clark and Scheuhammer 2003, Finkelstein *et al.* 2012, Rideout *et al.* 2012). In Europe the bird species with the most consistently high proportions of deaths attributed to lead poisoning is the white-tailed eagle (14 – 28% of deaths attributed to effects of lead) (Elliott *et al.* 1992, Kenntner *et al.* 2001, Krone *et al.* 2006, Helander *et al.* 2009).

In the UK, Pain *et al.* (2007) reported lead concentrations from tissue samples from carcasses of 44 red kites found dead or that were captured sick and died subsequently in England between 1995 and 2003. Elevated liver lead concentrations (>15 mg/kg dw in these birds)[3] and *post mortem* examination analyses indicated that four (9%) of the birds had probably died from lead poisoning; several others had elevated liver lead but were diagnosed as dying of other causes. Walker *et al.* (2012, 2013) reported liver lead concentrations for another sample of 38 carcasses of red kites collected in England in 2010 and 2011 and found no cases with elevated liver lead concentrations.

Pain *et al.* (1995) reported lead concentrations from the livers of 424 individuals of 16 raptor species found dead in Britain and sent for analysis to the Institute of Terrestrial Ecology, Monks Wood, from the early 1980s to the early 1990s. There were eight species for which ten or more carcasses were analysed: short-eared owl *Asio flammeus*, buzzard, little owl *Athene noctua*, kestrel *Falco tinnunculus*, sparrowhawk, peregrine falcon, merlin *Falco columbarius* and long-eared owl *Asio otus*. The other eight species with fewer than ten carcasses included three of the species most likely on the grounds of diet to consume carrion contaminated with ammunition-derived lead (red kite (6 carcasses), golden eagle (5), white-tailed eagle (1)), and one species especially likely to prey upon waterfowl with shot-in or ingested shotgun pellet-derived lead in their tissues (western marsh harrier (1)). Of the species with 10 or more carcasses, feeding ecology would suggest that peregrine falcon and buzzard would be susceptible to preying upon or scavenging (in the case of buzzards) game species. Elevated lead concentrations in liver (>20 mg/kg dw)[3], within the range associated with lead poisoning mortality in raptors, were recorded in one peregrine falcon (4% of species sample)

[2] Earlier data for red-legged partridges (1933-1992) were excluded as Butler (2005) considered it possible that cases of lead ingestion were missed by the pathologists and considered it unlikely that a detailed search was part of all *post mortem* examinations, particularly when no clinical signs of lead poisoning were evident.

[3] A review by Franson and Pain (2011) suggested that birds with no history of lead poisoning usually have liver lead concentrations of <2 mg/kg wet weight (c. 6.3ppm dry weight) and frequently of <1 mg/kg ww (c. 3.1 ppm dw). In falconiformes, these authors suggested a liver lead range for sub-clinical poisoning of 2<6 ppm ww [6.3-18.6 ppm dw] with clinical poisoning associated with liver lead concentrations exceeding >6ppm ww. 'Elevated' liver lead could be considered as above background, *i.e.* 6.3 ppm dw with clinical poisoning occurring at levels above approximately 18.6 ppm dw. These figures can vary somewhat as there is no absolute wet weight to dry weight conversion factor for bird livers (1ppm ww was converted to 3.1 ppm dw by Franson and Pain (2011)).

and one buzzard (2% of species sample). Another one each of these species had liver concentrations of 15-20 mg/kg dw. No individuals of any other species had >15 mg/kg dw, although some had elevated liver lead concentrations in the range of 6-15 mg/kg dw.

Walker *et al.* (2012, 2013) reported liver lead concentrations for a sample of 30 carcasses of sparrowhawks collected in Britain in 2010 and 30 in 2011. Although one sample had a lead concentration of 12.6 mg/kg dw which is close to the threshold for clinical effects, the concentrations in all of the others were <2 mg/kg. It is unlikely that sparrowhawks will be frequently exposed to lead gunshot in their prey; it is possible that occasional exposure may occur in large females that could feed on pigeons that have been shot and wounded but survive.

While some data are available as described above, the necessary measurements of tissue lead concentration have not been reported from sufficient numbers of carcasses of several species potentially at risk to draw any reliable conclusions about the proportion of predatory and scavenging birds dying from lead poisoning in the UK. In particular, sufficient observations are lacking for white-tailed eagle, golden eagle and western marsh harrier. It should also be noted that the geographical distribution within the UK of the locations from which carcasses of scavenging and predatory birds were collected and sent for analysis is likely to be atypical of the distribution of the species as a whole for some of the species with potentially high risks of exposure to ammunition-derived lead. In particular, the collection of carcasses of buzzard, golden eagle and white-tailed eagle from areas in which large numbers of red deer are culled and viscera discarded is probably infrequent relative to the proportion of the population of these species in such areas. Carcasses are usually collected by members of the public, and areas with high levels of culling of deer tend to be remote from human populations.

There is strong evidence that a sometimes substantial proportion of predatory and scavenging birds die from lead poisoning from studies in North America and Europe (see earlier sections of this paper). The small numbers of samples of raptor carcasses collected from largely lowland England suggest that exposure is likely in a small proportion of individuals of those species that would be predicted to be at risk from their feeding ecology. Studies on red kites show that risks may vary locally. There has been little research in the UK on some of the potentially most at risk species (*e.g.* white-tailed and golden eagles, and marsh harriers) and in those areas (*e.g.* upland deer shooting areas and coastal areas) where the risks are likely to be most significant. However, source, pathway, receptor links clearly exists for these species and further research is required.

Few studies have been conducted on the possible impacts of ammunition derived lead in carnivorous mammals, but those that have show little evidence for direct poisoning. Rogers *et al.* (2012) reported that blood lead levels of grizzly bears *Ursus arctos* in the Greater Yellowstone Ecosystem, USA, were not appreciably higher during the hunting season, despite the presence of carcasses and discarded viscera of deer during the hunting season. In addition, they found that lead concentrations in blood and tissues of wolves *Canis lupus* and mountain lions *Puma concolor* in the region were low. Hence, in this region there was no evidence that ingestion of lead from hunter-killed carcasses or viscera was leading to the absorption of lead by these mammalian carnivores. Similarly, Millán *et al.* (2008) found relatively low levels of lead in liver, muscle and bone in five species of carnivorous mammals in Spain.

EFFECTS OF AMMUNITION DERIVED LEAD ON WILDLIFE FOLLOWING INGESTION OF LEAD CONTAMINATED SOIL, WATER AND BIOTA (EXPOSURE ROUTE 3)

There appear to be substantial inter-specific differences in the tolerance of invertebrates to lead of ammunition origin in soils and water. At a cast-off shooting range in Finland, Rantalainen *et al.* (2006) found microbes and enchytraeid worms to be negatively affected by the contamination while soil-dwelling nematodes and microarthropods appeared unaffected. Migliorini *et al.* (2004) found the abundance of Collembola, Protura and Diplura to be positively correlated with major detected contaminants (lead and antimony) in soils from a clay pigeon shooting range, while Symphyla showed a negative correlation with these pollutants. Concentrations of lead in the saprophagous *Armadillidium sordidum* (Isopoda) and the predatory *Ocypus olens* (Coleoptera) increased with the soluble lead fraction in soil, showing that a significant portion of metallic lead from spent pellets is bioavailable in the soil and can be bioaccumulated by soil organisms. Reid and Watson (2005) found soil levels of 6,410 +/- 2,250 and 296 +/- 98 mg(Pb)/kg dw, respectively at a clay-pigeon shooting site soil and an un-shot control site. At 6.1 +/- 1.2 mg(Pb)/g dw, shooting site body burdens of earthworms *Aporrectodea rosea* were almost 1,000 times higher than those from the control site

(7.1 +/- 9.0 µg(Pb)/g dw). An experiment in which earthworms collected from both sites were exposed to soil that had been artificially augmented with lead found a decrease in condition of earthworms from the control site, but not of those from the shooting site, suggesting the development of high tolerance to lead in the shooting site worms.

Exposure to lead from ammunition sources in areas of high shooting intensity has been reported to have impacts on small mammals and amphibians. White-footed mice *Peromyscus leucopus* and green frogs *Rana clamitans* sampled within the shot-fall area of a shooting range with high pellet density had depressed ALAD enzyme levels (Stansley and Roscoe 1996), a recognised indicator of sub-clinical lead toxicosis in mammals, and the mice also had reduced haemoglobin levels. Stansley *et al.* (1997) exposed eggs of pickerel frogs *Rana palustris* and bullfrogs *R. catesbeiana* to 0, 25, 50, 75 and 100% lead-contaminated surface water from a trap and skeet range. Total lead concentrations in 100% range water treatments varied from 840–3,150 µg/l, with the filterable form accounting for approximately 4–5% of the total. Hatching was not affected in either species but there was highly significant mortality (100% and 98%) in pickerel frog tadpoles after 10 days of exposure to 100 and 75% range water; mortality was not significantly increased in bullfrogs.

It has been shown experimentally that pigeons *Columbia livia* dosed with soil contaminated with lead from a shooting range absorbed lead in a dose-response manner as reflected in blood, tissues, feathers and erythrocyte protoporphyrin, a biomarker of lead effect (Bannon *et al.* 2011). In the field, Vyas *et al.* (2000) found elevated erythrocyte protoporphyrin levels in some ground foraging passerines held in aviaries in the vicinity of a clay pigeon shoot in Maryland, USA, relative to controls. The authors could not determine whether this was from ingestion of one or a combination of shot directly, degraded shot in soil (soil can be an important routes of exposure to lead in some bird species and situations (Beyer *et al*. 1998)) or other lead-contaminated dietary components. A case of lead poisoning has also been described in a grey squirrel *Sciurus carolinensis* in the vicinity of a law enforcement firing range in Georgia, USA (Lewis *et al.* 2001).

These studies, and those cited in preceding sections, show that where invertebrate and vertebrate animals are exposed to elevated levels of lead of ammunition origin, irrespective of the exposure route (*i.e.* ammunition fragments, soil, water or biota) it can exert sub-lethal negative effects on animal physiology (*i.e.* both welfare and individual survival) in many species, and in some animals may cause mortality. Effects are related to exposure levels and amounts absorbed, thus animals (*e.g.* birds) ingesting ammunition fragments directly are at particularly high risk as described in preceding sections. Nonetheless, local effects on a range of wildlife in areas of intensive ammunition use appear likely in many exposed species. While some inter-specific differences in susceptibility to the effects of lead occur across many taxa, the few studies available suggest that this may particularly be the case in invertebrates, with the possibility that this may be acquired (for one species studied). Insufficient data exist to be able to evaluate numbers of animals potentially affected *via* routes other than direct ingestion of ammunition fragments by birds.

CONCLUSIONS

The toxic effects of lead on humans and other vertebrates have long been known and most uses of lead causing elevated exposure to humans and wildlife have been phased out or heavily regulated across most of the world (Stroud 2015). Lead derived from ammunition now appears to be the most significant geographically widespread and common source of unregulated environmental lead contamination to which wildlife is exposed. Lead from ammunition has primarily been studied in birds, with the two main exposure pathways being direct ingestion of spent gunshot (*e.g.* by wildfowl and terrestrial gamebirds), and ingestion by predators and scavengers of lead gunshot, bullets, or fragments from these, in the flesh of their prey. Thousands of tonnes of lead ammunition, primarily gunshot, is deposited and accumulates in the UK environment every year. Lead ammunition degrades very slowly, and while deposited gunshot settles through soils and sediments it may take several decades to become unavailable to feeding animals. Predators and scavengers can be exposed to lead in dead and unretrieved game, discarded viscera from shot deer, and in the flesh of prey that have been wounded but survived. Studies on a variety of species/populations of live wildfowl have shown that a high proportion individuals (an average of >20% across 22 species) carry gunshot in their flesh.

Studies of exposure to, and poisoning by, lead from ammunition in birds have included: experimental dosing studies, *post mortem* examinations of birds, X-radiography studies of live birds for incidence of ingested ammunition or fragments, examination of regurgitated pellets for ammunition or ammunition fragments, investigations of temporal and spatial relationships between ammunition ingestion/poisoning and shooting seasons or intensity, isotopic studies to investigate the source of elevated tissue lead concentrations; studies of changes in survival in wild birds with different levels of gunshot ingestion, and others. These studies have been conducted in many countries across the world, primarily over the last 65 years and have shown that lead poisoning from ammunition sources is geographically widespread and causes substantial suffering and mortality in many avian taxa.

Lead from ammunition is known to affect a wide range of biological and physiological systems in birds and other vertebrates, and birds can die rapidly after ingesting lead from ammunition (acute poisoning), or gradually following lower levels of exposure or absorption, or repeated exposure (chronic poisoning). Lead poisoning from ammunition lead was first recorded in the UK well over a century ago (Calvert 1876) and reports of lead poisoned birds grew rapidly from the 1950s onwards in the UK and globally. Wildfowl are the best studied taxa, but where lead ingestion has been investigated in other taxa that feed in shot-over areas, including terrestrial gamebirds, it has generally been found. Lead poisoning in predatory and scavenging birds, primarily raptors, has also been widely reported, although relatively few studies have been conducted in the UK.

In the UK, we can broadly estimate the numbers of birds from certain avian taxa that are likely to die as a direct result of ingesting lead gunshot every winter. These estimates are based upon published gunshot ingestion incidence in different species, and corrected for hunting bias (*i.e.* that hunters are more likely to shoot lead poisoned birds), turnover of gunshot in the alimentary canal, and increases in mortality as a result of ingesting different numbers of gunshot. These estimates suggest that 50,000-100,000 wildfowl are likely to die each winter (*i.e.* during the shooting season) as a direct result of lead poisoning. Wildfowl that die outside of the shooting season will be additional, as will birds dying from the indirect results of lead poisoning. Several hundred thousand wildfowl may suffer welfare effects.

Estimates of mortality for terrestrial gamebirds in the UK are likely to be less accurate and precise due to fewer studies, but we estimate that about 600,000 terrestrial gamebirds are likely to have ingested gunshot at any one time and many times more throughout the shooting season. All birds that ingest lead gunshot may suffer some welfare effect, and a proportion of them, perhaps of the order of hundreds of thousands, are likely to die from lead poisoning each year.

There is strong evidence from studies in North America and elsewhere that a sometimes substantial proportion of predatory and scavenging birds die also from lead poisoning. A few studies from the UK have reported lead poisoning in certain raptor species, and the source and pathways exists for a wider range of species to be affected, but further research on this is needed.

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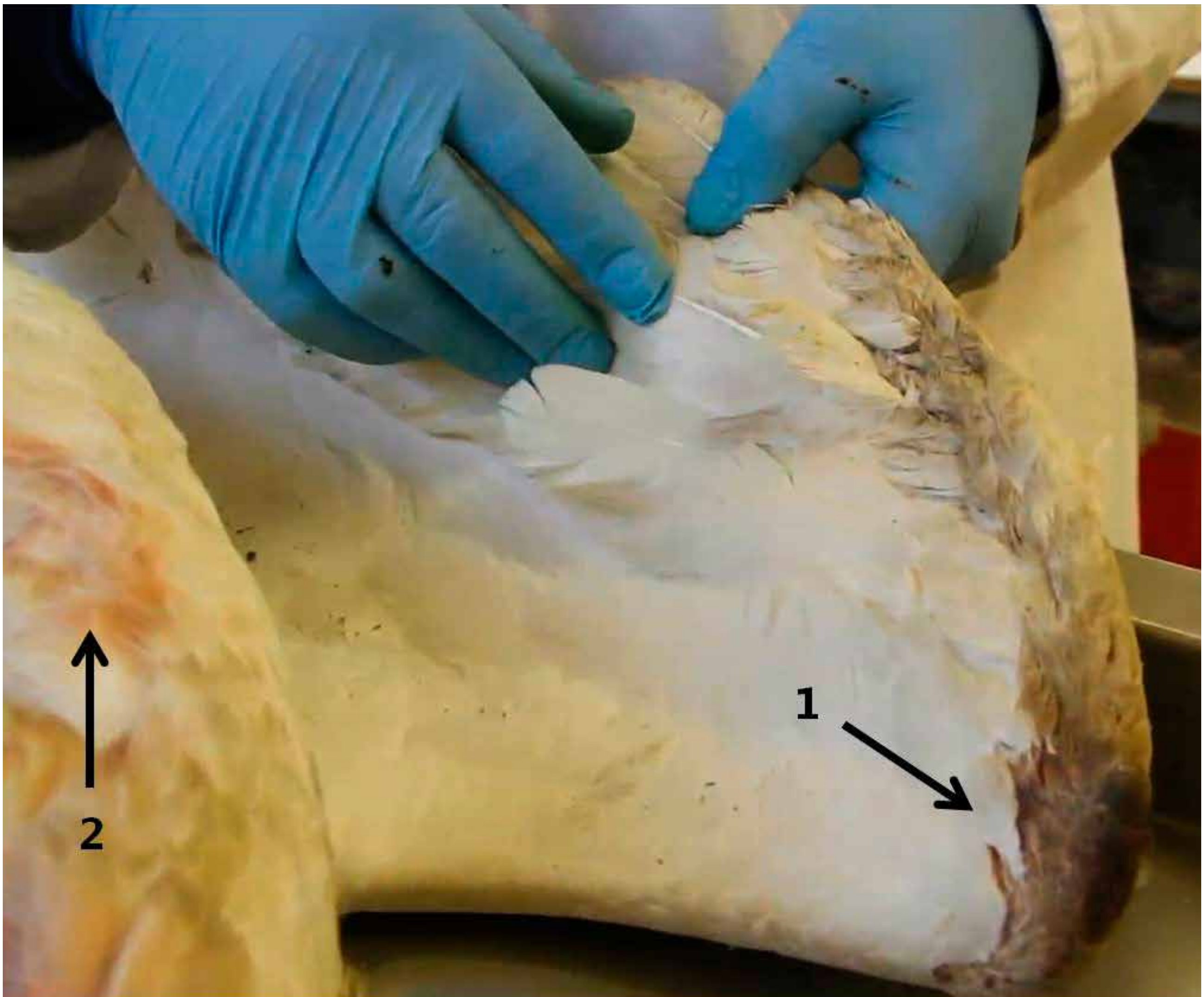

Muddy and bloody carpel joint of a lead poisoned whooper swan *Cygnus cygnus* (1): due to paralysis of the bird's legs it had been using its wings to propel itself on land prior to death. The blood staining on the bird's breast (2) illustrates that the abrasions have been bleeding.

Photo Credit: WWT

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

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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.

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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

Practical and social barriers to switching from lead to non-toxic gunshot – a perspective from the EU

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ABSTRACT

Denmark has a long hunting tradition and a very high density of hunters. The total annual bag is approximately 2.3 million specimens. More than 90% is harvested by shooting, be that driven shoots of pheasant and mallard, walk-up shooting of upland game, decoyed waterbirds or open sea motor boating targeted at sea ducks.

In Denmark, the use of lead shot was first regulated in 1985 by setting up a ban on *inter alia* the use of lead shot for hunting in 26 wetlands designated as Ramsar-sites and for clay pigeon shooting in certain areas. Denmark enforced a total ban on the use of lead shot in 1993 in all areas outside forests and with a subsequent enforcement of a lead shot ban in forests in 1996. Since then all use, trade and possession of lead shot has been banned throughout the country (Kanstrup 2006).

The phase-out of lead shot raised a number of practical and social barriers. The first barrier was connected to the availability of alternative shot types. Also the quality and efficacy of alternative shot types, safety to hunters, and the risk of damage to guns and machinery in the forestry industry, were raised as potential obstructions to the implementation of the regulation. However, all issues were discussed and managed. The hunters' community made their own investigations of the lethality *i.e.* effectiveness of non-lead shot. New guidelines were drawn up to ensure safe hunting practice, and gunsmiths developed good practice to guide hunters to the appropriate combination of gun, cartridge and shot. Since the mid-1990s non-lead shot has been available and can be obtained for any hunting purpose in any habitat and with any type of shotgun. A good deal of focus has been put on the quality of shotgun cartridges, and efficacy of non-lead types is proven to be comparable or even higher than lead shot.

During the phase-out period many Danish hunters feared that the process would cause a decline in numbers of hunters and weaken the socio-political power of the hunters' community. However, today, 30 years after the first regulation of lead shot and almost 20 years after the total ban, the number of hunters in Denmark is the highest (177,000) since the registration of hunters was introduced in the 1930s. The annual bag of quarry species has shown a high degree of fluctuation but a general trend of decline. However, there seems to be no connection between this decline and the regulation of lead shot since the 1980s. The decline is caused by other regulations of hunting, *e.g.* full protection of several species, combined with a general population decline in central quarry species *e.g.* upland game.

The Danish example of a total ban on lead shot for hunting has demonstrated that this can be achieved without jeopardising the hunters' interests and weakening the hunters' community. On the contrary, it is believed, though never investigated, that the public image value of hunting not being connected to a pollutant such as lead is of paramount importance for the perception and long-term political sustainability of hunting.

Key words: *social barrier, practical barrier, Denmark, hunting tradition, transition, sustainability of hunting*

NARRATIVE

The land surface area of Denmark is 44,000 km and the surrounding shallow sea area is approximately the same again. The coastline is approximately 7,000 km and the human population is just below six million. With a population of registered hunters of 177,000, Denmark has one of the highest densities of hunters according to surface area and as a proportion of the population (~3%). According to Danish legislation, 45 game species can be hunted. In addition, several species are regulated according to a special scheme for prevention of damage to agriculture and other society interests. The annual harvest is monitored according to a mandatory bag statistic programme that has been in operation since 1941. The total annual bag is approximately 2.3 million (2013) with pheasant *Phasianus colchicus* (700,000) and mallard *Anas platyrhynchos* (480,000) representing about half of the total (Naturstyrelsen 2014). The most common hunting practice is driven shoots of pheasant and other bird species based extensively on the release of reared birds. Mixed shooting of upland game with the use of flushing and pointing dogs and decoying of wood pigeon *Columba palumbus* and ducks is also very widespread. A special tradition is shore and sea shooting from punts and small motorboats with diving ducks as the primary quarry. Rifle hunting/stalking is a growing interest. Roe deer *Capreolus capreolus* are the most common deer species and are hunted by shooting with rifles as well as shotguns. Red deer *Cervus elepahus* and fallow deer *Dama dama* populations are increasing and spreading to most parts of the country. Consequently, the hunting interest and need to manage their populations is increasing. The larger deer species (red and fallow) can only be hunted with rifles.

Table 1: **The annual bag for 2013 of quarry species or groups of species, including the distribution of shotgun and rifle hunting.**

Species	Individuals killed by:		
	Shot	**Bullet**	**Other***
Roe deer	40,000	87,400	
Other hoofed mammals	18,200		
Hare	55,300		
Rabbit	10,400		
Red fox**	20,000	17,500	
Other mammals	90,00		8,000
Partridge	28,800		
Pheasant	710,800		
Wood pigeon	278,500		
Mallard	486,000		
Other dabbling ducks	158,500		
Diving ducks	71,200		
Geese	77,100		
Gulls	21,700		
Coot	10,900		
Woodcock	34,000		
Snipe	10,700		
Crows and magpie	90,000		25,000
Rook		90,700	
Other birds	9,800		
Total	**2,122,700**	**213,800**	**33,000**

Source: Naturstyrelsen (2014). *"Other" includes trapping and bow hunting. **Distribution of red fox *Vulpes vulpes* bag killed by shot or bullet is judged by the author.

Table 1 shows the annual bag for 2013 with the distribution of quarry species or groups of species. The data are additionally divided into those killed with shot or bullets, indicating that about 90% of the annual harvest is shot using shotguns.

In summary, Denmark is a country with a long hunting tradition, and a large population of hunters whose main interest is in hunting with shotguns. This is comparable to other North European countries, including the UK. In the context of evaluation of the impact of legislation changes on the use of shot materials Denmark is therefore regarded as representative of most countries of relevance.

Lead shot phase-out

AVAILABILITY OF NON-LEAD ALTERNATIVES

In Denmark, the use of lead shot was first regulated in 1985 by setting up a ban on *inter alia* the use of lead shot for hunting in 26 wetlands designated as Ramsar-sites and for clay pigeon shooting in certain areas. Only American brands of steel shot were available, and at that time many hunters regarded these as being unsuitable for hunting in Denmark.

Hence, the availability of non-lead shot became a practical barrier from the beginning. However, a Danish programme of producing steel shot was initiated (DanArms), and a variety of different shot types designed for different purposes was introduced. In addition, new American and other products were introduced to the Danish market. Denmark decided to ban all use of lead shot in 1993. However, the use of steel shot was considered unacceptable to foresters because of its hardness and the consequent risk of damage to machinery used in the timber industry from steel shot embedded in trees. This delayed the introduction of the lead shot ban in forests until 1996 and led to pressure to develop softer shot alternatives ("forest shot") such as bismuth, tin and wolfram products. These alternatives, particularly bismuth, have proved to be popular. Since the mid-1990s, non-lead shot can be obtained for any hunting purpose and any type of shotgun. Steel shot is the cheapest alternative, the price being comparable to that of lead shot, though steel shot for clay pigeon shooting tends to be slightly cheaper. The price of non-steel alternatives is significantly higher. Concern over the use of hard shot in forests is today less pronounced, and many forest properties now allow any type of shot to be used.

SAFETY

A central concern, and therefore also a barrier to the phase-out of lead shot, was that non-lead shot could cause an increased risk to humans either by guns exploding or shot ricocheting. Furthermore, some hunters and members of the firearms industry claimed that non-lead shot would cause increased wear and risk of damage to certain types of guns. However, the successful introduction of steel shot for clay pigeon shooting allayed the concerns of many hunters by showing that steel shot cartridges were not dangerous to fire. New constructions of cartridges, development of new powder types, and not least a focus on the functionality of the plastic wad to avoid direct contact between load and barrel, resulted in new a generation of non-lead shot cartridges that have been shown to be very useful and have become very popular amongst Danish hunters. The marked demand driven by the legislation forced the manufacturers to create and develop the necessary products. Thirty years of experience in the use of non-lead shot types has provided no evidence that the change from lead shot has jeopardised personal safety or caused damage to guns. Analysis of insurance statistics gives no indication of an increased number of cases of injuries following the phase-in of non-lead shot, and concern over an increase in accidents caused by ricochets from hard steel shot has proved groundless.

LETHALITY

The most pronounced barrier connected to the phase-out of lead shot was a general perception in the hunting community that the efficacy and lethality of non-lead shot was not sufficient for hunting under typical Danish circumstances. Many hunters claimed that by solving the problem of lead toxicosis in waterbirds by banning lead we would only cause another problem by increasing the level of wounding loss. Research in shot lethality was at that time limited to American studies. Despite these studies supporting steel shot as an acceptable, non-toxic alternative to lead (Humburg *et al.* 1982), it became obvious that there was a need to undertake studies in Denmark. Consequently, reviews and field research was initiated by the state administration and research institutions (Hartmann 1982). Also the Danish Hunters' Association introduced a research programme mainly on eider duck *Somateria mollissima* shooting in the 1980s (Kanstrup 1987). In the following years, new lethality studies were performed in other European countries and there were further American publications. The particular focus on the quality of non-lead shot has resulted in very sophisticated high performance products. Recently, Pierce *et al.* (2014) reviewed historical studies and showed comparable lethality performance by lead and non-lead shot based on field test hunting of mourning doves *Zenaida macroura*. In summary, development has shown that steel and other non-lead metals can be manufactured into pellets and loaded into high quality cartridges in a way that ensures a well performing and lethal shot. Several studies show that the practical efficiency and lethality of a shot is connected primarily to the ability of the shooter to hit his/her target. The change from lead to non-lead shot in Denmark has put a positive focus on the need to educate and train hunters. Noer *et al.* (2001) showed that during the period when lead shot was phased out the frequency of wounding of different game species (*e.g.* pink-footed goose *Anser brachyrhynchus* and red fox *Vulpes vulpes*) in Denmark declined. Danish hunters have become acquainted with non-lead shot. A generation of new hunters has never fired a lead shot cartridge.

SOCIAL BARRIERS

Many Danish hunters were worried that the phasing out of lead shot would cause a decline in numbers of hunters and weaken the socio-political power of the hunting community in Denmark. The same concern is raised today in other countries as an argument against the phase-out of lead shot. The validity of this argument can be tested by using the Danish example of a 20 year total ban on lead shot. The hypothesis is that if hunters began giving up hunting due to the phase-out of lead shot this would cause a decline in the harvest of game and/or numbers of hunters. In the following section two parameters are analysed: firstly, the number of hunters in Denmark over time, and secondly, the hunting bag of three groups of quarry species harvested with shotguns over time. Data for both are available from the 1970s and 1980s respectively and data for the period of the phase-out of lead shot can easily be extracted.

Since the 1930s Danish hunters have been registered as it is a legal requirement that they possess a hunting license. The system is administered by the Government, and since 1989 by the Ministry of Environment. Data are published and are openly available. Figure 1 shows the number of hunting license holders in Denmark in the period from 1980 to 2013.

In general, the number of hunters remains stable over the whole period. It has fluctuated between 160,000 and 175,000, and thus has changed by less than 10% over the period of 33 years. There seems to be a slight decline from the year 2000 and thereafter, but this is unlikely to be a reaction to the regulation of lead shot that came into force earlier. Neither is it likely that the new hunting act of 1993 had a significant impact. The most likely reason for the small fluctuations is that the number of hunters is affected by the popularity of hunting and therefore on societal trends more than legal regulations. Today, 30 years after the first regulation of lead shot and almost 20 year after the total ban, the number of hunters in Denmark is the highest (177,000) since registration was introduced in the 1930s. There seems to be no indication, that the regulation and total phase-out of lead shot for hunting has had any negative impact either on the number of hunters or on the long term popularity of hunting.

The annual harvest is monitored by the Danish Centre for Environment and Energy/Aarhus University and basic data are publicly available.

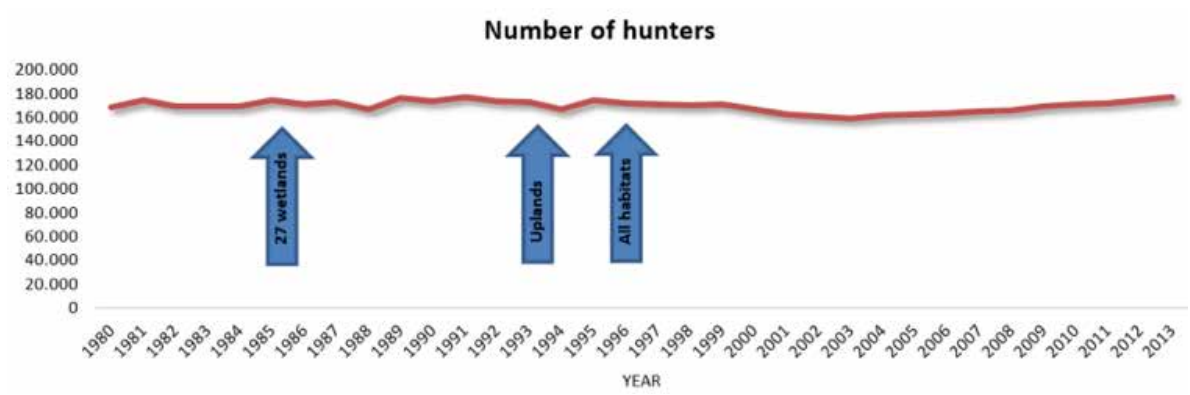

Figure 1: **Number of hunting license holders in Denmark from 1980 to 2013.** *Arrows indicate the time of regulation of lead shot in three hunting habitats. Source: Annual publications from the Danish Nature Agency protocols.*

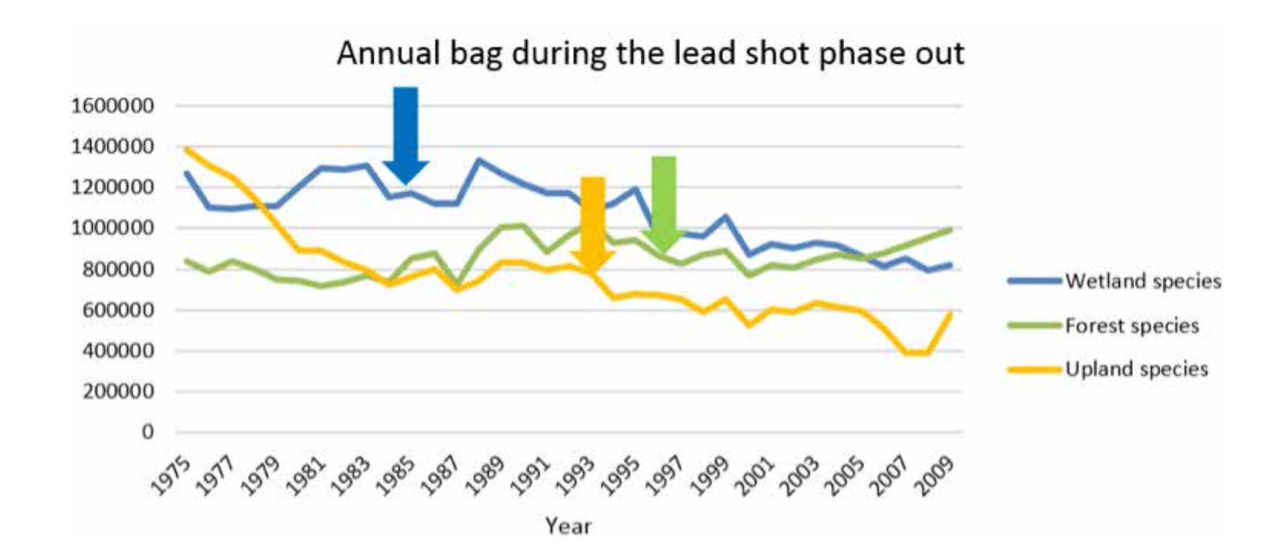

Figure 2: **Annual bag of three groups of quarry species during the period of phase out of lead shot for hunting in the three habitats: wetlands, uplands and forests.** *Arrows indicate the time of regulation of lead shot in the particular habitat. Source: The Danish Bag Statistics.*

Data for species hunted with shotguns in the period 1975 to 2009 are shown in Figure 2.

The annual bag of quarry species in all habitats in Figure 2 shows a high degree of fluctuation during the whole period. In the years after the regulation of lead shot in certain wetlands (26 Ramsar sites) there seems to be a slight increase in the harvest of both wetland and other species. From the mid-1990s the bag of all groups of species shows a slight decline. There is no reason to believe that this is due to hunters giving up hunting because of the lead shot ban. The legal basis for the lead shot regulation was a new hunting law that came into force in 1993. However, this act changed other principles of hunting, *inter alia*, shorter open seasons for certain species, *e.g.* woodpigeon and seaducks, and a new network of hunting free sanctuaries in Danish Special Protection Areas causing a general decline in the hunting potential mainly in coastal wetlands. Together with a general decline in populations of upland game species such as grey partridge *Perdix perdix* and European hare *Lepus europaeus*, this has caused a general reduction in the annual harvest (Asferg *et al.* 2009). During the last approximately 20 years the total annual bag has been relatively stable at about 2-2.5 million specimens annually. The bag of forest species tends to have increased slightly.

In conclusion, the Danish example of a total ban on lead shot for hunting has demonstrated that this can be achieved without jeopardising the hunters' interests and weakening the hunting community. On the contrary, it is believed likely that the public image value of hunting not being connected to a pollutant such as lead is of paramount importance for the long-term political sustainability of hunting.

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Pheasant shooting is popular in the UK and remains popular in Denmark 20 years after the transition to non-toxic shot.

Photo Credit: SGM/Shutterstock.com

The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult

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ABSTRACT

A range of pressures and policy drivers exist to reduce human and wildlife exposures to the toxic effects of lead from ammunition sources, awareness of which has increased in recent years. The replacement of lead ammunition with non-toxic alternatives is widely recognised as a practical and effective solution to address the risks. As a consequence a range of users of ammunition for natural resource management are making, or have made, this transition. This paper explores a resistance to change from many in the recreational shooting community.

Compliance with the current regulations restricting use of lead shot in England in order to reduce the pollution of wetlands and poisoning of wildfowl has been shown to be poor and morbidity and mortality remains high across Britain. Unfortunately a high profile campaign run by the shooting organisations to reduce illegal use of lead shot has been ineffective.

A questionnaire survey of shooters' behaviours and attitudes was undertaken to better understand the situation, combined with a review of coverage of the subject area in the shooting media. Together with personal experiences of the authors, these highlight a number of sociological and political barriers that combine to inhibit both compliance with existing regulations and a transition to wider use of non-toxic ammunition.

These barriers to change are set within a wider context of a long held perception in the shooting and wider field sports communities that 'hunting is under threat'. The barriers are reinforced by the misperceptions that lead poisoning is not a problem for either wildlife or human health; and that non-toxic alternatives are not fit for purpose and/or too costly. There are cross-cutting issues of the regulations' unenforceability, cultural traditions within the shooting communities, as well as polarised loyalties between key stakeholder groups, and mistrust of those outside these communities. In combination, this has led to issues of biased assimilation of information and solution aversion (meaning that the evidence is immaterial if the solution to the problem remains undesirable). There has also been a popular narrative in the field sports media dismissing the evidence and discrediting the messengers. These barriers to change appear to have been supported by commercial interests and the political power of the field sports lobby including the ammunition manufacturers.

In other countries, recognition of lead's toxic impacts and transition to the use of non-toxic ammunition have been fully 'owned' by shooting communities working in combination with governments recognising joint responsibilities and interests. Within the UK, the polarisation of stakeholder groups has inhibited such ownership, and prevented constructive collaborative working and the agreement of a common solution. It is argued that the opportunity for the conservation and shooting communities to work together on resolving problems was missed in the early stages of the existing regulations. Now, the atmosphere of the debate is likely non-conducive to those within the shooting community who might like to speak out in favour of a more sustainable lead-free approach to shooting.

A range of ecological, economic and public relations benefits to making the transition to non-toxic ammunition are described. Whilst there are some costs to the shooting community, these are arguably outweighed by the costs of not changing.

Key words: *compliance, regulations, sociological aspects, political aspects, conflict, costs, barriers, lead ammunition*

Author contributions: *Wrote the paper: RC, JN. Performed the game dealer survey (including purchasing, radiography, pathology and laboratory analyses, data analyses): JR, MO, KB, MB, JN, RC. Undertook the media survey: RC.*

INTRODUCTION

As a Contracting Party to the African-Eurasian Migratory Waterbirds Agreement (AEWA), the UK has an obligation to phase out the use of lead shot over wetlands (AEWA 1999, 2002, 2008) (with the initial deadline for this being 2000). Consequently, restrictions on the use of lead shot were introduced in England in 1999 (HMSO 1999, 2002a, 2003), Wales in 2002 (HMSO 2002b), Scotland in 2004 (HMSO 2004) and Northern Ireland in 2009 (HMSO 2009). In England and Wales, the Regulations make it illegal to use lead shot for shooting wildfowl, coot *Fulica atra* and moorhen *Gallinula chloropus*, and over certain listed wetlands (Sites of Special Scientific Interest) and the foreshore. In Scotland and Northern Ireland the use of lead is not permitted over any wetlands.

Despite this UK-wide legislation, lead poisoning from ammunition sources remains a cause of significant mortality and morbidity for primarily waterbirds and likely also terrestrial gamebirds (which consume lead shot directly from the environment) and raptors (which consume lead shot and bullet fragments within prey and carrion) (Newth *et al.* 2012, Pain *et al.* 2015). Newth *et al.* (2012) detected elevated blood lead levels in a third of live wildfowl tested in Britain. Additionally they found no reduction in mortality from lead poisoning in the 11 year period following introduction of legislation in England in 1999. This ongoing problem is likely due to illegal use of lead gunshot where waterbirds feed (partial restrictions having been shown, within the UK and more widely, to be difficult to enforce (AEWA 2012)) and/or legal use of lead shot in terrestrial waterbird feeding habitats (Newth *et al.* 2012). Recently deposited lead gunshot is likely to be more readily available to waterbirds than shot deposited historically which may become increasingly inaccessible over time as it becomes incorporated into the substrate (Anderson *et al.* 2000, Newth *et al.* 2012).

The issue of the risks from the toxic effects of lead from ammunition sources (both gunshot and bullets) has prompted much discussion from different stakeholder groups in the UK and internationally, including the shooting[1] and wildlife conservation[2] communities as well as public health bodies[3] and animal welfare organisations[4]. A number of key findings and developments related to lead in the last decade have been critical to the discourse in the UK, including:

1. A greater understanding of the degree and extent of fragmentation of lead ammunition within shot game to which the human consumer is then inadvertently exposed (*e.g.* Watson *et al.* 2009, Pain *et al.* 2010, BfR 2011, Iqbal *et al.* 2011);
2. Further to the 2008 Peregrine Fund conference, "Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans"[5] and its proceedings (Watson *et al.* 2009), the subsequent increasing body of scientific reports of risks posed by lead from ammunition to the health of humans (*e.g.* EFSA 2010), wildlife and domestic animals (*e.g.* Payne *et al.* 2013), and of wider environmental contamination *i.e.* lead ammunition poses a cross-cutting One Health[6] issue (*e.g.* Johnson *et al.* 2014);
3. Department for Environment, Food and Rural Affairs (Defra) funding the Wildfowl & Wetlands Trust (WWT) and the British Association for Shooting and Conservation (BASC) to undertake a study into compliance with existing regulations in England (Cromie *et al.* 2010) as poor compliance had been measured in 2002 (Cromie *et al.* 2002): the results indicating continued poor compliance and suggesting that the law had been ineffective in achieving its aim;
4. Defra and the Food Standards Agency (FSA) setting up the Lead Ammunition Group[7] in 2010 in response to concerns about risks of lead ammunition to wild and domestic animal health and human health: in the following five years the group aimed to assess and address these risks and reported to government with its findings in June 2015[7];
5. 'A Scientific Opinion on Lead in Food' by the European Food Safety Authority (the European Union's independent provider of scientific advice on risks from food) (EFSA 2010): with consequent food safety advice regarding game shot with lead ammunition produced by the health/food agencies of at least five European countries (BfR 2011, AESAN 2012, Food Standards Agency 2012, VKM 2013, SNFA 2014);
6. As a Contracting Party to the UN-Convention on Migratory Species, the UK adopting Resolution XI.15 (UNEP-CMS 2014a) in 2014 whose guidelines (UNEP-CMS 2014b) include a 2017 deadline for the phase out of all lead ammunition in both terrestrial and wetland habitats.

[1] Those primarily involved in recreational but also subsistence shooting (including some pest control activities as part of this). [2] Those organisations whose sole remit is wildlife conservation - a label to describe *e.g.* WWT and RSPB, accepting overlap with the conservation work of the shooting community. [3] Those organisations or bodies with responsibility for human health *e.g.* in relation to food safety such as the Food Standards Agency. [4] Those organisations whose remit is animal welfare: may include organisations who deal with treating sick wildlife and its rehabilitation. [5] https://www.peregrinefund.org/subsites/conference-lead/
[6] One Health: the collaborative effort of multiple disciplines — working locally, nationally, and globally — to attain optimal health for people, animals and the environment. [7] Lead Ammunition Group website http://www.leadammunitiongroup.org.uk/

The replacement of lead ammunition (both shot and bullets) with non-toxic alternatives is recognised widely as a practical solution to this One Health problem (UNEP-CMS 2014b, Group of Scientists 2013, 2014) *i.e.* one mitigation measure which would bring health benefits across the medical, veterinary and conservation sectors. Given the global drivers to reduce exposure to lead for both humans (*e.g.* WSSD 2002) and wildlife populations alike (UNEP-CMS 2014a, 2014b), this substitution would likely bring a range of benefits for the shooting community and wider society, namely:

1. Substantial reduction in wildlife poisoning: mortality, morbidity and associated welfare concerns (*e.g.* Anderson *et al.* 2000, Samuel and Bowers 2000, Stevenson *et al.* 2005). From the shooting perspective, removal of this significant mortality factor has potential to result in greater numbers of individuals of quarry species to shoot. Indeed, replacement of lead ammunition for waterfowl hunting in the USA has been described as a key cost effective waterfowl conservation tool (Thomas 2009);

2. Reduction in environmental pollution and uptake of lead from soils into plants and lower animals (*e.g.* Sneddon *et al.* 2009);

3. Reduction in risk to humans consuming game shot with lead. Due to the particular sensitivity of the developing brain to the effects of lead (*e.g.* USATSDR 2007, CDC 2012), this is of particular importance to children, especially those most likely to be consuming such meat frequently *e.g.* children in shooting households (a BASC/Countryside Alliance survey of game-eating habits estimated that 5,500 – 12,500 children under eight years of age from their community eat game at least once a week (Lead Ammunition Group 2014)). Such levels of consumption have the potential to result in intellectual and other developmental deficits, *e.g.* BfR (2011), AESAN (2012), Andreotti and Borghesi (2012), Food Standards Agency (2012), VKM (2013), NFAS (2014), Green and Pain (2012, 2015);

4. Reduction in waste of harvested animals where substantial proportions of carcases are recommended to be discarded to eliminate the greatest proportion of lead-contaminated meat (*e.g.* a 60 cm diameter around the wound canal for mammalian game species shot with bullets (Knutsen *et al.* 2015));

5. Reduction in potential risk to the wider public image of the shooting community as tacitly poisoning;

6. Reduction in risk of markets for game meat being affected negatively within the UK, the European Union and beyond if restrictions are introduced for food safety reasons (*e.g.* if minimum lead levels are introduced for game meat to bring in line with other meat, fish, shellfish and mollusc restrictions (EC 2006));

7. Reduction in potential risk of future economic impacts on the shooting community (particularly if societal awareness or controls on lead increase) in the case of perceptions leading to blight affecting the value of land or produce; or the principle of the polluter being asked to pay for the remediation of contaminated land where there are actual impacts such as on domestic stock or human health.

By necessity, the practicalities and technical aspects of production and use of non-toxic ammunition have been, or are being, addressed (*e.g.* Gremse *et al.* 2014, Gremse and Reiger 2015, Thomas 2013, 2015). Despite evidence of poor compliance with existing regulations in England (Cromie *et al.* 2002, 2010), there are undoubtedly some shooters who have been using non-toxic ammunition routinely since the introduction of regulations on use of lead shot for shooting wildfowl/or over some wetlands. Additionally, a number of UK organisations using ammunition in natural resources management (not for recreational shooting *per se*) *e.g.* government agencies and NGOs, have either made the transition to non-toxic ammunition or are in the process of doing so.

Although it has taken many decades of science and policy development (often associated with industry resistance), exposures of people to lead in paint, petrol and pipes have been significantly reduced at a global scale (Stroud 2015). The scene is now set for change on use of lead ammunition: the evidence is extensive and robust (Group of Scientists 2013, 2014); there are clear international and national policy drivers (Stroud 2015); ammunition users are not being asked to stop their current activities, they are being asked instead to use different ammunition, which is increasingly available; and there are a range of benefits, as mentioned above. Despite consensus between conservation (BirdLife International) and international shooting organisations (The European Federation for Associations of Hunting and Conservation - FACE - and the

[8] This International Council for Game and Wildlife Conservation (CIC) Workshop's Resolution states that *"It is now technically feasible to phase out the use of lead ammunition for all hunting"* (accepting some development needs for some calibres of bullets).

International Council for Game and Wildlife Conservation - CIC) on the risks from lead ammunition to wildlife (BirdLife International/FACE 2004) as well as people (CIC 2009, Kanstrup 2010[8]) resistance to change remains firm amongst many in the UK shooting community. Why then is this transition so protracted (given that this was first recommended by the Royal Commission on Environmental Pollution in 1983 (RCEP 1983))?

The publication of the Newth *et al.* paper in the autumn of 2012, indicating a continuing problem of lead poisoning in waterbirds in Britain, gained some media coverage. This created heightened tension in the debate and was met with a strong negative reaction in the UK shooting media and shooting organisations. Since then, retaining the current *status quo* has been strongly argued for by the two main UK shooting organisations (BASC and Countryside Alliance) as illustrated by a campaign message of the latter organisation 'give your voice to keep lead' and the publication 'The Case for Lead' (Countryside Alliance 2013). As part of this, in appreciating that non-compliance with the current law related to the use of lead shot was a problem (Cromie *et al.* 2002, 2010) and could put at risk the use of all lead ammunition in other habitats, the shooting and country land management organisations came together in the summer of 2013 to launch a campaign to encourage individuals to comply with the law on the use of lead shot. This 'Use Lead Legally' campaign was subject to a high profile launch at the Country, Land and Business Association (CLA) Game Fair in July 2013 and was kept high profile in the shooting media and on the websites of the two main shooting organisations for several months. It was successful in terms of generating interest and signatories to pledge to not break the law.

The legislative *status quo*, but including significantly improved compliance with the law, would bring some gains for some waterbirds but would not address risks to waterbirds feeding in terrestrial environments, gamebirds, raptors and scavengers and wider environmental contamination (Pain *et al.* 2015), nor protect human health for frequent game consumers. In the absence of political legislative action, wider change to use of non-toxic ammunition would need to involve a willingness to change; the practicalities of change being resolved *e.g.* gun proofing for steel shot for those wanting a comparably priced shot and not wanting to buy the more expensive alternatives; and practice and shooting within acceptable ranges. The latter is an important aspect of the lead ammunition debate - ranges acceptable for lead are analogous for ranges acceptable for steel but it is likely that judgement of shooting distance for some shooters may need honing (various shooters, *pers. comm.*). A 'sporting shot'[9] at a bird such as a pheasant flying high is arguably out of range and would be made more difficult, and potentially additionally unethical[10] to shoot at, if using steel shot. More dense non-toxic shot such as tungsten would behave in a similar way to lead.

Despite many shared conservation objectives and collaborative projects, the relationship between the field sports[11] and conservation communities can be problematic. Thus, the lead debate sits within this more general environment of mistrust and tension which has increased in recent years due to concerns over the sustainability of some other shooting practices (*e.g.* Brown *et al.* 2014, ECRA 2014, Avery 2015) and a perception that conservation organisations are anti-hunting (*e.g.* see results of shooting media survey below). There is also a legitimate perception among hunters in general that legislation is one-way and only leads to further restriction on their sports[12].

Appreciating this landscape, this paper provides a narrative of what will be termed 'the lead ammunition debate' (or 'the debate'), reflects on the recent chronology of events and looks at responses of the shooting community to these and the likely impacts of these responses.

The paper aims to explore some of the sociological and political barriers to change in order to help inform those involved in 'the debate' as well as interested wider society. The objectives include:

1. reviewing compliance with the law in England over time and specifically measuring compliance following the campaign by the shooting organisations to reduce illegal use of lead (the 'Use Lead Legally' campaign launched in 2013);
2. exploring the understanding and attitudes of shooters using a formal questionnaire survey; and
3. gaining an appreciation of the narrative to which the shooting community is exposed by undertaking a content analysis of the shooting media.

The paper contains both data and opinions of the authors based upon dealing with the issue for many years. It reflects on some of the other sociological and political aspects too

[9] The bird has a good chance of either being missed altogether or being hit by a small number of pellets at lower velocity but surviving. [10] Ethics are personal but The Code of Good Shooting Practice says 'Guns must be competent at estimating range and shoot within the limitations of their equipment to kill cleanly and consistently.' http://www.codeofgoodshootingpractice.org.uk/ [11] The total hunting/field sports community *i.e.* broader than just shooting, [12] As an example, the 1954 Protection of Wild Birds Act had a quarry list of 33 species whilst the equivalent list of the 1981 Wildlife & Countryside Act had just 19 species.

infrequently recognised in natural science literature but of paramount importance in resolving conflicts (Redpath *et al.* 2015). A small number of lessons learned are suggested to assist in development of solutions for other conflict situations.

METHODS

'Measuring' responses of shooters to the lead issue and appraising the atmosphere of the debate has been done by a range of means of differing robustness, namely:

1. A *'game dealer survey'*: to measure compliance with the Regulations in England following the Use Lead Legally campaign launched in 2013.

The methods used for purchase of ducks, for pathological examination to determine recent from non-recent shot, and the shot analysis techniques used were based upon Cromie *et al.* (2010) and are provided as Supplementary Information in Annex 1.

This game dealer survey is a measure of behavioural responses of shooters following the Use Lead Legally campaign and likely reflects a range of motivations.

Measuring compliance with the current regulations on use of lead shot is complex and previously Defra contracted ADAS to undertake a project to review different compliance methodologies (ADAS 2007). That report concluded that a game dealer survey was "an absolute method of measuring compliance, which had some constraints relating to limited coverage of types of shooting and range of species. Its main strengths were seen as its practicality, ease of implementation and that it had the least chance of a biased sample when compared with other sampling methods". It is recognised that it is not necessarily a good reflection of compliance of 'coastal wildfowlers'[13].

This method has received criticism from some in the shooting community who suggest that a large proportion of the ducks sold in England are sourced in Scotland where there is a possibility of them having been shot legally with lead if they were killed when they happened to be away from a wetland. However, it seems implausible that all the game dealers in England which supplied ducks in this study, were dishonest about the English provenance of their ducks at the time of purchase and additionally improbable that a large proportion of the many ducks shot in England do not end up being sold in England. Outlets known (from Cromie *et al.* (2010)) to source their ducks from Scotland were not approached.

Purchasing of ducks for the survey was undertaken during November 2013 to February 2014 *i.e.* some four to seven months after the launch of the Use Lead Legally Campaign.

2. A *'shooter survey'*: a formal questionnaire survey investigating understanding and attitudes of shooters.

This formal questionnaire survey of BASC members was undertaken between 2008 and 2010 as part of the Defra-funded compliance study (Cromie *et al.* 2010). The questionnaire explored shooters' understanding of the current regulations in England, whether they obeyed the law, their attitudes towards the regulations and surrounding issues. It would be fair to say that since the questionnaire survey was conducted the lead debate has become more polarised, however, it is reasonable to suggest that the findings are still valid. For the full methodology and results see Cromie *et al.* (2010).

3. A *'shooting media survey'*: analysing the message content being provided by the shooting media to the shooting community to help understand the narratives which may be influencing shooters' opinions.

To help understand the influences to which the shooting community are exposed, some of the narratives relating to lead ammunition in the shooting press were explored. A summative content analysis was used (Hsieh and Shannon 2005) *i.e.* selecting articles containing key words and then exploring the contextual usage. Some 94 articles (letters, pieces or editorials) containing the words 'lead shot' or 'lead ammunition' in the UK shooting/fieldsports printed press of nine 'popular' publications from July 2010 to July 2015 were reviewed (magazines focussed on clay pigeon shooting, target shooting and airgun shooting were not included). This was not an exhaustive review (and articles in 2011 and 2013 will be underrepresented as their collection was *ad hoc* and opportunistic rather than systematic at that time). Of the nine, two were weekly publications with an average circulation of 22,000 (range 20,000-24,000), six were monthly publications with an average circulation of 23,400 (range 11,500-31,600) and one was a bi-monthly publication with a readership of 300,000). It is not possible to calculate the total readership of

[13] 'Coastal wildfowlers': Shooters most likely to be in wildfowling clubs which have codes of practice, which may not allow sale of shot ducks to game dealers. In England, coastal wildfowlers should have been using non-toxic shot since 1999 so arguably are best placed to advise other sections of the shooting community on its use, even acting as advocates.

these articles as people with an interest in shooting are likely to read more than one shooting magazine, yet not necessarily read the entire publication nor consistently over time.

Events *e.g.* the holding of meetings or mere mentions of statements of fact relating to lead poisoning (other than its toxic effects) were not noted. Similarly, tone was not recorded due to its subjectivity. However, wherever an opinion of relevance to the toxicity of lead, lead ammunition or the debate more generally was provided this was noted. Of the 94 articles, 72 expressed one or more opinion (48 normal articles, 19 letters, two responses to letters and three editorials). These were noted and then grouped as appropriate into common themes, the results of which are presented herein.

It is accepted from the outset that other than the shooting media there is vast array of influences that ultimately give rise to particular belief systems and subsequent behaviours. These include heritage, social grouping, interactions on social media and so on and these deserve further investigation but are not explored within this paper.

4. Stakeholder classification

To help understand, and attempt to simplify, the lead ammunition debate (accepting the problems this may cause) stakeholders were grouped into categories. Stakeholders were identified according to the following criteria: those who are influenced by the debate, those who may influence the debate and those who have an interest in/knowledge about the debate. Stakeholders were identified, differentiated and categorised using the authors' knowledge and external expert opinion and through assessing information from a range of sources including electronic media, publications, conference proceedings and peer reviewed literature and reports (Reed *et al.* 2009).

Key segments identified included the conservation community, the shooting organisations and the shooting community. The latter includes what we are terming the 'shooter in the field' to try and illustrate an 'average' individual shooter (of whatever type of shooting), likely not involved in organisational politics, but aware of the lead ammunition debate from the shooting media, social media and shooting friends and/or family. It is fully appreciated that such categorisation can be unhelpful when analysing a debate already subject to polarisation. Furthermore, none of these segments are homogenous (for example, the British shooting community includes a broad range of shooting types undertaken by a wide cross section of society (Cromie *et al.* 2010)).

RESULTS AND DISCUSSION

Is the current law being broken in England?

A previous game dealer survey undertaken across England in the winter of 2001/02 (*i.e.* two years after introduction of the English Regulations) found a low level of compliance with 68% of 40 ducks having been shot illegally with lead (Cromie *et al.* 2002). The larger scale study funded by Defra, undertaken over two winters (2008/09 and 2009/10) found compliance had not improved with 70% of both 253 and 239 ducks from respective winters having been shot illegally with lead (Cromie *et al.* 2010). Of particular significance for this paper is that public knowledge of the survey in the second winter did not affect compliance.

From the shooter questionnaire survey (Cromie *et al.* 2010), some 45% of 558 respondents who were legally obliged to use lead said they did not always obey this law. Although the first author has been frequently told, and knows, of wildfowling clubs that require use of non-toxic shot, the author can also recount numerous conversations with shooters who said that they, or other shooters, do not comply with the law. It is acknowledged that the extent of this practice is unknown and it is possible that these situations are more likely to occur during terrestrial bird shooting when waterbird shooting is more opportunistic.

DID THE USE LEAD LEGALLY CAMPAIGN INCREASE LEVELS OF COMPLIANCE?

The winter 2013/14 game dealer survey conducted when the Use Lead Legally campaign had been running for some four to seven months, found 77% of 84 ducks to have been shot illegally with lead (see Table 1). This level of non-compliance was worse than in the previous surveys. The ratio of mallard *Anas platyrhynchos* to other duck species was not directly comparable to the Defra-funded study but had it been (*i.e.* by adjusting the proportion of mallard to make it comparable), the level of compliance for this study would have been significantly worse than the Cromie *et al.* (2010) study (Chi-squared test $p=0.023$) (75/92)(see Figure 1).

Table 1: **Proportions of 84 Mallard, Teal *(Anas crecca)*, Wigeon *(A. penelope)* and Gadwall[14] *(A. strepera)* purchased from 32 game dealers in England shot with lead and non-toxic shot in winter 2013/14.**

	Mallard		Teal		Wigeon		Gadwall		Total	
Shot type	Number	%	Number	%	Number	%	Number	%	Number	%
Lead	72	84	3	50	7	47	2	100	84	77
Bismuth	8	9	1	17	7	47	0	0	16	15
Steel	5	6	2	33	1	7	0	0	8	7
Tungsten	1	1	0	0	0	0	0	0	1	1

[14] It is actually illegal to sell gadwall (they are not listed on Part III of Schedule 3 of the Wildlife & Countryside Act 1981), the purchaser intended to purchase wigeon and/or teal however was offered gadwall in the absence of those species and thus they were purchased in innocence (and very possibly sold in innocence too given that it is the only common dabbling duck species *not* listed on this Schedule).

Of 32 game dealers, 31 (97%) sold ducks shot with lead (in comparison with 73% of 84 suppliers in the Defra-funded compliance study (Cromie *et al.* 2010), which was significantly more (Chi-squared test p=0.005).

Further results are provided in Annex 1 Supplementary Information.

COMPLIANCE OVER TIME

Figure 1 provides a timeline of compliance as measured by game dealer surveys and the shooter survey (Cromie *et al.* 2010) since the introduction of the Regulations in England in 1999 following a voluntary ban in wetlands introduced in 1995. In addition to the continued poor compliance (as measured by two methods), it serves to illustrate that various events such as the Use Lead Legally campaign or increased awareness of the issue of lead poisoning and/or non-compliance have not improved compliance.

Findings from the shooting media survey

Within the 72 shooting media articles reviewed, some 131 opinions were recorded, ranging from 1-6 opinions per article. Figure 2 illustrates the variety and number of opinions within the articles reviewed.

Overall, 87.8% of opinions (n=115) cited in 72 articles reflected a resistance to change (see Figure 2 for the range of opinions) while 12.2% (n=16) acknowledged a problem of either the toxicity of lead for humans or wildlife, or that the law needed to be obeyed (Figure 2). A small proportion of articles (0.7% n=5) contained both 'resisting' and 'acknowledging' opinions.

Concern about the efficacy and costs of non-toxic ammunition was the single most prevalent theme, accounting for 15.3% (n=20) of all opinions cited, followed by "lead ammunition is not a problem for human health" (11.4%, n=15), "lead poisoning is not a problem for wildlife and "lead is a scapegoat for an anti-shooting agenda" (both 10.7%, n=14).

From additionally looking at the two main shooting organisations' websites over time, reviewing other internet shooting media and social media on an *ad hoc* basis, the shooting papers' content reflects the broader prevalent narrative.

Dividing the survey by article type, 19 published letters on the subject were reviewed and had a lower proportion of blue 'resisting change' opinions than the average article (including editorials and the editors writing a response to a letter) (84.4% of 32 opinions *vs* 88.9% of 99 opinions respectively). Correspondingly the letters contained a higher proportion of orange 'accepting there's a problem' opinions in comparison with other types of article (15.6% of 32 opinions vs 11.1% of 99 opinions respectively). Although this difference is not statistically significant (Chi-squared test p>0.05) it may be suggestive of a greater acceptance of a problem coming from the average shooter in the field rather than the shooting media.

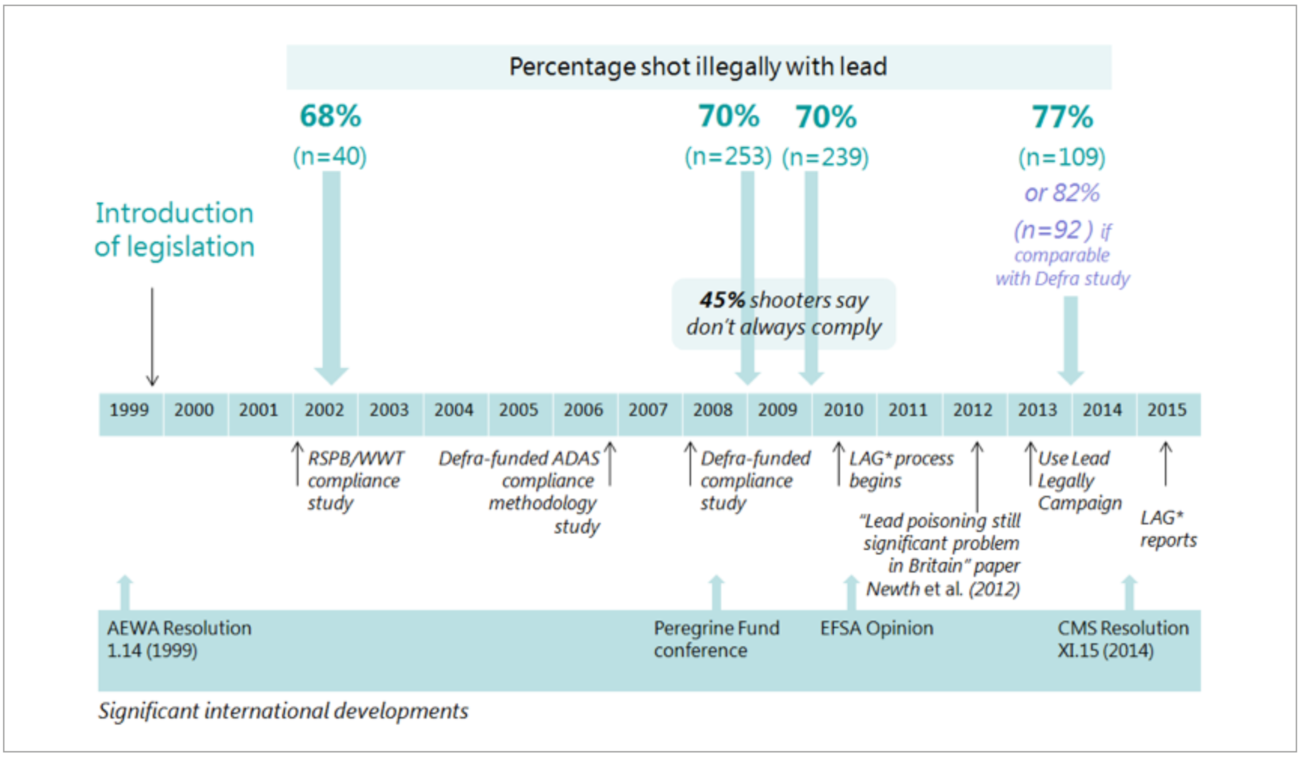

Figure 1: **Timeline illustrating introduction of the lead shot Regulations in England and the four points at which compliance was monitored, plus other relevant events.***LAG: Lead Ammunition Group.*

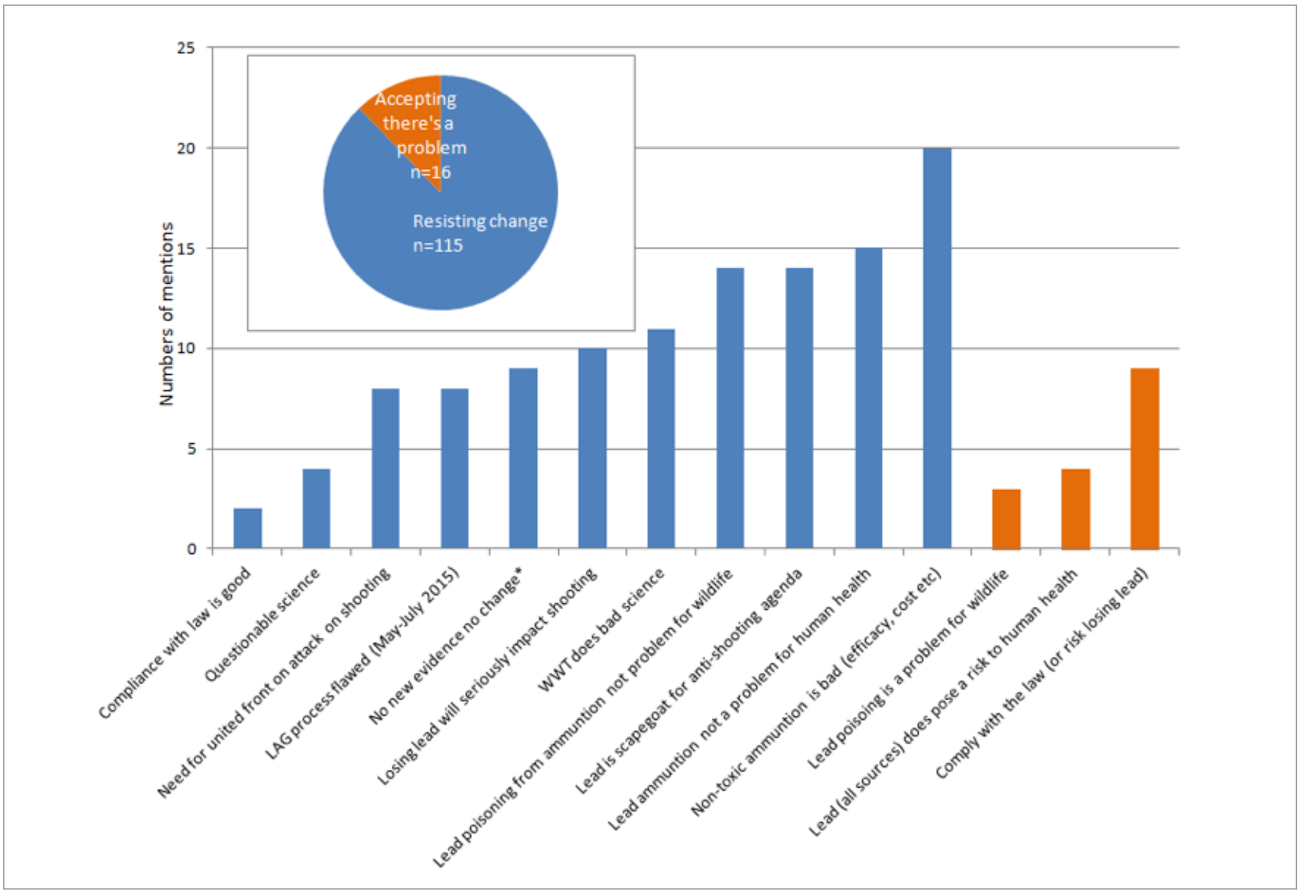

Figure 2: **Opinions relating to lead ammunition cited in 72 articles in the printed shooting media between July 2010 and July 2015.** *Blue bars represent opinions which likely resist change or resist acceptance of a problem, orange bars acknowledge a problem. The pie chart summarises these opposing sets of opinions. *Further evidence is required before a change in approach to lead ammunition can be considered.*

Printed media may not have the greatest influence on shooter attitudes but is likely to contribute, particularly those articles written by trusted commentators. The role of *e.g.* British newspapers in shaping public opinion on a range of topical subjects has been the subject of social science research and has indicated a range of influences (*e.g.* McNair 2009).

Why did the Use Lead Legally campaign not achieve its aim?

The shooter questionnaire survey (Cromie *et al.* 2010) indicated that the main reasons for non-compliance with the existing law were:

1. "Lead poisoning is not a sufficient problem to warrant restrictions" *i.e.* shooters were not convinced of the morbidity and mortality caused and thus the need for the regulations (indeed the media survey found frequent reference to 'never seeing bodies');

2. "Don't like the alternatives", shooters reporting that they felt the non-toxic alternatives were too expensive, not effective and/or not widely available;

3. "Not going to get caught" *i.e.* shooters knew that using lead would not involve penalties as the law is not enforced.

The Use Lead Legally campaign did not seek to address any of these three issues but requested shooters to obey the law to *prevent further restriction on the use of lead ammunition* - 'use it legally or we'll lose it' *i.e.* a different reason and thus likely to involve different behavioural motivation from the above.

The main narrative from the shooting media in the one year prior to the 2013/2014 game dealer survey reinforced these first two themes above.

What are the barriers to change?

The above-mentioned reasons from the shooter questionnaire survey and themes from the shooting media survey are likely to create motivation to resist either current regulations or future complete transition to non-toxic ammunition and deserve further investigation. In this section the three known (*i.e.* from the shooter survey) and four proposed barriers are explored and potential means by which to address them are briefly described.

1. "LEAD POISONING IS NOT A SUFFICIENT PROBLEM TO WARRANT RESTRICTIONS":

i.e. shooters are not convinced that this is a significant cause of mortality: Pain *et al.* (2015) estimate in the region of 100,000s of game birds and wildfowl dying of lead poisoning annually. Lead poisoning, as a disease, suffers from the same problems of perception as other insidious (often chronic) diseases which, by their nature, are often largely unseen by most people. It is likely that the overwhelming majority of shooters have no direct experience of the deaths and illness of wildlife caused by the ingestion of lead ammunition.

Surveillance for causes of morbidity and mortality in wildlife relies to a large extent on visually detecting and then examining animal carcases. Hence, garden bird diseases *i.e.* those seen proximate to human habitation are relatively well surveilled and studied (*e.g.* Robinson *et al.* 2010). Acute events such as oil spills or epidemics of avian botulism result in visible (to humans) numbers of carcases with animals dying at a rate quicker than predation and decomposition remove them. However, diseases and intoxications occurring on broader geographical scales and extended timescales, or in remote areas, or where predators and scavengers abound, are usually undetected by human eyes (Prosser *et al.* 2008) hence lead poisoning is something of an 'invisible disease' (Pain 1991). The problem of lead poisoning cases not being reported may be confounded further since lead poisoning weakens affected animals and can predispose them to another cause of death *e.g.* predation, flying accident or concurrent disease (Mathiasson 1993, Kelly and Kelly 2005), and this ultimate problem may be noted in surveillance reporting without an appreciation of the underlying sub-clinical poisoning.

Indeed, some of the negative effects of lead on human health (such as diminished cognitive function, chronic kidney disease and elevated blood pressure (Lanphear *et al.* 2005, Iqbal *et al.* 2009, EFSA 2010)) might not alert the patient, nor the physician, to the cause. As an illustration, an environment and health specialist commented, with respect to lead, 'you don't take your child to the doctors due to poor exam results' (Ráez-Luna *pers. comm.*[15]). The prevalent narrative from the shooting media is that no-one has ever 'seen' cases of lead poisoned people or wildlife which facilitates the logical conclusion that such poisoning does not occur.

It is possible that if lead poisoning of wildlife was perceived as a problem, shooters might want to take responsibility for

[15] Plenary session at the conference: http://ecohealth2014.uqam.ca/

the problem for reasons of: ethics of shooting[10], as poisoning might be seen in a similar light to crippling or harming animals; maintaining healthy populations of birds for shooting and conservation; potential for negative impacts on the public image of shooting; and/or the problem representing 'unwise use' of a natural resource (Lecocq 2002).

To date, the conservation community has failed to persuade the shooting community (and wider public no doubt) of the substantial problem and impacts of lead poisoning. Publishing science is valuable for scientists and policy makers but may have little impact on broader societal understanding in the absence of interpretation of that science for the benefit of specific audiences (*e.g.* Miller 2001). Awareness-raising tools have been shown to have a beneficial role if targeted on specific weaknesses in knowledge that are most directly related to attitude and behaviour change (Bath 1998, AEWA 2009). However, with such a strong narrative within the shooting media that lead poisoning is not a (significant) problem (Figure 2), awareness-raising of the issue within the shooting community would have to firstly address the prevalent narrative which would involve politically difficult changes of organisational positioning. Thereafter, awareness-raising would rely on building communication of tailored messages using appropriate tools (*e.g.* video and images, infographics, facilitated workshops *etc.*), most importantly delivered by *trusted* and credible messengers (AEWA 2009). Exactly who these messengers may be is difficult to identify in the UK as those involved in dealing with lead poisoning are often portrayed as anti-shooting (Figure 2 illustrates the opinion that lead is used as a scapegoat for an anti-hunting agenda), and a vocal advocate from within the UK shooting community (*e.g.* a wildfowler who has been using non-toxic ammunition for >15 years and still enjoys his/her sport) has, to the authors' knowledge, yet to emerge and be accepted.

2. "DON'T LIKE THE ALTERNATIVES":

Including price, efficacy and availability: this has been a serious barrier in other countries (*e.g.* AEWA 2009), is illustrated well in the media survey (Figure 2), and is by the first author's experience the foremost concern of the shooter in the field. Techniques such as non-toxic ammunition shooting clinics/demonstrations, run by shooters, which demonstrate the efficacy of non-toxic ammunition, have been shown to work well to help change perception of non-toxic ammunition (AEWA 2001, Friend *et al.* 2009). Research such as that of Mondain-Monval *et al.* (2015) to indicate the role of hunter effectiveness rather than shot type is also valuable (effectiveness was essentially related to practice of the shooter plus their assiduity (including judgment of distance) and was negatively related to wind strength and number of shots fired *i.e.* a lassitude effect).

Economies of scale and market forces, particularly when markets are guaranteed *i.e.* following legislative requirements (Kanstrup 2010) could potentially help to bring down the price of some of the less frequently used non-toxic ammunition types (steel, the most frequently used non-toxic shot type across the world, is currently comparably priced to lead)(Thomas 2015). It is perhaps worth noting from the game dealer surveys (above and Cromie *et al.* 2002, 2010) that bismuth, rather than steel, was the most commonly found non-toxic shot for wildfowl shooting. If there is perhaps a particular preference for this shot type, then its price may be less of a barrier for wildfowlers who would typically fire fewer shots per 'shooting event' than driven game shooters where many shots are often fired (accepting that even in these situations ammunition still remains a small part of the driven game shooting costs).

3. "NOT GOING TO GET CAUGHT":

It is a reality that non-compliance with the law in the UK is likely to go undetected with all but no enforcement. In over 15 years of the lead Regulations in England, there has only ever been one conviction and that was an offence only detected after a shooter had (seemingly by accident) illegally shot a swan[16]. The authors are unaware of any convictions in Scotland, Wales and Northern Ireland.

It is likely that compliance is higher in wildfowling clubs than in other shooting situations as there is some level of "oversight" of shooting activities and associated peer pressure. Stricter enforcement with a real possibility of penalty has been shown to work in some situations in the USA (Thomas 2009) and Spain (Mateo *et al.* 2014) with use of government supported enforcement officers. Given current government finances it seems unlikely that increased policing and enforcement of the current laws will be undertaken. Alternatively greater "oversight" of shooters could be created by *e.g.* introduction of licensing measures.

Several other barriers are proposed

These following barriers are based primarily on discussions with a broad range of stakeholders, following the narrative in the

[16] http://www.shootinguk.co.uk/news/swan-shooting-conviction-not-landmark-ruling-say-basc-25682

shooting media as described and communications from the two main shooting organisations. These are namely:

4. "TRADITION":

Shooting and wider hunting activities are deeply traditional within the UK, with hunting being a significant element of British culture including art, literature, music, language and lore. The word "traditional" is often used by shooters to describe themselves or their pastime and likely involves a range of concepts such as fine old gun craftsmanship, inherited stories and guns, pride in maintaining tradition, and a sense of wanting to be out in the countryside and free of intrusive regulation. Persuading individuals to adopt what are seen as 'non-traditional' behaviours is particularly complex yet can be achieved if the issue becomes unacceptable to society *e.g.* changes to human rights such as voting rights (*e.g.* Stewart *et al.* 2012) and/or the benefits clearly outweigh the costs *e.g.* wearing seatbelts or not smoking in enclosed public spaces (*e.g.* Fhaner and Hane 1973, Fong *et al.* 2006). The societal importance of these issues may be different to shooting but all of these examples involved great initial resistance to change.

Tackling change to the tradition of using lead ammunition is likely to involve a combination of reduction of the barriers outlined here, a clear establishment of the costs of not changing (see later section on costs), the benefits of changing (including more birds to shoot), and leadership from the shooting community and/or from influential, respected and trusted individuals from within (*e.g.* Kanstrup 2010). It is worth noting that in a country such as Denmark, the cultural acceptance/tradition of using non-toxic shot (accepting that they had no choice after a national ban on lead ammunition) has become established since their transition in 1996 (Kanstrup 2015).

5. "POLARISED ENHANCED LOYALTIES":

The opportunity for the conservation and shooting communities to work together to address the above issues following the introduction of the Regulations across the UK was missed. Although there had been wide stakeholder involvement leading up to this point (Stroud 2015) and collaborative initiatives thereafter *e.g.* a jointly owned public relations strategy, there was likely a sense of the job having been completed and that the law would be obeyed. Despite good information about the law and the use of non-toxic alternatives provided primarily on the BASC website (Cromie *et al.* 2010), with hindsight, hearts and

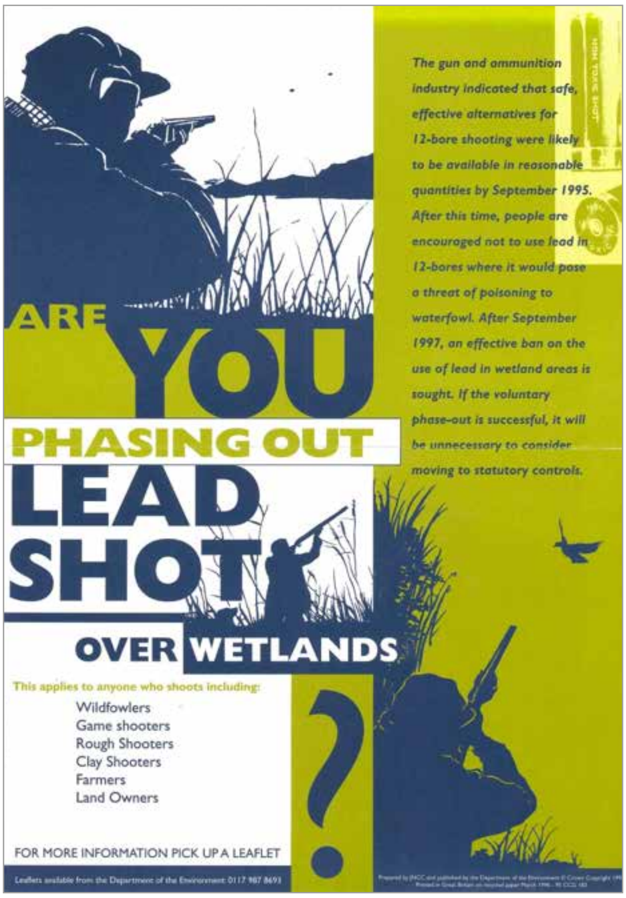

Figure 3: **Information poster produced ahead of the voluntary phase out of lead in wetlands in 1995** *(note the industry assurance of the availability and efficacy of non-toxic shot).*

minds of the wider shooting community had probably not been won. It would have been valuable at that time to have prioritised development of collaborative persuasive resources concerning the actual problem of lead poisoning as well as the efficacy of the non-toxic shot. For historical interest Figure 3 is a poster produced as a joint government and shooting and conservation community resource prior to the voluntary phase out of lead shot in wetlands in 1995.

Since that time there has been the aforementioned range of other developments, including wider understanding of risks of lead ammunition to wildlife, livestock, humans and the wider environment, plus the associated calls and policy drivers for its substitution with non-toxic alternatives (*e.g.* Watson *et al.* 2009, EFSA 2010, UNEP-CMS 2014a, 2014b). As the "threat to lead ammunition" has emerged and change has become more likely, the discourse has become more polarised (as exemplified by the shooting media analysis) with a recurring narrative of this being "an attack on shooting". This has been likely fuelled by leaked organisational position documents (Balmain 2010, Gray 2010, Finch 2012), the shooting media coverage, issues of trust and inter-organisational politics. Again, all this is set in the broader context of tensions between the field sports and conservation communities on a range of issues of sustainability of some hunting practices and the suspicion that conservation concerns are actually motivated by an anti-hunting agenda.

The shooting media survey illustrates a prevalent theme as being the 'evidence for needing change is absent or invented/exaggerated'. Social scientists may term this mistrust as 'biased assimilation' where, in polarised debates, either side may seek and assimilate evidence that reinforces their current beliefs and existing attitudinal position and reject the contradictory counterargument (McCright and Dunlap 2011, Corner *et al.* 2012). From the shooting perspective, Ali (2015) suggests that the lead scientists may suffer from 'white-hat bias' whereby they select the evidence that supports their own understanding of the situation.

This current debate may well be subject to what is termed 'solution aversion' whereby an objection to the possible solution (in this case transition to non-toxic ammunition) results in the scepticism about the seriousness of the problem even if it is based on sound science (Campbell and Kay 2014). These authors reflect on the motivated disbelief that this creates. If the debate is being framed within this context, although there is often a call from the shooting community for more evidence (*e.g.* Ali 2015), it would suggest that further evidence is unlikely to be accepted by the shooting community if the solution to the problem remains undesirable.

6. "DISCREDITING THE EVIDENCE, THE MESSENGERS AND THE PROCESS":

Those, in particular scientists and researchers, involved in work which is controversial and/or contentious to industry can find themselves in invidious positions. Needleman and Gee (2013) reflect on this, for example, regarding the removal of lead from petrol and EEA (2001, 2013) provides other examples.

For the lead ammunition debate, likely related to the model of biased assimilation (McCright and Dunlap 2011, Corner *et al.* 2012), it would seem that a practice has developed of discrediting both the providers of evidence and the messengers of unpalatable messages. The portrayal of the chair of the Lead Ammunition Group, provides a good example of this. As the ex-Chief Executive of BASC (a position he held for 25 years), he is from the heart of the shooting community. This position likely facilitated his ability to keep the complex and polarised Lead Ammunition Group process together through its five years of deliberations (indeed senior personnel from the shooting community expressed confidence in the process (Douglas 2014)) and the minutes of the meetings, which were observed by both Defra and FSA, indicate the extent of the procedural approach[17]). Only once his final report was drafted, which both highlighted the problem and the possible solution, did the shooting stakeholders resign (Lead Ammunition Group 2015). Since then both he and the process he led have been widely criticised in the shooting media (Figure 2)(*e.g.* Walker 2015, White-Spunner 2015).

The process of scientific investigation involves peer review and evaluation by independent experts usually involving open and thorough critiques (Spier 2002) thus few scientists can afford not to be resilient to criticism. The media survey, and wider narrative, however indicates a dismissal of the evidence and particular criticism of some of the key scientists. In 2009 Friend *et al.* wrote "Little of what we have presented here reflects the bitterness that characterized much of the struggle to transition to the use of non-toxic shot for waterfowl hunting in the US. Nor does it reflect the heavy personal costs to those who championed the use of nontoxic shot, among them state and federal employees, outdoor columnists, members of the general public, academicians, researchers, and others." Friend's words could have been written about the UK yet the situation here is surely even more polarised as within the USA the conservationists and hunting community are far more integrated and often the same thing. Personal costs in the UK situation no doubt include academics and personnel from the conservation community and also those in the shooting community who have had to deal professionally with lead over the years, finding themselves criticised and unpopular with colleagues from both poles of the debate.

7. "WHERE THE ECONOMIC AND POLITICAL POWER LIES":

Following a five year ineffective voluntary phase-out, restrictions on the importation, sale and use of practically all sizes of lead angling fishing weights in the UK in the 1980s (Stroud 2015) to prevent poisoning of species such as mute swans *Cygnus olor*, were met with dismay by many anglers (M. Brown *pers. comm.*). However, the change was accepted and non-toxic alternatives were quickly seen as the norm (Cromie *et al.* 2010). The shooting

[17] Lead Ammunition Group website http://www.leadammunitiongroup.org.uk/

community and organisations have arguably a stronger political and lobbying voice than the angling community. Like many membership organisations, the two main shooting organisations are in the position to both provide leadership as well as reflecting their memberships' views. Driven grouse and pheasant shooting is big business in the UK (Public and Corporate Economic Consultants (PACEC) 2006, 2014) and is seen as 'quintessentially British' (White-Spunner 2012). Whilst those from this industry fear that a transition to non-toxic ammunition may have negative economic impacts - with a perception that range for shooting will need to be restricted *i.e.* fewer shots at 'high birds' (White-Spunner 2012, and see Introduction), or is an unwelcome challenge, an incentive will remain to support the shooting organisations in their resistance to change. Similarly the ammunition manufacturers, with economic imperatives, have often been influential in their resistance to change away from lead ammunition particularly at the European level[18] (Gremse 2015).

Overall, the current polarised debate and its powerful players create significant barriers to change.

Limited space in the landscape for having a different voice

It would appear that defending the use of lead ammunition and maintaining the *status quo* have become an economic issue for the main shooting organisations. A weakening public stance from either of the two main organisations has the potential to be financially damaging in the short term through potential losses to both various supporter funding streams and membership. In the late 2000s, BASC, being aware of both the science and the policy direction of the issue, began to suggest internally that the use of lead ammunition (both bullets and shot) was no longer sustainable and that the shooting community should prepare itself for change (*e.g.* Balmain 2010, Gray 2010). Perhaps had they been the single shooting membership organisation they could have dealt with the subsequent reaction and provided leadership on the issue (as was the case in Denmark (Newth *et al.* 2015)).

It is the authors' opinion that the debate has since become so polarised that it would indeed have to be a confident advocate from the shooting organisations or wider community who would speak up in defence of the evidence on lead and promote non-toxic ammunition. This sort of leadership was present in Denmark at the beginning of their lead discussions and from the outset the shooting community owned both the problem and led the solution (Kanstrup 2006, Newth *et al.* 2015).

SO WHAT MESSAGE IS THE SHOOTER IN THE FIELD RECEIVING?

Away from organisational politics, the commercial interests of driven game shooting and ammunition manufacturers, what should the average man or woman who enjoys shooting make of the debate? It seems from the outside that they are in an unenviable situation of being provided with a narrative that the evidence is non-existent or exaggerated and promoted by those with an anti-shooting agenda, and that the much lauded Lead Ammunition Group process was flawed after all.

If, being concerned about the problem of lead poisoning, they were to support a change to non-toxic ammunition this could be perceived as disloyal to fellow shooters and contribute to some sort of collective weakening of field sports in the UK. Indeed, this is a prevailing message that lead ammunition represents 'the thin end of the wedge' and that all attacks on shooting should be resisted collectively, a theme illustrated from the shooting media survey. In the authors' experience there is an apparent defensiveness from many shooters as they feel that their pastime and activities are being eroded. This is reflected in a resistance in British conservation and wider society to flexible sustainable harvesting practices and indeed, once a hunting right has gone it is rarely returned[12].

The costs of changing and not changing

It is beyond the scope of this paper to put an economic value on the current costs of the impact of lead ammunition vs the cost of making the transition to non-toxic ammunition.

Overall, a transition to non-toxic ammunition would reduce costs (as in resourcing or negative impacts) for:

1. Government: although resourcing would be greater in the short term for extending current regulations to all habitats and species, there would be no need for longer term awareness raising, enforcement, monitoring *etc.*

2. Conservation community: as they would no longer need to keep undertaking expensive research and surveillance work to feed into advocacy work.

[18] Various processes outlined on the website of Association of European Manufacturers of Sporting Ammunition (AFEMS) http://www.afems.org/

3. Welfare organisations: who, over time, would need to intervene and treat fewer poisoned individual animals.

4. Those at risk of lead poisoning: fewer health impacts for frequent game consumers, including children and pregnant women; and wildlife.

5. Wider environment: less lead getting into soils and subsequently plants/invertebrates *etc*.

The main costs of the transition would be borne by :

1. The shooting community *e.g.* if necessary, proofing of existing shotguns for steel shot, or possible new shotguns or more expensive shot types for very old valuable guns; increased cost of non-lead bullets or possibly new rifles in some circumstances. Arguably these costs are partially offset by the costs of not changing on risks to public image, game markets and potential of the polluter being asked to pay for contamination.

Costs to ammunition manufacturers of a reduction in sales of lead ammunition are likely to be offset by income from sales of non-toxic ammunition.

CONCLUSIONS AND LESSONS LEARNED

Given the evidence from human and ecosystem health science on impacts of lead ammunition, possible restrictions on the sale export/import of game meat containing elevated lead levels, and further policy developments on lead ammunition (including CMS Resolution 11.15), it is clear that the direction of travel of this issue is leading to a phase out of lead ammunition. To date, however, attempts by the conservation and shooting communities respectively to persuade shooters of the problem of lead poisoning and to comply with the existing law have not worked (as illustrated in part by the results contained herein). The issue of the risks from lead ammunition has been lost to some extent in the complexities of various sociological barriers and the politicisation of the problem. Indeed, the lessons learned probably differ little to other conflict resolution situations (Newth *et al.* 2015, Redpath *et al.* 2015) and include:

1. A need for facilitated processes beginning with a focus on shared objectives - in this case broader conservation goals of healthy (numerically and physiologically) populations of native British quarry species;

2. Ensuring the sound evidence base is shared and interpreted and tailored for specific audiences;

3. Insufficient effort has been made to maintain healthy channels of communication between the shooting and conservation communities with a dedication to openness and constructive discourse and development of trust and mutual understanding;

4. Trusted voices from the middle ground with an understanding of both aspects of the conflict have been largely missing from the issue;

5. Addressing one area of conflict within a landscape of other tensions is particularly complex.

The Lead Ammunition Group represents an ambitious participatory stakeholder process which judging by the minutes of the meetings[19] managed to cover a broad range of issues in great detail and provided an opportunity for responding to a number of the lessons learned. It is perhaps unfortunate that some of the stakeholders have left that process prior to the arguably more important government-determined next steps (Lead Ammunition Group 2015, Swift 2015).

Although the shooter may deposit the lead, this is in many ways not the actual root of the issue. It would be more than patronising to paint the shooter in the field as some sort of innocent in this piece (given the strong feelings lead often/usually produces) but behind them lie powerful sources of resistance to change. In addition to issues of tradition and politicisation, these include perceived or real financial impacts for ammunition manufacturers, the driven game shooting industry and the funding and economics of the shooting organisations.

At the time of writing the Lead Ammunition Group has reported to government and decisions are now political (Swift 2015). Perhaps the debate is so polarised that the shooting community knows that imposition of restrictions is more likely than an acceptance of change and leadership from within. It is hoped that leadership from the shooting organisations or wider community (or another as yet unidentified trusted third party) may emerge yet. This is arguably preferable to the alternative of the issue shifting into a broader public debate.

[19] http://www.leadammunitiongroup.org.uk/meetings/

By whatever means it happens, resolving the lead ammunition problem once and for all would ultimately result in one less area of tension for the shooting and conservation communities. This could bring a range of benefits and is important given that there are many shared conservation objectives. In summary, the lead ammunition debate in the UK may have its basis in the natural science of toxicology in a range of hosts but is defined by a range of political and sociological barriers.

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ANNEX 1

Supplementary Information

METHODOLOGY OF GAME DEALER SURVEY FOR 2013/14 STUDY

For the sake of brevity, more detailed methodologies *e.g.* full *post mortem* examination protocols, or diagnostic decision trees, are not presented herein but are presented in Cromie *et al.* (2010).

TIMESCALE

Ducks were purchased during the period of late November 2013 to February 2014.

PURCHASE OF SHOT DUCKS

Using the database of game suppliers in England created during the Defra-funded compliance study (Cromie *et al.* 2010), plus identifying new outlets *via* internet searches, WWT staff and colleagues purchased shot wild ducks from suppliers that fell into three main categories, namely: game dealer/butcher outlets (which may also have web-sales); internet game dealers; and farm/estate shops.

Purchasing was undertaken by either opportunistic walking into retail outlets to purchase birds, placing orders directly on the internet or more commonly by placing an order by telephone with subsequent collection in person or postal delivery of birds. An assumption was made that this is how ducks are normally purchased and thus it did not affect normal supply to game dealers.

Birds were labelled according to their order number and stored frozen at -20°C until further analysis.

Region and provenance of birds

Purchasing was carried out in eight of the nine Government Office regions of England (Figure S1) (London being omitted, as per the Defra-funded compliance study, as birds were unlikely to be locally sourced).

There was no intention in this study to investigate regional compliance due to the relatively small sample sizes from each region. The 'across the country' purchasing was undertaken to try to provide as unbiased a sample as possible.

Figure S1: **Government Office regions of England** *from which ducks were purchased with the exception of London.*

Suppliers were asked at the time of enquiry about the geographical provenance of the ducks they sold, and were given no reason to suggest that provenance would influence the likelihood of a sale. There was consequently no financial or other incentive for those from whom we purchased game to be anything other than honest about the provenance of the ducks. If suppliers said the birds were, in effect, not locally sourced *e.g.* they came from Scotland[20] or likely came from outside the Government Office region[21] (as determined by the shopper), they were not ordered. The purchasing conversation at ordering and/or collection often involved the supplier telling the shopper about their duck-supplier, some naming the local estates or wetland areas from which they'd been shot. Anecdotal comments supported this *e.g.* through indicating that they had several more duck should we need them as Mr X or Mr Y local hunter/shoot had been successful over the previous few days. Where labels were attached to purchased ducks, these were examined to try to gain further information about provenance.

Although suppliers from whom ducks were purchased gave assurances that birds were locally sourced, there is no foolproof way to ascertain exact provenance and it is possible that some may have been sourced outside England (where they may have been shot legally or illegally with lead). A large game dealer is reported to supply Scottish shot ducks to English outlets

[20] One supplier only [21] A small number of suppliers

(Stephen Crouch, *pers. comm.*). The possibility was therefore suggested that some of the birds purchased in England may have been sourced from Scotland, where ducks can be legally shot using lead ammunition if in terrestrial environments[22]. To reduce this possibility those suppliers identified in the Defra-funded compliance study as sourcing birds from Scotland were not approached, and ducks were not purchased from the one supplier contacted within this study who said his ducks were sourced from Scotland.

Given the above discussion on efforts made to identify provenance of birds and appreciating the number of ducks both shot *and* purchased in England, it seems unreasonable to unduly suspect that the information provided by game dealers concerning the ducks in the present study (and that of the Defra-funded study (Cromie *et al.* 2010) whose methods were replicated here), is anything other than honest.

While 100 per cent proof of provenance is not available, the weight of the evidence provided by the game dealers points towards the ducks being shot in England.

Sample size and species

The previous English game dealer surveys (Cromie *et al.* 2002, 2010) indicated that ~70% of purchased ducks were shot with lead. With an assumption that compliance would have improved since then an *a priori* power analysis to give a 95% confidence of detecting birds shot with lead indicated at least 30 ducks needed to be tested. Suspecting that this sample size may attract criticism, a larger sample size of 100 birds containing shot, purchased from across England, was aimed for.

As the majority of ducks sold are 'oven-ready' with feathers, head, wings, legs and viscera removed, shot are sometimes no longer present in carcases. Thus, knowing the proportion of birds likely to be carrying shot at purchase (77% from Cromie *et al.* 2010) a sample size of at least ~15 were purchased per region to ensure ~12 birds would be carrying shot and in total shot from some 100 birds could be analysed. These ~15 birds were purchased from between three to six game dealers per Government Office region.

As supplied mallards may be disproportionately shot by inland duck shooters, significant efforts were made to purchase wigeon and teal as these *may* represent the coastal or other wildfowlers to a greater extent – accepting that both species use inland waters too.

RADIOGRAPHY AND *POST MORTEM* ANALYSIS

Radiography

To quickly eliminate birds without shot and to aid recovery of shot by pathologists, all carcases were subjected to X-raying to reveal the embedded radio-dense pellets.

***Post mortem* examination**

Free-living wildfowl may contain embedded shot which proved non-lethal from previous exposure to shooting (*e.g.* Noer and Madsen 1996, Hicklin and Barrow 2004, Newth *et al.* 2011, Holm and Madsen 2013). The provenance of such embedded shot is impossible to obtain so it was important to ensure that only shot that had most recently entered the bird at time of death were analysed.

Pellets were determined to be 'recent'[23] and 'non-recent' depending on the *post mortem* examination findings.

Shot were judged to be 'recent' when they were:

1. found at the site of fractured bones (ensuring that these are fractures that occurred at the time of death and not those caused thereafter) or within the bones themselves;
2. present within vital organs such as heart and lungs;
3. present within large areas of haemorrhage and bruising showing that they entered the bird at, or very shortly before, the time of death and the bird would have been unable to fly far with the damage inflicted;
4. present at the end of shot tracks containing feathers that had not been 'walled off' by the body in any way showing that they had recently occurred;
5. found at the back of the bird (or opposite side of entry) having been tracked through the rest of the body including vital organs.

[22] The law in Wales is analogous to that of England however in Scotland there are restrictions on use of lead over all wetlands and as mallards are predominantly birds of wetlands, if the law is adhered to in Scotland, one would expect the majority of ducks shot there to be shot with non-lead ammunition.
[23] The word 'recent' was decided on during the Defra-funded compliance study (Cromie *et al.* 2010) and means entered bird at or shortly before time of death. The word 'lethal' could be used instead (accepting that not all shot entering the duck's body are necessarily lethal if they do not cause significant injury *e.g.* a shot breaking a wing bone is not in itself lethal although it results in the death of the bird).

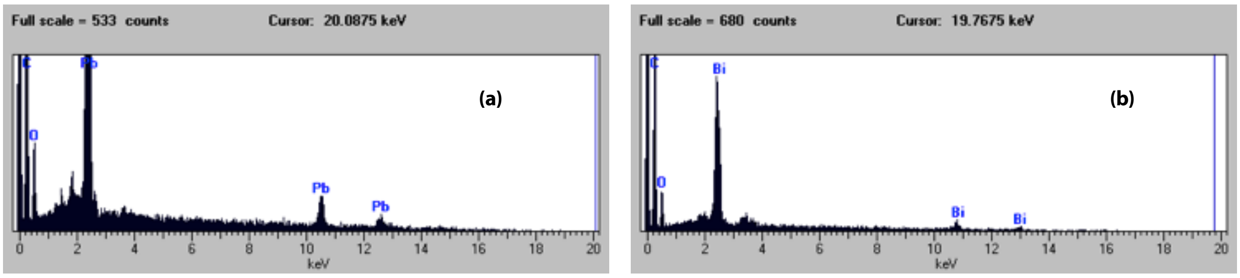

Figure S2: **The 'X-ray output' from scanning electron microscopy** *showing both a shot originally classified as 'lead with inconsistencies'* **(a)** *and a bismuth sample* **(b)**. *The peaks indicate the shot to contain oxygen (O), carbon (C) and lead (Pb) (a) or bismuth (Bi) (b), peak height illustrating relative abundance.*

Shot were judged to be 'non-recent' when they:

1. had been 'walled off' by the body showing they have been present for some time;
2. showed no sign of bruising or haemorrhage around them;
3. were found in non-vital areas such as loose in the coelomic cavity (accepting that they may or may not have been 'recent' but were likely to be non-lethal).

SHOT ANALYSIS

Shot type was identified using the methodology employed during the Defra-funded compliance study[24]. In brief, these were based on their physical, chemical and additionally atomic properties *i.e.* aspects of appearance and malleability, ferromagnetic properties, reaction to nitric acid and potassium iodide, and, for a sub-set of shot (32/109), including those for which there were some inconsistencies in other methods[25], examination under scanning electron microscope which produces definitive characteristic X-ray "profile" of the elements present[26]. These techniques readily identify steel, bismuth and lead, and distinguish them from each other. From a brief review of types of shot available on the market, lead, bismuth, steel and tungsten matrix shot types were used as positive controls throughout the analyses. Provisional diagnosis of shot type was made using results of appearance, malleability and ferromagnetism. Results of chemical analyses and scanning electron microscopy were considered conclusive.

FURTHER RESULTS OF THE 2013/14 GAME DEALER STUDY

Of 159 ducks purchased from 32 game dealer outlets, 109 contained recent shot. Overall, 77% of these 109 ducks had been shot with lead. Bismuth was the most commonly used non-toxic shot (15%) followed by steel (7%). Figure S2 illustrates the outputs of a lead and bismuth sample from scanning electron microscopy.

Table S1 summaries the numbers of birds purchased regionally, the number containing recent shot and the proportion of these that had been shot with different shot types.

[24] Melting point was omitted as it was extremely onerous and time consuming, difficult to measure and provided no additional confidence to the results.
[25] Five of the lead samples (including one copper coated lead shot) had slight inconsistencies *e.g.* not looking obviously like lead in all characteristic or the precipitate changing colour during the chemical analysis. Two samples, which were ultimately non-lead, had been described as "unsure" prior to scanning electron microscopy analysis. [26] A high energy beam of electrons scans the sample surface and interacts with the sample atoms to produce characteristic x-rays which identify the elemental composition, the areas under each peak provides a measure of relative abundance of elements in the sample.

Table S1: **Proportion of birds shot with lead and other shot types according to region purchased,** including, for information only, birds with non-recent shot and birds containing no shot (as 'oven ready').

Government Office Region	Recent shot						Non-recent shot		No shot	Total purchased
	Lead	Bismuth	Steel	Tungsten	Total	% lead	Lead	Bismuth		
East	9	6	1		16	*56*		1	8	25
East Midlands	11	2			13	*85*			1	14
North East	9	7	1		17	*53*			5	22
North West	15		3		18	*83*	1		7	26
South East	6	1	3		10	*60*	1		11	22
South West	9				9	*100*	1		4	14
West Midlands	11				11	*100*			3	14
Yorkshire & Humber	14			1	15	*93*			7	22
Total	**84**	**16**	**8**	**1**	**109**	***77***	**3**	**1**	**46**	**159**

Driven game shooting is big business in the UK and a perception of threat to this represents a barrier to transition to non-toxic ammunition.

Photo Credit: Gail Johnson/Shutterstock.com

Key questions and responses regarding the transition to use of lead-free ammunition

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A paper written with reference to the Oxford Lead Symposium rapporteur's records.

ABSTRACT

Questions and concerns about the use of lead-free ammunition in hunting were encountered during the Oxford Lead Symposium. Many originated from commonly-held, but unsubstantiated, reports that have hindered the transition to use of lead-free ammunition in the UK and elsewhere. This paper examines and answers the principal reservations raised about the use of lead-free hunting ammunition. The issue of how the evidence for lead exposure and toxicity to wildlife from discharged lead shot cartridges could be better communicated to the public to enhance adoption of lead–free ammunition is addressed. The paper presents evidence to assuage concerns about the effectiveness and non-toxicity of lead ammunition substitutes, their suitability for British shooting and weapons, and their role in wildlife health protection. Collectively, these answers to concerns could lower the public resistance to use of lead-free ammunition and thus make game shooting a more environmentally-sustainable pursuit.

Key words: *Lead-free ammunition, misconceptions, use, shooting, ballistics, toxicity, barrel damage, efficacy, shot pattern, ricochet, availability*

INTRODUCTION

Despite a large volume of scientific evidence that spent lead shotgun and rifle ammunition poses risks to wildlife and human health (Watson *et al.* 2009, Group of Scientists, 2013, 2014), there has been, with a few notable exceptions, marked reluctance across the international shooting community to adopt lead-free substitutes. Exceptions include Denmark and The Netherlands, which banned all use of lead gunshot – as long ago as 1996 in Denmark (Kanstrup 2015). Other nations, including the UK, have begun to prohibit lead use where the evidence of lead poisoning of wildlife has been, historically, most apparent. In England in 1999 this resulted in a ban on lead shot use for hunting waterfowl or over certain, listed, wetlands, with regulations following in the other UK countries. However, compliance with the English regulations still appears to be very low 15 years on (Cromie *et al.* 2015). No nation has yet to regulate the use of both lead-free shotgun and rifle ammunition for hunting, although the state of California will do so in 2019 (Thomas 2015). At the recent Conference of the Parties to the Convention on Migratory Species (COP 11, Quito, November 2014), a resolution was passed, the guidance to which calls for the replacement of all lead ammunition, in all habitats, with non-toxic alternatives within three years (UNEP-CMS 2014 a,b). While it is for Parties (of which the UK is one) to decide how to implement these guidelines, the political imperative in the Resolution's wording is clear: countries with an established poisoning problem (of which the UK is one) are expected to act responsibly and implement the guidelines (see Stroud (2015), for this and further requirements to restrict lead shot under multilateral environmental agreements). Non-toxic shot types have long been widely available, and the international arms industry has developed effective non-toxic substitutes for bullets (*e.g.* Gremse and Reiger 2015). The primary barriers to a complete transition to lead-free ammunition use by game and target shooters in the UK now appear to be socio-political. Part of this seems to relate to the attitudes and beliefs of the shooting community, and their ability to influence government policy. The arguments used to oppose change are varied. Some of these are based on perceived wisdom and hearsay, and many myths have been perpetuated across decades. There also appears to be an anxiety that that use of lead-free ammunition would be detrimental to shooting sports (Cromie *et al.* 2015).

During the Oxford Lead Symposium's discussion sessions, the question of how we might tackle the misunderstandings and myths surrounding lead poisoning and the options for moving to non-toxic alternative ammunition was repeatedly raised. To help address this, in this paper we have outlined some of the issues and comments raised during the symposium's discussion sessions, and have included answers, supplemented by additional information provided by symposium participants. Where appropriate, reference has been made to other papers in this symposium proceedings, which provide supplementary detail.

One of the issues raised related to possible ways of overcoming some of the barriers to change (many of which relate to people's perceptions regarding alternative ammunition types). One way of helping to overcome barriers is through providing relevant information to help dispel some of the misconceptions about the alternatives to lead ammunition. We have therefore also included a section specifically dealing with this, compiled by those symposium participants with specific shooting and/or ballistic expertise (*i.e.* the authors of this paper).

The issues below are not a comprehensive synthesis of the discussions, but include the key issues around which there was debate during the symposium.

KEY QUESTIONS COVERED

How can the problem be communicated better and the debate depolarised?

The point was raised during the meeting that the need is not to build a larger body of evidence, but rather better to communicate the evidence that already exists. The public debate surrounding the issue has become polarised in the UK, and there appears to be the perception that the current move to phase out the use of lead ammunition is some form of attack on game shooting sports. While there are always likely to be organisations and individuals both opposed to, and in favour of, game shooting sports, it is very important for all involved organisations to separate this from the issue of using toxic lead ammunition for shooting. Subject to certain restrictions, the stalking and sports shooting of many animal species is currently legal in the UK countries, and that is not an issue for debate here. Both the legal pursuit of shooting sports, and the established rural economy that derives from them, are acknowledged by all of the main stakeholders in the current debate. The drive towards lead-free ammunition for all shooting in the UK is about ensuring the shooting, where it takes place, is environmentally sustainable, and does not pose avoidable health risks to either wildlife or human health. The use of non-toxic alternative ammunition types should put game shooting on a more sustainable environmental and economic basis without its leaving a collateral toxic legacy. Science has long recognised a single problem of humans' use of lead products and their and wildlife's consequent exposure to toxic risk (RCEP 1983, Group of Scientists, 2013, 2014, Stroud 2015). Thus, the use of lead in paints, petrol, solders, and glass has been banned or heavily regulated to protect human health. The use of lead ammunition in sport shooting remains as an outstanding significant release of lead to the environment that poses risks to the health of wildlife that ingest it, and to humans who frequently eat shot game. Ending the use of lead-based ammunition in shooting would significantly lower the exposure risks to both wildlife and humans. In this way, one of the last, major, releases of lead to the UK environment would be halted. The shooting community would assume any cost (negligible for steel shot) for the transition, and would internalise this cost, rather than externalising it to the general environment and society. This is consistent with the Polluter Pays Principle. Land owners who send shot game (gamebirds and venison) to the retail market would benefit from the assured export and sale of meat uncontaminated by elevated levels of lead to the UK and foreign public, and compliance with any food safety standards that might apply now or in future.

Lead poisoning is in many ways a 'hidden disease'; how can we address that barrier effectively?

Whilst large-scale mortality events from lead poisoning do occasionally occur (*e.g.* as reported in O'Connell 2008) this is the exception rather than the rule. Lead-poisoning mortality is usually inconspicuous, often resulting in frequent and largely invisible losses of small numbers of birds that remain undetected. Moribund birds often become increasingly reclusive and dead birds may be scavenged before being detected (*e.g.* Pain 1991). This is why lead poisoning of birds is referred to as an 'invisible disease'. Unlike cases of diseases such as botulism, where large numbers of birds often die in one place, few people find those scattered individuals that have died from lead poisoning. However, it is estimated that in the UK, as many as 50,000-100,000 wildfowl and larger numbers of terrestrial birds may die from lead poisoning each year (Pain *et al.* 2015).

The rarity of shooters observing sick lead poisoned birds is a frequently cited reason for underestimating the extent of the problem. Addressing this barrier will require good communication regarding the nature and likely extent of the problem by all stakeholder groups, not least by shooting interests. The use of visual footage of lead poisoned birds from animal recovery centres may also help to illustrate the reality and welfare impacts of the disease.

Is ingested lead shot poisonous to all animals?

Lead is poisonous to all animals, irrespective of the source. Ingested lead from ammunition is particularly a problem for birds. The amount of ingested lead that will produce similar signs of toxicity may differ among individual birds, as well as species. The absorption of dissolved lead into the blood can be influenced heavily by different factors. Thus a diet rich in animal protein and calcium interferes with the absorption of lead in the blood (Snoeijs *et al.* 2005, Scheuhammer 1996). A diet low in protein and calcium, but high in starch and fibre (such as in winter), may not moderate the absorption of lead from shot. Also, if the dietary items are large and hard, they will require much grinding with grit, and this, simultaneously, increases the physical breakdown and dissolution of gunshot. Consequently, the toxic effects of lead shot ingestion may vary according to the seasonal diet of individuals, and also by species, as in herbivorous and carnivorous waterfowl (USFWS 1997).

The physical condition of an animal also influences it susceptibility to lead toxicosis. Animals that are stressed or starving, with few body reserves, are more likely to show signs of lead poisoning than animals in robust health with the same amount of ingested lead shot.

The size of lead shot may also influence the dissolution in the avian gizzard. Large lead shot are retained longer in the gizzard and are progressively broken down until they are so small that they pass through the sphincter into the intestine. Small diameter lead shot may pass through without much abrasion and ultimately exit the body in the faeces. Thus the amount of lead absorbed into the body may be different even though the same total weight of lead shot was ingested.

Some birds may ingest only one or two lead shot at the same time. This level of lead may or may not be fatal, depending upon a range of factors such as those described above. When not fatal, ingestion of small numbers of shot could result in sub-clinical signs of lead poisoning which, if more lead shot were ingested, could result in chronic poisoning or acute and possibly fatal poisoning.

Are any of the substitute shot types also toxic?

During the Symposium discussion session, panellists were asked whether any of the substitutes were also toxic. Lead shot substitutes made from iron, tungsten, bismuth and tin were developed first in the USA, and are now used internationally. In the USA and Canada any substitute for lead shot must undergo mandatory experimental testing to receive approval under federal law. To be approved, a candidate shot must first undergo laboratory toxicity testing as ingested shot in mallard ducks *Anas platyrhynchos* over two generations. This involves testing for metal accumulations, harmful effects on all of the major organ systems of the body, and any effects on all aspects of reproduction, including the ability of hatched birds to thrive. In addition, it must be shown that the shot in stipulated very high densities has no adverse effects on aquatic and terrestrial plants and animals, and the quality of soil and waters (USFWS 1997). It must also be shown that the proposed substitute would not have a harmful effect on human health if it were eaten in cooked game meat. Shot made from iron, tungsten, and bismuth-tin alloy have been unconditionally approved for use in North America (Thomas *et al.* 2009). The same shot types can, therefore, be used in other countries without fear of environmental toxicity. Shot made from zinc failed the testing and cannot be used legally in North America, and should not be used elsewhere (Levengood *et al.* 1999). Lead shot that has been coated with plastic may degrade more slowly in the environment than uncoated shot. However, the coat can be ground down rapidly in a waterbird's gizzard exposing the lead (Irby *et al.* 1967). Similarly, damage to the coat, as when pellets strike the ground, collide with each other, or hit the target, will still allow the lead core to be exposed and corrode, releasing lead to the environment.

Is there evidence that using non-toxic shot results in reduced mortality of wildfowl?

Evidence suggests that regulations requiring the use of alternative ammunition types are very effective, if adhered to. For example, in the USA and Canada, the mandatory transition to steel shot for waterfowl hunting in 1991 and 1999, respectively, resulted in a significant reduction in the mortality of ducks from lead poisoning within a few years (Anderson *et al.* 2000, Samuel and Bowers 2000, Stevenson *et al.* 2005). Spain has required the use of non-toxic shot for hunting in its Ramsar sites from 2001, and since that time, a measurable reduction in lead–induced mortality has occurred (Mateo *et al.* 2014). In the UK, a similar situation occurred with angler's lead weights. Mute swan *Cygnus olor* mortality from lead poisoning following the ingestion of lead angler's weights decreased and their population increased following restrictions on the use of lead angling weights (Sears and Hunt 1991, Perrins *et al.* 2003).

In regions of California inhabited by condors *Gymnogyps californianus*, a ban on the use of lead-core rifle ammunition has been in effect since 2007. Consequently, there has been a significant decline in the blood lead levels of golden eagles *Aquila chrysaetos* and turkey vultures *Cathartes aura* that would, otherwise, be exposed to secondary lead poisoning from scavenging the gut piles from shot game (Kelly *et al.* 2011). Thus the regulations of the 2007 Ridley-Tree Condor Preservation Act (California state law requiring hunters to use lead-free ammunition in condor preservation zones) are having the desired effect.

However, regulations do not work if they are not complied with. In England lead gunshot has been banned for shooting wildfowl or over certain listed wetlands since 1999. Three consecutive studies of compliance with the regulations (Cromie *et al.* 2002, 2010, 2015) have shown that about 70% of ducks, shot in England and sourced from game providers and other commercial outlets, were shot illegally using lead gunshot. The proportion of wildfowl dying of lead poisoning did not change following the introduction of legislative restrictions on the use of lead (Newth *et al.* 2012) and large numbers of birds continue to suffer lead poisoning in England.

While legislation that is complied with has been effective at reducing lead poisoning in birds, in the UK evidence suggests that partial restrictions (dealing just with certain taxa or habitats) are unlikely to be effective.

Effective transition to non-toxic ammunition for all shooting would both remove the majority of the risk to wild birds, and also substantially reduced risks to the health of humans that frequently consume game meat.

How do we deal with lack of compliance with the existing regulations?

As described in Cromie *et al.* (2015), compliance with the 1999 regulations requiring the use of non-toxic shot for shooting wildfowl and over certain listed wetlands in England remains very low. This is despite long-standing efforts on the part of shooting organisations to encourage compliance, including a campaign to this effect in 2013. There may be many reasons behind this, but the difficulty of policing partial regulations, which in England require the use of non-toxic shot for shooting some species/in some areas, but allow the use of lead for shooting other species/in other areas, is likely to play an important part. Under current circumstances in England, it seems highly probable that many people will continue to use lead gunshot illegally in the absence of a ban on its use (and possibly also sale, possession and import) for all shooting.

It is also notable that even where there is a high degree of compliance with the current regulations, the problem of lead poisoning would not be solved for the wildfowl species that graze terrestrial habitats, for terrestrial birds, or scavenging and predatory birds. Nor would this tackle potential risks to the health of frequent consumers of game, as most game eaten comprises terrestrial gamebirds which are currently legally shot with lead.

How can we enhance shared learning and speed up implementation of the use of non-toxic alternatives?

Legislation requires the use of non-toxic ammunition for some (or in a few cases all) shooting with shotguns and/ or rifles in many countries, although we have heard that compliance can be very poor (especially with partial restrictions as in England). There exist other politically binding imperatives to replace lead ammunition with non-toxic alternatives, *via* multilateral environmental agreements such as the Convention on Migratory Species and the African-Eurasian Migratory Waterbirds Agreement (see Stroud 2015). In addition, an increasing number of national food safety authorities are publishing advice recommending that women of pregnancy age and young children eliminate or significantly reduce the consumption of game shot with lead ammunition from their diet (see Knutsen *et al.* 2015). The science around the toxicity of lead at low levels of exposure is extremely compelling and agreed upon by all major authorities, but there appears to be little awareness of the issue more broadly, including across the general public, medical practitioners, retailers and restaurateurs. For example, the food safety advice published by the UK Food Standards Agency (FSA) in October, 2012 (FSA 2012) was not included in National Health Service advice on a healthy diet in pregnancy when they revised their guidance either in 2013 or January, 2015[1].

It appears that a concerted communication effort will be needed across all stakeholders, including the shooting community and the general public, to increase awareness of the problem, and to share knowledge on and facilitate the implementation of possible solutions, including the use of non-toxic alternative types of ammunition.

In 2010 the Department for Environment, Food and Rural Affairs (Defra) and the FSA invited key organisations to form an independent strategic group to advise Government on the impacts of lead ammunition on wildlife and human health. The purpose of this group (the Lead Ammunition Group - LAG) was to bring together relevant stakeholders and experts to advise Defra and the FSA on:

(a) the key risks to wildlife from lead ammunition, the respective levels of those risks and to explore possible solutions to any significant threats;

(b) possible options for managing the risk to human health from the increased exposure to lead as a result of using lead ammunition.

The Lead Ammunition Group's report [subsequently submitted in June 2015] will provide much needed information and guidance.

This symposium enabled an open examination of the evidence and stimulated and facilitated debate both around the health risks of lead ammunition to wildlife and humans and solutions available including those already implemented elsewhere. These proceedings should provide a helpful 'one stop shop' for information on the issue in the UK, along with examples of how others have effectively dealt with this.

However, increased public awareness and good communications should ideally come from within the shooting community. Regulation requiring the use of non-toxic ammunition would of course solve the problem, and there would need to be a sensible phase in time to enable adaptation.

While all of the information is accessible to facilitate and enhance shared learning, implementation of the use of non-toxic alternatives ultimately requires political will for change.

Are there economies of scale for non-toxic ammunition production?

Steel is widely available and is by far the most commonly used alternative to lead shot. Prices of lead and steel shot are currently comparable, and depending upon world metal prices, steel shot may be slightly cheaper or slightly more costly than lead, but differences are small. The more expensive shot types are tungsten and bismuth, which are sold and used in far lower volumes. Tungsten is a strategic material and is always likely to be more expensive than lead. With bismuth, if the market is large enough, the price could come down somewhat. For bullets, an economy of scale effect is predictable. In the USA, where a larger demand for lead-free bullets exists, the prices for lead-free and lead-core equivalent bullets do not differ much when sold in large retail stores (Thomas 2013a). Knott *et al.* (2009) indicated

[1] http://www.nhs.uk/conditions/pregnancy-and-baby/pages/healthy-pregnancy-diet.aspx

that the price of lead-free rifle cartridges sold in the UK would likely decline as the size of that market increased.

COMMON QUESTIONS CONCERNING ALTERNATIVE AMMUNITION TYPES

The following questions have been raised variously across many countries, including in the UK, and over many decades. These are relevant to the UK situation and to broader communication of the issue.

Is there evidence that the use of lead-free ammunition regulations may reduce participation in shooting sports or significantly affect its economic viability?

While the use of lead bullets has not been restricted in many areas or countries, several examples exist of countries or regions where the use of lead gunshot has been prohibited for all shooting. An example relevant to the UK is that of Denmark, where alternatives to lead have been used for almost 20 years (since 1996). As outlined in these symposium proceedings (Kanstrup 2015), non-toxic shot use by Danish hunters has not been accompanied by a change in the number of hunters. Game shooting is a relatively expensive sport, and the costs of non-lead ammunition are a small part of the total costs of shooting game with rifles and shotguns (Thomas 2015). For the individual shooter, steel shot of similar quality to equivalent lead shot is of broadly comparable cost (this fluctuates with world metal prices). Other alternative shot types are more costly, perhaps by up to about five times, but these are less frequently used and still represent a small proportion of the costs of sports shooting. The use of lead-free ammunition on shooting estates has many benefits. In addition to reduced environmental contamination, this reduces the exposure of wildlife and livestock to spent lead shot and its health effects. In addition, for both large and small game animals sold in national and international food markets, a low-lead status of the meat will ensure that consumers are not exposed to unnecessarily high levels of dietary lead, which have the potential to put at risk the health of frequent consumers of game meat. Proposals to restrict the use of lead ammunition will help to give shooting sports a more sustainable future without the toxic footprint of lead contamination, and this should help to secure both the environmental sustainability and long-term economic viability of shooting estates.

Are alternative shot types as effective as lead in killing birds?

In the USA, concern arose, initially, in the 1980s over the ballistic efficiency of early types of steel shot for waterfowl hunting in the USA (Morehouse 1992). This issue was investigated early on in the USA, because it was among the first to end the use of lead shot for wetland shooting, and because it had the capacity to investigate hunters' use of this shot type.

Concern largely related to a perceived potential for increased "crippling loss" of waterfowl shot with steel. The term "crippling loss" refers to birds that have been shot but are unretrieved, either because they have not been killed outright, or because they have been killed but the carcass cannot be found. In the former case, birds are generally wounded due to poor shooting skill and/or errors in distance estimation.

Crippling rates of birds can be high (generally in the range of 10-50%), irrespective of the shot types used (*e.g.* Haas 1977, Nieman *et al.* 1987). Morehouse (1992) reported a slight increase in waterfowl crippling rates in the USA during the early steel shot phase-in years of 1986-1989, but that the rates for both ducks and geese declined towards early 1980s levels in 1991. A large-scale European study on the effectiveness of steel shot ammunition indicated similar performance levels with lead shot when hunting waterfowl (Mondain-Monval *et al.* 2015). Mondain-Monval *et al.* (2015) also showed that hunter behaviour and judgement, the abundance of birds, and strong wind conditions played significant major roles in determining the effectiveness of hunters' ability to bring birds to bag. Noer *et al.* (2007) indicated that the wounding of geese by Danish shooters could be reduced by hunters' confining their shooting to a maximum distance of 25 m, a practice that requires awareness and determination.

A definitive, large-scale, comparative study of the effectiveness of steel and lead shot for shooting mourning doves *Zenaida macroura* was conducted in the USA (Pierce *et al.* 2014). The study revealed that hunters using lead shot (12 gauge, with 32 g of US #71/2 shot) and steel shot (12 gauge, with 28 g of US #6 and US #7 shot) produced the same results in terms of birds killed per shot, wounded per shot, wounded per hit, and brought to bag per shot. Hunters in this double-blind study wounded 14% of targeted birds with lead shot, and 15.5% and 13.9% with #7 and #6 steel shot, respectively. Hunters missed birds at the rate of 65% with lead shot, and 60.5% and 63.6% with #7 and #6 steel shot, respectively. Pierce *et al.* (2014) concluded that *"... (shot) pattern density becomes the primary factor influencing ammunition performance"*, and this factor is controlled by the shooter.

Steel Shot Lethality Tables have been compiled by T. Roster[1] of the (then) US Co-operative Nontoxic Shot Education Program (CONSEP). These data are invaluable for hunters to gain proficiency in the use of steel shot. The critical point of the tables is emphasizing shooting within the effective range of the shotgun cartridge at which pattern shot density and pellet energy are, together, capable of producing outright kills. It would be advisable to reproduce the same tables in UK hunter information packages.

In summary, crippling of birds is related to the shooter rather than the ammunition, and the evidence suggests that while shooters may need to adapt to using different ammunition, steel shot can be used as effectively, without increased wounding of birds.

Does non-toxic shot deform in the animal's body like lead shot?

The lethality of gunshot is not a function of its ability to "mushroom" in the body. This is a common confusion with expanding rifle ammunition. Soft lead pellets that hit large bones in animals' may lose their round shape, often fragment, and remain in the carcass. The lethality of shotgun shot relates to the number of pellets that penetrate the vital regions of the animal and cause tissue disruption. It is accepted that a minimum of five pellets hitting the vital regions are required to produce rapid humane kills (Garwood 1994), *i.e.* it is the pattern density of shot rather than the energy in a given shot that defines lethality (Pierce *et al.* 2014).

Very soft pellets that may deform during passage along the gun barrel also contribute to poorer quality patterns. Gunshot makers will use up to 6% antimony to harden the shot to ensure that lead shot does not get hit out of roundness during firing and fly away from the main shot pattern and not contribute to the shot pattern's density. Another process involves plating lead shot with nickel to harden the pellet surface, prevent deformation, and generate better killing patterns at distant ranges. Steel shot patterns well because of its relative hardness, and if delivered accurately, kills effectively from multiple hits without the need of deformation.

[1] T. A. Roster, 1190 Lynnewood Boulevard, Klamath Falls, Oregon 97601, USA.

Are lead-free shotgun cartridges made in a broad range of gauges and shot sizes?

Manufacturers in Europe make and distribute cartridges according to hunters' demands, which, in turn, are driven by regulations. Given that the main requirement is currently for wetland shooting, the main types of lead-free cartridges produced are suited for this type of shooting (*i.e.* 12 gauge cartridges in shot size US #5 and larger). If regulations were in place requiring hunters to use lead-free shot for upland game shooting, industry would make and distribute them for this purpose. Pressure constraints prevent steel shot being loaded into cartridges smaller than 20 gauge. Cartridges containing steel, Tungsten Matrix, and Bismuth-tin shot are already made in 12 gauge 2.5, 2.75, and 3.0 inch, and 20 gauge 2.75 and 3.0 inch cartridges but at production levels consistent with current market demand. Cartridges in 16 ga and 28 ga and .410 bore can be made easily with Tungsten Matrix or Bismuth-tin shot, but a strong reliable market is required to make them widely available.

Can gun barrels be damaged by using lead shot substitutes?

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. 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 US #4 steel, 3.5 mm diameter) 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". This is the essence of the concerns. Ring bulges are also known to occur in shotgun barrels when large hard lead shot are fired through tight chokes. A gun barrel with a ring bulge can continue to fire steel shot. It is a cosmetic change, and not related to safety or the risk of exploding barrels.

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 (single or double) having "fixed" full and extra full 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* US #4 (< 3.5 mm) 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.

This concern about ring bulges does not apply to Tungsten Matrix or Bismuth-tin shot, both of which perform similar to lead shot during firing and passage through the barrel.

Do lead shot substitutes pattern like lead shot?

The lead-free shot, Tungsten matrix and Bismuth-tin, have ballistic properties and densities similar to lead shot. Both types are fired from the barrels at approximately the same velocity as lead shot, and in the same shot containers. Both shot types respond to barrel choking as lead shot, and have similar shot string lengths. Manufacturers give steel shot similar muzzle velocities as lead shot, so there is no perceptible difference to shooters. Steel shot, by virtue of their spherical shape and hardness, do not contribute as many fliers (mis-shaped or deformed pellets) to the fringes of shot patterns, and so add more shot to the main killing region of the patterns. Steel shot strings are slightly shorter than lead shot strings. Steel shot cartridges produce slightly tighter patterns than lead shot with a given barrel choke, so do not need to be fired through barrels with much choking.

Can my gun be used with non-toxic shot cartridges?

Any gun that can fire lead shot cartridges safely can also fire non-toxic shot cartridges safely, provided that they are the same length, and of an equivalent shot weight. Thus Tungsten Matrix shot cartridges or Bismuth-tin cartridges can be used confidently in any European gun with any choke constriction. One would not fire 2.75 inch lead shot cartridges in a gun proved for 2.5 inch cartridges, or 3.0 inch lead shot cartridges in guns proved for 2.75 inch cartridges simply because they were not made and proved to handle these larger cartridges. The same considerations apply to the use of Tungsten Matrix and Bismuth-tin shot cartridges. The only possible concern about the use of steel shot pertains to the choke region of the barrel (as addressed in the previous points). Any UK-made gun can shoot steel shot safely provided the cartridge length matches the chamber length, and provided that the shot sizes are consistent for use with a given choke boring. The cartridge makers have made enormous progress in the development of more progressively-burning gunpowders to make their steel shot cartridges compatible for use in older guns. Shooters are always advised to ensure that the cartridges, whether lead shot or non-toxic shot, are of the same size as the chambers of their guns. The European Proof Commission will add a special proof mark (a Fleur de Lys) mark on the actions and barrels of guns to indicate that they have been proved safe for magnum-size steel shot loads.

Can non-toxic shot be used with biodegradable wads?

Tungsten Matrix cartridges and Bismuth-tin cartridges are made with shot contained in degradable fibre wads for use in areas where plastic wads are not allowed, whether on wetland or upland sites. Steel shot requires containment in a hard wad that is released to the environment. However, the UK company, Gamebore, has begun to make a biodegradable wool felt wad that protects the shotgun barrel, and provides an environmentally-friendly material for shooting steel shot in sensitive areas.

Is ricochet a problem with lead-free ammunition?

All types of shot and bullets can ricochet (*i.e.* deflect) from a hard surface such as water, rocks, or the surface of tree trunks, if they hit the surface at an acute angle. Shot made from soft lead, Tungsten Matrix and Bismuth-tin may break up on direct contact with rocks. Steel shot will bounce off hard surfaces, and is not so prone to fracture. Bullets made from pure copper or gilding metal can ricochet as readily as lead core bullets, especially if they have a pointed meplat (*i.e.* spitzer points). It is the responsibility of shooters to be aware of the backdrop to each shot, regardless of the type of shot or bullet used. The issue of richochet of lead-free bullets or gunshot has not arisen as a serious concern among US hunters, and has not been raised to prevent a transition to their use.

How long would it take for industry to ramp up production of lead-free shot?

UK cartridge companies (Gamebore and Eley) currently make two proprietary brands of non-toxic shot cartridges, Tungsten Matrix and Bismuth-tin. At least five UK companies currently make steel shot cartridges, and more distributors import steel shot cartridges from European and American companies (Thomas 2015). This array of steel shot is available for both game and clay target shooting (Thomas 2013b). The majority of cartridges made in the UK are made for clay target shooting, rather than game shooting.

The UK companies already have the technology in place to produce all the non-toxic cartridges that UK shooters will demand. What is presently limiting production is the assured market demand from the shooting community. Voluntary measures to adopt lead-free cartridges do not create a strong market demand that companies can rely on. Also, a lack of compliance with existing non-toxic shot regulations for shooting over UK wetlands (currently about 70+% non-compliance) does not encourage companies to make more non-toxic shot than is ordered.

Any regulations that would require greater use of lead-free cartridges would require an appropriate phase-in time. The vast majority of steel shot incorporated into cartridges originates in China, and the Chinese companies would need adequate time to increase projected production. The same consideration applies to tungsten originating from Chinese mines and refiners. The cartridge cases and shot cups designed for steel are not the same as those used for lead shot cartridges, and so increasing their production volume takes time. It also takes time for UK makers to make, test, advertise and distribute their cartridges, and for the wholesalers to stock and prepare their products for sale. Given the experiences of the USA, a transition time of three years to the date of entrance of legislation appears reasonable, for both UK and European makers. This is also the timeframe suggested in the guidance to the CMS (November 2014) Resolution recommending a phase out of the use of lead ammunition.

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Current partial UK regulations do not protect birds feeding in terrestrial environments such as these pink-footed geese *Anser brachyrhynchos*.

Photo Credit: Erni/Shutterstock.com

OXFORD LEAD SYMPOSIUM: CLOSING REMARKS

Professor Ian Newton OBE, FRS, FRSE

So much first-class information has been presented during the symposium that I cannot attempt to summarise it all, but what I would like to do is pick out what I think are the main issues to emerge:

Lead must now be one of the most thoroughly and extensively studied of anthropogenic toxins. At this symposium, we have heard only parts of the evidence available on its biological impacts, mostly relating to the UK; when added to findings from the rest of the world, we have a huge body of scientific evidence, which is consistent and overwhelming in its messages. In what I have to say now, I will rely mainly (but not entirely) on this current symposium.

Effects on people

Toxic effects of lead on people have been recognised for centuries (Stroud 2015). It is a non-essential component of the diet which, at very low levels, affects multiple physiological systems, including nervous, renal, cardiovascular, immune and reproductive systems. It also affects the behaviour of animals, and has been implicated in the criminal behaviour of some people. Influential medical publications have listed lead as 'probably carcinogenic'.

Owing to this knowledge, most important sources of lead in the environment of the UK have already been significantly reduced or eliminated (paints, gasoline, lead-pipes *etc.*), while other remaining uses (as in batteries or lead-sheeting) are well controlled. This leaves lead-based ammunition as the remaining greatest source of emissions of lead to the environment that remains largely unregulated. An estimated 5,000 tonnes of lead ammunition are deposited on the UK every year, raising existing environmental levels, especially in areas of concentrated shooting activity (Pain *et al.* 2015).

Since additives to petrol were regulated, the main source of lead contamination of people has been *via* the diet, that derived from lead ammunition is the most readily controllable source. Lead obtained from wild meat, whether in the form of shot pellets or bullet fragments, has been linked with elevated blood levels in people, such blood levels tending to increase linearly with the amounts of game meat consumed. Links between the use of lead ammunition and lead in the human body, and between lead in the body and human health and well-being are now firmly established by several independent studies (*e.g.* see Green and Pain 2015, Knutson *et al.* 2015).

In recent years, lead has been shown to affect adults and children at far lower concentrations in body tissues than formerly thought, and at lower concentrations than current regulations acknowledge (although acceptable levels have been reduced over the years (Green and Pain 2015)). There is no level of lead exposure in children or adults known to be without deleterious effects. In other words, there is no toxicity threshold: the concept of a 'safe level' is redundant. Exposure in childhood to even slightly elevated levels of lead produces measurable and lasting neurological deficits in intelligence and behaviour. Neonates and children with growing brains are especially susceptible.

Relatively new findings concern the behaviour of bullets and shot: the way that lead-based ammunition leaves behind tiny fragments on passage through an animal. These can be distributed widely within carcasses, including places distant from the wound tract. This makes it almost impossible for people to avoid ingesting lead along with meat. The bits of lead are so small and scattered that no normal butchery can remove them. So the consumption of lead-killed meat almost inevitably results in the consumption of undetected lead. While this fact may have been known to some for years, new studies have re-emphasised it in a most dramatic way, for example from X-ray images of shot animals (Green and Pain 2015, Gremse and Reiger 2015).

Average levels of lead in game meat, measured in recent years, have been many times higher than the suggested maximum permissible concentration in domestic meat. Some individual meals prepared from gamebirds killed with lead shot have over one hundred times the *maximum permissible* level for domestic meat (Green and Pain 2015).

Since the impacts of lead are largely hidden, usually undetectable without medical study, we can reasonably assume that we have much bigger human health problems caused by lead ammunition than previously recognised. Lead poisoning could potentially affect people anywhere in the UK, if they eat wild waterfowl or game, but particularly those for whom wild game forms a significant part of the diet (such as some of the shooters themselves and their families and associates). Diabetes, mental and renal problems are some familiar illnesses that are known to be exacerbated by lead. Recent surveys have shown that, among the hunting community alone, up to 12,500 children in the UK are now exposed to dietary ammunition-derived lead from game meat in sufficiently large amounts to be at risk from some health consequences (as defined by the European Food Safety Authority).

Effects on wildlife

Lead is similarly toxic to a range of other vertebrates, especially mammals and birds. Some species, such as waterfowl, game birds and pigeons, ingest spent gunshot incidentally along with the grit needed in food breakdown, while meat-eating scavengers ingest lead fragments from the carcasses and discarded gut piles of shot animals on which they feed. A deer shot through the thorax with a lead bullet may have large numbers of lead fragments in the pile of viscera discarded in the field by the hunter. Worldwide, more than 130 wild bird species are known to be affected in this way. In some species thousands or tens of thousands of individuals die from lead poisoning every year in North America alone. There is no reason to think that the situation is much different in Europe. These incidental casualties include quarry species which the hunters themselves would otherwise seek to preserve. Recent estimates imply that some 50,000-100,000 waterfowl may die of ingested lead poisoning in the UK each year (Pain *et al.* 2015). This lead poisoning does not normally produce obvious mass mortalities of the type that can result from disease, because birds die slowly through the year, a few at a time, their carcasses swiftly removed by scavengers. Lead-caused mortality is therefore largely hidden, invisible to the average hunter or country-dweller.

While this incidental mortality of waterfowl, game birds and scavengers may be substantial, we have few assessments of its effects on population levels. For lead-poisoning to reduce a population, or cause it to be smaller than it would be in the absence of lead, it has to be additive to other deaths, and not compensated by reduction in other mortality. However, quantitative circumstantial evidence indicating population-level effects is available for some waterfowl (Mateo 2009), and for some scavenging birds of prey, such as eagles and vultures (various in: Watson *et al.* 2009). Such evidence is available for the white-tailed eagle *Haliaeetus albicilla* in central Europe and the Steller's sea eagle *Haliaeetus pelagicus* in Japan (the latter problem having been reduced recently by a legal ban on lead bullets). The evidence on population effects is particularly striking in the California condor *Gymnogyps californianus* in North America, which can no longer maintain a self-sustaining population in its historic range: the mortality from ingested lead-based ammunition well exceeds its natural reproductive rate. Wherever lead-based bullets of current design are used as now in game hunting, it is recognised that the condor is unlikely to survive without intensive remedial intervention anywhere in North America. It is being kept from extinction in the wild only by a programme of conservation management involving annual releases of captive-bred birds, coupled with veterinary care, involving frequent capture of wild individuals and treatment to reduce their blood-lead levels (Green *et al.* 2008).

Of course, we are not concerned with Condors in Europe, but southern and central Europe has vultures that are certainly affected by lead, though population-level effects have not been documented. And northern Europe has scavenging raptors that are exposed to ammunition-derived lead, but again no research to examine population-level effects has been done.

If lead ammunition was banned, given all the lead already in the environment, how can we be sure that such a ban would reduce the mortality of affected species, and that their populations (if reduced by lead) would recover? Well, first of all, the uptake of lead by waterfowl and others is much greater in the shooting season than during the rest of the year, which implies that birds are ingesting recently-applied lead, not older stuff much of which presumably eventually sinks into the substrate, putting it beyond reach. A seasonal cycle in lead uptake is also apparent in raptors and other scavengers that feed on the carcasses of quarry species (Pain *et al.* 2015). Most strikingly, however, we have the example of the sedentary mute swan *Cygnus olor* in Britain (Perrins 2015).

These birds got their lead mainly from fishing-weights rather than gunshot, and following a ban in lead fishing weights in 1987, lead-caused mortality declined from 25% per year in the 1970s to 2% in more recent years, and populations switched from decline to increase. On the most affected river systems, swan numbers doubled within a decade (Perrins *et al.* 2003). This showed convincingly that, if effective restrictions were imposed, this highly vulnerable species could and did respond by recovery.

Alternatives to lead

Non-toxic alternatives to lead ammunition have been developed, are widely available, and apparently perform well, once the right ammunition has been identified for a particular purpose and gun, and hunters have got used to it (Gremse and Reiger 2015, Kanstrup 2015, Thomas 2015). The argument that lead is best, and that alternatives are less good, is no longer tenable. Steel shot is of similar price to lead shot, but some other alternatives are currently more expensive. Nevertheless, the cost of new ammunition is still trivial compared with the other costs of hunting (Thomas 2015). Lead gunshot was banned totally in Denmark nearly two decades ago and in some other countries more recently, apparently without any detrimental effect on the sport (Kanstrup 2015). The same numbers of people are still hunting, and at similar level. Lead is clearly dispensable as a form of ammunition. In Germany, research on the new non-toxic bullets has been undertaken to improve their performance, and to smooth the transition from lead (Gremse and Reiger 2015).

More research

One standard way to avoid making controversial decisions is to call for more research, from which we can usually benefit. But over the years, evidence on the problems caused by lead ammunition has continued to accumulate, and specific gaps in knowledge have been identified and filled, continually updating our information base. Recent information has served mainly to confirm what we already know, and that the problems persist, but it has added further worrying facts. The essential messages have not changed. Surely we already have sufficient scientifically-robust information to take action against the use of lead-based ammunition for sport hunting. It would be irresponsible not to do so.

Previous restrictions on the use of lead ammunition

Previous legislation in England in 1999, concerning the use of lead over wetlands and for wildfowl shooting, has been lamentably ineffective, because of lack of compliance and enforcement. People evidently feel that they will not be caught, and the statistics on prosecutions confirm this. There has been no decline in lead poisoning in waterfowl examined in Britain from before and after this ban (Newth *et al.* 2012). Among ducks intended for human consumption purchased in Britain in 2008-10, at least 70% had been shot with lead ammunition (Cromie *et al.* 2015). A laudable campaign, led by hunting organisations to encourage compliance, did not change this.

Future restrictions on the use of lead ammunition

There are two approaches towards getting hunters to switch from lead to less toxic alternatives. One is by persuasion; informing them of the facts and hoping they will make the switch themselves. This approach has clearly not worked: witness the continued use of lead shot over wetlands for more than a decade after the 1999 ban; witness the continuing opposition by some hunters and their organisations to restrictions in the use of lead. This leaves us with the only other approach which is mandatory. All other major uses of lead have long been banned or strictly regulated by law, yet this particular use, which provides a direct and important route for lead into the human blood stream, remains unrestricted. Legislation proved necessary in Denmark to cut the use of lead; as in Britain, the dissemination of scientifically-collected findings and appeals to the better nature of hunters had not worked. Danish hunters now accept it, and (as confirmed by surveys) would not go back.

Awareness problems

The questions that remain in my mind are not so much to do with the effects of lead, on which the scientific evidence is overwhelming, widespread and unequivocal. Rather they concern the attitudes of many hunters and their representatives. What a pity we had so few representatives of hunting organisations attending the symposium, while the majority of those invited declined to attend. Given all the information we now have on the impacts of lead on human health and well-being, on its effects on wild bird populations, and given that satisfactory alternatives to lead are now available, why is it that a large sector of the hunting community in Britain and elsewhere remains opposed to the replacement of toxic lead by non-toxic alternatives? Do they just not know about the evidence, do they not understand the problems, do they not believe the results of robust science replicated in region after region, or have they been continually fed with misleading information? Do they think the problems are not big enough to worry about (the invisible problem syndrome), do they just object to any further regulation or change of any kind, or do they see the banning of lead as a step on the way to banning hunting? How can those organisations that represent hunters and yet continue to oppose restrictions on lead justify to their own members the stance they have taken, given the knowledge we now have? Why do these organisations not take a lead in educating their members, and supporting a legal ban in the use of all lead ammunition? Given this intransigence, is it time to put these issues more forcefully before the general public?

Whatever the answers to these questions, all raised during our discussions at the symposium, there is clearly a communication problem. No-one has suggested that decisions on such important issues as lead poisoning should be left to hunters alone. If it were just hunters who wanted to put only themselves at risk, without affecting other people, domestic livestock or wildlife, it is their choice. But their behaviour *does* affect other people (including their families and associates), domestic animals and wildlife. There are issues of health, well-being and mortality, and also of animal welfare. In the UK, hundreds of thousands of wild bird and mammal carcasses end up each year in the human food chain for consumption by people not involved in hunting, being sold by butchers, supermarkets, hotels, restaurants, pubs or online shopping outlets. Yet all this meat is distributed to the unsuspecting public without any accompanying health warnings. Campaigns to promote the sale of game meat as healthy food omit to mention the lead within. In the presence of the information now readily available, and which has been available for several decades, how can this be allowed to continue? How will the shooting bodies who oppose restrictions on lead justify to their members and the general public the stance they have taken for more than three decades after all other major uses of lead, from paints to petrel to pipes, have been banned or seriously restricted? Europe is moving in the right direction, but far too slowly.

We wish the Lead Ammunition Group well in their deliberations, and look forward to their report. The recent Convention on Migratory Species resolution on poisoning (UNEP-CMS 2014) is also important because it puts our government under an obligation to do something. My own view is that a legislative ban is needed on the use of lead in all ammunition used for hunting. At one stroke this would alleviate the problems created for people (especially the hunters themselves), for wildlife and for domestic livestock by this unnecessary but highly toxic material. Of course, a date for the ban would need to be set ahead, to give hunters and manufacturers time (ideally no more than two years) to shift to other materials. After our day of excellent science, practical experience and discussion, these are the thoughts I would like to leave you with.

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Embedded lead gunshot in the flesh of small ducks exposes predators such as this marsh harrier *Circus aeruginosus* to lead poisoning.

Photo Credit: B. Townsend

APPENDIX 1
Contributors

EDITORS

Professor Richard J. Delahay

Professor Richard Delahay is a wildlife biologist with expertise in the epidemiology and management of disease in wildlife populations. Following completion of a PhD at Aberdeen University on the epidemiology of threadworm infections in red grouse, he has worked as a post-doctoral researcher for the Institute of Terrestrial Ecology, Oxford University and the Forestry Authority before holding scientific posts in a succession of Government research agencies, and currently holds an Honorary Visiting Chair at Exeter University. He is an author on over 120 peer-reviewed scientific papers and the principal editor of a book on managing disease in wild mammals.

Professor Chris J. Spray

Professor Chris J Spray MBE, FRSA, MA (Cantab), PhD, MCIEEM holds the Chair of Water Science & Policy at the UNESCO Centre for Water Law, Policy & Science at the University of Dundee. Before joining the university in 2009, he had over 25 years of practical experience of integrated water resource management from a number of distinct perspectives. These included working in regulation and policy as Director of Environmental Science for the Scottish Environment Protection Agency; in water supply and services as Director of Environment for Northumbrian Water Group; in river basin management planning as chair of Tweed River Area Advisory Group; and with a wide range of environmental NGOs (past trustee of Tweed Forum, FBA, RSPB, WWT, BTO). His current research focuses on wetland ecosystem services (co-author of UKNEA chapter on water and wetlands); on the use of the Ecosystem Approach for delivery of the Scottish Land Use Strategy; and on water science and catchment restoration. His PhD at Aberdeen was on territorial behaviour of carrion crows, after which he studied the population dynamics of mute swans, including publishing papers on lead poisoning. His interest in the linkages between science and policy are currently also being pursued as a part-time Senior Research Fellow for NERC working with the Welsh Government.

CHAIRS AND CONVENORS

Lord John Krebs

The Lord Krebs Kt, MA, DPhil, FRS, FMedSci, Hon DSc completed his undergraduate degree in Zoology (1966) and DPhil (1970) at Pembroke College, the University of Oxford. After a year as a Departmental Demonstrator in Ornithology at Oxford he moved to the University of British Columbia as an Assistant Professor of Ecology (1970-73). John then spent a period at the University College of North Wales in Bangor as lecturer in Zoology (1973-75) before returning to Oxford as University Lecturer in Zoology in the Edward Grey Institute of Field Ornithology. John was a Fellow of Wolfson College until 1981, when he became EP Abraham Fellow of Pembroke College. Between 1988 and 2005 he was a Royal Society Research Professor at Oxford. From 1994 to 1999, John was Chief Executive of the Natural Environment Research Council and was Chairman of the UK Food Standards Agency between 2000 and 2005. John was appointed as an independent cross-bench peer in 2007.

He was the Chairman of the House of Lords Science and Technology Select Committee between 2010 and 2014, and was the Chairman of the UK Science and Technology Honours Committee from 2008 to 2014. He serves on the UK Climate Change Committee (and chairs its Adaptation Sub-Committee), and is a Trustee of the Nuffield Foundation. From 2007 until 2015 John was the Principal of Jesus College, the University of Oxford.

Professor Colin Galbraith

Professor Colin Galbraith is Director of his environmental consultancy, dealing with a range of environmental issues in Scotland and at the global level. He was until recently the Director of Policy and Advice in Scottish Natural Heritage. In this capacity he was the principal adviser on policy, scientific and technical matters for the organisation for over twelve years. Colin has been involved with the United Nations for a number of years and has made contributions through the Convention on Migratory Species (CMS) and to the Millennium Ecosystem Assessment in particular. This work area involves him in high profile nature conservation issues including the conservation of the African Elephant and developing new international agreements to assist the conservation of Albatross, and in reviewing the impact of climate change on the ecology of threatened species.

He is currently the Vice Chairman of the Scientific Council of the CMS. He has been an Honorary Professor in Conservation Science at the University of Stirling since 2002.

Professor Ian Newton

Professor Ian Newton OBE, FRS, FRSE is an ornithologist with a particular interest in the things that limit bird numbers, with research at different times on seed-eating birds, waterfowl and birds-of-prey. Throughout his working life, he was employed by the Natural Environment Research Council, and for many years he was head of a unit at Monks Wood Research Station which studied the effects of pesticides and pollutants on birds. He has authored eight books on different aspects of avian biology, and published more than 300 papers in the scientific literature. He has also served as President of the British Ecological Society and the British Ornithologists' Union, and as Chairman of the Royal Society for Protection of Birds and the British Trust for Ornithology.

Professor Chris Perrins

Prof. Chris Perrins LVO, FRS joined the Edward Grey Institute of Field Ornithology at the University of Oxford as a student in 1957. Chris retired in 2002 but remains at the University as a Professor Emeritus. His main studies have been on population biology: Great Tits (in Wytham Woods), seabirds, especially Manx Shearwaters (on the Pembrokeshire islands of Skokholm and Skomer) and Mute Swans (especially on the River Thames and at Abbotsbury, Dorset).

In the 1970s, Chris was asked to study the reason for the decline in Mute Swans in the UK. Intensive studies showed that the greatest single cause of mortality of the birds was lead poisoning – almost entirely from the ingestion of lead angling weights. Not only did the lead cause the deaths of many swans, but many of the living birds were carrying high lead burdens. The importation and sale of lead angling weights from 0.06 and 28.35 grams (No.6 shot to 1oz) was prohibited in 1987 and their use banned by most regional water authorities shortly afterwards. Nationally, the Mute Swan population doubled in the ten years to 1997, with the largest increases being observed on the lowland, heavily fished, rivers.

PRESENTERS/FIRST AUTHORS

Dr. Ruth Cromie

Dr. Ruth Cromie gained a PhD for vaccine development in wildfowl from University College, London, in 1991. Since then she has worked on various aspects of wildlife health from diagnostic technologies to environmental management in both wild and captive animals in the UK and overseas including the Durrell Institute of Conservation and Ecology, Smithsonian Institution and Hong Kong University.

As WWT's Head of Ecosystem Health, Ruth is responsible for organisational health and welfare standards, plus WWT's Ecosystem Health programme which includes surveillance, research, advocacy, contingency planning, capacity building and policy work. Ruth regularly teaches and examines wildlife health and conservation biology on a number of post-graduate programmes.

Ruth is an active member of the UN-Convention on Migratory Species (CMS)/Food and Agriculture Organization (FAO) Co-convened Scientific Task Forces on both Avian Influenza and Wild Birds, and Wildlife and Ecosystem Health. Ruth has worked on resolutions for both the CMS and the Ramsar Convention on Wetlands promoting integrated approaches to dealing with health, in particular of domestic and wild animals, as well as recent production of the Ramsar Wetland Disease Manual which is a substantive practical resource written specifically for land/wetland managers.

Professor Rhys E. Green

Professor Rhys Green gained a BA in Zoology and a PhD in Applied Biology from the University of Cambridge where he has been Professor of Conservation Science in the Zoology Department since 2006. After completing his PhD he worked for the Game Conservancy for four years on the ecology of grey and red-legged partridges, subsequently joining the RSPB as a research biologist in 1982. He became RSPB's Principal Research Biologist in 1993, a role that he retains to date.

Rhys has worked on a wide variety of research topics, from the effects of climate change on geographical range and population processes, to the development of techniques for practical habitat management and the manipulation of demographic rates of threatened birds. More recently his research has included the effects of veterinary pharmaceuticals on population processes in birds and the effects of contamination from spent lead ammunition on wildlife and human health.

Rhys sits on the Game & Wildlife Conservation Trust (GWCT) Scientific Advisory Group. He has been awarded the Marsh Award for Conservation Biology (1997), the Tucker Medal by the British Trust for Ornithology for outstanding services to its scientific work (2000) and the Godman-Salvin Medal by the British Ornithologists Union as a signal honour for distinguished ornithological work (2009). He is currently on the editorial boards of five peer-reviewed journals and has more than 200 scientific publications, of which 18 recent peer-reviewed publications cover environmental contaminants, including lead.

Carl Gremse

Carl Gremse gained a Master's degree in Forestry Sciences in 2004 from the "Georg – August – University Goettingen", Germany, Faculty of Forest Sciences and Forest Ecology. Since 2005 he has been working as a researcher at the University of Applied Sciences Eberswalde, Faculty of Wildlife Biology, Management and Hunting Practice. Since 2006, he has been the leading researcher in the German projects into the suitability of lead-free projectiles for use in hunting practice. His main research focus includes methods to assess suitability of a projectile under avoidance of field trials and the possible deduction of threshold values for performance standards to be introduced into German hunting and animal safety legislation. Carl is currently in the process of completing his PhD at the Faculty of Biology, Chemistry and Pharmacy at Freie Universtät Berlin. He has published part of his work in the scientific journal PLOS ONE, contributed to the book "Trends in game meat hygiene" (Wageningen Academic Publishers) and is working on further publications together with scientists from the Federal German Institute for Risk Assessment (BfR), the University Hospital at RWTH Aachen, the Swedish University of Agricultural Sciences (SLU) and the Leibniz – Institute for Zoo- and Wildlife Research (IZW), Berlin.

Dr. Niels Kanstrup

Dr. Niels Kanstrup is a Danish biologist and hunter and has worked in wildlife management and hunting since 1985. Niels was an employee for the Danish Hunters Association between 1985 and 2007 and has worked as a private consultant for the Danish Academy of Hunting since 2007. He is heavily involved in international nature and wildlife management issues through active participation in a number of organisations including the Federation of Associations for *Hunting* and Conservation of the European Union (board member), the International Council for Game and Wildlife Conservation (president of Migratory Birds Commission), the African-Eurasian Migratory Waterbirds Agreement (member of Technical Committee) and others.

Niels has expertise in sustainability models and co-management, and, in particular, issues relating to non-toxic ammunition where he has been involved in studies, meetings and clinics globally, concerning its use and efficacy.

Dr. Helle K. Knutsen

Dr. Helle Knutsen is a toxicologist and senior scientist at the Norwegian Institute of Public Health (NIPH). She is a member of the panel on contaminants (CONTAM) of the European Food Safety Authority (EFSA) and of the Norwegian Scientific Committee for Food Safety (VKM). She graduated with a PhD in molecular biology from the University of Oslo in 1995, and started at the NIPH in 1999. She has authored several papers on associations between dietary contaminant exposure and biomarkers in humans, and in 2012 chaired a working group on risk assessment of lead in cervid game meat for the VKM.

Dr. Debbie J. Pain

Dr. Debbie Pain has a first class degree in Environmental Chemistry from London University and a DPhil from the University of Oxford. She has worked on lead poisoning for 27 years. She started working on the biochemistry of lead poisoning in birds in 1983, carrying out her DPhil research in both the UK and with the US Fish and Wildlife Service in the USA. She subsequently worked for four years as a research scientist at an independent Biological Research Station in the Camargue, France. During this period she led the IWRB (International Waterfowl and Wetlands Research Bureau) task force on Poisoning of Waterfowl by Toxic Lead Shot for the Hunting Impact Research Group, organised the scientific programme for an IWRB lead poisoning workshop (Brussels, 1991) and edited the workshop proceedings (IWRB Spec. Pub. 16). She subsequently spent 16 years at RSPB where she ran the International Research Unit.

During her career she has worked on a wide range of topics in the UK and overseas including the impacts of a range of environmental contaminants, farming systems and birds, identifying causes of poor conservation status in threatened birds and developing practical conservation solutions. She has more than 100 scientific publications and has co-written/edited three books. Thirty six of her peer-reviewed publications are on contaminants, 26 of these on lead. For the last three years she has been Director of Conservation at the Wildfowl & Wetlands Trust (WWT).

David A. Stroud MBE

David Stroud MBE is Senior Ornithologist with the UK's Joint Nature Conservation Committee and is currently Chair of the Technical Committee of the African-Eurasian Migratory Waterbirds Agreement (AEWA). As well as AEWA, he has worked with a number of other multi-lateral environment organisations especially those related to birds and wetlands, and including Ramsar's Scientific and Technical Review Panel, the EU Birds Directive's Ornis Committee (and its Scientific Working Group), several avian Working Groups established by the Contention on Migratory Species (CMS), and the CMS MoU on raptor conservation. He has also worked closely with several international non-government organisations including Wetlands International, IUCN and the International Wader Study Group.

Professor Vernon G. Thomas

Prof. Vernon G. Thomas completed his BA degree in Physiology, Psychology, and Philosophy at the University of Oxford in 1966. He gained a PhD degree in Ecology in 1975 at the University of Guelph, and was then hired as a professor to be part of the Wildlife Management Program. Vernon's teaching and research specialities at the graduate and undergraduate levels included Wildlife Management, Natural Resources Policy, Ornithology, Mammalogy, Ecology, and Developmental Biology. Vernon retired in 2010, but remains at the University as a Professor Emeritus.

His main research focus in later years has been the transfer of science to environmental policy and law, especially in protected areas creation, invasive species control, reducing environmental contamination from lead, and promoting use of managed pollinators in agriculture and biodiversity conservation. Vernon has worked, and continues to work, internationally in all these areas. One of his specialities is the presentation of briefs to parliamentary committees in Canada, Europe, and the USA. His research has influenced, directly, the amendment of Canadian federal law, as in the case of The Parks Act being revised to require lead-free fishing weights in all National Parks, and the introduction of mandatory ballast water exchange regulations for shipping under the National Transportation Act. Vernon's recent research was influential in California's passing legislation in 2013 that will end the use of all lead-based ammunition for hunting in that state in 2019, or sooner.

RAPPORTEUR

Tim Jones

Tim Jones has a technical background in the conservation of wetland ecosystems and waterbirds, having worked for Wetlands International and as European Regional Coordinator for the Secretariat of the Ramsar Convention on Wetlands. He has a worldwide network of contacts in both governmental and non-governmental sectors and has built up a strong reputation for leading insightful project and programme evaluations and providing expert report-writing services for major environmental conferences such as those of the Convention on Migratory Species (CMS) and the Ramsar Convention on Wetlands.

APPENDIX 2

Wildlife and Human Health Risks from Lead-Based Ammunition in Europe. A Consensus Statement by Scientists

On 22 March 2013 a group of eminent scientists signed a consensus statement on **Health Risks from Lead-Based Ammunition in the Environment** with a particular focus on impacts in the USA http://www.escholarship.org/uc/item/6dq3h64x. The statement below, based upon the USA statement, is intended to perform a similar function, but with a focus on impacts in Europe.

We, the undersigned, with scientific expertise in lead and human and/or environmental health, draw attention to the overwhelming scientific evidence, summarised below, on the toxic effects of lead on human and wildlife health. In light of this evidence, we support action in Europe to reduce and eventually eliminate the release of lead to the environment through the discharge of lead-based ammunition, in order to protect human and environmental health.

1. Lead is a non-essential toxic metal that occurs naturally, but has been widely distributed by human activities. Today, most exposure to lead in the general population across the European Union (EU) is from the diet (EFSA 2010) because other sources of exposure, such as plumbing, paints and petrol have been reduced by regulation. Lead is one of the most well-studied contaminants and overwhelming scientific evidence demonstrates that:

    a. Lead is well established to be toxic to multiple physiological systems in humans and other vertebrate animals. The most sensitive systems are the haematopoietic, nervous, cardiovascular and renal systems (EFSA 2010). In addition, The International Agency for Research on Cancer classified inorganic lead as *probably carcinogenic to humans* (Group 2A) (IARC 2006).

    b. No 'safe' blood lead level in children has been identified below which negative health effects cannot be detected (CDC 2012). Absorption of lead leading to even slightly elevated levels injures the developing human brain and is associated with lasting effects on intelligence (IQ) and behaviour.

2. Due to lead's harmful effects, most previously significant sources of lead in the environment in Europe, such as leaded petrol, lead-based paint, and lead-based solder, have been significantly reduced or eliminated over the past 50 years. EU standards of lead in drinking water have been, and continue to be, substantially reduced to protect public health (SCHER 2011). Lead-based ammunition is the most significant unregulated source of lead deliberately emitted into the environment in the EU.

    a. The release of toxic lead into the environment *via* the discharge of lead-based ammunition is largely unregulated. Other major categories of lead consumption, such as leaded batteries and sheet lead/lead pipes, are largely regulated in their environmental discharge/disposal.

3. The discharge and accumulation of spent lead-based ammunition in the environment poses significant health risks to humans and wildlife. The best available scientific evidence demonstrates that:

    a. The discharge of lead-based ammunition substantially increases environmental lead levels, especially in areas of concentrated shooting activity (Mellor & McCartney 1994; Rooney *et al.* 1999).

    b. While regulations exist and are effective in restricting the use of lead gunshot in some EU countries (Denmark and the Netherlands), most EU countries have only partial or limited restrictions on lead ammunition use. Emissions of ammunition-derived lead to the environment remain because of lack of regulation and, where regulations exist, poor compliance and lack of effective enforcement (AEWA 2012). For example, compliance with regulations introduced in 1999 restricting the use of lead gunshot for shooting wildfowl in England has been shown to be very low with 70% of locally-sourced wildfowl purchased having been shot illegally with lead (Cromie *et al.* 2010). Despite this, there have been no primary prosecutions and only one secondary prosecution for non-compliance with the regulations.

c. Birds such as gamebirds and wildfowl ingest spent lead gunshot mistakenly for food or the grit that helps them to grind up food in their muscular gizzards. Ingestion of lead gunshot by waterfowl is associated with increased death rates (Tavecchia *et al.* 2001). Large numbers of birds of these kinds suffer and die annually in Europe because of poisoning due to ingested ammunition-derived lead (Mateo 2009).

d. Lead-based gunshot and bullets used to shoot wildlife can fragment into numerous small pieces within the animal, some of which may be distant from the wound tract; many of these are sufficiently small to be easily ingested by scavenging animals or incorporated into meat prepared for human consumption (Hunt *et al.* 2009; Grund *et al.* 2010; Knott *et al.* 2010; Pain *et al.* 2010).

e. Although the effects of ingestion of spent lead ammunition are best documented for waterfowl, they have also been reported for more than 60 bird species from other taxonomic groups (Pain *et al.* 2009). Lead poisoning from the ingestion of spent lead-based ammunition fragments in carrion and prey animals is a significant source of poisoning and mortality in predatory and scavenging birds of prey, including European vultures (Donázar *et al.* 2002; Mateo 2009) and the white-tailed eagle *Haliaeetus albicilla*, in parts of the EU (Pain *et al.* 1993, 1997; Fisher *et al.* 2006; Nadjafzadeh *et al.* 2013).

f. Lead-based ammunition is a significant source of lead exposure in humans that ingest wild game (Hanning *et al.* 2003; Johansen *et al.* 2006; Tsuji *et al.* 2008), and blood lead levels in people consuming game meat shot with lead-based ammunition have been shown to be elevated in European countries and elsewhere, in proportion to the amounts and frequency of game consumed (Dewailly *et al.* 2001; Iqbal 2009; Meltzer *et al.* 2013; Bjermo *et al.* 2013).

g. High concentrations of ammunition-derived lead are often found in edible tissues of both small and large game animals shot with lead ammunition and can be present in tissues at a considerable distance from obvious wounding so that they are difficult to remove during food preparation (Pain *et al.* 2010; FSA 2012a). Meat from game animals contaminated in this way is consumed by people associated with shooting and, in some countries (such as in the UK), is also sold in supermarkets and other food outlets to consumers who are largely unaware of associated risks.

h. Several EU countries have produced advice on the risks to human health of frequent consumption of game meat shot with lead ammunition, particularly to young children, pregnant women or women wishing to become pregnant (BfR 2011; AESAN 2012; FSA 2012b; VKM 2013).

4. Non-toxic alternatives to lead ammunition have been developed, are widely available, and perform well (Thomas 2013). The sport of shooting and its associated trade in ammunition and other supplies appears to remain viable in countries where the use of lead shot in ammunition has already been banned (*e.g.* within Europe, lead shot in ammunition has been banned for all shooting since 1993 in the Netherlands, since 1996 in Denmark and since 2005 in Norway).

Based upon (1) overwhelming evidence for the toxic effects of lead in humans and wildlife, even at very low exposure levels, (2) convincing data that the discharge of lead-based ammunition into the environment poses significant risks of lead exposure to humans and wildlife, and (3) the availability and suitability of several non-lead alternative products for hunting, we support a phase out and eventual elimination of the use of lead-based ammunition and its replacement with non-toxic alternatives.

Signed,

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APPENDIX 3

Abbreviations used in the Proceedings of the Oxford Lead Symposium

ACCLPP	Advisory Committee on Childhood Lead Poisoning Prevention
ADAS	Agricultural Development and Advisory Service
AESAN	Agencia Española de Seguridad Alimentaria y Nutrición
AEWA	African-Eurasian Migratory Waterbirds Agreement
AFEMS	European Sporting Ammunition Manufacturers Association
AIC	Agricultural Industries Confederation
ATSDR (U.S.)	Agency for Toxic Substances and Disease Registry
BASC	British Association for Shooting and Conservation
BBC	British Broadcasting Corporation
BCE	Common Era
BfR	Federal German Institute for Risk Assessment
BLI	Bird Life International
BMD	Benchmark Dose
BMDL	Benchmark Dose (Lower Confidence Limit)
BMEL	Bundesministerium für Landwirtschaft und Ernährung
BMELV	Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz
BMR	Benchmark Response
BMU	Bundesministerium für Umwelt
B-Pb	Blood Lead
CCW	Countryside Council for Wales
CDC	Centers for Disease Control and Prevention
CEFCD	Concise European Food Consumption Database
CEH	Centre for Ecology & Hydrology
CGerLI	Centre for German Legal Information
CIC	International Council for Game and Wildlife Conservation
CLA	Country Land and Business Association
CLEAR	Campaign for Lead-free Air
CMS	Convention on the Conservation of Migratory Species
CODEX Alimentarius	The Codex Alimentarius Commission, established by FAO and WHO in 1963 develops harmonised international food standards, guidelines and codes of practice to protect the health of the consumers and ensure fair practices in the food trade
CONSEP	US Co-operative Nontoxic Shot Education Program
CONTAM	AM EFSA Panel on Contaminants in the Food Chain
COP	Conference of the Parties
CWS	Canadian Wildlife Service
DBU	Deutsche Bundesstiftung Umwelt
DEFRA	Department for Environment, Food & Rural Affairs
DETR	Department for Environment, Transport & the Regions
DEVA e. V.	Deutsche Versuchs- und Prüfanstalt für Jagd- und Sportwaffen e. V
DoE	Department of Environment
EC	European Commission
ECHA	European Chemicals Agency
EEA	European Environment Agency
EEC	European Economic Community
EFSA	European Food Safety Authority
EN	English Nature
EPA	Environmental Protection Agency
EU ML	European Union Maximum Level (of a contaminant in food)
FACE	European Federation of Associations for Hunting and Conservation
FAO	Food and Agriculture Organisation
FRS	Fellow of the Royal Society
FSA	Food Standards Agency
FSAS	Food Standards Agency Scotland
GFR	Glomerular Filtration Rate
HMSO	Her Majesty's Stationery Office
HNR	Human Nutrition Research
IARC	International Agency for Research on Cancer

ICCM	Conference on Chemicals Management
IOC	International Olympic Commitee
IQ	Intelligence Quotient
IQR	Inter-quartile range
ISSF	International Shooting Sports Federation
IWRB	International Waterfowl and Wetlands Research Bureau
JECFA	Joint Food and Agriculture Organisation/World Health Organisation Expert Committee on Food Additives
JNCC	Joint Nature Conservation Committee
KS1	Key Stage 1
LAG	Lead Ammunition Group
LOD	Limit of Detection
LOQ	Limit of Quantification
LTSH	Landtag Schleswig Holstein
MKULNV	NV Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz
ML	Maximum Level
MOP	Meeting of the Parties
MRC	Medical Research Council
NCC	Nature Conservancy Council
NDNS	National Diet and Nutrition Survey
NGO	Non-Governmental Organisation
NHANES	U.S. National Health and Nutrition Examination Surveys
NISRA	A Northern Ireland Statistics and Research Agency
NNR	National Nature Reserve
NOAEL	No Observed Adverse Effect Levels
NWHL	National Wildlife Health Laboratory
PACEC	Public and Corporate Economic Consultants
PNEC	Predicted No Effect Concentrations
ppm dw	Parts per million dry weight
ppm ww	Parts per million wet weight
ppb	Parts per billion
PTWI	Provisional Tolerable Weekly Intake
RA	Risk Assessment
RAC	Committee for Risk Assessment
RCEP	Royal Commission on Environmental Pollution
REACH	Registration, Evaluation, Authorisation and restriction of Chemicals
RSPB	Royal Society for the Protection of Birds
SAICM	Strategic Approach to International Chemicals Management
SATs	Standard Assessment Tests
SBP	Systolic Blood Pressure
SCA	Swedish Chemicals Agency
SCF	European Commission's Scientific Committee for Food
SE	Standard Error
SEAC	The Committee for Socio-economic Analysis
SSSI	Site of Special Scientific Interest
SST	Shooting Sports Trust
TEL	Tetra-Ethyl Lead
UCL	University College London
UNEP	United Nations Environment Programme
USATSDR	SDR The Agency for Toxic Substances and Disease Registry
USFWS	U.S. Fish and Wildlife Service
VKM	Norwegian Scientific Committee for Food Safety
VMD	Veterinary Medicines Directorate
WG	Working Group
WHO	World Health Organization
WSSD	World Summit on Sustainable Development
WWT	Wildfowl and Wetlands Trust
δ-ALAD	AD delta-aminolevulinic acid dehydratase

APPENDIX 4

Conversion Factors used for Lead Concentrations

Concentrations of lead in tissues can be measured in different units. This section is provided to help the reader compare studies.

Unit	Symbol	is equivalent to	Conversion factor
parts per million	ppm	mg/kg & µg/g	1
milligrams per kilogram	mg/kg	µg/g & ppm	1
micro grams per gram	µg/g	mg/kg & ppm	1
micromols per kilogram	µmol/kg	ppm 207.2 X 1000	4.83
micromols per kilogram	µmol/kg	µmol/l	1
micromols per litre	µmol/L	µmol/dl X 10	10

Exact conversions

One decilitre = 100 mls

To convert mols to grams multiply by 207.2
(*i.e.* 1 mol = 207.2 g)

To convert grams to mols divide by 207.2
(*i.e.* 1 g = 0.00483 mols)

Micro (µ) = millionth, milli (m) = thousandth and deci (d) = hundredth

ppm=µg/g=mg/kg

Approximate conversions

One litre is approximately equal to 1kg for blood (1.05 kg but this is usually rounded up to 1 kg).

To convert soft tissue dry weight lead concentration to wet weight lead concentration divide by 3.1, and to convert soft tissue wet weight lead concentration to dry weight lead concentration multiply by 3.1.

To convert bone dry weight lead concentration to wet weight lead concentration divide by 4, and to convert bone wet weight lead concentration to dry weight lead concentration multiply by 4.