



# THE TRANSITION TO NON-LEAD AMMUNITION:

an essential and feasible prerequisite for  
sustainable hunting in modern society

Doctoral dissertation in Applied Ecology

2021

Niels Kanstrup





---

# **The transition to non-lead ammunition: an essential and feasible prerequisite for sustainable hunting in modern society**

Niels Kanstrup

Aarhus University, Department of Bioscience

# Data sheet

A dissertation submitted in fulfillment of the requirements for the degree of Doctor of Technology in Applied Ecology. 2021.

Title: The transition to non-lead ammunition: an essential and feasible prerequisite for sustainable hunting in modern society

Author: Niels Kanstrup

Institution: Aarhus University, Department of Bioscience, Kalø.

Contact: [nk@bios.au.dk](mailto:nk@bios.au.dk); +4520332999.

Please cite as: Kanstrup, N. 2021. The transition to non-lead ammunition: an essential and feasible prerequisite for sustainable hunting in modern society. A dissertation submitted in fulfillment of the requirements for the degree of Doctor of Technology in Applied Ecology. 450 pp.

Photos: Niels Kanstrup

Number of pages: 450

# Contents

<b>1</b>	<b>Foreword</b>	<b>5</b>
<b>2</b>	<b>Acknowledgements</b>	<b>7</b>
<b>3</b>	<b>Resumé på dansk</b>	<b>8</b>
<b>4</b>	<b>Summary</b>	<b>12</b>
<b>5</b>	<b>Introduction</b>	<b>17</b>
5.1	Wildlife management and footprint of hunting	17
5.2	Aim and objectives	19
5.3	Scientific and reference composition	20
<b>6</b>	<b>Background</b>	<b>21</b>
6.1	Definitions and scoping	21
6.2	Arms/firearms and their ammunitions	27
6.3	Destiny of ammunition parts	27
6.4	The lead problem (impact wildlife, ecosystems, humans)	28
6.5	Non-lead ammunition	48
6.6	Dispersal of other ammunition components	61
6.7	Regulations	66
<b>7</b>	<b>Transition</b>	<b>69</b>
7.1	Lead is not needed in ammunition	69
7.2	Availability of alternative ammunition depends on the demand	73
7.3	Lead ammunition is not sustainable	76
7.4	The precautionary principle applies	78
7.5	Role of stakeholders	80
7.6	An anti-hunting ploy?	87
7.7	Game meat	89
7.8	Transition tools	91
7.9	Transition benefits all	96
7.10	Target shooting	98
<b>8</b>	<b>Future perspectives</b>	<b>101</b>
<b>9</b>	<b>Conclusions</b>	<b>108</b>
<b>10</b>	<b>References</b>	<b>110</b>
	<b>Annex 1. Dissertation papers</b>	<b>135</b>

# 1 Foreword

This dissertation is a result of 35 years of professional advisory, research and practical experience within the field of wildlife management. It is the culmination of my work with lead in hunting ammunition.

Shortly after I was first employed by the Danish hunters in November 1985, the government issued its first regulation of lead ammunition on 24<sup>th</sup> December (yes, Christmas Eve) the same year. As a wildlife biologist employed by hunters, this issue was to become one of my core activities and interests. In the beginning, as someone with an academic background, my employer expected that I could make such an unpopular and “unnecessary” initiative disappear, ensuring that hunters could continue hunting unaffected by this irrelevant, external pressure to change.

Reality soon proved to be very different. Instead of lobbying against the governmental initiative, it became evident that my endeavour was to develop research and outreach programmes to ensure that hunters and their representative organisations would become pivotal in a strategy to integrate ammunition into a far broader concept of sustainability of hunting. From a modest beginning as a rather faint, lone, internal voice, my role developed into addressing national governmental and public audiences. My affiliation with international hunting and nature conservation communities enabled me to explore how the use of lead ammunition affected the perception of hunting as a sustainable activity, seen in the light of its direct impact on wildlife and ecosystems; not least given the contemporary progress made in society to remove human exposure to toxic lead where ever possible. During my presidency of the CIC Migratory Birds Commission and membership of the African Eurasian Waterbird Agreement (AEWA) Technical Committee (2001-2009), lead ammunition was an ever-present issue, where my role became that of an advocate for a rapid phase-out. This was achieved by reports, posters, oral presentations and practical demonstrations at multiple international gatherings, including conferences and workshops in beautiful places around the world such as Norway, Romania, Iran, Jordan, Senegal, USA and Argentina, just to mention a few.

In hindsight, it is perhaps unsurprising that, given this role, the organisations and lobbies whom I formally represented began to question my commitment as a true advocate of their interests. During this period, I was labelled a “Danish anti-lead activist” by the European ammunition makers, a community with close relationships to hunters. It became increasingly obvious that I needed to change my working position and with the establishment of the Danish Academy of Hunting in 2007 I achieved a platform to advise independently on all aspects of sustainable hunting and its effective implementation, including the issue surrounding the use of lead ammunition and possible transition to non-lead alternatives.

In 2017, I was invited to affiliate my business to Aarhus University and since then my activities concerning lead ammunition have become concentrated more strategically into the form of a research programme. This initially embraced projects to demonstrate the severe toxicological impacts of lead ammunition but has increasingly concentrated on demonstrating how we can successfully change to the use of non-lead and non-toxic alternatives to lead.

From this grew the title of this dissertation: “The transition to non-lead ammunition: an essential and feasible prerequisite for sustainable hunting in modern society”, indicating that not only is it *necessary* to shift from lead to non-lead ammunition but also that it is infinitely *possible*.

The purpose of the dissertation is described in more detail in later sections. However, in addition to the more prosaic submission of a body of academic work, it springs from a personal desire to remove an unnecessary source of poisoning of the environment, wildlife and humans. Here, lead poisoning of wild animals is particularly on my mind. This is not just because of the extra mortality that lead poisoning causes to wildlife populations, but at least as much because of the avoidable suffering that the poisoning inflicts on the millions of exposed wild animal individuals. Thus, the dissertation represents an expression of a personal deep passion and respect for wild animals - for these animals as individuals and collectively in strong and healthy populations.

The gathered experiences presented here are an important reminder that hunting needs to review its practices on a regular basis to ensure they align with current thinking, which, together with its broader sustainability, will safeguard its future acceptance in wider society.

Niels Kanstrup

May 2021

## 2 Acknowledgements

This dissertation is a personal endeavour. Most of it was written outside of professional work time i.e. private time that could alternatively have been invested in supporting my family. Therefore, I am deeply thankful to my wife, Anna, and my children, Johannes and Eva, for their understanding, indulgence, and support. Of similar indispensable value was the huge contribution of my colleague Tony Fox who was so kind not only to give critical technical comments to section drafts as they developed but gave the whole dissertation a much needed linguistic overhaul. I also owe great thanks to my colleagues Thorsten Balsby for his valuable contribution to much of the scientific work behind the dissertation and Hans Peter Hansen for support and critical discussion of elements demanding socio-economical expertise. Also, my colleagues Christian Sonne and Rune Dietz were of great importance due to their contribution to research projects and their strong encouragement to realize the whole project. Not least, I am grateful to Ole Hertel, Flemming Skov, and Aksel Bo Madsen the hierarchy of Aarhus University, Department of Bioscience, for providing the formal and practical institutional support to the project throughout.

From far across the sea, Vernon Thomas has been indispensable in his support of much of the scientific work behind the dissertation, in particular those elements related to law and management. I am also very grateful to many other international experts, not least the colleagues who supported the publication of the *Ambio* lead ammunition special issue in 2019 and who contributed to several joint publications. First and foremost these are Ruth Cromie, Debbie Pain, Rafael Mateo, and Jon Arnemo, but a huge thank you also to other co-authors and key-collaborators, including Melissa Lewis, Mariann Chriel, Marcela Uhart, Anna Trinogga, Carl Gremse, Oliver Krone, John Swift, David Stroud, Ian Dickie, Rhys Green, Mark Pokras, Sigbjørn Stokke, and Bo Söderström. Furthermore, I owe gratitude to my friend Tom Roster who has inspired the work from the very beginning and provided his great expertise and hospitality during my participation in his legendary research and education programmes.

In addition, I want to thank Kalø colleagues and external contacts for providing laboratory work, field assistance, technical support, dissertation layout and proofreading and other valuable contributions including Claus Lunde Pedersen, Lars Haugaard, Kavi Askholm Møllerup, Peter Mikkelsen, Preben Clausen, Jens Søndergaard, Karin Balle Madsen, Tinna Christensen, Anne Mette Poulsen, Poul Hartmann, Frank Vigh-Larsen, Dick Dyreby, Lars T. Andersen, Nicholai V. Knudsen, Eva K. Kanstrup, Johannes V. Kanstrup, Susanne and Lars Kjelgaard, Michael Johansen, and Charlotte Reenberg. Many individual hunters assisted with collection of data, and gun stores gave valuable information on ammunition.

Finally, I want to express my sincere thanks to 15. Juni Fonden, which provided extensive funding for many research projects that form the basis for the dissertation. The National Agency for Protection of the Environment and Danish Centre for Environment and Energy are also acknowledged for provided funding.

Many thanks to all for their great contribution and support!!!

### 3 Resumé på dansk

Denne afhandling er resultatet af 35 års virke som rådgiver, forsker og aktiv jæger. Den bygger på en syntese af de mange års arbejde, herunder forskningsresultater, der inden for emnet blyholdig og blyfri jagtammunition er publiceret bl.a. i form af de 26 artikler, der indgår i afhandlingen (Annex 1).

Arbejdet er en anerkendelse af vildtforvaltning som en central disciplin i moderne naturbevarelse. Vildtforvaltning er op mod 100 år gammel, og der er til stadighed behov for, at den udvikles i takt med det omgivende samfund. Vildtforvaltning har rødder i filosofien om bæredygtig udnyttelse af vildtbestande gennem jagt, og der har traditionelt været mest fokus på, hvordan jagt påvirker bestandene i form af effekten af den konkrete afhøstning og i mindre grad andre påvirkninger, herunder mere vedvarende og ofte negative konsekvenser. Samfundet stiller i stigende grad krav til bæredygtigheden af udnyttelse af naturressourcer som fx forståelsen af, i hvilket omfang naturlige systemer kan modstå eller tilpasse sig påvirkninger (resistens), og i hvilken grad de er i stand til at restituere sig efter en påvirkning (resiliens/reversibilitet).

Afhandlingen inddrager det faktum, at der ved jagt spredes ammunitionsrester, og at dette skal ses som en del af jagtens aftryk på naturen og økosystemerne – som en del af begrebet jagttryk, hvormed det bør indgå i vurderingen af jagtens bæredygtighed på lige fod med andre påvirkninger. Afhandlingen påpeger de alvorlige toksikologiske konsekvenser, der følger af spredning af bly fra den traditionelle anvendelse i jagtammunition. Det er afhandlingens formål at sætte dette i fokus, dokumentere problemer og løsninger og fremlægge forslag til en forvaltning, der kan sikre et effektivt skifte fra blyholdig til blyfri ammunition i alle forgreninger af jagt. Afhandlingen tager især afsæt i danske og europæiske forhold, men dens data, resultater og konklusioner har relevans overalt, hvor der udøves jagt med skydevåben, og skal ses som en inspiration til at håndtere andre beslægtede miljø- og naturforvaltningsudfordringer.

Bly er et vidt udbredt metal, som samfundet har gjort brug af i årtusinder. Næsten lige så lang tid har der været kendskab til stoffets giftighed, men det er først inden for det seneste halve århundrede, at samfundet af sundhedshensyn aktivt har søgt at udfase bly. Dette er sket, hvor det har været teknisk og politisk muligt, fx ved ophør med blytilsætning til benzin og maling, men i mange tilfælde først efter omfattende forskning og kampagner mod industriinteresser og lobbyisme. Ammunition, herunder til jagt, har traditionelt været fremstillet af bly, og ved affyring af ammunition spredes blyholdige ammunitionsdele til det omgivende miljø, hvor det er en kilde til forgiftning af vilde dyr og deres levesteder. Jagt er i dag den største enkeltkilde til spredning af bly i naturen. Ligeledes afsættes ammunitionsrester i byttedyret, hvor det er en kilde til forgiftning af konsumenter, uanset om dette er i de naturlige økosystemer, hvor ramte byttedyr eller rester heraf er fødegrundlag for rovdyr og ådselædere, eller der er tale om mennesker, der spiser vildtkød. Der har siden midten af 1800-tallet været kendskab til, at blyammunition fra jagt kan forårsage forgiftning af fugle, og over de seneste 70 år er omfanget af dokumentation for forgiftningsrisikoen vokset meget voldsomt baseret på forskning primært i Nordamerika og Europa. Ud over ophobningen af bly i det naturlige miljø medfører forgiftning fra ammunitionsbly øget dødelighed blandt både jagtbare og ikke-jagtbare ofte sårbare arter, hvilket kan påvirke disses bevarelsesstatus ufordelagtigt. Samtidig

medfører blyforgiftningen svækkelse og lidelse hos de enkelte dyr og har således betydelige negative dyreværns-mæssige konsekvenser.

Den fortsatte anvendelse af bly til fremstilling af ammunition bygger primært på traditionen herfor, og samtidig er der store kommercielle interesser i at bevare bly som ammunitionsmateriale. Ydermere er bly billigt og nemt at arbejde og anses for at have gode ballistiske egenskaber. Der findes dog for næsten alle brugsformer serieproducerede, markedsførte alternative ammunitionstyper, hvor bly er erstattet med fx jern, bismut og kobber, der er ugiftige, sikre og effektive. Ud over bly spredes der også andre materialer ved afgivelse af skud under jagt, og her er der især fokus på plastikkomponenter i haglpatroner, hvor materialet traditionelt har været polyætylen, men hvor der er bestræbelser på at erstatte disse med bionedbrydelige materialer, herunder både polymerer og fibre.

Forgiftning fra ammunitionsbly har været genstand for stor videnskabelig opmærksomhed, herunder talrige konferencer, og mængden af publiceret viden i form af enkeltstudier og kompilering af videnskab er meget omfattende. En række internationale organisationer har taget initiativ til at fremme udfasning af blyhagl til jagt, herunder AEWA (Den Afrikansk-Eurasiske Vandfugleaftale), som allerede i 1995 opfordrede medlemsstater til udfasning af blyhagl til jagt i vådområder i år 2000. Hovedparten af de europæiske lande har i dag gennemført regler for jagt med blyhagl i vådområder, men det generelle billede er, at reglerne kun kontrolleres og overholdes i begrænset omfang. Ligeledes adresserer de geografisk set isolerede regelsæt ikke problemet set i en større global kontekst, herunder fx på niveau af internationale forekomster af trækfugle. Senest har Europakommissionen besluttet udfasning af blyhagl til jagt i vådområder i alle medlemslande fra 2023, og kommissionen planlægger restriktioner også på blyhagl til jagt i andre økosystemer samt på bly i riffelammunition. En række lande uden for Europa har forbudt blyhagl til jagt i vådområder, fx USA og Canada. Kun Californien har et generelt forbud mod al blyholdig jagtammunition og dermed også riffelammunition. I Europa har kun Tyskland omfattende regulering af blyholdig riffelammunition, mens den danske regering har bebudet et indgreb med virkning fra 2023.

Forskning og erfaringer fra en række lande, der har gennemført regulering, har givet sikker vidnesbyrd om de gode muligheder, der er for at udfase bly. Især for blyhagl har de erfaringer, der er siden det totale forbud, som Danmark gennemførte i 1996, været genstand for stor opmærksomhed, herunder i forhold til både den praktiske anvendelse, forvaltningen, herunder overholdelse, og betydningen for bevarelse af jagt som en rekreativ aktivitet. Omfattende forskningsprogrammer i især Tyskland, Danmark og Norge viser, at blyfri riffelammunition både er sikker og effektiv. Blyfri ammunition er generelt til rådighed for jægerne til priser, der for de fleste typer er sammenlignelige med priser på traditionel ammunition. Øget efterspørgsel stimulerer produktudbuddet, der er størst i lande med regulering af blyammunition. For enkelte små våbenkalibre er udbuddet af blyfri ammunition fortsat begrænset, men også her forventes det, at øget efterspørgsel vil stimulere udviklingen af typer, der opfylder anvendelsesbehovet. På basis af denne del af afhandlingen konkluderes, at bly kan undværes som materiale i jagtammunition.

Dele af afhandlingen arbejder indgående med blyammunition i relation til de almene krav om bæredygtighed, som er opstillet for jagt som naturudnyttelse. Selv om nogle naturlige systemer har en vis indbygget resistens mod blyforurening, er det overordnede billede, at de fleste systemer påvirkes negativt og

vedvarende selv ved lave doser af eksponering. Mange naturlige systemer har god evne til at restituere, når en given belastning ophører (resiliens). For spredningen af bly i områder med intensiv jagt, hvor der fx i danske fugleområder er påvist en akkumuleret belastning med hagl svarende til 250 kg/ha, er der dog tale om en irreversibel belastning, der vil eksponere økosystemet i mange år frem, uanset at spredningen af denne type bly blev forbudt i 1986. En bredere vurdering tilsiger, at jagt, der unødvendigt baseres på et giftigt materiale, som samfundet bestræber sig på at udfase, hvor det i øvrigt er muligt, i omfattende grad udfordrer de krav, der politisk stilles til bæredygtig jagt. Ud fra dette konkluderes, at jagt med blyammunition ikke er bæredygtig.

En væsentlig årsag til, at blyammunition trods den omfattende dokumentation af dets giftighed og uforenelighed med bæredygtig naturforvaltning fortsat er det langt mest udbredte ammunitionsmateriale, er først og fremmest en svag regulerings- og kommunikationsindsats fra myndighedernes side. Et resultat heraf er, at jægere og andre borgere generelt er mangelfuldt inddraget i processen om udfasningen. Her har den primære målgruppe for kampagner og inddragelse frem for alt været NGO'er herunder særligt jagtorganisationer og repræsentanter for ammunitionsindustrien, hvor temaet i mange tilfælde er blevet genstand for interne politiske og kommercielle dagsordner. Initiativer til udfasning af blyammunition er i nogle tilfælde blevet kategoriseret som et angreb på jagten og jægerens rettigheder, hvilket har medført en udhuling af jægerens respekt for og dermed overholdelse af regelsæt.

Det er først i de senere år, der er kommet fokus på bly fra jagtammunition som en kilde til eksponering af mennesker, der spiser vildtkød, hvor der især er lagt vægt på risikoen for særligt udsatte grupper, fremfor alt børn og kvinder i den fødedygtige alder. Dette aspekt har accentueret behovet for en udfasning, fordi et afgørende element i evalueringen af jagtens bæredygtighed er, at byttet anvendes som en sikker føderessource. Samtidig er der i den europæiske befolkning en generel trend i retning af at udskifte konventionelt producerede fødevarer med mere naturlig frembragte produkter, hvor vildtkød af mange anses for at være et godt alternativ. I denne sammenhæng er det afgørende, at jægere som primærproducenter kan garantere for fødevaresikkerheden. Dette er for nylig kommet til udtryk i Storbritannien, hvor private fødevarekæder på eget initiativ har indledt en kampagne til at undgå, at vildt nedlagt med blyammunition optræder på markedet.

Udfasning af blyammunition til jagt er ikke effektiv uden centrale reguleringsindgreb på nationalt eller internationalt niveau. Nogle lande har iværksat forsøg på frivillige ordninger, hvor jægerne opfordres til skifte fra blyholdig til blyfri ammunition, men erfaringen viser, at frivillige systemer er ineffektive, og at selv lovindgreb har ringe effekt, hvis de ikke kan kontrolleres centralt, fx ved ikke kun at omfatte anvendelse, men også besiddelse og handel, sådan som det er tilfældet i Danmark. Ud over sådanne direkte indgreb findes der indirekte tiltag, herunder fx, som det foreslås i afhandlingen, fastsættelse af maksimumsgrænser for blyindhold i vildtkød svarende til de gældende grænser for andre kødprodukter.

Uanset typen og niveauet er det afgørende, at indgreb ledsages af grundig kommunikation og inddragelse af brugerne, herunder både befolkningen som sådan og jægerne som en central gruppe. Videnskab og almindelig logik tilsiger, at en forvaltning, der sikrer en overgang fra blyholdig til blyfri jagtammunition, over tid vil fjerne risikoen for eksponering af økosystemer, vildt og mennesker, og det er en generel konklusion, at dette vil være til gavn for

alle, herunder ikke mindst jægerne igennem en sikring af befolkningens langsigtede positive opfattelse af jagt.

Blyholdig jagtammunition er et simpelt miljøproblem, og en udfasning er, sammenlignet med løsning af andre miljøproblemer, ikke et særskilt komplekst emne. Blandt de perspektiver, som den fremtidige håndtering af emnet rummer, fremhæver afhandlingen behovet for en forstærket forskningsindsats på tværs af sektorerne, således at de sundhedsmæssige perspektiver i højere grad end tidligere anskues samlet for det naturlige miljø, økosystemerne, vildtet og mennesker. WHO-initiativet One Health er en åbenlys platform for at fremme en sådan udvikling. En styrkelse af en forskningsindsats på tværs af de klassiske naturvidenskabelige discipliner, samfundsvidenskab og teknologi synes ligeledes at være en væsentlig forudsætning for at sikre en effektiv, langsigtet og stabil overgang, herunder sikring af, at alternative ammunitionstyper til stadighed udvikles som sikre og effektive. Ligeledes er der behov for en langt mere effektiv informations- og kommunikationsindsats, hvor viden konverteres til visdom, hvor der i højere grad koordineres mellem de enkelte sektorer, og hvor der lægges vægt på betydningen af den enkelte borger.

Lykkes en udfasning, vil det ikke blot eliminere et miljøproblem og de afledte omkostninger, som dette har for samfundet, men også demonstrere, at natur- og vildtforvaltning har kapacitet til at tilpasse sig udfordringer, der opstår som følge af tendenser i et moderne samfund i hastig udvikling. Det vil medføre betydelige gevinster og samtidig skabe grundlag for en forbedret konstruktiv dialog mellem de institutioner, interessenter og enkeltpersoner, der arbejder for at fremme biodiversiteten og sikre mål for naturbeskyttelse og bæredygtighed.

## 4 Summary

This dissertation is the result of 35 years of work as a consultant, scientist and active hunter. It is based on a synthesis of many years of work, including research results that have been published on the subject of lead and non-lead hunting ammunition in the form of *inter alia* the 26 articles included in the dissertation (Annex 1).

The work is a recognition of wildlife management as a core element in modern nature conservation. Wildlife management has its roots in the philosophy of the sustainable exploitation of game stocks through hunting. While game management has traditionally focused most on how harvest affects the size of huntable stocks, it has paid less attention to some other adverse impacts of other features of hunting. Wildlife management is 100 or more years old and has a constant need to maintain pace with the changes occurring in society. Increasing societal awareness of the need for sustainability in the use of natural resources has also brought into focus the need for understanding the concepts of systems to be able to counteract the impact of perturbations (resistance) and the capacity of a system to respond to perturbations and recover after the source of change is removed (resilience).

The dissertation is based upon the fact that hunting disperses ammunition fragments in the environment. These fragments must be regarded as a part of hunting's footprint on nature and ecosystems and as such form part of the concept of hunting pressure. For this reason, it is essential to integrate the consequences of dispersing this material into the environment into the overall evaluation of hunting sustainability at the same time as assessing other impacts. The dissertation particularly identifies the highly toxic consequences of dispersing lead fragments into the natural and human environments through the traditional use of lead in hunting ammunition. The purpose of this dissertation is to put this contribution to the environment in sharp focus and document some of the problems that this material creates, as well coming forward with solutions to reduce environmental impacts and presenting proposals for management that, in particular, can ensure the effective change from lead to lead-free ammunition in all branches of hunting. The dissertation is mainly based on material gathered under Danish and European conditions, but these data, results and conclusions are relevant everywhere where hunting with firearms is practiced, and should also be seen as a means to deal with other, related environmental and nature management challenges.

Lead is a widespread and highly adaptable metal that society has used for millennia and its toxicity has been recognised for almost as long. Yet, it is only within the last half century that society has actively sought to phase out the use of lead, for example in petrol and paint, for human health reasons, and only after prolonged research and active campaigning against industries and lobbying. Ammunition, including that used for hunting, has traditionally been made of lead, and its use has spread the purified metal in the environment where it serves as a major source of poisoning for wild animals and constitutes a major contamination of their habitats. Hunting remains today the largest single source of dispersed lead in nature. Ammunition residues are deposited within the tissues of target quarry prey, where it becomes a source of poisoning for consumers, regardless of whether this occurs in natural ecosystems, where wounded or killed animals or their body parts end up as food

for predators and/or scavengers, or if it is humans who consume the contaminated game meat. It has been known since the mid-19<sup>th</sup> century that lead ammunition from hunting can cause poisoning of birds ingesting lead shot pellets, and over the past 70 years the legacy of evidence for the risk of poisoning has grown very rapidly based on research primarily carried out in North America and Europe. In addition to the accumulation of lead in natural environments, poisoning from lead ammunition has resulted in increased mortality among both huntable and non-huntable often vulnerable species, which can adversely affect their conservation status. At the same time, lead poisoning causes increased morbidity and suffering in the individual animals and thus has significant adverse animal welfare consequences.

The continued use of lead for the production of ammunition is based primarily on the tradition for doing so, reinforced by the inertia from the great commercial incentive to continue using lead as a basis for ammunition material. Furthermore, lead is cheap and easy to process and is considered to have good ballistic properties. However, for almost all uses, there are mass-produced, marketed alternative types of hunting ammunition, where lead has been replaced with, for example, iron, bismuth and copper, which are non-toxic, safe and effective. In addition to lead, other materials are also spread as a consequence of discharging weapons during hunting, and here the focus is especially on plastic components in shotgun cartridges, for which currently efforts are being made to replace these with biodegradable materials, including both polymers and fibers.

Poisoning from lead ammunition has been the subject of great scientific attention, including numerous conferences, and the amount of published knowledge in the form of individual studies, reviews and compilations is now very extensive, convincing and unanimous. A number of international organisations have taken the initiative to promote the phasing out of lead shot for hunting, including the African Eurasian Waterbird Agreement (an international treaty under the United Nations Environment Program's Convention on Migratory Species), which as early as 1995 called on member states to phase out lead shot for hunting over wetlands by the year 2000. Most European countries today have implemented rules for hunting with lead shot in wetlands, but the general picture is one where these rules are only controlled and complied with to a limited extent. Likewise, the patchy geographical implementation of differing levels of regulation fails to address the problem when seen in a larger global context, including, for example, the international flyway levels used by migratory birds. Most recently, the European Commission decided to phase out lead shot for hunting over wetlands in all member states from 2023 and is also planning restrictions on lead shot for hunting in other ecosystems as well as on lead in rifle ammunition. A number of countries outside Europe have banned lead gunshot for hunting in wetlands, such as the United States and Canada. At the global level, only California has a general ban on all hunting ammunition containing lead, including rifle ammunition. In Europe, only Germany has implemented extensive regulation of lead-containing rifle ammunition, while the Danish government has also announced a phase-out from 2023.

Research from a number of countries that have implemented regulation has provided reliable evidence of the experiences associated with the successful phasing out of lead. In the case of lead shot in particular, the experience gained since the total ban implemented by Denmark in 1996 has been the sub-

ject of much attention, both in relation to its practical use, management (including compliance) and the importance of sustaining hunting as a recreational activity. Extensive research programmes in Germany, Denmark and Norway show that lead-free rifle ammunition is both safe and effective. Lead-free ammunition is generally available to hunters at prices that for most types of hunting are comparable with prices of traditional ammunition. Increased demand stimulates the development of an appropriate product range, which is conspicuously greatest in countries that have already regulated the use of lead ammunition. For some small caliber ammunition types, the supply of non-lead alternative ammunition can still be limited, but here too it is expected that increased demand will stimulate the development of types of ammunition designed to meet all general needs. On the basis of this part of the dissertation, it is concluded that there is no longer any need for lead to play any role as a material incorporated into any form of hunting ammunition.

Sections of the dissertation work to evaluate to what degree the use of lead ammunition is compatible with general principles of sustainability, which are increasingly established by society for hunting as a form of utilisation of nature. Although some natural systems have a built-in resistance to lead contamination, the overall emerging picture is that most systems are adversely and persistently affected even at low doses of exposure to the toxin. Many natural systems demonstrate the potential to make a good recovery following the cessation of a given stressor (i.e. they show resilience to that stressor). In contrast, the historical legacy of decades of dispersed lead shot in one studied shallow Danish Special Protection Area subject to intensive waterbird hunting showed persistence of accumulated lead shot, corresponding to 250 kg/ha in the sediments, an irreversible toxic load that will continue to be accessible to waterbirds in that ecosystem for many decades into the future. Despite legislation banning the use of such lead shot within Denmark over wetlands since 1986, this poison remains active and accessible, underlining the legacy of the historical and unnecessary use of such a toxic material in an indiscriminate way, which conflicts with all commonly accepted definitions of sustainability. Based on this, it is clearly to be concluded that hunting with lead ammunition cannot be considered sustainable.

Despite the extensive scientific documentation of the toxicity of lead and its incompatibility with sustainable nature management, lead remains by far the most widespread material used to manufacture ammunition. Effective conversion of knowledge into action has been slow and sluggish. One major reason for this is the weakness of some of the responsible statutory authorities to effectively regulate and communicate the need for regulation to relevant stakeholders and citizens. As a result, hunters and other interest groups have generally been inadequately informed about and involved in the phasing out process. The main target groups for campaigns and involvement have primarily been the relevant NGOs, especially the hunting organisations and representatives of the ammunition industry, where the theme has become the subject of internal political and commercial agendas. In some countries, initiatives to phase out lead ammunition have been categorised as an attack on hunting and hunters' rights – perceived as an anti-hunting ploy – which has led to an erosion of hunters' trust in the process and ultimately in their respect for, and thus compliance with, rules and legislation.

Only in very recent years has focus centered upon the exposure of people to lead poisoning as a result of eating game meat containing hunting ammuni-

tion, with emphasis on risks to particularly vulnerable groups, especially children and women of child-bearing age. This aspect has accentuated the need for phasing out all lead in ammunition since fundamental for hunting to be a sustainable source of food is that harvested game represents a safe and healthy food resource. This is critical at a time when large sectors of European society are demanding more “naturally produced foods” as a reaction to the increasingly intensive animal production methods associated with industrialised farming. Seen in this context, game meat from animals that have had a free ranging and unhindered natural foraging life is considered by many to be a preferable alternative to battery farmed animals. In this context, it is increasingly important that hunters, as primary producers, can guarantee food safety quality standards. This issue has recently come to the fore in the UK where a major supermarket chain has launched a campaign on their own initiative to prevent game with lead ammunition from appearing in their shops, which naturally has major consequences across the entire game meat market.

The removal of lead from ammunition for hunting cannot be effective without key regulatory action at national or international level. Some countries have launched experiments by implementing voluntary schemes where hunters are encouraged to switch from leaded to unleaded ammunition, but experience inevitably shows that voluntary systems are ineffective. Studies show that legislative intervention also can be limited in effect if not policed and controlled effectively. For example, legislation must not only control the use of lead ammunition but also its possession and trade if it is ever to be truly effective, as was shown to be the case in Denmark. Furthermore, indirect measures can also be effective, including, for example, as proposed in this dissertation, setting maximum limits for lead content in game meat corresponding to the limits applicable for other conventionally farmed meat products.

Regardless of the type and level of regulation, it is crucial that it is accompanied by a comprehensive communication strategy and the involvement of stakeholders, recognising both hunters as the core group but also individual hunters and the wider population as a whole as key players in the wider issue. The results of field studies and simple logic lead to the conclusion that the transition from lead to non-lead hunting ammunition eliminates the risk of exposure and poison to ecosystems, wildlife and humans. Given this reality, the inevitable conclusion is that this process will benefit everyone, not least the hunters themselves, because implementation also creates a longer-term positive perception of hunting in the wider population.

Hunting ammunition containing lead is a relatively simple environmental problem to resolve, and its removal from use is not inherently complex compared to solving other environmental problems. Future perspectives emphasised in this dissertation include the need for intensified inter-disciplinary research efforts, incorporating human health with the welfare of the natural environment, the ecosystems, the wildlife and people, in a way not hitherto attempted. The WHO initiative One Health is an obvious platform within which to promote such development. Strengthening research efforts across the classical science disciplines, social sciences and technology is also an essential prerequisite for ensuring an efficient, long-term and stable transition, including mechanisms to secure the constant development of alternative ammunition types that are both safe and efficient. There is also a need for a much more effective promulgation of information and communication to convert knowledge to wisdom, to coordinate better between individual sectors, with greater emphasis on the importance of the individual citizen.

Successful phasing out of lead in ammunition will not only eliminate an environmental problem and the additional associated costs that this has for society, it will also demonstrate that nature and wildlife management has the capacity to adapt to new challenges that arise as a result of a modern society in rapid transition. It has the potential to bring significant benefits as a result of creating the basis for an improved constructive dialogue between the stakeholders working to promote biodiversity and ensure objectives for nature conservation and sustainability.

## 5 Introduction

### 5.1 Wildlife management and footprint of hunting

The science of wildlife management reaches back almost 100 years, when the term was first used and defined by the pioneer Aldo Leopold as *“the art of making land produce sustained annual crops of wild game for recreational use”* (Leopold 1933). Later authors redefined the term, e.g. *“...wildlife management involves much more than meeting the biological needs of wildlife. It also requires the management of human activities that affect wildlife and human use of the wildlife resources...”* (Gabrielson 1951), *“the art of making land produce valuable populations of wildlife”* (Bailey 1984) and *“the art and science of manipulating populations and habitats for the animal and for human benefit”* (Anderson 1991). There exists no single and global definition of the term. Its use, scope and interpretation differ widely between jurisdictions, national traditions, policies and stakeholder interests. The same applies to the word “wildlife”, which is also subject to many different working definitions (Arroyo et al. 2016). However, for the purposes of this dissertation, the Danish definition of wildlife will apply: Mammals and birds, including migratory birds, which naturally occur in Denmark.

Common to most definitions and interpretations of wildlife management is an implicit element of exploitation, whereby humans manage wildlife in a manner that enables the utilisation of natural wildlife resources, be it either consumptive or non-consumptive, recreational or commercial. One synonym for such exploitation is simply “use”, but there are range of other terms implying consumptive use with approximately the same meaning, one being “harvest” resulting, if successful, in a certain “yield” or “bag”. Wildlife resource use is a cornerstone of wildlife management in which the management of habitats plays an important contributory role. Although wildlife management figures prominently in national legislation in many countries, that legislation tends to shape wildlife management through regulation of use rather than through active enabling of mechanisms to maintain wildlife in a healthy state, such as by prescriptive habitat management. For example, while the Danish Act of Hunting and Wildlife Management sets as a target to *“maintain the quantity and quality of wildlife habitats [...] by establishment, re-establishment and protection of such habitats”*, the law in practice only regulates utilisation. Such regulations may be spatial (e.g. hunting rights, wildlife reserves, hunting-free zones) or temporal (e.g. open seasons, open days, open hours), or they may stipulate hunting methods (e.g. weapons, equipment, calls) (Kanstrup 2006 (**Paper 5**)).

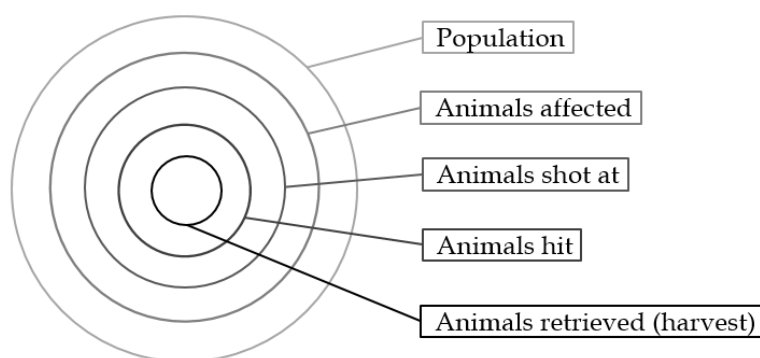
Not only does responsibility for the management of wildlife habitats generally lie outside wildlife management legislation, it is often heavily affected by other legislation, for instance that relating to agricultural, fishery and land use planning policy. This situation seems to be common to many other countries; indeed, it seems to be a general observation that most wildlife management policies are primarily concerned with regulation of the short-term element of the hunting footprint, i.e. that which is *removed* from wildlife populations and ecosystems in the form of the harvest.



Most wildlife management policies are primarily concerned with the short-term element of the hunting footprint in terms of what is removed from wildlife populations and ecosystems in the form of the harvest.

Another element of utilisation which is, however, poorly represented and assessed within the whole spectra of wildlife management is the longer-term impact of utilisation in terms of what such activity imposes on the ecosystems. In recent decades there has been some concern about hunting disturbance affecting individual behaviour, which ultimately affects their distribution and behaviour in time and space, as well as limits their utilisation of resources (Fox and Madsen 1997). In principle, this should be regarded as an ecosystem footprint left by hunting. The same applies to wounding, i.e. quarry animals that are hit, not instantly killed and ultimately not retrieved. From a strict biological viewpoint, wounding could be regarded as an add-on to the harvest, dependent on what level the wounding is lethal or non-lethal. However, as wounding implies animal suffering, it addresses the whole issue of hunting ethics and it should be regarded as an aspect of the ecosystem footprint of hunting. Kanstrup (2006 (**Paper 5**)) suggested hunting sustainability to be assessed with more refinement; thus, rather than just be evaluation of the harvest rate of the population, it should integrate other impacts of hunting, including animals affected by disturbance, indirect shots and wounding (Figure 5.1).

**Figure 5.1.** The gradient from all animals in the population (outer circle) to the animals that are harvested (innermost circle). In between lie the birds that are affected by the disturbance caused by the harvesting activity (circle 2 from outside), animals that are shot at indirectly or directly (circle 3 from outside), animals that are hit but not necessarily retrieved (circle 4 from outside). After Kanstrup (2006 (**Paper 5**)).



It is evident that harvest methods based on the use of firearms cause ammunition parts to be dispersed and left behind in natural habitats or in non-retrieved but hit quarry animals, and their associated ecosystems also represent an ecosystem footprint (Kanstrup and Thomas 2020 (**Paper 1**)). However, very few jurisdictions recognise this as a consequence of utilisation and in recent decades, only very few international and national bodies have shown a slightly increased awareness of the problem. The focus so far has mainly been on a subset of risks posed by the dispersal and deposition of toxic lead shot in wetlands, whereas the dispersal of lead shot in other habitats and the risks from the use of lead rifle bullets to humans, wildlife and the environment in general has, until very recently, been ignored (Mateo and Kanstrup 2019 (**Paper 2**)).

## 5.2 Aim and objectives

There is a need to focus more closely on the impact of hunting in terms of what this activity imposes on the natural ecosystems – its footprint. This is essential to develop tools and guidance to sustain hunting as an integrated, legitimate, and accepted part of modern society. This dissertation represents an approach to fulfil this need by highlighting the level of dispersal of toxic ammunition parts, namely lead-based gunshot and rifle bullets, and to a lesser extent other ammunition components into natural ecosystems. As an example (see later sections for more details): Bird hunting in Europe annually disperses up to 50,000 tonnes of shot, the vast majority of which at the time of writing is still toxic lead shot (ECHA 2019). Such shot causes poisoning of birds and is estimated to kill 1 million wildfowl per year in Europe as well as causing sub-lethal poisoning in another > 3 million (Pain et al. 2019). Dispersed lead shot persists and creates an enduring global toxic legacy, the cost of which is externalized to society (Kanstrup and Thomas 2020 (**Paper 1**); Pain et al. 2019 (**Paper 3**)). One lead-cored bullet may leave 4.5 g lead in a deer carcass after expansion on entry (Stokke et al. 2017) and cause contamination with up to 50 million lead nanoparticles per g meat (Kollander et al. 2017). Poisoning due to feeding on the remains of lead ammunition in deer carcasses and discarded gut piles is the most important cause of deaths (23% of mortality) in some populations of White-tailed Sea Eagle *Haliaeetus albicilla* (Kenntner et al. 2001).

These examples demonstrate that elements of what hunting leaves behind impact populations and individuals of wildlife on a level that may be comparable with direct harvest impacts. The need to address lead ammunition in particular in the context of wildlife management is further accentuated by the fact that whilst the harvest selects for a specific individual of a particular species,

poisoning from dispersed spent lead ammunition is highly non-selective and may cause adverse impacts on any species or any individual irrespectively of its conservation status (Kanstrup et al. 2018 (**Paper 4**)).

The objective of this dissertation is to define the nature and extent of the problem and its solutions with regard to our past use of lead in hunting ammunition and its effects on wildlife and their environment. It will also document and thereby contribute to a better understanding of the mechanisms that enable an effective transition from lead to non-lead ammunition from worked examples and to demonstrate that not only is such a transition feasible but essential to sustain hunting.

The chapter “Background” (Chapter 6) documents definitions, the persistent problems of the use of lead ammunition, the evident non-lead alternative ammunition types, and the regulations that have been enacted to create a change in behaviour. However, the essential section of the dissertation is the chapter “Transition” (Chapter 7), in which the multiple concerns that have been raised during the last four decades of discussion are addressed, and in which drivers and barriers to transition are identified. Much of this is based on the Danish history and experience of phasing out lead ammunition for hunting – a history in which the dissertation author has been an active participant in his capacity of being both a hunter, professional advisor and scientist. However, massive evidence from similar approaches in North America and multiple European countries also contributes to the narrative. Hence, the dissertation, its data, discussion and conclusions can apply to any geographical region with a tradition for hunting with firearms resulting in the dispersal of ammunition into natural ecosystems.

The dissertation is not about phasing out lead ammunition by phasing out hunting but about how hunting can become sustainable in the long term, primarily by severing its traditional connection to a highly toxic substance (Kanstrup et al. 2018 (**Paper 4**); Kanstrup and Thomas 2020 (**Paper 1**)).

### 5.3 Scientific and reference composition

The scientific composition and documentation of this dissertation consists of 26 peer-reviewed articles of central relevance for the work first-authored (17) or co-authored (9) by the dissertation author (Annex I and indicated as (**Paper x**) in bold in the text), other (18) articles first- or co-authored by the dissertation author and c. 250 other publications of relevance, the majority of which are peer-reviewed. All are included in the reference list (Chapter 10).

## 6 Background

### 6.1 Definitions and scoping

#### 6.1.1 Hunting

The word hunting is present in the Middle-English language spoken from late 10<sup>th</sup> until the late 15<sup>th</sup> century. The form *hunten*, (*v.* to hunt, some sources also: *huntian*) and several substantive forms, including *hunte*, (*sb.* hunter, also *honte* and *hunta*) *hunteresse*, (*sb.* huntress), *hunting* (*sb.*); and *huntinge*, (*sb.* on hunting, some sources also *a-hunting* or *on hontyng*) are documented (Mayhew and Keat 2003).

The original Anglo-Saxon meaning of the word in English was something rather different, i.e. the pursuit sport of hunting usually on horseback (e.g. fox hunting). Today, it is used widely in the international nature conservation language where it is generally taken to mean killing quarry (i.e. legally huntable) animals, usually with weapons. However, the word shooting is still widely used for certain types of hunting, e.g. Pheasant *Phasianus colchicus* shooting. In addition, stalking is used for the hunting of deer, wildfowling for hunting of waterbirds etc. A term with approximately the same meaning as hunting is present in many European countries, e.g. France (*chasse*), Spain (*caza*), Portugal (*Caçando*), Germany (*Jagd*) and the Scandinavian region (*Jakt* or *Jagt*).

The word hunting is a key word used 504 times in the dissertation. Therefore, the following definition and description are given. It applies to the entire text. When used in this dissertation, “hunting” means the activity of chasing wild mammals and birds with the intention of killing them for sport, food, commercial purposes, conservation and/or research. Killing implies the use of weapons defined here as a mechanism where a basic construction (the weapon) propels one or more projectiles intended to hit and kill the target animal. The scope of this dissertation is limited to hunting achieved with the use of firearms, i.e. guns, in which the release of energy from burning of a powder load propels a projectile or a load of shot pellets and, to a limited degree, to arms where the projectile is propelled by compressed air (air guns).

Hunting has been an integral part of man’s historical development as a source of food. In many countries, hunting remains a crucial source as part of the population's food supply, but in Denmark and other western countries, hunting over the past half century has developed to become almost exclusively a recreational leisure activity (Kanstrup 2006 (**Paper 5**); Kanstrup and Thomas 2020 (**Paper 1**)). Worldwide, hunting has many different facets and rests on diverse national and regional purposes and traditions. Thomas et al. (2021 (**Paper 26**)) defined three overall components of European hunting: (i) waterbirds hunting, involving mainly migratory species whose flyways extend beyond national boundaries, performed with traditional smooth-barreled shotguns, (ii) hunting of sedentary bird species and small-sized mammals in terrestrial habitats, performed with shotguns and in some cases small-caliber rifles (e.g. .22 LR with rim-fire), and (iii) larger game (in a European context typically from the size of Roe Deer *Capreolus capreolus* and larger), performed with centre-fired hunting rifles ranging in caliber from 5.6 mm (e.g. 222 Win) to 7.62 mm (e.g. 30-06) or larger, depending on target animal size. These categories probably apply to most continents and countries worldwide. Target

shooting (both competition and training) is widespread in many countries and traditionally performed with weapons and ammunition similar to hunting weapons. Such activities occur mostly at designated shooting grounds, some of which may be located in natural or semi-natural environments.

Roe Deer is a popular quarry species in most European countries and hunted with both shotgun and rifle.



In some cases, hunting is motivated by the need to eradicate individuals or control populations of wild species that cause harm to societal interests, whether it is in the interests of the economy, public health and safety, or conservation of biodiversity. The pursuit of wild animals has also changed character in pace with technological developments, where the equipment and tools have undergone a radical change. The first tools were simple nets, traps, snares and primitive thrown weapons. Over time, more sophisticated weapons were invented, with the development of the bow and arrow considered a turning point that radically increased the efficiency of the hunt. Firearms came to Europe in the 14<sup>th</sup> century and evolved over the next few centuries into effective tools for use in both war and wild animal pursuit. Throughout the 19<sup>th</sup> and 20<sup>th</sup> centuries, the modern types of firearms that are used for hunting today were developed. Although these weapons continue to be refined, there has been no radical development of the basic technology over the past 100 years.

#### **6.1.2 Hunting pressure – the sum of hunting impacts**

Hunting has an impact on populations, habitats and ecosystems. A commonly used term for the impact of hunting is “hunting pressure”, which is often conceptualized as the intensity of hunting in a given area, in some cases meaning the number of guns actively hunting in a given area measured, for example, as active hunters per hour per sq. km. In other cases, hunting pressure may be assessed from the level of hunting that migratory birds are subjected along a flyway from hatching place to winter quarters and back, measured in terms of number of guns encountered per population. However, hunting pressure

is poorly defined (Vajas et al. 2020) and commonly only related to the impact of hunting on populations, mostly harvest and hunting effort, and in some cases the impact caused by disturbance of individuals or populations by the hunting activity (access, traffic, noise) (Cromsigt et al. 2013). A search on relevant platforms identified no studies indicating that hunting pressure relates to the habitat or ecosystem in terms of wear, degradation, construction of infrastructure or dispersal of hunting ammunition parts.

To assess the sustainability of hunting, it is crucial to work from a concise definition of the impact of hunting. In this dissertation, the term hunting pressure defines the sum of hunting impacts on wildlife individuals and populations and their habitats and ecosystems, as illustrated in Figure 6.1, where the single slices (impacts) represent parts of the total hunting pressure.

$I_{\text{harvest}}$  is the impact of harvest, also named yield or bag, and is commonly assessed in terms of the number of specimens (perhaps identified from age and sex) killed and retrieved per year. If the population size is known, harvest can be expressed in terms of harvest rate, i.e. the percentage of a population that is harvested in a unit of time, typically per year. Harvest and harvest rates may be identified at a flyway, national, regional, local or district level.

**Figure 6.1.** The elements of direct impact of hunting that form the total hunting pressure.



For the harvested individual, harvest is fatal and the impact therefore complete. In terms of the population, harvest can be regarded quantitatively in the sense that it reduces the population size corresponding to the harvested number of individuals. If ecological, a sustainable harvest will not cause a long-term population decline because production will compensate for the harvest, often supported by density-dependent mechanisms (Gunnarsson et al. 2013). However, harvest may cause populations to be kept at a level below the carrying capacity. Depending on management objectives, this will be regarded to be either sustainable (if such harvest is a part of a management scheme for conflict wildlife species with a fixed acceptable population level, e.g. large carnivores, geese and invasive species) or unsustainable (if such harvest causes a long-term unfavourable conservation status for the species).

Harvest may also affect populations qualitatively in the sense that harvested individuals may be of particular importance for the population in terms of maintenance of social structures or sustain a pool of social experience and genes. This may impact the social survival and gene diversity and thereby the well-being of the population, in particular of longevity species with complex social structures as seen, for instance, in African Elephant *Loxodonta africana* (Archie and Chiyo 2012), Lion *Panthera leo* (Sogbohossou et al. 2014), Red Deer *Cervus elaphus* (Lone et al. 2015) and Geese *Anserini* (Gupte et al. 2019; Madsen 2010).

$I_{\text{wounding}}$  expresses the impact of wounding of game, which is defined as hit, not instantly killed and non-retrieved animals. If the animal dies from its wounds, the impact should be added to the harvest impact. If the animal survives, the wounding may cause lower probability of surviving or reproduction, hence the wounding may impact population parameters. The wounded animal may suffer from its wounds or be unaffected. Lost game including the uncertainty of the fate and eventual suffering of the lost individual – surviving or not – should always raise concerns about the ethics of hunting.

$I_{\text{disturbance}}$  quantifies the disturbance following the total hunting activity including the impact of any stimulus affecting huntable or not huntable wildlife. This may be visual (moving vehicles, people, approaching/chasing dogs); auditory (noise from vehicles, human voices, barking dogs, gun blasts) and/or olfactory (smell of people/dogs, fear pheromones from other animals, blood from killed/wounded animals). The impact of such disturbance may be direct in terms of animals to flush and thereby increase energy consumption and susceptibility to predation and accidents, or indirect as disturbance may alter behaviour in terms of increased shyness and increased flight distances and thereby reduce habitat utilisation (Boer et al. 2004; Fox and Madsen 1997).

$I_{\text{landscape}}$  expresses the impact of hunting on the landscape being subject to the hunting activity. This may have many different forms and be of short- or long-term influence, for example where the landscape and vegetation over years have been designed to sustain certain wildlife species and hunting practices, for instance, par force hunting<sup>1</sup>. Hunting may result in extensive traffic and in erosion of vegetation. Shooting hides, blinds and stands may be constructed for the single hunt. However, they are often placed more permanently and bear witness of the local hunting activity. The same applies to equipment to support local stocks of huntable species, including pens for release of game birds and feeding installations.

$I_{\text{ammunition}}$  includes the impact on ecosystems, wildlife and humans caused by the dispersal of ammunition parts (Kanstrup et al. 2019). Hunting stands apart from other forms of outdoor life activities in that it inevitably involves the dispersal of ammunition parts into the environment (Kanstrup and Thomas 2020 (**Paper 1**)). Some other activities may inadvertently cause the loss of foreign bodies in nature; thus, anglers may lose weights and jigs, and campers may drop cans and bottles. However, only hunting has the unavoidable consequence of dispersing gunshot, wads and bullets into the hunted ecosystems every time the trigger is pulled. The whole concept of this dissertation lays within the  $I_{\text{ammunition}}$  element of  $P_{\text{hunting}}$ .

<sup>1</sup> <http://whc.unesco.org/en/list/1469>

Shooting stands may be placed more permanently and represent an element of hunting pressure (landscape).



### 6.1.3 Sustainability/resistance/resilience (reversibility)

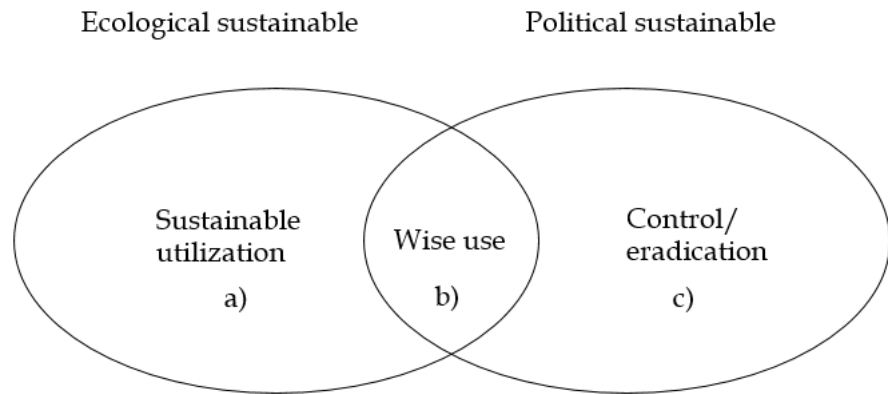
The term “sustainability” is widely used in the formulation of nature resource planning and management. As a descriptive concept, it defines relatively simple resource utilisation models based on population dynamics. However, as a normative concept, sustainability captures much more complex ideas of intra- and intergenerational justice when human survival and well-being depend on biodiversity capital and ecosystem services. Sustainability takes multiple definitions of which many are derived from the UN summit 1987, which defined development to be sustainable when it meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987).

The definition and practical implementation of sustainability of hunting began in Europe with discussions and the spirit of international dialogue and cooperation for conservation that prevailed after the Second World War. This was founded on recognition of research-driven conservation of wild species for their existence value as well as for the benefit of humankind. Many of those involved in drafting the text of, for instance, the 1971 Ramsar Convention on Wetlands of International Importance<sup>2</sup> and the ensuing multilateral environmental agreements (MEAs) came from a generation of hunter-naturalists. They ensured that principled hunting as a wise use of resources was based on the concept of hunters taking a sustainable harvest of a shared natural resource and, as such, this concept was firmly embedded within these treaties (Kanstrup et al. 2018 (**Paper 4**)). Sustainability often conceptualised in the structure of three pillars: environmental, economic and social (also described informally as planet, profits and people). To analyse the sustainability of harvest (hunting), Kanstrup (2006 (**Paper 5**)) condensed this structure to two pillars: ecological, and political (Figure 6.2), where “ecological” aspects were descriptive and strictly related to mathematically formulated potential harvest yields, and “political” aspects were normative and included all relations to society (economic, social, public perception of hunting relating to motivations for hunting) influenced by traditions, culture, ethics and a series of

<sup>2</sup> <https://www.ramsar.org/>

other societal elements and determined by what is “allowable” within a political region, typically a country, and within a given time period.

**Figure 6.2** Terms of sustainability. Fields of activities: a) ecologically, but not politically, sustainable harvest; b) ecologically and politically sustainable activities (“wise use”); c) politically acceptable activities that cause reduction or (local) extinction of populations according to clearly set goals. After Kanstrup (2006 (Paper 5)).



Throughout this dissertation, the understanding and interpretation of hunting sustainability is inspired by the 1987 UN definition of sustainable development, meaning that hunting, in general, is regarded as sustainable if it is planned and managed to meet the needs of the present without compromising the ability of future generations to meet their own needs. At the same time, the dissertation will address hunting sustainability in a simple structure of a descriptive “ecological” and a normative “political” pillar (Kanstrup 2006 (Paper 5)).

The “resistance” of a system to a perturbation is a measure of how much the system changes and to what degree the system is able to counteract the impact of such persistent perturbation. It is well established, although also recently disputed, that populations can resist harvest due to the mechanisms of density dependence (e.g. reduced mortality from non-harvest factors and increased productivity) released as a response to the harvest, thus removing or reducing the quantitative impact of the harvest for, for example, deer species *Cervidae* (Putman et al. 1996), duck, goose and swan species *Anatidae* (Gunnarsson et al. 2013) and gallinaceous bird species *Galliformes* (Bro et al. 2003; Willebrand and Hörnell 2001).

As to other hunting impacts,  $I_{\text{disturbance}}$  may be subject to rather strong resistance as individuals adapt in response to disturbance by changing behaviour, flight distances and habitat-related activity patterns, examples being Red Deer (Lone et al. 2015) and waterbirds (Fox and Madsen 1997). Such responses may suppress harvest rates and decrease the impact from the disturbance. Furthermore, it may change the spatial population distribution and reduce resource utilisation.

As poisoning from lead ammunition causes additional mortality in some populations, resistance to  $I_{\text{ammunition}}$  goes via the density-dependent systems as described for harvest if such systems are in function. In terms of lead poisoning of the individual specimen, some physiological resistance mechanisms may apply, for instance that lead is stored in hard tissues like bones and teeth where it is considered to be non-toxic because of its unavailability to other tissues (Wani et al. 2015).

“Resilience” is the extent to which a system can recover after the source of change is removed. This can also be regarded as the reversibility in a system.

Multiple examples show how populations display a strong resilience to the impact of harvest and overharvest, in particular to the quantitative elements of harvest, for example marine mammals (Kovacs et al. 2014), birds of prey (Mariano González et al. 2008) and geese (Fox and Madsen 2017). Resilience also relates powerfully to hunting disturbances as documented for, for example, waterbirds (Madsen 1998) and farmland birds (Casas et al. 2009), and the capacity for the landscape to support wildlife will regenerate when the impact from hunting ceases. If not maintained, a landscape designed and managed for hunting will be subject to natural vegetation succession and disappear although remains may be visible for a longer period. System resilience to the ammunition impact is covered later (sections 7.3).

Sustainability, resistance and resilience are interconnected. When considering the overall aim, which (as defined here) “*to meet the needs of the present without compromising the ability of future generations to meet their own needs*”, sustainability depends on the ability of a system to resist and recover from a perturbation.

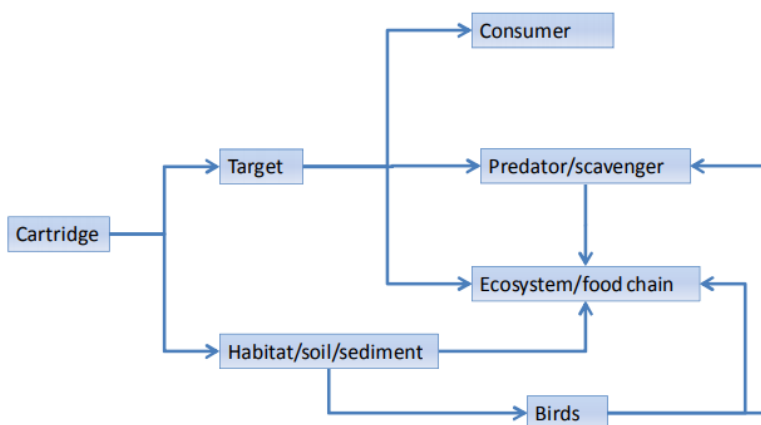
## **6.2 Arms/firearms and their ammunitions**

Hunting weapons of relevance to this dissertation are divided into two main categories: smooth-running shotguns (or shotguns), where the ammunition consists of single spherical pellets with a charge of 150-300 (c. 30 g) and hunting rifles firing a single projectile with a charge within the range 3-18 g for normal hunting in Europe. Ammunition for shotguns may also comprise a few large shot (buckshot) or a single projectile (slug).

In such firearms, on firing, the combustion of a gunpowder charge transfers kinetic energy to the charge of pellets or to the projectile being ejected. This energy is converted to two main components after firing: friction with the air and impact when it hits the prey. The energy on impact is decisive for the ability of the ammunition to penetrate and cause lethal injury in the target animal. The basic physical properties of the shot pellets or projectile are crucial, requiring high density and strength, with the result that metals, especially relatively high density metals, have proved to be the most suitable substances for ammunition. Lead has traditionally been considered to have the best physical properties for the manufacture of ammunition. Because it is easy to process and relatively inexpensive, it has, over time, been and remains today the dominant metal for the production of gunshot and rifle projectiles for hunting purposes (Kanstrup et al. 2021 (**Paper 6**); Kanstrup and Thomas 2019 (**Paper 7**); Kanstrup et al. 2016 (**Paper 8**)). Alternatives to lead ammunition are described in section 6.5.

## **6.3 Destiny of ammunition parts**

The destiny of gunshot and rifle bullets after a shot has been discharged has been visualised in many studies. An international workshop in 2009 defined it in a simple flowchart (Kanstrup 2009) (Figure 6.3, left), whereas Arnemo et al. (2016) depicted it in a pictorial abstract, both indicating the main routes of lead ammunition from the discharge of a shotgun or rifle to the toxic exposure of waterbirds ingesting lead gunshot and the remains of lead bullets in the carcass of a moose, exposing scavengers and other consumers to contamination (Figure 6.3, right).



**Figure 6.3.** The flow from dispersal of ammunition lead to ecosystems, wildlife and consumers. Sources: Kanstrup (2009) and Arnemo et al. (2016). See section 6.4.6 for more details.

## 6.4 The lead problem (impact wildlife, ecosystems, humans)

### 6.4.1 Lead facts

The basic chemical properties of lead are summarised in this box:

A chemical element, symbol Pb (plumbum)  
 Atomic number: 82  
 Specific gravity: 11.34 g/cm<sup>3</sup>  
 Melting point: 327.5° C  
 Four stable isotopes: <sup>204</sup>Pb, <sup>206</sup>Pb, <sup>207</sup>Pb, <sup>208</sup>Pb with relative abundances of, approximately, 1.5%, 24%, 22% and 52.5%;  
 Abundance-weighted average atomic mass: 207.2 amu  
 Valence: +2 or +4  
 Appearance: freshly cut: silvery/bluish, exposed to air: grey.

### 6.4.2 Lead use

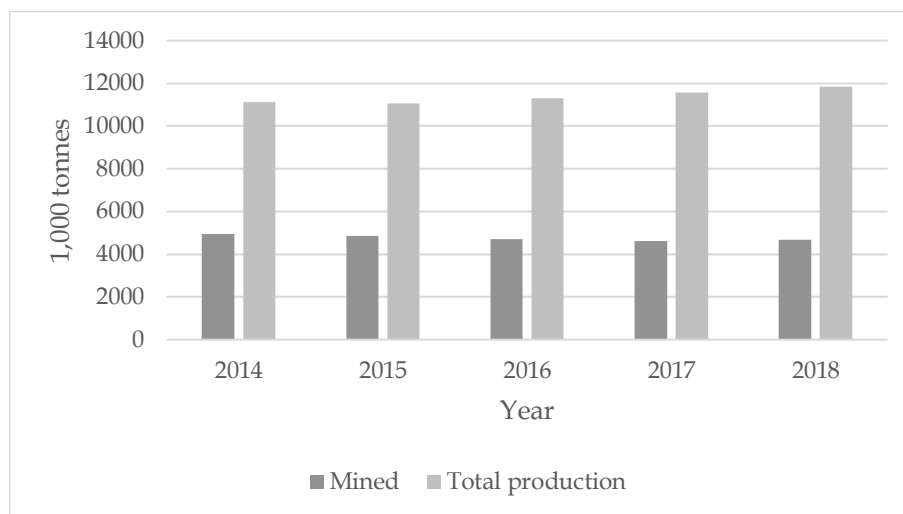
The high specific gravity, low melting point, malleability and resistance to corrosion has made lead very useful to human applications. These properties, combined with the relatively high abundance and low cost of lead, have resulted in its extensive use in, for instance, construction, batteries, weights, solders, pewters, fusible alloys, paints, gasoline, radiation shielding and, not least, ammunition in the form of bullets and shot pellets.

Lead is believed to be the first metal to have been won from its ores by humans (Nriagu 1983a) and its use dates back to early times. References are given to

mines as early as 7,000-6,500 BC (Ceracy and Cottingham 2010; Lessler 1988). The Old Testament mentions lead in the tale of Moses leading the out of Egypt (c 1250 BC): *"But you blew with your breath, and the sea covered them. They sank like lead in the mighty waters"*. Lead was widely used throughout antiquity, a fact well documented in several publications (Lessler 1988; Nriagu 1983a; Nriagu 1983b). However, lead production declined after the fall of the Roman Empire and did not reach comparable levels until the Industrial Revolution.

The present annual global production of lead is about eleven million tonnes. Lead is mined at a rate close to 5 million tonnes a year. Secondary lead production (recycling) accounts for slightly more than half of all lead produced (and an increasing proportion, Figure 6.4) (ILA 2019). Most lead is used in readily recyclable applications and, unlike many other materials, the value of lead makes recycling from most applications economically profitable and self-sustaining.

**Figure 6.4.** The global production of lead in the period 2014-2018.  
Source: ILA (2019).



### 6.4.3 Lead toxicity

Lead in its inorganic or organic form is a toxic heavy element in the environment, for which there is no demonstrated biological need (Wani et al. 2015). Poisoning of animals through exposure to lead is encountered with the greatest frequency of all metals (Thompson 2018).

Lead may enter the body by ingestion, inhalation or, more rarely, through the skin. The most common route of entry is by ingestion, although inhalation of lead fumes may play a larger role in industrial environments. Exposure to lead may arise from embedded shot, bullet or shrapnel fragments (Linden et al. 1982). When absorbed, lead enters into the bloodstream and accumulates in tissues or is excreted as waste. Some lead is absorbed into soft tissues, for instance the brain, liver and kidneys. Most of the absorbed lead is transferred to hard tissue (e.g. bone and teeth) where it accumulates. Lead can stay deposited in the body for many years after the exposure has stopped.

The recognition of lead poisoning in humans dates back to the Classics when Dioscorides (a Greek physician and pharmacologist) was said to have noted that *"Lead makes the mind give way"* (Koller et al. 2004). Later evidence of lead poisoning in humans is found in a dissertation on poisons by the Nicander of Colophon (a Greek physician) dating back to the 2<sup>nd</sup> century BC. He refers to

abdominal colic and nerve tremors associated with lead poisoning (Hernberg 2000). In the early modern period, Paracelsus (a physician, alchemist and astrologer) identified lead toxicity in what he called “the miner's disease” (Hernberg 2000). In the early 18th century, it was demonstrated “that potters who worked with lead became paralytic, splenetic, lethargic, cachectic, and toothless, so that one rarely sees a potter whose face is not cadaverous and has the color of lead” (Ramazzini 1713). In his “Famous Letter On Lead Poisoning”, Benjamin Franklin described the risk of lead poisoning of distillery and print-house workers and concluded “You will see by it, that the Opinion of this mischievous Effect from Lead, is at least above Sixty Years old; and you will observe with Concern how long a useful Truth may be known, and exist, before it is generally receiv'd and practis'd on” (Franklin 1786).

In the 1800s, documentation of the toxic impact of lead accumulated as the evidence was amassed, as evident, for instance, from the quote: “If we were to judge of the interest excited by any medical subject by the number of writings to which it has given birth, we could not but regard the poisoning by lead as the most important to be known of all those that have been treated of, up to the present time” (Orfila 1817). Some of the first modern clinical descriptions of lead toxicity became available in the early 1800s; for instance Tanquerel Des Planches in his book “Traité des maladies de plomb ou saturnines” (Des Planches 1839) gave a detailed description of the abdominal, neurological and arthritic aspects of lead poisoning. This publication was cited in the Danish Medical Journal (dk: Ugeskrift for Læger) in 1842 and one of the conclusions here was (author's translation): “All the lead compounds hitherto placed in prolonged contact with the human organs have been able to produce chronic lead poisoning, and it is thus to be assumed that this is a property of lead in any form” (Ahrensen and Kayser 1848), highlighted with yellow in Figure 6.5.

**Figure 6.5.** A Danish reference to some of the first modern clinical descriptions of lead toxicity (Ahrensen and Kayser 1848).

Blyet og dets forskjellige Præparater maae for at frembringe denne Sygdom og saaledes indvirke paa Organer, med hvilke de ikke fra først af have kunnet være i Berørelse, optages i Blodet; dette kan kun skee, naar de ere opløste eller i Dampform. De forskjellige Blypræparater ere næsten alle mere eller mindre opløselige i en Mængde organiske og uorganiske Bædster, og de fleste af dem kunne med Lethed, formedelst deres fiint fordeelte Tilstand, føres omkring i Luften, hvorimod det metalliske Bly, der vanskelig bringes i en saadan Tilstand, alene synes at være istand til at kunne fordampe. Blypartiklerne lægge sig saaledes i Støv eller Dampform paa de organiske Hinder, opløses i disses Bædster og absorberes af Haarkarrene. Alle de Blypræparater, som hidindtil ere satte i en længere Berørelse med de menneskelige Organer, have været istand til at frembringe den kroniske Blyforgiftning, og man maa saaledes antage, at dette er en Egenkab, Blyet besidder under hvilken som helst Form.

Later, modern research demonstrated the toxic and adverse impacts of lead on multiple other physiological functions, and today it is well established that there is probably no biological function or enzyme activity that is not affected by lead, even when appearing in only small concentrations. Body systems

particularly sensitive to low levels of exposure to lead include the hematopoietic, nervous, cardiovascular, reproductive, immune, endocrine and renal systems (EFSA 2010; Gidlow 2015; Wani et al. 2015). Concerns vary with the age, length of exposure and conditions of the poisoned individual, the most susceptible populations being young individuals, infants in the neonatal period and fetuses (Chandramouli et al. 2009).

Due to its capacity to interfere with biochemical processes in cells in the entire body, lead causes a wide spectrum of systemic adverse effects (Kosnett et al. 2007). Lead interferes with multiple biochemical processes in the body by binding to sulfhydryl and other nucleophilic functional groups, causing inhibition of enzymes and changes in the calcium/vitamin D metabolism. Neurotoxic effects of lead are well documented and relate to the ability of lead to replace and interfere with the action of calcium as a regulator of cell functions. The lead ion form  $Pb^{++}$  is of similar size and valence as  $Ca^{++}$ ; thus, lead is a potent reversible and selective blocker of voltage-dependent calcium channels at low concentrations (Büsselberg et al. 1993). Lead also contributes to oxidative stress in the body (Flora et al. 2012; Saxena and Flora 2004). Clinical signs of lead toxicosis vary with the individual and species involved, duration of exposure and amount of lead absorbed. They include neuropsychiatric effects, such as delayed reaction times, irritability, difficulty in concentration, and headache, and gastrointestinal effects like abdominal colic, involving paroxysms of pain. Lead interference with the hematological systems causes anemia. The health impacts of lead range from subtle, subclinical changes in function to symptomatic, life-threatening and lethal poisoning (Wani et al. 2015). Lead is classified as probably carcinogenic for humans by IARC (International Agency for Research on Cancer)<sup>3</sup>.

Multiple scientific reviews and co-authored books on the biochemical interference, the pathophysiology and the toxicology of lead are available, of which some date back to the late 1800s and several are recent (Ahamed and Siddiqui 2007; Goyer and Clarkson 1996; Grandjean 2013; Hernberg 2000; Juberg 2000; Kosnett et al. 2007; Markowitz 2000; Nriagu 2009; Rutishauser 1932; Sachdeva et al. 2018; Tscherkess 1925; Wani et al. 2015).

Several societal effects of lead poisoning of humans have been documented, including evidence that lead levels directly affect property and violent crime rates (Bellinger 2008; Grandjean 2013; Nevin 2007; Stretesky and Lynch 2004). An elevated blood lead level in childhood causes reductions in IQ test scores, cognitive skills and occupational status in adulthood (Bellinger 2008; Grandjean and Landrigan 2014; Lanphear et al. 2005; Reuben et al. 2017). Studies have suggested that for every 10  $\mu\text{g}/1\text{dl}$  increase in blood lead, there is a loss of 4–7 IQ test scores (Winneke et al. 1996). In a systematic review, Apostoli et al. (1998) found that concentrations of blood lead  $> 40 \mu\text{g}/\text{dl}$  seemed to be associated with a decrease in sperm count, volume and motility, thus suggesting adverse effect on male fertility. Lindbohm et al. (1991) found that there may be an association between paternal lead exposure and the risk of spontaneous abortion.

The blood lead level (BLL, common unit:  $\mu\text{g}/\text{dl}$ ) is the most commonly used biomarker for lead exposure in humans (Sakai 2000). Several studies have

<sup>3</sup> <https://www.iarc.fr/>. Webpage of the International Agency for Research on Cancer

documented the magnitudes of concentrations associated with possible health impacts. Gidlow (2015) reviewed and summarised data from the existing literature and concluded that  $BBL < 5 \mu\text{g/dl}$  represents background levels which cause no risk of health impacts, but that  $5\text{--}10 \mu\text{g/dl}$  cause possible impacts like hypertension, kidney dysfunction and spontaneous abortion. At levels of  $11\text{--}20 \mu\text{g/dl}$ , the risk expands to *inter alia* possible subclinical neurocognitive deficits, reduced birth weight and postnatal developmental delay. At  $21\text{--}29 \mu\text{g/dl}$ , hypertension and kidney dysfunction are evident, and subclinical neurocognitive deficits and spontaneous abortion are possible. At  $30\text{--}39 \mu\text{g/dl}$ , clinical neurocognitive deficits become possible and the risk of spontaneous abortion is evident. At levels from  $40$  to  $79 \mu\text{g/dl}$ , major bodily dysfunctions become evident and development of lead-related symptoms like anemia and pain is common. At lead levels exceeding  $80 \mu\text{g/dl}$ , all health impacts, including also gout and severe brain damage (encephalopathy), are very likely. Levels above  $100 \mu\text{g/dl}$  are regarded to be fatal (see Gidlow (2015) for details).

In his book “Only one chance”, the Danish MD and professor Philippe Grandjean concludes “.. *lead as brain drainer number one*” (Grandjean 2013) – a conclusion not far away from what Dioscorides was quoted as saying 2,200 years earlier: “*Lead makes the brain give way*”.

Up to the 1990s, it was assumed that low levels of exposure to lead would not have significant adverse effects on human health. However, this was followed by increasing recognition that thresholds below which exposure was safe could not be determined. In 2010, the CONTAM Panel (Panel on Contaminants in the Food Chain) concluded that the current provisional tolerable weekly intake of  $25 \mu\text{g/kg}$  body weight was no longer appropriate as there is no evidence for a threshold for critical lead-induced effects (EFSA 2010), as concluded also by Grandjean (2010) and in the context of lead ammunition summarised by Green and Pain (2019).

Lead poisoning is often regarded as a “silent epidemic” because the early clinical symptoms are non-specific and commonly confused with those of other diseases. However, several cases of acute lead poisoning of humans are documented, including among paint workers (Gordon et al. 2002) and 17 stranded Norwegian sealers who died from lead poisoning in Kapp Thorsden, Spitsbergen during the winter of 1872-73, probably from food tins with a high lead content (Aasebø and Kjær 2009).

Buekers et al. (2009) reviewed 19 studies of adverse impacts of lead exposure of wild mammals and birds, including impacts on growth, reproduction and hematology and using BLL as index of exposure. The study suggested a critical BLL at  $18 \mu\text{g/dl}$  for mammals and  $71 \mu\text{g/dl}$  for birds based on the 5<sup>th</sup> percentile of the “no observed effect concentrations”.

#### **6.4.4 Lead in ammunition**

Lead has been used in ammunition since Antiquity when used for the production of egg-sized and football-shaped sling bullets (often with sarcastic inscriptions meant to insult the receiving enemy). Since then, leaded ammunition has undergone an enormous technical development aimed to maximise the highest rate of propulsion from firearms, long-range precision and impact.

Lead gunshot pellets are spherical balls consisting mainly of lead but also of other elements, including antimony, arsenic and tin. Traditionally, some types

of lead shot pellets have been coated with a layer of nickel in order to enhance surface hardness to protect the shot against deformation.

Modern bullet construction is sophisticated and designed to optimise internal, external as well as terminal ballistics. In reality, pure lead has poor physical properties to fulfil the demands made upon ammunition. Lead is mainly used as a component to enhance mass and expansion capability to optimise terminal impact in terms of energy and transfer of energy into injury and killing efficiency. Several other elements are added to leaded ammunition, including antimony, copper and zinc. Antimony has the ability to harden lead and, together with a copper/zinc (gilding metal) jacket surrounding the lead core to protect the bullet during the internal and external ballistics, controls the bullet performance in the terminal impact. A large variety of lead-based bullets are available, including full-jacket types and highly sophisticated constructions that integrate the jacket and lead core to control expansion (bonded bullets). Depending on construction, the lead content of modern hunting bullets is approximately 75%, the remaining being primarily copper and zinc. Bullets based on tin and tungsten are also produced and marketed (see later).

#### **6.4.5 Lead ammunition's toxicity on wildlife and humans**

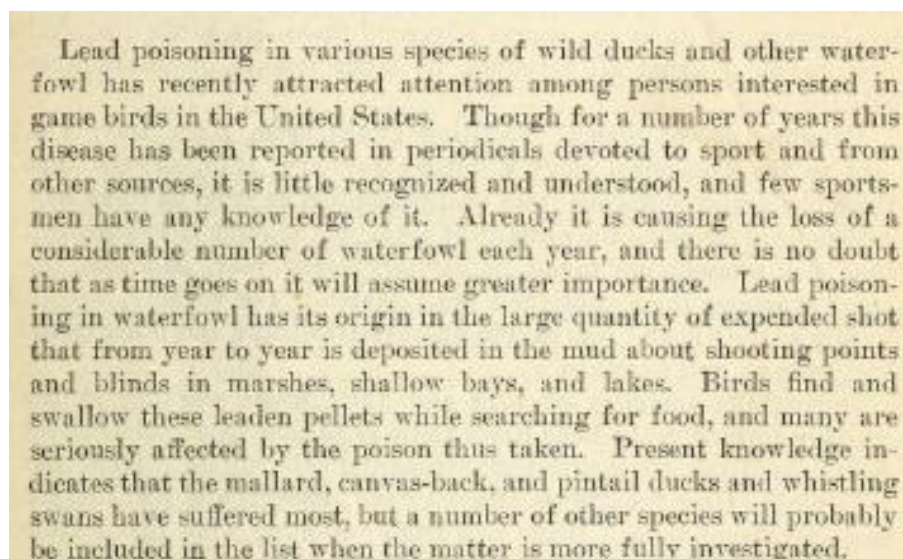
The adverse impacts of lead on humans described above apply, in principle, to any living organism. The toxic effects are the same, although there may be differences in sensitivity among species and differences related to diet, sex, behaviour and age of individuals (Thomas et al. 2015 (**Paper 9**)). However, it was not until the early 1900s that the focus widened to include also the risk of lead poisoning of non-human organisms. Some concern was raised about lead poisoning of domestic animals, including cattle, horses and dogs (Aronson 1971; Thompson 2018). Poisoning of cattle is usually a result of a single ingestion of a material containing a large quantity of lead but can also be caused by a long-term ingestion of crops or pasture contaminated by lead from industrial sources (Aronson 1971).

It is well established that wild animal species rarely encounter lead from natural sources but rather are exposed to lead remains arising from human activities including industrial and domestic uses like paint, mine tailings, garbage dumps and contaminated sediment or water (Arrondo et al. 2020; Chin-Chia et al. 2020; de la Casa-Resino et al. 2014; Gil-Jiménez et al. 2020). However, the primary source of lead contamination in wildlife is through consumption of lead from spent hunting ammunition in the environment and there is growing evidence that this source also poses a risk to human consumers of game meat (Kanstrup and Thomas 2020 (**Paper 1**)). Evidence for the poisoning of wild species as a result of lead gleaned from ammunition sources is overwhelming (Kanstrup et al. 2019).

The threat of lead from hunting to poison wildlife was first recognised in the US more than 120 years ago (Calvert 1876; Grinnell 1894). In 1919, Alexander Wetmore, an assistant biologist in the U.S. Biological Survey, in a professional paper published by the United States Department of Agriculture, published the first thorough scientific study of lead poisoning in waterbirds based on his own research and with reference to published reports on waterbird poisoning in the decades prior to Wetmore's work (W.S. 1919; Wetmore 1919). The details in Wetmore's introduction (Figure 6.6), including his prediction of lead poisoning to assume greater importance "*as time goes on*", are striking and his documenta-

tion in subsequent sections of the symptoms, post-mortem appearance of poisoned ducks, results of experimental work and estimation of prevalence of shot in marsh areas deserves all credit and needs no single revision or adjustment seen in the light of the subsequent massive accumulation of supporting evidence amassed to the present. Wetmore even predicted similar ingestion of lead shot by upland birds species and assessed the potential for sub-lethal impacts: *“A point that may develop greater importance than the direct killing of individual birds by lead is the effect that lead may have upon the constitution and bodily functions of birds that do not actually succumb to its poisonous properties”*.

**Figure 6.6.** Section of Wetmore's article in 1919 (Wetmore 1919).



Lead poisoning in various species of wild ducks and other waterfowl has recently attracted attention among persons interested in game birds in the United States. Though for a number of years this disease has been reported in periodicals devoted to sport and from other sources, it is little recognized and understood, and few sportsmen have any knowledge of it. Already it is causing the loss of a considerable number of waterfowl each year, and there is no doubt that as time goes on it will assume greater importance. Lead poisoning in waterfowl has its origin in the large quantity of expended shot that from year to year is deposited in the mud about shooting points and blinds in marshes, shallow bays, and lakes. Birds find and swallow these leaden pellets while searching for food, and many are seriously affected by the poison thus taken. Present knowledge indicates that the mallard, canvas-back, and pintail ducks and whistling swans have suffered most, but a number of other species will probably be included in the list when the matter is more fully investigated.

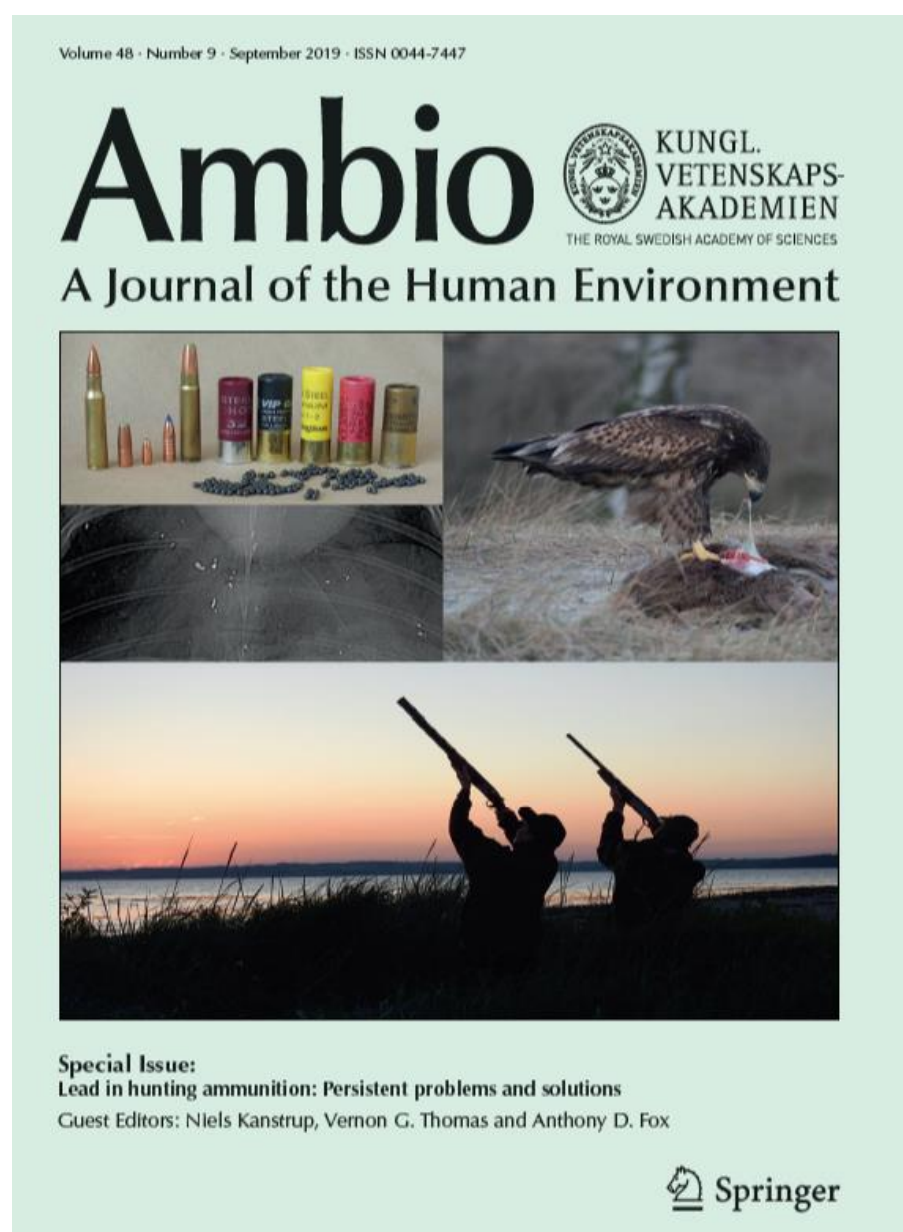
In his famous and very well-cited publication “Lead Poisoning as a Mortality Factor in Waterfowl Populations” (Bellrose 1959), the American scientist Frank C. Bellrose gave a review of accounts of lead poisoning in North America, some dating back to as early as 1874, with more cases reported from the 1890s and an increasing number in the 1920s and 1930s. Nineteen more “recent” (in the time perspective of Bellrose) reports from the period 1938-1957 were summarised for each of the four major North American waterbird flyways, all documenting the species (ducks, geese and swans) affected and the number of birds lost relating to number of birds present (mortality rates of < 0.5%–10.9%).

Bellrose's work from the 1950s revolutionised research in waterbird lead poisoning in North America (Feierabend 1983; Sanderson and Bellrose 1986; Sanderson and Havera 1989) and also generated concerns in Europe (Mateo 2009), for instance in Denmark where research programmes were initiated in the 1960s and 1970s (Clausen and Wolstrup 1979; Kanstrup 2018 (**Paper 10**)). In a literature review of scientific papers dealing with the environmental and health consequences of the use of lead in ammunition, Arnemo et al. (2016) isolated 570 peer-reviewed papers published during 1975-2016 and found that more than 99% of them raised concerns over the use of lead-based ammunition. The annual number of articles published showed a strong increase over the period covered. Research programmes were supplemented with international gatherings of experts to discuss the phenomenon, as for instance the workshop convened by the International Waterfowl and Wetlands Research Bureau 1991 from which the proceedings (Pain 1992) became of particular importance. A major review was undertaken by The Wildlife Society in 2008 (TWS 2008). The same year, The Peregrine Fund addressed the implications of lead from spent ammunition for both wildlife and human health (Watson

et al. 2009). Further documentation came from a symposium held at Oxford University 2014 resulting in 384 pages of proceedings (Delahay and Spray 2015). A major compilation of evidence on problems connected to ammunition lead was presented by Kanstrup et al. (2019) (Figure 6.7,) including both new research papers and summaries of key conclusions from earlier reviews updated with results from the substantial literature published during 2015-2019 (Kanstrup et al. 2019 (**Paper 24**)).

While the initial concerns more than 100 years ago were targeted at waterbirds ingesting lead gunshot, the perspective of the problem has widened in concert with the growing body of strong evidence showing that lead gunshot has more serious adverse consequences than formerly appreciated for multiple wildlife species. These include predators and scavengers consuming meat from animals with elevated tissue lead levels or containing either lead gunshot or fragments of lead rifle bullets (Pain et al. 2019). Furthermore, studies have shown that human consumption of shot game meat is an additional source of lead exposure and concomitant human health risks are featured in several recent compilations (Arnemo et al. 2016; Delahay and Spray 2015; Green and Pain 2019; Watson et al. 2009).

**Figure 6.7.** Front cover of the Ambio Special Issue (Kanstrup et al. 2019) – the most recent compilation of evidence of adverse impacts of lead in ammunition used as a key reference, for instance for the 2020 European Scientists' Open Letter on the Risks of Lead Ammunition (European Scientists 2020).



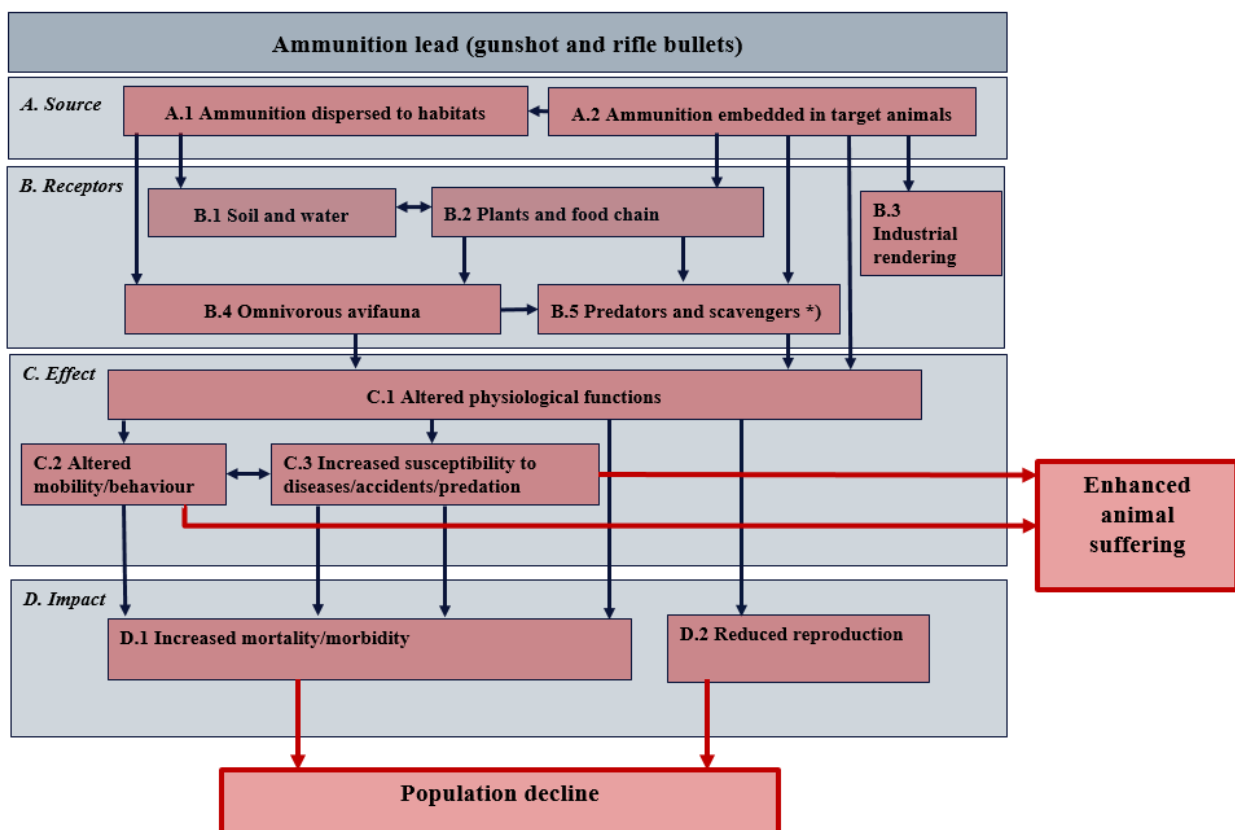
The majority of evidence for the adverse impacts of lead from hunting ammunition has been generated in North America and Europe. However, documentation is available from multiple other regions including South East Asia (e.g. Japan; Ishii et al. (2020)), Oceania (e.g. Australia; Hampton et al. (2018)), Africa (e.g. South Africa; van den Heever et al. (2019)) and South America (e.g. Argentina; Ferreyra et al. (2015)).

The issue has been subject to several consensus statements and open letters from scientists supporting elimination of the use of lead-based ammunition and its replacement with non-toxic alternatives (Bellinger 2013; European Scientists 2018; European Scientists 2020; Group of Scientists 2014). In 2020, a group of 10 scientists and others who are hunters with extensive experience of the issues surrounding the use of lead ammunition and shooting in Europe, issued a fact sheet for non-hunting decision makers detailing the key points about the importance of switching to non-lead ammunition including practical aspects of the use of alternatives (Hunting Experts 2020).

#### 6.4.6 Dispersal, effects, impacts and consequences

Figure 6.8 demonstrates the main route of lead ammunition from the source to ecosystems, wildlife and ecosystems. This section gives a more detailed review of the single steps and refers to Figure 6.8.

#### AMMUNITION LEAD – DISPERSAL, EFFECTS, IMPACTS AND CONSEQUENCES

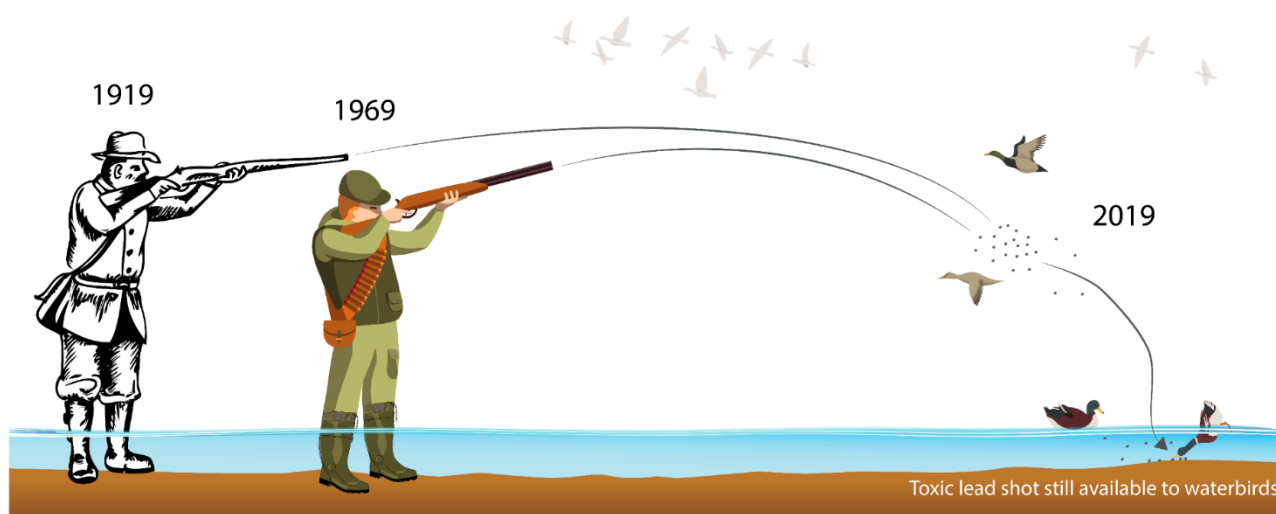


**Figure 6.8.** Summary of dispersal, effects, impacts and consequences (the two red-framed boxes) of lead gunshot and rifle bullets used for hunting. The following text documents the single steps in the flowchart and gives references to some unique historical research and to the most recent documentation.

## A. Source

### A1 Ammunition dispersed to habitats.

Hunting stands apart from other forms of outdoor life in that it involves the dispersal of ammunition parts in the hunted habitat and environment (Kanstrup and Thomas 2020 (**Paper 1**)). In the case of normal gunshot, a load normally consisting of c. 30 g (150-300 shot pellets) is dispersed every time the trigger is pulled. Cartridge consumption per hit target animal varies considerably depending on the skills of the shooter, the shooting distance and quarry size and speed. For shot gunning, the cartridge consumption in a single shooting episode ranges from 1.5 to > 10 shots per hit bird (Haas 1977; Noer et al. 2001; Pierce et al. 2015). Only a small proportion of the pellets are likely to hit and be retained in a killed animal, e.g. for Mallard *Anas platyrhynchos*  $\leq 1\%$  (Cromie et al. 2010); thus,  $\geq 99\%$  are dispersed to the hunted habitat. According to industry figures, approximately 21,000 tonnes of lead from shotgun cartridges used in hunting are dispersed annually into the environment in the European Union (27), although some estimates indicate that the tonnage is probably significantly higher (AMEC 2012; ECHA 2018; Tukker et al. 2006). If this amount of lead shot was evenly dispersed into the entire European Union surface, it would correspond to addition of one shot (c. 130 mg) per 40 m<sup>2</sup> per year. However, the dispersal is highly uneven and concentrated to hunted areas with particular high dispersal in hunting hotspots (Figure 6.9) (Kanstrup et al. 2020 (**Paper 14**); Mateo 2009). The most recent update on shot densities in European wetlands is given by Pain et al. (2019), confirming densities of > 300 shot/m<sup>2</sup> in hunted areas and documenting also densities > 1,000 shot/m<sup>2</sup> in wetlands in the vicinity of shooting ranges.



**Figure 6.9.** In some hunting hotspots, lead shot densities are comparable with those measured 40 years ago and 33 years after regulation of the use of lead shot. Present densities of lead shot exceeded 200 shot/m<sup>2</sup> corresponding to > 250 kg shot/ha. Most shot was in the upper 10 cm of the sediment and thus still accessible to waterbirds (Kanstrup et al. 2020 (**Paper 14**)).

Compared to gunshot, a much larger proportion of rifle bullets hit the target. The hitting rate may be rather high, for instance in deer stalking > 95% (Aebischer et al. 2014), or relatively low in driven hunts where the target animals are more mobile. Unpublished data from hunting of European Elk *Alces alces* in Norway suggests that the average consumption of rifle bullets per bagged animal was c. 1.5 and depending on shooting distance and speed of

the target animal (Sigbjørn Stokke, pers. comm<sup>4</sup>). Furthermore, the weight of the single bullet is less than the weight of a gunshot load (< 4 g for small calibers, e.g. .222 Rem, and > 10 g in larger, commonly used calibers, e.g. 30-06 Springfield) and, in addition, in most countries, the total number of harvested animals shot with rifles is considerably lower than those harvested with shotguns. Therefore, the total dispersal of lead from rifle ammunition is much lower than the tonnage of lead from gunshot. Nevertheless, it is estimated that more than 150 tonnes of lead are dispersed annually into the environment in the European Union by hunting with lead bullets (ECHA 2018).

Depending on bullet construction, part of each projectile will stay in the target in the form of fragments of visible sizes down to nanoparticles (Kollander et al. 2017) (see next section), whereas a major part of the bullet core normally will pass through the target animal body and become embedded in the natural vegetation, soil or sediment.

It is well documented that lead ammunition embedded in human body tissues can be mobilised and cause health effects. Recent studies suggest that the same applies to wild animals such as deer (previous gunshot wounding) and vultures (rifle bullets) (in Pain et al. (2019)).

#### *A2 Ammunition embedded in target animals*

The number of gunshot pellets retained in a target animal after the hit depends on several factors, including precision of the shot cloud, shooting distance, shooting angle, animal size and anatomy, shot load and velocity, and shot size. Even a killing shot does not necessarily leave gunshot embedded in the target animal as pellets may pass through the target animal body. For small target animals, the average number of embedded shot per target may be less than one, for instance among Mourning Doves *Zenaida macroura* (Pierce et al. 2015). Andreotti et al. (2016) found 3.6 lead shot per bird in harvested Woodcock *Scolopax rusticola*. In a sample of pheasants, the average was c. 5 shot per bird (Kanstrup, unpublished), and in Roe Deer an average exceeding 30 embedded shot per animal was documented by Strandgaard (1993). Lead shot normally fragment during penetration of the target animal tissue and leave traces of both invisible and visible particles (Andreotti et al. 2016; Pain et al. 2010). Kanstrup (2012 (**Paper 12**)) found that the lead concentration in a sample of Pheasant breast meat penetrated by six lead shot was 0.122 mg Pb/kg compared to below 0.0033 mg Pb/kg in a control sample.

Owing to the softness of lead, lead bullets including shotgun slugs normally fragment on impact into a cloud of small pieces (Hunt et al. 2009; Kanstrup et al. 2016 (**Paper 13**); Kollander et al. 2017; Wilson et al. 2020) and thereby cause lead metal deposition in the tissues of the hunted animal. The target animal may, depending on size and hunting circumstances, be hit by more bullets, for instance 1.4 per European Elk (Stokke et al. 2010). The total deposit of lead in the animal carcass may be substantial, for instance 3.0 g and 2.6 g for lead-core and bonded lead-core, respectively (Stokke et al. 2017). This study estimated, based on the harvest of 166,000 Elk in Fennoscandia during the 2013/2014 hunting season, that lead-based bullets deposited 690 kg of lead in moose carcasses. If projected to the 2012 harvest of Wild Boar *Sus scrofa* given for 18 European countries by Massei et al. (2014), these estimates correspond to an annual deposit of 5-6 tonnes of lead in carcasses of this game species in

<sup>4</sup> Sigbjørn Stokke: sigbjorn.stokke@nina.no

these countries. Fewer studies have been made on small rifle calibers, for instance .22 LR and .22 and .17 airguns that are also used for hunting in some countries. However, McAuley et al. (2018) demonstrated the significant impact that lead ammunition in this caliber can have on lead concentrations in meat by showing that the mean lead concentration was 0.968 mg/kg in impacted compared to 0.013 mg/kg in non-impacted breast meat from harvested Ruffed Grouse *Bonasa umbellus* and Spruce Grouse *Falcipennis canadensis*.

Decomposition of discarded remains of harvested animals (see below) and of hit, but non-retrieved, target animals also constitutes a source of particles of metallic lead (shot and bullet fragments) in the environment.

## **B. Receptors**

### *B1. Soil and water*

Metallic lead is rather stable and dispersed lead ammunition may remain almost intact in the exposed areas for a very long period. Kanstrup et al. (2020 (**Paper 14**)) found present densities of lead shot in a Danish hunting hotspot equivalent to > 250 kg lead per ha to be comparable with densities detected in the 1970s, despite a phase-out of lead shot during the 1980s and high compliance rates at least since 2000. Other studies investigating pellet degradation in natural environments have demonstrated that lead gunshot pellets remain unchanged for considerable periods of time and complete decomposition of particulate lead likely takes tens or even hundreds of years (Kanstrup et al. 2020 (**Paper 14**)). However, over time and depending on soil characteristics such as temperature, moisture, substrate chemistry and biotic functions (Rooney et al. 2007; Sullivan et al. 2012), lead ammunition may dissolve and a significant portion of metallic lead from spent gunshot thereby becomes bio-available in the soil (Migliorini et al. 2004). Most studies on lead ammunition in soil and water have been performed at shooting ranges and have demonstrated elevated lead concentrations in soils (Cao et al. 2003) as well as long-term leakage of lead into nearby watercourses, the latter presenting, though, a low risk of contamination of groundwater (Clausen et al. 2011; Okkenhaug et al. 2018). In a small-scale pilot study, Kanstrup (2019, unpublished) found lead concentrations of 4.9 mg/kg (dw) in sediment at a hunting hotspot with densities > 250 lead shot per m<sup>2</sup> compared to 2.5 and 2.8 mg/kg at two control sites. These concentrations were regarded as being below background levels for the actual sediment, although just below the critical level of lead permitted in agricultural soil for food production (Schupp et al. 2020). However, further research on the long-term contamination of sediment and the associated ecosystems from this source of lead should be carried out at a larger scale and include also determination of lead concentrations in the communities of plants and invertebrates.

Lead ammunition embedded in tissues of the hunted animal may ultimately contaminate soil and water when such tissues decompose and disperse into the natural ecosystem (box A.2 via B.2 to B.1 in Figure 6.8). The tissues may come from different sources, including hit but non-retrieved animals that die, offal from killed animals left by the hunters after gralloching and remains (head, feathers, skin, bones and tissues around the wound channel) discarded into natural habitats after the butchery of carcasses. These sources and routes are poorly investigated but appear to be of minor importance in terms of their ultimate dispersal into soil and water.

The Mute Swan *Cygnus olor* is one of the omnivorous bird species at highest risk for ingestion of lead gunshot when foraging in shallow wetlands holding a legacy of gunshot from hunting activities.



### *B2. Plants and food chain*

Decomposition of tissues from target animals will result in increased tissue availability in successive links in the food chain. Lead ammunition in soil and water may also be assimilated by plants and transferred to the food chain (Cao et al. 2003; Migliorini et al. 2004). Contamination from dispersed lead shot pellets was suggested as a potential source of the elevated levels of lead in fish from the Spanish Tablas de Daimiel National Park floodplain (Fernández-Trujillo et al. 2021).

### *B3. Industrial rendering*

While single hunters commonly discard offal from killed animals in nature, by-products from large-scale hunting events, such as game bird shooting and driven hunts organised by professional outfitters, are commonly handled by industrial rendering plants that are supplied with game by-products directly from the hunting district or via a game handling establishments. The true volume of such material handled by this industry is poorly documented. It is commonly recognised that the dressing weight of Cervidae is c. 50% (Janiszewski et al. 2015; Kay et al. 1981); thus, half of the harvested mass of game animals may ultimately be processed as by-products. Kanstrup and Balsby (2019 (**Paper 15**)) documented that only the breast meat from Pheasant was processed for consumption, so the remaining carcass (> 85% by weight) was discarded at a Danish game handling establishment and from there subsequently delivered to an industrial rendering company. The end products of this industry include protein feed for domestic animals, soap and biofuel. The levels of lead ammunition in such products have been little studied and are poorly documented. However, given that the shot/carcass ratio is generally low in such material to begin with and that the lead concentration levels of are diluted even further after mixing with other, non-contaminated by-products from multiple other sources, it seems likely that lead in end products constitutes a minor risk to downstream and end product consumers/users. This aspect is not further investigated in this dissertation. However, it could be a subject of further research.

#### B.4 Omnivorous avifauna

There is overwhelming support for the suggestion that ammunition-derived lead is the major contributor to elevated concentrations of lead in the tissues of wild birds. Birds are highly susceptible to the ingestion of dispersed gunshot pellets along with or in confusion with food items, for example seed, or simply as grit items. This applies in particular to species with an omnivorous and opportunistic diet, which forage intensively in habitats where gunshot is heavily dispersed and not densely vegetated, including most species of dabbling ducks (Anatinae) for which there is abundant documentation of their susceptibility to ingestion of lead gunshot.

However, there is evidence from other omnivorous bird species, including other waterbirds and terrestrial bird species such as Phasianidae (Figure 6.10), of the widespread ingestion of gunshot (Pain et al. 2019). Ingestion rates are affected by the density of accessible shot in the feeding habitat, availability, composition of natural grit and diet. It is commonly accepted that rates of shot ingestion are higher in granivores, which ingest more grit of a larger size, compared to herbivorous waterbirds (Green et al. 2000; Mateo et al. 1998; Mateo and Guitart 2000).

**Figure 6.10.** Pheasant carcass showing the gizzard with ingested shot (17 bismuth and 1 steel) and the embedded shot that killed the bird (all steel). From Kanstrup and Balsby /2019 (**Paper 15**).



Rates of shot ingestions are commonly expressed in terms of *prevalence*, i.e. the percentage (%) of sampled birds with one or more ingested shot pellet in the digestive tract

$$p = 100 (N - N_0)/N$$

where N is the sample size and  $N_0$  is the number of birds in the sample with zero ingested shot. In general, prevalence may vary between zero and 50%; for instance, for Northern European populations of Mallard, average prevalence was assessed to 3.6% (Mateo 2009), although extreme values have been reported for some species, e.g. 70% for Pintail *Anas acuta* (Mateo et al. 2013). In a recent Danish study of Mallard, the prevalence was 9.6% (hereof 81.8% only with non-lead shot) (Kanstrup and Balsby 2019 (**Paper 16**)).

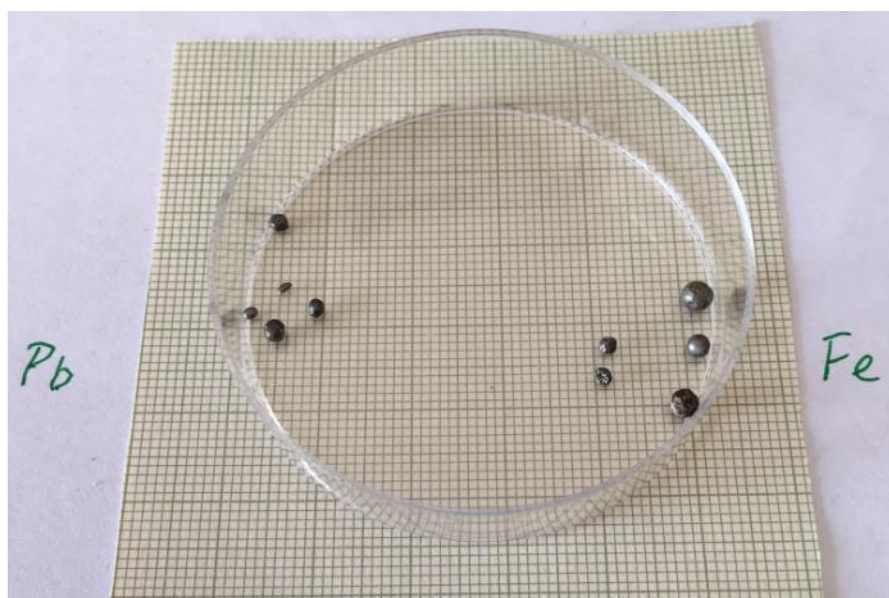
Prevalence does not integrate the presence of more than one ingested shot pellet per gizzard. To extend the quantification of shot ingestion, the *incidence*

of shot levels ( $i$ ) is used to define the number of gizzards with 0 ( $i_0$ ), 1 ( $i_1$ ), 2 ( $i_2$ ), 3 ( $i_3$ ) etc. ingested shot (Bellrose 1959). To assess the total exposure of a sample/population, Kanstrup and Balsby (2019 (**Paper 16**)) defined *occurrence* ( $o$ ) as the average number of ingested shot per bird in the total sample

$$o = \left( \sum_{n=i_0}^{n=i_{\max}} N i \right) / N$$

and found that  $o$  in a sample of mallard of which the majority of ingested shot was steel shot was 0.32 compared to 0.17, 0.08 and 0.07 in three historical studies of Mallard with only ingested lead shot. This difference was expected because high incidences of lead shot levels elevate the probability of mortality; accordingly, the potential for high occurrence is more pronounced in birds having ingested non-toxic shot. However,  $o$  (and prevalence) also depends on the degradation rate, which may also differ among shot types, although this is very poorly elucidated to date (Kanstrup and Balsby 2019 (**Paper 16**)). Figure 6.11 shows 5 lead and 5 steel shot removed from a single mallard gizzard. A degree of degradation/deformation can be seen in both types.

**Figure 6.11.** Lead and steel shot removed from a mallard gizzard during the laboratory work in the project by Kanstrup and Balsby (2019 (**Paper 16**)). Degradation is obvious for both shot types, but relative degradation rates are poorly studied.



#### B.5 Predators and scavengers

Predators and scavengers are exposed to lead ammunition when ingesting remains of metallic lead embedded in discarded offal from killed animals or in the carcass of non-retrieved animals wounded with lead ammunition (both lead bullets and gunshot) (Bassi et al. 2021; Monclús et al. 2020). At least 5–6 million gut piles from deer and boars may be discarded annually throughout Europe (Thomas et al. 2020 (**Paper 17**)).

A typical “snowstorm” of bullet fragments in the backside shoulder of a killed Red Deer, where the bullet left the body. The core part of the bullet was not retained in the animal; however, a rather large fragment of the jacket was stopped by the skin.

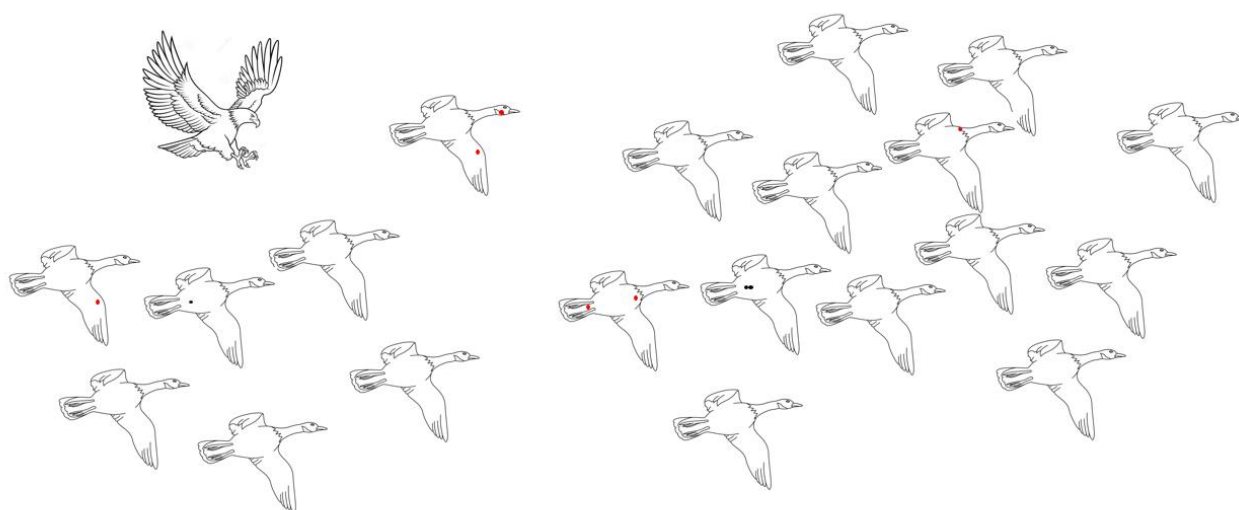


This pathway includes ingestion by predators and scavengers of avian prey with ingested lead shot or bullet fragments in their digestive tract (in some cases assessed from monitoring the density of ammunition in regurgitated pellets (e.g. Gil-Sánchez et al. (2018))). As a result of non-lethal hits (wounding) during previous hunting attempts, many prey animals (small game, both birds and mammals) have gunshot embedded in their tissues without this seriously affecting their survival and/or behaviour. Terminology and definitions vary slightly among studies. However, most recently “crippling rate” was defined by Clausen et al. (2017) as the number of animals with one or more embedded shotgun pellets divided by the number of animals examined (x-rayed); hence, it is an expression of the prevalence of inflicted animals in a sample and thus in the investigated population (depending on the representativeness of the sample). Their study found an approximate crippling rate of 20% in the Svalbard-breeding population of Pink-Footed Goose *Anser brachyrhynchus* in the years from 2002 and onwards. Noer et al. (2001) used the term “pellet carriers” with a similar definition and found this to be 14.9% for Mallard examined in 2001. Holm and Madsen (2013) found average infliction rates in first year and older Barnacle Geese *Branta bernicla* examined in 2009 to be 5.7% and 13.3%, respectively. Furthermore, their study found that the number of pellets in crippled first year geese ranged between 1 and 2 (average 1.5) and in older geese between 1 and 4 (average 1.3). Similarly, Falk et al. (2006) found an average of 1.8 shot in inflicted Common Eider *Somateria mollissima* in a Greenlandic sample investigated in the period 2000-2002. Based on crippling rates and data on average numbers of embedded shot in crippled animals, the number of embedded shot per animal in the total sample can be calculated as an analogue to the occurrence of ingested shot (see above). An

example: If the crippling rate in the population  $P$  is 20% and the average number of embedded shot in crippled animals is 1.5, the occurrence of embedded shot is 0.3.

Most populations of huntable animals – and in some cases also protected species (e.g. Newth et al. (2011)) – carry a significant but often disregarded load of ingested and embedded gunshot, which is a potential source of ingestion to predators when such animals are preyed upon. Although lead shot has been substituted with non-toxic shot ammunition under some jurisdictions, it is still the most widely used shot type, meaning that this source of poisoning continues to constitute a risk to predators and/or scavengers when inflicted animals finally succumb to other causes of mortality, including lethal impacts of the infliction. These populations are “polluted” in the sense that they represent a pool of a toxic substance available to predators and scavengers. For migratory species, including millions of waterbirds, this pool is constantly on the move, constituting a source of unforeseeable pollution independent of national borders. An illustrative example is given in Figure 6.12.

Another mechanism of poisoning comes from predation or scavenging upon prey animals with elevated lead levels due to their own primary ingestion of gunshot, for example omnivorous bird species. Such prey may be in the form of carrion or alive prey of which some may be moribund or suffer from sub-lethal impacts of lead poisoning, making them more susceptible to predation (see also C.3).



**Figure 6.12.** A figurative illustration of the exposure of birds of prey to ingested and embedded shot in their prey based on empirical data from published evidence: a flock ( $n=20$ ) of an arbitrary avian prey species with ingested shot (black dots; occurrence=0.15 (10% with pellets, average number 1.5)) and embedded shot (red dots; occurrence=0.3 (20% with pellets, average number 1.5)), in this case amounting to 6 birds bearing shotgun pellets out of 20 birds accessible to the bird of prey. The figure illustrates something of the “lottery” faced by the attacking eagle, i.e. the differential risk of choosing a prey infected or not infected with shot. Infected birds may show abnormal behaviour and be an easier prey than uninfected birds, hence the probability of the predator to choose an infected bird is larger than the prevalence of birds with shot (in this example 30%).

The pathways taken by lead ammunition to poison predators and scavengers have been well documented, for example for birds species such as California Condor *Gymnogyps californianus*, White-Tailed Eagle, Stellers Eagle *Haliaeetus pelagicus*, Golden Eagle *Aquila chrysaetos* and the Tasmanian Wedge-Tailed Eagle *Aquila audax fleayi* (Church et al. 2006; Ishii et al. 2020; Kenntner et al. 2001;

Madry et al. 2015; Pay et al. 2020, Menzel et al. 2021), just as evidence is emerging also for contamination of mammalian predators and scavengers (reviewed by Pain et al. (2019)).

From a strictly biological standpoint, humans *Homo sapiens* can be regarded as predators and/or scavengers when consuming game meat and they therefore suffer the same risk of contamination as described for wildlife species exposed to lead ammunition, including residues from both gunshot and rifle bullets in the consumed meat, especially among people regularly consuming large amounts of game in their diet (Iqbal et al. 2009; Johansen et al. 2006; Knutsen et al. 2015; Lindboe et al. 2016; Ertl et al. 2016). Several studies document the risk of gunshot becoming stranded in the appendix, including one Danish study that found the mean blood lead level in patients with retained lead gunshot to be 11.4 µg/dl or almost twice the mean level in controls (Madsen et al. 1988). The exposure of lead from ammunition to human consumers was reviewed by Green and Pain (2019) who found that “*approximately 5 million people in the European Union may be high-level consumers of lead-shot game meat and that tens of thousands of children in the European Union may be consuming game contaminated with ammunition-derived lead frequently enough to cause significant effects on their cognitive development*” (see later sections). Recently, Wilson et al. (2020) found clear indications that both wildlife and humans may ingest lead fragments from White-tailed Deer *Odocoileus virginianus* hunted with lead shotgun slugs just as Tammone et al. (2021) provided evidence of lead exposure risk in consumers of culled invasive alien mammals in El Palmar National Park, Argentina. Sevillano-Caño et al. (2021) concluded that game animals showing high number of impacts (lead pellet strikes), would not be suitable for consumption and would need to be discarded.

## C. Effect

### C.1 Altered physiological function.

The biochemical interference, the pathophysiology and the toxicology of lead are briefly described in section 6.4.3 along with key source references. In summary, lead adversely affects the nervous system (e.g. causing encephalopathy, neuropathy, palsy, slow motor conduction, brain dysfunction), the hematopoietic system (e.g. inhibition of blood ALAD, heme synthesis, reduced erythrocyte survival, anemia), the renal system (e.g. chronic nephropathy and renal failure) and the cardiovascular system (increased capillary permeability). The evidence of these effects originates primarily from human health and medical science, but it applies to all vertebrates, including wildlife species (reviewed in Eisler (1988)), and was recently documented for birds of prey by Descalzo et al. (2021).

### C.2 Altered mobility/behaviour

Signs of sub-lethal lead exposure mainly documented for birds include reluctance to fly, loss of balance, wing drop, green diarrhea, loss of muscle tissue and fat reserves, lethargy and convulsions (Friend and Franson 1988; Pattee and Pain 2003). These symptoms cause altered mobility and behaviour. Acute exposure to high levels of lead causes birds to die rapidly without such signs.

### C.3 Increased susceptibility to diseases/accidents/predation

Lead causes reduced immunocompetence and a higher susceptibility to pathogen incidence and, furthermore, reduced bone mineralization and, in consequence, increased bone fragility (Gangoso et al. 2009; Scheuhammer and Norris 1996; Vallverdú-Coll et al. 2015). The most comprehensive and recent

study on the immunotoxic effects of lead on birds was done by Vallverdú-Coll et al. (2019), who found that lead can impact the avian immune system and thereby reduce the resistance to infection.

As a consequence of both altered mobility/behaviour (C.2) and the high risk of suffering from diseases caused by lead, poisoned animals are more susceptible to accidents as demonstrated, for instance, for Golden Eagle (Ecke et al. 2017). Also, the sub-lethal effects of lead poisoning reduce the ability of the animals to escape predators (Friend and Franson 1988), thereby enhancing the risk of predation, including enhanced susceptibility to hunting. Pain et al. (2019) give a thorough review and update on this aspect.

## **D. Impact**

### *D1. Increased mortality and morbidity*

As a result of the lethal effects of very high lead contamination and the elevated susceptibility to diseases, accidents and predation at lower levels, lead-poisoned animals suffer increased mortality. This was documented very early by Bellrose (1959), who estimated the annual loss caused by lead poisoning of the North American population of waterbirds to range between 2 and 3%. Based on the same methodology (proportions of birds with different numbers of ingested gunshot, turnover rates of gunshot in the intestines and mortality rates recorded in laboratory studies), Andreotti et al. (2018) estimated that 700,000 individuals of 16 waterbird species die annually in the European Union (EU28) (6.1% of the wintering population), that 1 million waterbirds across Europe (7.0%) die from acute effects of lead poisoning and that a threefold number, equivalent to > 2 million waterbirds, suffer sub-lethal effects. Less precise estimates are given for bird taxa other than waterbirds. As a very preliminary assessment extrapolated from the mortality in waterbirds, ECHA (2018) suggested that 1 to 2 million terrestrial birds also die from lead poisoning every year.

### *D2. Reduced reproduction*

In an early study, Grandjean (1976) showed a correlation between high lead concentrations and thin eggshells of lead in European Kestrels *Falco tinnunculus*, and significant testicular degeneration has been demonstrated in ringed adult Turtle Doves *Streptopelia risoria* following shot ingestion (Veit et al. 1983). In female Mottled Ducks *Anas fulvigula* obtaining lead during autumn and winter, sub-lethal concentrations may negatively impact female nesting potential, egg survival, subsequent hatching and even brood rearing success (McDowell et al. 2015). Assi et al. (2016) reviewed several studies and found adverse impacts of lead on the reproductive system and reproduction in mammals (including humans).

## **Consequences**

The elements and processes described in Figure 6.4 and in the previous section can be condensed to: Lead from hunting ammunition is a source of poisoning of receptor organisms causing a toxicological effect resulting in an impact on population parameters. There are two major consequences of this:

### *Population decline*

Pain et al. (2019) and Garvin et al. (2020) give a thorough review of the possible effect of lead from ammunition on avian population size and trends. A key question here is whether the increased mortality and reduced reproduction caused by lead will be compensated for by density-dependent enhancement

of survival and/or breeding success. Lead poisoning is commonly discussed with reference to huntable species that are normally considered to have more pronounced density dependence systems than non-huntable species. However, complete density dependence has rarely been demonstrated, not even for huntable species, and taking into account that many other species, including vulnerable and threatened species, are exposed to lead ammunition (Kanstrup et al. 2018 (**Paper 4**)), it is reasonable to regard lead-induced mortality to be additive, thus having negative consequences for population size and trends. The same applies to the reduced productivity caused by lead, which is most likely not compensated for by density-dependent mechanisms.

European studies support the above results by demonstrating negative correlations between growth rates and population trends as well as the prevalence of ingested lead shot in several waterbird populations (Green and Pain 2016; Mateo 2009), just as ingestion of lead from rifle ammunition is known to have severe impact on the conservation status of several species of avian predators and scavengers (Pain et al. 2019). These findings suggest that ingested lead from hunting ammunition, be that gunshot or rifle ammunition, affects population sizes and trends.

#### *Enhanced animal suffering*

Most concern regarding lead poisoning of wildlife has traditionally been focused on the consequences for population sizes and levels. The animal welfare consequences of lead ammunition use have been widely ignored because they are a difficult and emotive topic (Kanstrup et al. 2018 (**Paper 4**)). However, in recent times, enhanced animal suffering as a direct consequence of lead poisoning has come into greater and sharper focus. The degree of poisoning varies depending on small subclinical dose levels to acute poisoning, the latter leading shortly to death. Between these extremes are various symptoms and degrees of poisoning, ranging from states where the physiological consequences are limited and perhaps of little significance to the poisoned individual. In more severe cases, clinical symptoms appear in the form of behavioural changes, consistent with severe and prolonged discomfort, distress and pain. In such cases, it is inferred that the poisoned individual is subjected to a serious health and welfare pressure that can be considered stressful from an animal welfare standpoint.

No clear standards are established to determine when the suffering of wild animals reaches a threshold for concern. This is especially because the response will depend on whether the suffering is due to natural causes (e.g. starvation, predation and diseases) or is inflicted by humans. In the latter case, ethics raise the question of whether such suffering is unnecessary. It is a widespread principle, and in some countries a legal requirement, that hunting practices avoid unnecessary animal suffering (discussed in more detail in Kanstrup et al. 2018 (**Paper 4**)). In recent decades, there has been increasing concern about animal welfare effects associated with wounding of hunted animals (Clausen et al. 2017). Wounding ratios (see introduction chapter) differ markedly depending on hunting cultures, methods and other circumstances and may reach one wounded individual for every specimen killed and retrieved. At the same time, the animal welfare aspect may vary from very light injuries with no or little impact to severe physiological damage causing prolonged distress and pain. Subjectively, lead poisoning is assessed to constitute levels of suffering that are comparable or exceed those of wounding. For instance, LAG (2015) estimated the number of birds suffering welfare problems because of ammunition-derived lead to be at least as large as the number

killed by lead poisoning annually, and Andreotti et al. (2018) estimated the number of waterbirds suffering from sub-lethal impact to be three times those dying from lead poisoning.

## 6.5 Non-lead ammunition

Lead has been believed to be the best metal for ammunition due to its ubiquity, density and softness. However, the preference for lead in ammunition is more likely the result of tradition shaping the demand and subsequent economies of scale relating to commercial production than to any true ballistic and technical advantage to the use of the material (Kanstrup 2018 (**Paper 10**)). Symptomatic of this, the development of the first non-lead rifle hunting bullet (the Barnes X bullet first introduced in 1986) was not driven by concerns for the toxicity of lead but motivated by a need to improve terminal ballistics<sup>5</sup>.

Although the problems arising from the dispersal of hunting lead shot in the environment have been known and recognised since the late 1800s, the production of alternatives using non-lead materials was not initiated in North America until the 1970s. Iron was the first metal to be used as an alternative to lead in gunshot and today iron shot (normally called steel shot) is the most commonly used and available alternative (Kanstrup and Thomas 2019 (**Paper 7**)). However, due to some of the physical properties of iron, for instance hardness and density, other metals more similar to lead have also been introduced (Kanstrup 2018 (**Paper 10**)). Of these, bismuth (mixed with c. 6% tin) is the most common, but tungsten products (either as a mixture of powdered metal and a high-density polymer or as a composite mixed with other metal) are also available. Other less frequently used metals are copper, tin and zinc (Kanstrup 2018 (**Paper 10**)). The variety of lead substitutes for gunshot has not changed in the past 20 years.

The dominant substitute metal for lead in rifle hunting bullets is copper. However, in recent years, other metals have been introduced, including brass (alloyed copper/zinc), tungsten, nickel, tin and zinc. Most non-lead bullets are homogenous although some newer products are constructed with a jacket surrounding a core made from tin or tungsten. The list of non-lead rifle bullets, including metals used and construction, is constantly developing (Kanstrup and Haugaard 2020).

Shotgun slugs are legal for hunting in multiple countries, and in some regions they are even required for large deer hunting. Non-lead sabot types (designed for use in rifled shotgun barrels) have been developed based mainly on copper or copper alloys although some are made with iron, brass and zinc components. Non-lead rifled slugs designed for use in smoothbore shotgun barrels are commonly made from tin or zinc.

Rifled guns in which ammunition is propelled by compressed air (air guns) can legally be used for hunting purposes, especially hunting of small bird game species such as corvids and for target shooting. The ammunition material for these types has traditionally been lead based. However, non-lead types based primarily on tin are now available, and even though no scientific research programmes have yet assessed their performance, popular tests have

<sup>5</sup> <https://www.barnesbullets.com/history/>

been carried out that give a good indication that the precision of non-lead types is equal to that of traditional types<sup>6</sup>.

### 6.5.1 Toxicity

Most of the metals used as alternatives to lead in ammunition are heavy metals that, dependent on dose, are toxic to living organisms.

The chemical composition of non-lead ammunition is regulated only in the USA and Canada and only for gunshot and for the use in waterfowl hunting. Apart from this, there are no formal structures, internationally or nationally, to ensure that the switch from lead to non-lead ammunition does not just substitute one toxic problem with another. However, most substitute elements play vital roles in biological processes and are regarded to be much less toxic than lead. Furthermore, the potential toxicity of lead ammunition substitutes is well investigated and documented in recent studies (Fäth and Göttlein 2019; Paulsen et al. 2015; Paulsen and Sager 2017; Thomas 2018). Thomas (2018) summarised the existing evidence and established a set of standards for the chemical composition of non-lead hunting ammunition (and fishing weights). These standards set maximum allowable levels of the substances known to be of severe toxicity, including lead, zinc and nickel, thus ensuring that non-lead products manufactured with reference to these standards can be regarded to be safe for use in hunting ammunition seen from an eco-toxicological and human health point of view.

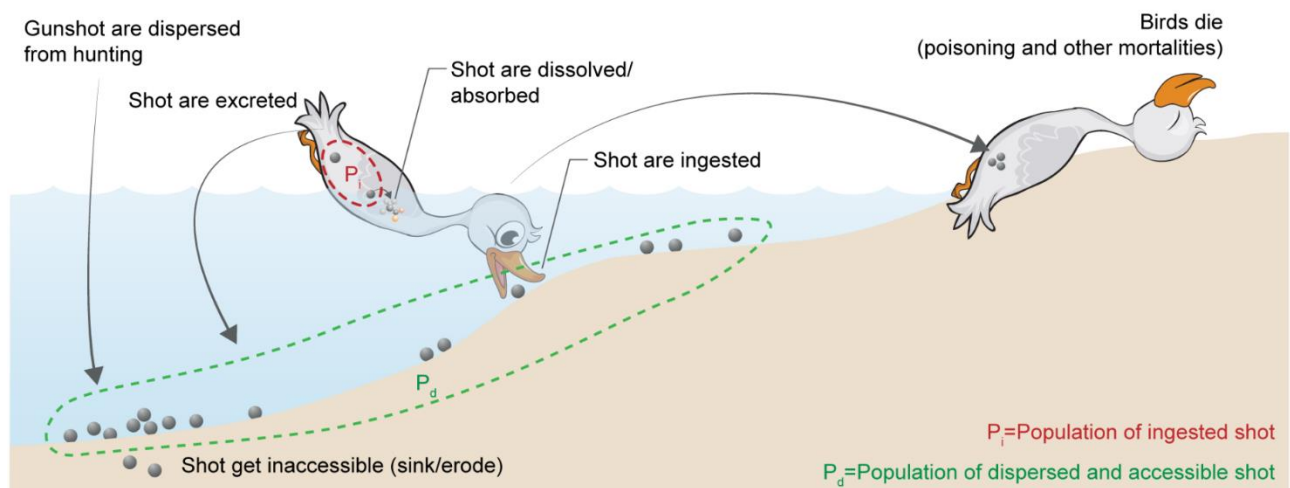
The present and most commonly used alternative ammunition types, i.e. steel and bismuth/tin in gunshot and copper in rifle bullets, fulfil the standards suggested by Thomas (2018). In the case of rifle ammunition, an additional dimension is that non-lead bullets, with few exceptions, are designed to either expand/deform with very low loss of mass during the passage of the target or fragment in a limited number (usually 4) pieces, thus not causing any contamination of the target tissues with metal particles. Against this background, rifle bullets with traces of toxic substances even slightly beyond the levels suggested by Thomas (2018) may be regarded as being toxicologically safe.

Despite the fact that most present alternatives are not of direct concern in relation to poisoning of wildlife, ecosystems and human consumers, there remains the need for authorities to raise awareness and establish benchmarks for the composition of all present and future products (Thomas 2018; Thomas et al. 2009).

### 6.5.2 Accumulation in ecosystems

Dispersed gunshot accumulate in natural ecosystems and may be regarded as a “population” analogous to other populations determined by the balance between “recruitment”, i.e. addition of new pellets to the substrate from hunting, excretion by birds and accumulation of dead organisms that have accumulated pellets, and “mortality”, i.e. pellets becoming inaccessible by sinking deeper into sediment layers, pellets that corrode into fragments too small to constitute a problem and shot ingested and thereby removed by birds (Kanstrup and Balsby 2019 (**Paper 16**)), Figure 6.13.

<sup>6</sup> <https://www.pyramydair.com/blog/2011/07/testing-non-lead-pellets-part-1/>

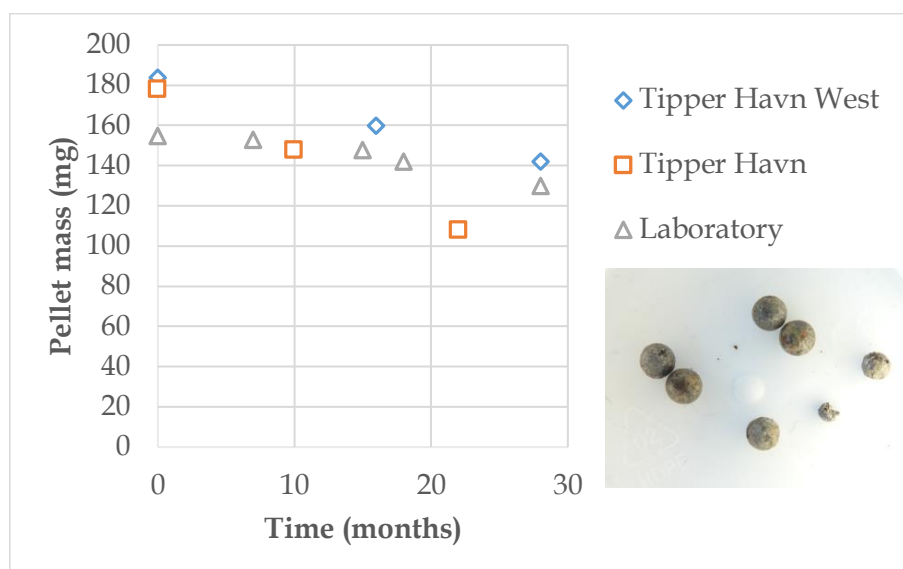


**Figure 6.13.** The connection and flow between the two “populations” of gunshot:  $P_d$  = dispersed and accessible shot;  $P_i$  = ingested shot retained in the bird’s gizzards (from Kanstrup and Balsby 2019 (**Paper 16**)).

Lead ammunition remains unchanged for considerable periods of time. Complete decomposition of particulate lead likely takes tens or hundreds of years depending on *inter alia* temperature, moisture, substrate chemistry and biotic functions. Hence, lead shot persist in ecosystems and remain available to avifauna for decades after deposition (Kanstrup et al. 2020 (**Paper 14**)). Degradation rates of non-lead ammunition in natural systems have been poorly investigated. However, Kanstrup et al. (2020 (**Paper 14**)) found an average mass loss of steel shot (initial average weight 178 mg) equivalent to 19% during the first year of exposure in a Danish wetland (Ringkøbing Fjord). The same study included a laboratory test that demonstrated that steel shot (initial weight 155 mg) lost weight, although at a slower rate (3-4% weight loss per year) in a wet sediment taken from the same area (Ringkøbing Fjord). Both experiments have been continued after the 2019 publication, including retrieval of samples of shot from the field test and re-measurement of shot used in the laboratory test. The results are shown in Figure 6.14 and include also results from a study initiated in April 2018 where a sample of steel shot was placed at a location west of Tipper Havn (also in Ringkøbing Fjord). This sample was not included in Kanstrup et al. (2020 (**Paper 14**)) because the position of the seeding area was lost. However, it was relocated later and shot samples were retrieved after 16 and 28 months. For all samples, there was clear loss of mass. The “Tipper Havn West” sample lost, by average, 42 g in 28 months ( $n=17$ ,  $\text{min}=17$  g,  $\text{max}=93$  g), which is equivalent to 10% per year. Similar figures for the other samples are: Tipper Havn average loss: 70 g in 22 months ( $n=17$ ,  $\text{min}=28$  g,  $\text{max}=167$  g), 21% per year; Laboratory average loss: 25 g in 28 months ( $n=2$ ,  $\text{min}=24$  g,  $\text{max}=26$  g), 7% per year.

The results demonstrate that steel shot corroded in the laboratory as well as in the natural habitat. The rate seemed to differ between samples and between individual shot. However, for the field tests, mass loss ranged between 10 and 20% per year, although some single pellets lost up to 90% of their mass in less than two years. The results indicated a roughly linear weight loss and suggested that steel shot may fully corrode within 5-10 years after dispersal in the tested types of wetland.

**Figure 6.14.** Mass loss of steel shot seeded at two locations next to the small harbour at Tipperne, Tipper Havn. The inserted photo shows that pellets were degraded unevenly. They appeared shiny immediately after recovery but changed quickly “rusty”. Results from a laboratory test are included too. The figure is based on Kanstrup et al. (2020 (**Paper 14**)) and unpublished follow-up data.



### 6.5.3 Efficiency

One of the largest obstacles to the transition from lead to non-lead ammunition is the concern that non-lead alternatives fail to kill the target animal as efficiently as lead shot. This issue was raised very early in the North American debate on phasing out of lead shot from waterfowl hunting, and it was, and still is, a primary concern among European hunters, for instance British and Danish hunters (Cromie et al. 2015; Kanstrup 2018 (**Paper 10**); Kanstrup and Andersen 2003; Kanstrup et al. 2021 (**Paper 6**)). Hampton et al. (2021) gave a thorough review and recommendations on efficiency of shooting of free-ranging wildlife.

Efficiency (in the literature also called efficacy) of a gunshot is a popular but poorly defined expression of the shot's ability to kill the target promptly and humanely. The term can be analysed by breaking it down into the following components:

#### Energy

The energy of a shot is well defined and can be regarded as the ability of the propellant (powder) load to accelerate the shot load/bullet of a certain weight to a certain velocity (commonly expressed by the muzzle velocity ( $V_0$ ) or velocity at variable distances ( $V_x$ )). The (muzzle) shot energy ( $E_0$ ) is expressed by the formula:

$$E_x = \frac{1}{2} M V_x^2$$

where  $M$  = mass (weight) of the shot load/bullet. Corresponding units used in Europe are joule (J) for energy, kilogram (kg) for mass and metre per second (m/s) for velocity. A standard load of shot (30 g) with a standard muzzle velocity (400 m/s) provides  $E_0 = 2,400$  J. A standard rifle caliber, for example .308 Win (bullet weight 10 g, muzzle velocity 800 m/s) provides a muzzle energy at 3,200 J and, depending on bullet properties,  $V_{100}$  around 2,200 J.

#### Technical efficiency = ballistics

The way the energy is released into the shot cloud/bullet and transformed into the hitting and killing impact on the target is commonly referred to as ballistics, which can be divided into three sub-fields: (i) internal ballistics (covering the

progress from the propellant's ignition until the shot load/bullet exits the gun barrel), (ii) external ballistics (behaviour of the shot load/bullet in flight) and (iii) terminal ballistics (behaviour and effects of the shot load/bullet when it hits and transfers its energy to a target). Altogether, these elements of ballistics form what could be named the "technical efficiency" of the shot. External and terminal ballistics of a shotgun shot and a rifle shot differs fundamentally, the former being rather complex and the latter more simple.

The ballistics of a shotgun shot must be seen in more dimensions according first of all to the radial and longitude dispersal of the shot and the ability of single pellets to penetrate and release striking energy. This expresses the "shotgun dilemma", i.e. the constraints of the balance between the cover of pellets to ensure that the target is hit by a sufficient number of pellets in order to ensure that vital parts are hit (Cochrane 1976) and the pellet energy to ensure that pellets penetrate sufficiently to injure vital parts. Both relate to *inter alia* shooting distance. The pellet cover relates, in principle, to a linear formula with distance, although both radial and longitudinal dispersal of shot complicates this relationship. Shot shape and deformation play an essential role. Also the choke of the gun has an impact on the dispersal. Penetration corresponds to the single shot energy, which declines exponentially with distance.

The required number of pellets necessary to hit the target has been the subject of much discussion, but it is commonly accepted that minimum 5 pellets should impact the target body to ensure an acceptable likelihood of hitting vital parts (Garwood 1994). To ensure sufficient penetration, the single shot must conserve a minimum level of striking energy. Generally, this metric is rather poorly described in the literature. Burrard (1944) found that 1.08 J is sufficient for small game birds. This is calculated from practical experience of hunters in general that a (lead) shot can "kill" a bird at 41 m (45 yards). Lowry (1974) and Bløtekjær (2011) investigated the issue scientifically. In summary, the required level of striking energy of single shot can vary between 1 J and 5 J, depending on *inter alia* target body size, anatomy and shooting angle as well as the position of the target animal, i.e. whether vital parts are protected behind tough tissues or plumage will play a role. However, as a rule of thumb the killing of a medium-sized waterbird under normal conditions takes > 5 hitting shots with an energy of > 2 J each. The issue is further complicated by the theoretical role of the so-called "synergy" between hitting shot, whereby it is thought that a simultaneous hit of several shot in close proximity causes a so-called shock-impact, i.e. a physical and lethal impact on the nervous system resulting in an instant kill. However, this has never been experimentally verified. Lampel and Seitz (1983) clearly believed in shot synergy, whereas Lowry (1974) and Bløtekjær (2011) did not, although the theory is commonly accepted by ordinary hunters. Furthermore, the killing impact of gunshot pellets is commonly regarded to be related to its ability to deform in the target body (like a rifle bullet). However, this is also not supported by evidence and, overall, killing impact boils down to the simple probability of vital parts of the body to be hit and penetrated sufficiently.

All this applies equally to lead and non-lead shot. The question is whether the technical efficiency differs between the two shot types. There is no simple answer to this. Even among lead shot types, ballistics will differ depending on, for example, hardness. Soft lead has a tendency to deform during the internal ballistic progress, which will contribute to the numbers of misshapes (fliers) in the fringes of shot patterns and thus reduce shot densities in the main killing region of the pattern. In consequence, lead shot is commonly hardened by

addition of antimony (6%) or by plating with harder metals such as nickel. Furthermore, lead shot cartridges commonly contain a plastic shot cup (wad) to protect the shot from contact with the steel of the barrel and hence prevent deformed. Soft non-lead shot like bismuth/tin have ballistic properties very similar to lead shot. Steel shot has become the most commonly used non-lead shot type and has a lower density than lead shot and, consequently, slightly different ballistic properties. Due to their spherical shape and hardness, steel shot and similar hard shot produce tighter patterns than lead shot, which is reflected both in the radial and the longitude dimension. For this reason, there is no need for very tight gun chokings when using steel.

A comparison between lead and steel shot in terms of some basic ballistic parameters (size, weight, number, velocities and striking energy at 0, 20 and 40 m) is presented in Table 6.1.

**Table 6.1.** Ballistic parameters of lead compared with steel shot based on a 30 g load fired with  $V_0=400$  m/s. Shaded cells indicate values of lead and steel shot, respectively, corresponding to a 0.5 mm change of shot size when using steel shot (=2 US numbers).

Diameter mm	Mass G		Pellets #		$V_{20}$ m/s		$V_{40}$ m/s		$E_{20}$ J		$E_{40}$ J	
	Lead	Steel	Lead	Steel	Lead	Steel	Lead	Steel	Lead	Steel	Lead	Steel
2.5	0.09	0.06	325	464	260	225	180	140	3.1	1.6	1.5	0.6
3	0.16	0.11	188	269	280	240	205	165	6.3	3.2	3.4	1.5
3.5	0.25	0.18	118	169	290	260	225	180	10.7	6	6.4	2.9
4	0.38	0.26	79	113	300	270	235	195	17	9.6	10.5	5

The lower density of steel compared to lead is reflected in lower values for weight and velocity/energy on distance but a higher number of shot given the same load and shot size. An increase of shot size by 0.5 mm (which is normally recommended when changing from lead to steel – indicated with shaded cells in Table 6.1) – compensates for the lower weight, velocity and corresponding energy without any significant disruption of the pattern. However, for some of the parameters, the compensation is not complete. This is the reason why  $V_0$  in some steel shot cartridges is increased either by adjusting the powder load or type or reducing the shot load weight. Small shot (< 3 mm), mostly steel but also lead, with the demonstrated  $V_0$  (400 m/s) does not fulfil the > 2 J demand for producing sufficient penetration to kill medium-sized birds at great distance. This is the background for the general recommendation of change to larger shot sizes when changing from lead to steel and also for a recommended maximum shooting distance; in Denmark, for example, the shooting distance is 25 m for large waterbird (geese) hunting and 30 m for other bird hunting.

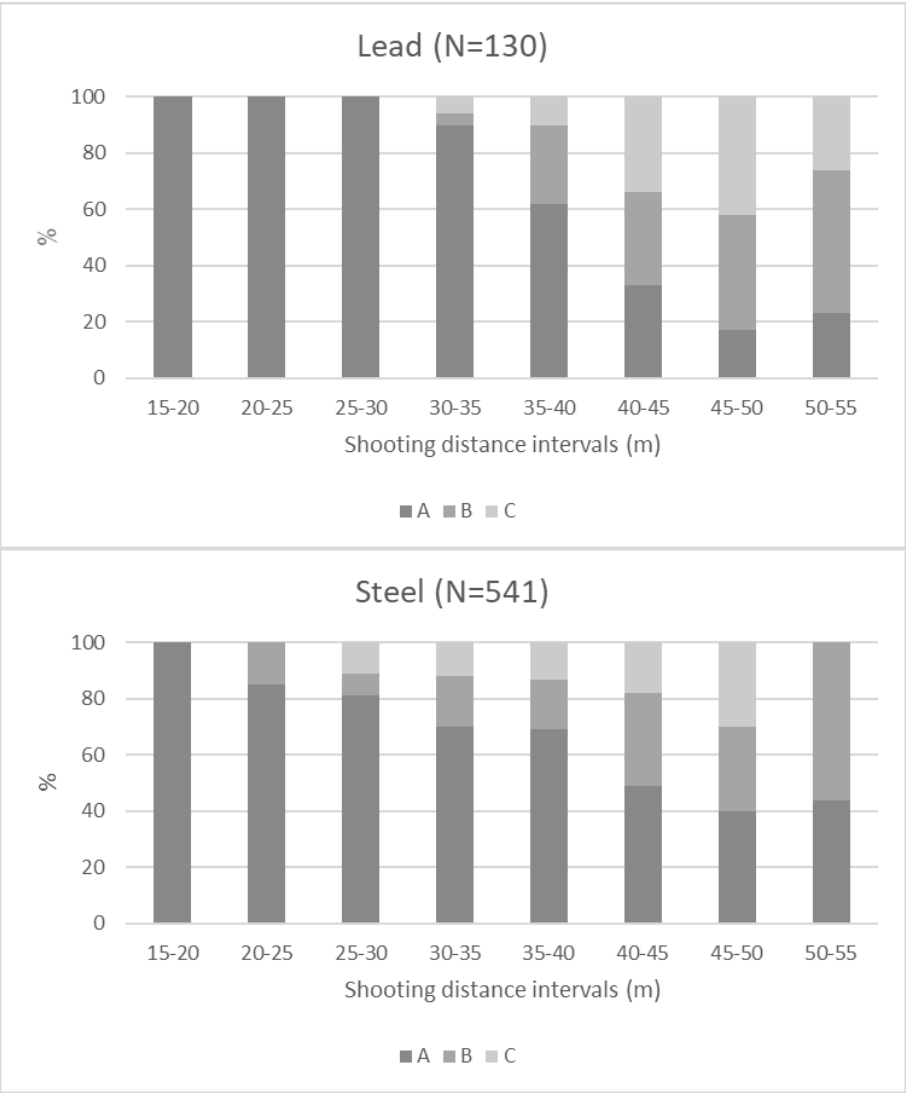
The efficiency of non-lead gunshot has been the subject of hundreds of experiments including both laboratory testing and practical field studies. Comparative studies of the efficiency of lead versus non-lead shot are extensive. The experience from Denmark, where there has been a ban on all use of lead shot since 1996, is that shot material plays a secondary role in shot performance, whilst the right choice of gunshot size, shooting distance and cartridge quality play a more important role (Kanstrup 2018 (**Paper 10**); Thomas et al. 2015 (**Paper 9**)). A pioneer study in Denmark was carried out in 1987 by the Danish hunters' organisations (Kanstrup 1987) based on a dataset derived from 671 Common Eider harvested with steel and lead shot. The study concluded that

shooting at distances beyond 35 m causes a high risk of wounding the target regardless of shot material (Figure 6.15). However, the study demonstrated that steel shot performed better at long distances than lead. It was published in the hunting magazine “Jagt & Fiskeri”.

In terms of technical efficiency, investigations of basic physical features and laboratory and field studies from the past 40 years demonstrate that commonly available non-lead shot types, *inter alia* steel shot with the right adjustment of shot size, fulfil the needs of ensuring a clean kill to the same extent as lead shot (Hunting Experts 2020).

In recent years, concerns similar to those for non-lead shotgun ammunition have been expressed about the technical efficiency of non-lead rifle ammunition, for instance among Danish hunters (Kanstrup et al. 2021 (**Paper 6**)). Despite the fact that a rifle shot basically is much less complex than a shotgun shot, hunters often pay greater attention to ballistics in rifle shooting, in particular external ballistics as this relates closely to the accuracy and precision of the ammunition. This is crucial as the basic functionality of a rifle shot is to make the single bullet hit precisely at a selected spot at the target from all relevant distances.

**Figure 6.15.** Redrawn graphics from a study of the lethality of lead versus steel shot carried out by the Danish hunters’ organizations in 1987 (Kanstrup 1987). The dataset consisted of 671 common eider harvested with steel and lead shot. Capital letters indicate target reaction: A: Clean kill; B: Lethally wounded but not dead instantly; C: Lightly wounded, able to move/escape. Data were not subject to closer statistical analysis and the article was not peer reviewed. Nevertheless, it had a major impact as it became a turning point for influencing the attitudes of senior staff in the organisation and formed the basis for the new narrative, demonstrating that it was possible to substitute lead shot with non-toxic alternatives.



With regard to terminal ballistics, much attention has been paid to rifle ammunition that has been subject to extensive research whose results confirm that non-lead bullets largely have a technical efficiency similar to that of lead-core ammunition and thus meet the efficiency requirements for ammunition used in traditional hunting (Gremse and Rieger 2012; Kanstrup and Balsby 2015; Kanstrup et al. 2016 (**Paper 13**); Martin et al. 2017; McCann et al. 2016; Stokke et al. 2019; Trinogga et al. 2013). Fewer studies have looked into the accuracy of non-lead versus lead bullets. However, Knott et al. (2009) concluded that there was no difference in accuracy between hunting with copper and lead bullets and further suggested that differences in killing impact between the two are small, especially when normal practice is followed. Similar conclusions were drawn in a recent Australian study comparing lead-based and lead-free bullets for aerial shooting of Wild Boar (Hampton et al. 2021).

Among gunshot ammunition, there is great complexity and variability among lead-based ammunition types that comprise a spectrum from traditional types with a rather thin metal jacket (producing a high degree of striking deformation and fragmentation) to heavy jacketed bonded types with a smaller lead core developed to ensure extensive penetration. The latter resembles to a high degree monolithic non-lead bullets, for instance copper bullets. Also, non-lead bullets are fabricated in different designs to produce either expansion or fragmentation. Hence, in terms of ballistics, lead and non-lead bullets do not constitute very distinct categories and the general debate would benefit from a differentiated approach taking these complexities into account.

Until now, most research into the efficiency of non-lead rifle ammunition has been directed at the larger rifle calibers ( $> 6$  mm). There are, however, still some reservations concerning the efficiency of small caliber rifles, for instance .22 LR (Hampton et al. 2020), .22 and .17 air guns, for which there remains a need for further testing and technical development.

Non-lead ammunition is available for small caliber rifles. The photo shows .177 air gun pellets, the one to the left being traditional lead and the two to the right tin-based pellets.



### Practical efficiency

Practical efficiency describes the efficiency of ammunition under the real and practical field circumstances, i.e. during the hunting or shooting. It is a simple product of the technical efficiency and the impact of “putting a hunter behind the gun”. Hence, the term covers the shot energy combined with constraints

of this energy to be transferred to the target via the ballistics (technical efficiency) of the shot combined with the constraints of the shooter to hit the target precisely and consistently.

The literature on shot gunning, i.e. the art of hitting the target, is overwhelming. The basis is that shotgun shooting normally means shooting at moving targets. This implies that the shooter must compensate for the distance (target distance) that the target moves from the time of ignition of the shot until the shot load reaches the target (flight time) at the actual shooting distance. The compensation is normally referred to as the "lead", i.e. the distance that the shooter must aim "in front of" the target to hit. The target distance depends on simple trigonometric rules with shooting distance, shooting angle and target velocity as the main variables. However, it is complicated by the flight time, which declines exponentially with shooting distance due to deceleration of the shot load. Furthermore, the radial and longitude dispersal of the shot cloud gives per se a compensation that is related also to shooting distance. Hence, the calculation of the target distance is complex and only very few, if any, hunters/shooters base the shooting on such basic formulas but judge the needed lead from a general subconscious evaluation of the shooting situation (speed, distance and other conditions). To many shooters, the lead is not a simple measurement that can be explained. The technique of "swinging" the gun, thus achieving the needed lead by moving the aim along the flight direction faster than the target, is commonly practiced. Shooting is analogue to many other sports and just like, for instance, football players, shooters depend on their personal talent. From the talent, shooters – like other sportsmen – develop, improve and maintain their skills by training.

It is not possible to consider all the parameters that affect the success of a kill based on shot gunning here. However, one basic factor should be considered: the shooting distance. As mentioned above, technical efficiency is highly dependent on shooting distance for two basic reasons: i) shot decelerate and lose energy with distance and ii) shot disperse three-dimensionally, whereby the pattern density declines, and, due to both factors, the likelihood of the target to be hit by a sufficient number of pellets declines. Both parameters decline exponentially in relation to shooting distance. It is well established that the shooters' ability to hit the target is highly related to the shooting distance. This is not only a general experience but has been demonstrated in several studies. As a part of a Danish campaign for reducing wounding loss (1997), special emphasis was given to the impact of shooting distances on the hitting frequency. For (all) 14 hunters participating in practical tests, Noer et al. (2001) found a clear dependence between hitting precision and shooting distance. Field studies performed by the same hunters showed that shooting distances significantly influenced the hitting probability, cartridge consumption and crippling loss.

Again the question is: Does the (adverse) influence of shooting distance on hitting probability apply to the same degree to non-lead as to lead shot? Again, the answer is not simple. The slightly tighter patterns produced by hard shot may require higher precision – something that is often mentioned by shooters that change from lead to steel without making basic adjustments to their equipment. The issue can be discussed in relation to the sport clay pigeon shooting that in some countries, including those in Scandinavia, is performed with steel shot. There are no indications that a change to steel shot

from lead shot leads to poorer hitting probability. On the contrary, some competition shooters request the possibility to use steel shot in international competitions (personal communication with Rasmus Bjerregaard)<sup>7</sup>.

The practical efficiency of rifle shooting differs slightly from that of shot gunning, mainly due to the fact that the target often is standing still and the shooter therefore does not need to consider the lead and swing as for shotgun shooting. However, driven hunting is widespread in many continental European countries and in many cases implies that the hunters shoot at moving animals, both wild boar and deer, which results in great challenges of achieving sufficient precision and thereby efficiency. This is not due to the precision of the rifle being used, which is an element of the technical efficiency, but simply due to the shooting abilities of the hunter; in other words a question of enhancing the practical efficiency. As for shot gunning, the shooting distance is crucial in rifle shooting. This applies not least to moving targets.

Regarding the overall (practical) efficiency of shooting, whether with a shotgun or a rifle, evidence demonstrates that the energy and the technical properties of particular shot and ammunition are seldom the limiting factor. The success of the shot in terms of a precise hit and clean kill is related much more to the shooter rather than to the ammunition. This applies equally to lead and non-lead ammunition. In this respect, there are many similarities between shooting and driving a car. In both cases, modern and well-adapted equipment will ensure the technical foundation for successful shooting/driving. Failures can almost always be attributed to the person behind the steering gun/wheel.

#### **6.5.4 Availability and price of non-lead ammunition**

Restricted availability of non-lead ammunition is a major source of inertia that has inhibited hunters from shifting from lead ammunition to alternatives (Chase and Rabe 2015; Kanstrup 2018 (**Paper 10**)). Kanstrup and Thomas (2019 (**Paper 7**)) assessed “product availability” by identifying ammunition manufacturers that produce non-lead shotgun ammunition and “market availability” (whether a given product can be purchased at the retail level) by compiling a list of non-lead cartridges brands available in retail gun and ammunition stores in 29 European countries. This was combined with a comparison of prices of non-lead and traditional lead shot cartridges. The study demonstrated that non-lead shot cartridges are available to purchasers in most European countries, but in a limited variety. Stocks of non-lead ammunition held in local retail shops may be very limited in variety and quantity, specification and brand.

Hence, seen from the point of view of a single hunter, such a small-scale local purchaser may not be able to purchase what might be best suited for his/her needs. Concerning prices, results support the general finding that prices of lead and steel shot are currently comparable, while bismuth and tungsten, which are both strategic metals, produced, sold and used in far lower volumes are always likely to be more expensive than lead.

Recent studies have also addressed the availability and price of non-lead rifle ammunition and demonstrated extensive product availability and prices comparable to those of lead ammunition in the USA and UK (Thomas 2013;

<sup>7</sup> Rasmus Bjerregaard is a Danish sporting champion and instructor. See <https://www.skydeinstruktion.dk/>.

Thomas 2015; Thomas et al. 2016 (**Paper 19**)). Similar studies with similar results have been carried out for the Danish market (Kanstrup 2015; Kanstrup et al. 2021 (**Paper 6**)). Knudsen (2020) identified at least 15 different brands of non-lead rifle cartridges available in the most common calibers (Figure 6.16).

**Figure 6.16.** Non-lead rifle cartridges available on the Danish retail market as of 2020. The illustrated cartridges are all caliber 308 Win but can be purchased in most appropriate calibers.



### 6.5.5 Damage to guns and hunter safety

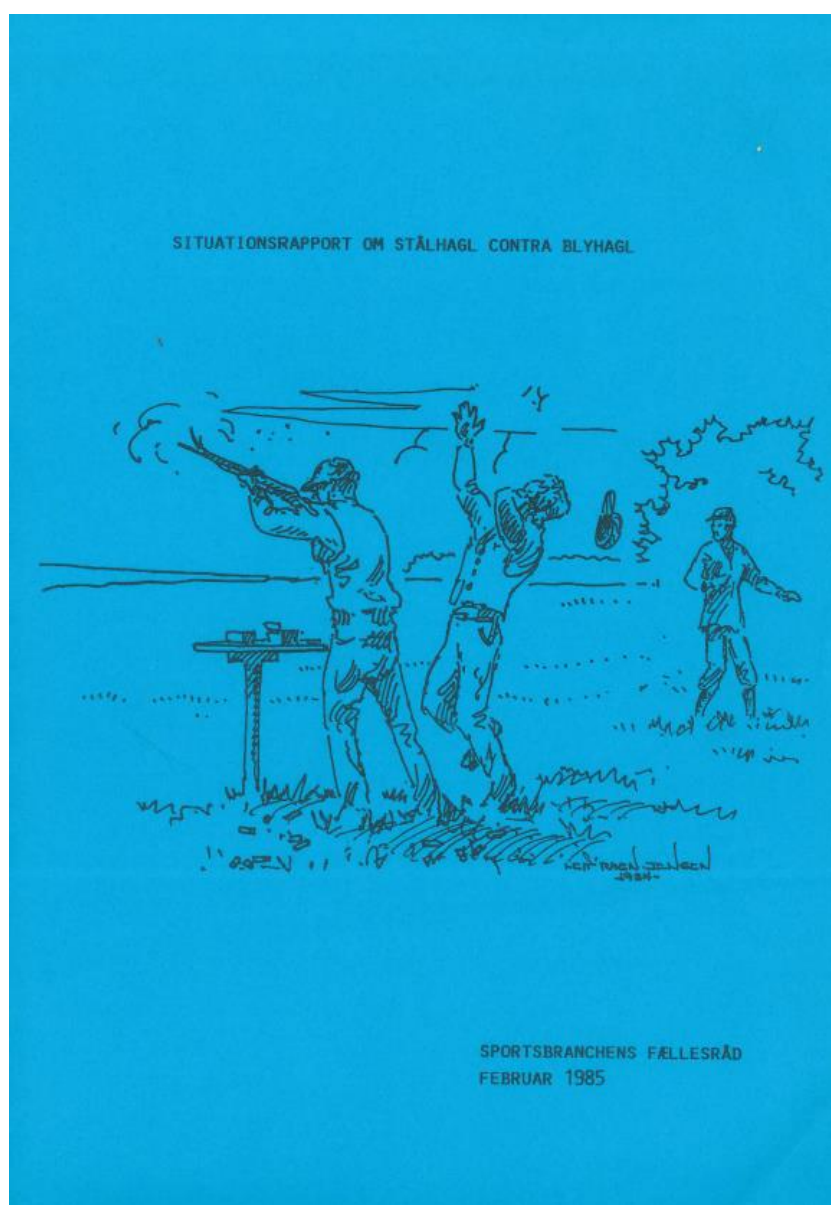
Considerable concern has also been expressed that, due to barrel construction, choke configuration and short chamber length, a significant and large number of guns are unable to use non-lead ammunition. As a result, restrictions on the use of lead shot are perceived as a risk to the safety of the hunters and a potential cause of damage to guns.

The proportion of guns currently in use that are unsuitable for lead shot ammunition alternatives has been discussed, but the estimates vary widely. In the UK, where all guns are certified, it is estimated that 600,000 hunters and other shotgun certificate holders possess c. 300,000 “older guns” out of a total of 1.35 million shotguns (LAG 2015). This suggests that less than 25% of all shotguns in use can be categorised as “older guns” that potentially are unsuited for non-lead alternatives. Furthermore, the figures showed that British certificate gun license holders possess, on average, 2.3 shotguns each, which indicates that some hunters keep guns for different purposes. Kanstrup et al. (2020) found that 34.3% of Danish rifle hunters possess more than one rifle. It is assumed that the more weapons the hunters are in possession of, the more adaptable they are to a transition.

In Denmark, the phase-out of lead shot was initiated in 1985, and also at that time the suitability of guns was a major issue (Kanstrup 2018 (**Paper 10**)). This was mainly due to the fact that the availability non-lead gunshot cartridges

was limited to a few American brands – all steel shot types that were not adapted to the guns commonly used by Danish hunters. However, the development of lead-free ammunition went much faster than expected, not least supported by European (including Danish) ammunition manufacturers (e.g. DanArms) who started production of specific gunshot types designed for Danish conditions, motivated by the demand arising from the initiation of the legislation. During the late 1980s and early 1990s, when the decision to ban all lead shot was taken (which came into force in 1996), the debate on guns silenced as the predicted severe damage to guns (explosions etc.) resulting from by non-lead shotgun ammunition never came to reality.

Front page of a report (Title: Present situation on steel versus lead shot) published by a Danish umbrella organisation for sport shooting in 1985. It illustrated the common narrative that a switch from lead to steel shot in clay target shooting would cause a severe risk of accidents from exploding guns and ricocheting gunshot. This never came to reality and the early regulation of lead shot for clay target shooting facilitated a smoother transition to non-lead shot in hunting (Kanstrup 2018 (**Paper 10**)). However, illustrations like this left many shooters with a misconception of the risk of using non-lead gunshot.



Today, it is widely accepted that any gun that can fire lead shot cartridges in a safe manner can also just as safely fire non-lead shot cartridges, provided that they have the same length and an equivalent load weight (Thomas et al. 2015 (**Paper 9**)). Thus, lead-like shot types, like tungsten matrix shot or bismuth-tin shot, can be used with complete confidence in any European gun with any choke construction. Also, standard loaded steel shot cartridges can be used in any gun suited to fire lead shot. The only remaining possible concern about the use of steel and other hard shot in standard guns pertains to the choke region of the

barrel, where large shot (larger than 3.5 mm diameter) passing through an abruptly developed, tightly-choked barrel could cause a small ring bulge to appear around the choke conus. However, this is not a safety but a cosmetic concern.

A final observation is that the gun industry has responded pro-actively in addressing the present and future needs as major gun manufacturers who export a large proportion of their guns to countries with non-lead shot regulations in place, such as the USA and Canada, have now for decades made their guns capable of firing lead as well as high performance lead-free shot loads, in particular steel shot.

In contrast to the discussion of the transition from lead to non-lead gunshot, the gun safety question has never been raised as a major concern in the non-lead rifle ammunition debate. Attempts to increase bullet length and muzzle velocity by adjusting the powder load and type to compensate for the lower weight of non-lead bullet types may raise barrel pressure above safe levels. Also, the deeper seating of longer non-lead bullets (to avoid increasing total cartridge length) may increase pressure. However, these features can be/have been accommodated through improved bullet design. This includes incorporating a number of radial grooves (see examples in Figure 6.16) that decrease the bearing surface (the area of the bullet that is in contact with the bore), which reduces friction and thereby pressure, just as such grooves make space for surface material (mostly copper) hewn off during passage down the barrel and thereby also prevent fouling (Thomas et al. 2015 (**Paper 9**)).

#### 6.5.6 Ricochets

All types of ammunition can ricochet (i.e. deflect) from a surfaces such as water, rocks or trees when hit at an acute angle. Such deflection may cause an unpredictable change of direction and thereby unintentionally hit property and injure persons in the vicinity. Ricocheting can be divided coarsely into two components: 1) ricochet angles and 2) energy of ricocheting ammunition.

Gunshot ricochet angles do not differ significantly between different types of shot. However, some types of non-lead shot have higher ricochet energy due to mass stability. This applies in particular to steel and other hard shot that has a higher tendency to direct rebound from hard surfaces as, for instance, documented for shooting at steel plates for pattern test (DEVA 2013b).

The ricocheting issue was central to the Danish debate and a primary concern during the transition from lead to non-lead gunshot in the 1990s. Today, more than two decades later, there is no evidence that the shift from lead to non-lead shot has caused any change in the risk of injury (Kanstrup 2018 (**Paper 10**)). Since 1985, the use of lead shot for training and competition shooting (clay pigeon) has gradually been phased out in Denmark. Today, lead shot is allowed on a few specially approved shooting grounds. Steel shot has become the only realistic alternative. However, after 20 years and millions of rounds, there has been no detectable change in the frequency of accidents either generally or in accidents caused by ricocheting shot (Danish Wing Shooting Association, pers. comm. (see Kanstrup 2018 (**Paper 10**)).

DEVA (2011) compared ricocheting in lead and non-lead rifle bullets and found no difference in ricochet angles but a higher ricochet energy in some non-lead types. However, no difference was detected between lead-core bullets with strong jackets (bonded) and non-lead bullets. As for slugs, DEVA

(2013a) found no difference in ricocheting tendency in non-lead compared to lead types.

In conclusion, based on research and practical experiences from countries with long-lasting regulation of lead ammunition (including also North America), there is no indication that a change from lead ammunition for hunting to other types involves any increased danger due to ricocheting. For all practical hunting purposes, LAG (2015) concluded: *“An unsafe shot with steel is an unsafe shot with lead”*. This statement could easily be extended to rifle shooting as well. Safety in hunting is a matter of the hunters' behaviour and cautiousness and not the ammunition. Thus, safety is achieved through education of hunters and proper planning rather than trusting certain types of traditional ammunition (Hunting Experts 2020; Kanstrup et al. 2021 (**Paper 6**)).

## **6.6 Dispersal of other ammunition components**

### **6.6.1 Plastic**

Wads serving to separate the propellant from the shot load are invariably lost down-range when a shot is fired. In some cases, cartridge shells are discarded in the hunting environment too. Traditionally, wads were made from fibres and shells from paper inserted in a basic brass construction holding also the primer. Wads and shells used in most modern shotgun ammunition are made from plastic although both paper shells and fibre wads are still produced and marketed.

Plastic wads are constructed to contain the shot load in a cup to prevent contact between shot pellets and the gun barrel. In cartridges with soft shot (e.g. lead), such contact may cause an undesirable damage to pellets (degrading the pattern). In cartridges with hard shot pellets (e.g. steel), the cup prevents the barrel from being damaged by the shot. This has accentuated the use of solid wads in steel shot cartridges and until now these have almost exclusively been made from plastic (Low Density Poly Ethylene).

The wad construction in other non-lead cartridges may also be plastic based, but in types with softer shot types, for instance bismuth shot, fibre types as those of traditional lead cartridges may be used. Kanstrup (2018, unpublished) examined a sample of shotgun cartridges, including lead (7), steel (6), bismuth (2), zinc (1), tin (1) and hevi-shot (1) shot (Figure 6.17). Most of the selected cartridges were produced in Europe. Only caliber 12 was included, but the design of shells and wads would apply equally to other calibers.

There were no major differences in the wads designed for lead shot (bottom row) compared to non-lead types (others). However, the fibre wads found in two lead shot cartridges (Figure 6.17, bottom, right) were not found in other types, though the fibre wad in one bismuth shot cartridge (top, 2<sup>nd</sup> from right) was a similar construction with no cup or other features to prevent contact between gun barrel and load.

**Figure 6.17.** Wad construction in a selection of shotgun cartridges. All caliber 12. Bottom: lead; Middle: steel; Top (from left): he Vishot, tin, tungsten, zinc and two bismuth. See text for details.

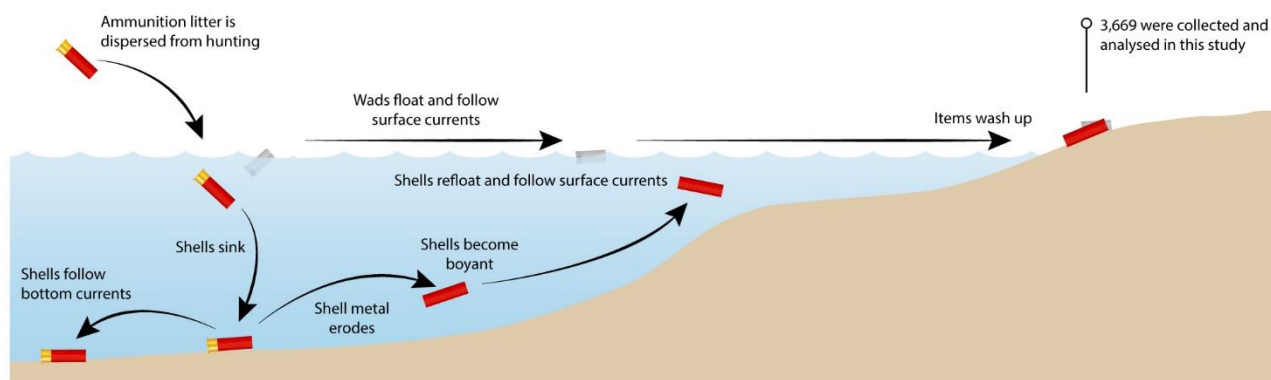


The main difference between lead and non-lead plastic wad types is the design of the buffer zone. The buffer function of the wad serves several purposes, *inter alia* to regulate the progress of the chamber pressure, to reduce recoil and to protect soft pellets from deforming during the initial ignition of the powder load. The buffer part can be seen to be a very pronounced feature (up to 15 mm) in four of the lead shot cartridges (Figure 6.17, bottom, 1<sup>st</sup> to 4<sup>th</sup> from left), the zinc shot cartridge (top, 4<sup>th</sup> from left) and one bismuth cartridge (top, right), while it is smaller or absent in the steel shot cartridges (middle row), the he Vishot (top, left) and the tin shot (top, 2<sup>nd</sup> from left) cartridges. The fundamental reason for this difference is the overall constraint on shell volume. The lower density of steel and other light non-lead types leads to higher load volume (unless the load weight is reduced), leaving less space for the wads' buffer designs (unless cartridge length is increased).

Plastic litter in the environment has become a major global issue and plastic ammunition components are an unwelcome addition to the problem. Macro plastic items are a cosmetic and aesthetic problem that causes serious harm to marine animals that ingest or become entangled by them. Micro plastic particles or beads created by the decomposition of macro plastic items are ingested

by small animals and filter feeders, then accumulate in food chains and create hazards for ecosystems, other wildlife and, potentially, human health (reviewed by Kanstrup and Balsby (2018 (**Paper 18**)).

There is no estimation of the total amount of plastic dispersed world-wide or within the European Union from ammunition. Based on the mass of a wad (3.1 g for a standard steel shot type) and the estimated annual consumption of cartridges, data from Denmark indicated a dispersal of plastic wads in coastal habitats during hunting of around 1,860 kg per annum (Kanstrup and Balsby 2018 (**Paper 18**)). The total annual dispersal of plastic from hunting ammunition in Denmark was estimated to 23-30 tonnes in 2018 (Regeringen 2018). In the UK, the annual deposition of waste plastic in the countryside from ammunition was estimated to 500 tonnes if all hunting cartridges fired contained plastic wads<sup>8</sup> (equivalent to app. 160 mill. rounds). A more recent estimate suggested that if all the cartridges used for shooting ducks and geese contained plastic wads, the dispersal of waste plastic wadding might amount to 6 tonnes in and around UK wetlands<sup>9</sup>. The OSPAR commission, which is an institution through which 15 governments and the European Union cooperate to protect the marine environment of the North-East Atlantic, provides frequent reports on plastic pollution, including cartridge shells and wads (OSPAR Code 43 = "shotgun cartridges"). Based on 2015 figures, this plastic type was among the top ten items in the North Sea/Skagerrak and the Baltic Sea/Inner Danish Waters (Strand et al. 2015).



**Figure 6.18.** The flow of ammunition litter when dispersed during hunting in coastal areas. Shells may be retrieved by the hunter and disposed of with household garbage. From Kanstrup and Balsby (2018 (**Paper 18**)).

The most thorough study of dispersal of plastic from ammunition is that undertaken by Kanstrup and Balsby (2018 (**Paper 18**)) (Figure 6.18), who concluded that litter from hunting ammunition is a significant source of plastic pollution in nature. In some Danish coastal areas, it is the most common source of macro pollution in the environment, suggesting that a substantial quantity of plastic ammunition litter will expose coastal habitats to harmful pollution for many years to come.

The mass of plastic waste entering the oceans worldwide in 2010 was estimated to 4.8 to 12.7 million tonnes (Jambeck et al 2015). Although the amount of plastic dispersed from hunting ammunition may seem minimal compared to those of plastic garbage deposited into the natural environment by the community in general, the hunting waste presents an aesthetical problem, it is a

<sup>8</sup> [Microsoft Word - LAG\\_meeting\\_minutes\\_12\\_250614.docx \(leadammunitiongroup.org.uk\)](#)

<sup>9</sup> John Swift personal communication 2017.

source of micro-plastic, and it is bad for the reputation of hunting. Hence, there is a major interest in reducing plastic waste from all ammunition, including that from lead shot cartridges.

Against this background, there is a need to find a solution and to substitute plastic with other materials or with degradable types of plastic. Such solutions are already available (GWCT et al. 2020; Hansen et al. 2021; Kanstrup and Balsby 2018 (**Paper 18**)) and used in the commercial production of cartridges, including three major groups of degradable materials: (i) PVAL (poly(vinyl alcohol)), (ii), PHA (polyhydroxyalkanoate), which does not readily decompose in typical hunting habitats, and (iii) fibre wads based primarily on paper with a liner (Figure 6.19).

Hansen et al. (2021) concluded that wads are available on the European market that will decompose, dissolve or bind to soil colloids in nature. The market is developing at a rapid pace and new products are constantly being introduced. The range of biodegradable products is still limited in terms of both materials and coverage of calibers, where 12/70 by far is the most widespread. The study involved accelerated degradation experiments and found that PVAL wads will decompose in all types of environments typical for shotgun hunting, for instance within a few hours in aquatic habitats and within a few weeks in drier upland habitats. The study indicated the same possibility for paper-fibre wads, whereas this was not the case for the specific PHA-based wads of the study. Furthermore, the study concluded that a biodegradable plastic with a relatively high content of short plant-based fibres provides an alternative that would ensure rapid biodegradation and adjustable density, just as a wad made by injection moulding from a paper pulp with a water-soluble binder has the potential for very rapid disintegration of the wad and subsequent rapid degradation in nature.

**Figure 6.19.** Wads made from biodegradable materials are available at the European market: (i) PVAL, (ii) PHA and (iii) fibre with a liner. Also shown is (iv) a traditional wad made from LDPE. All originate from shotgun cartridges caliber 12/70 (the most commonly used ammunition gauge).



The availability of degradable wads seems not to be limited by production technology or costs but mainly by uncertainty about whether the necessary requirements are met, including any future legal requirements. The demand has increased dramatically in recent years with the growing concern about plastic waste from hunting cartridges (including lead shot cartridges), driven

by a general concern about plastic waste in global terms<sup>10</sup> but also by aesthetic concerns relating to the effects of such waste on hunting habitats as well as worries of owners of hunting grounds. The development is supported by increasing demands from the sport shooting sector and some national hunting organisations (GWCT et al. 2020).

Techniques improving gun barrel steel in terms of hardness, strength, ductility etc. may produce new generations of guns adapted to hard shot that does away with the need to use protecting wads. As long ago as 1991, Kanstrup and Hartmann (1991) investigated the potential for this by firing 600 rounds of steel shot (3.4 mm) in a Mossberg cal. 12/76 pump gun and 660 rounds in the lower barrel of a Valmet o/u. The cartridges were loaded with classical fibre wads creating full contact between the shot and gun barrel. Both guns were steel proofed. “Before and after” measurements showed no significant changes (diameter, scratches, bulging etc.) of the gun barrel.

Shot shells are commonly made from plastic and, thus, represent a potential source of plastic waste in the natural environment. It is widespread practice and common shooting code that the shooter picks up spent shells for later disposal. However, under certain circumstances shells are frequently lost (Kanstrup and Balsby 2018 (**Paper 18**)). In some new cartridge brands, shells are made from PHA, which is not likely to decompose in the natural environment (Hansen et al. 2021). Conversely, widespread use of degradable shells could tempt hunters leave them to more often in the hunting habitat, which could jeopardise the common conduct of hunters of collecting shells and depositing them safely as garbage or recyclable products.

## 6.6.2 Metals

The metal component of a shotgun shell (the brass) comprises c. 3 g of metal (mostly iron) or c. 10% of the shot load mass. Based on the estimated annual dispersal of lead shot from hunting in the European Union (minimum approximately 21,000 tonnes, see earlier sections), this corresponds to an annual consumption of 2,000 tonnes of metal. Correspondingly, a rifle shell comprises a mass of metal (brass) comparable to that of the bullet (e.g. for a typical 30-06 cartridge, the shell mass is c. 13 g). This means that the annual consumption of rifle ammunition for hunting in the European Union is estimated to minimum 150 tonnes of bullet metal (27) (see earlier sections), which corresponds to a similar amount of shell metal. As cartridge shells are mostly retrieved by the hunter (rifle cartridges are often even reloaded), these amounts of metal are not all dispersed into the natural environment. In addition, even if dispersed, such metal constitutes no known eco-toxicological hazard. However, if dispersed, the metal represents a waste of a valuable resource similar to the loss of shot and bullet metal (Kanstrup and Thomas 2020 (**Paper 1**)), and any campaign to motivate hunters to retrieve, recycle or reuse empty shells as proposed by Kanstrup and Balsby (2018 (**Paper 18**)) would contribute positively to the long-term sustainability of hunting, both in terms of resource utilisation and public perception. Except for hunters who reload their own cartridges, spent shells have no value for the hunter. This could be changed by implementation of a deposit system for used empty cartridges as those adopted in some countries for reuse of other potential waste items such as plastic or glass

<sup>10</sup> <http://www.plasticpollutioncoalition.org/>

bottles, thereby enhancing the motivation for retrieval and recycling (Kanstrup and Balsby 2018 (**Paper 18**)).

## 6.7 Regulations

The increasing evidence of lead poisoning of waterbirds during the 1980s resulted in many national and multilateral environmental agreements including recommendations or legally binding regulations to reduce the dispersal of lead gunshot in wetlands (Kanstrup et al. 2018 (**Paper 4**); Thomas and Guitart 2005). Stroud (2015) found a steady but slow progress towards the goal of eliminating lead gunshot from wetlands around the world. However, this was only measured by the progress achieved through regulation, which in most cases amounted to only partial banning of lead, without accumulating and analysing information on enforcement of and compliance with regulations. Mateo and Kanstrup (2019 (**Paper 2**)) reviewed the degree of regulation of lead ammunition adopted across Europe and reported that, to date, the use of lead shot has been legally restricted in 23 European countries. Two countries, Denmark and The Netherlands, have implemented a total ban on the use of lead gunshot in all types of habitats, 16 countries have a total ban in wetlands and/or for waterbird hunting, and 5 have a partial ban implemented only in some wetlands. The use of lead bullets is not legally permitted in some German regions and, for instance, in national parks in Italy. In November 2020, the Danish government announced the phasing out of lead rifle ammunition for hunting by 2023 at the latest<sup>11</sup> (Thomas et al. 2021 (**Paper 26**)).

In 2015, the European Commission initiated a process to restrict the use of lead gunshot in wetlands under the REACH Regulation (Regulation for the Registration, Evaluation, Authorisation and Restriction of Chemicals). This resulted in an Annex XV dossier proposing a restriction on the use of lead gunshot in and over wetlands (ECHA 2017; Treu et al. 2020). After public consultation, the dossier was adopted by the two ECHA technical committees (Committee for Risk Assessment (RAC) and Committee for Socio-economic Analysis (SEAC)) in 2018. By autumn 2020, the slightly amended dossier was adopted by the REACH Committee and subsequently by the European Parliament (first the ENVI committee (Committee on the Environment, Public Health and Food Safety) and finally the full European Parliament), after which the European Commission was free to adopt the proposal for restriction. The amended REACH regulation was signed on 25 January 2021<sup>12</sup> with date of applicability in February 2023 (see Thomas et al. (2021 (**Paper 26**)) for more details on the individual procedural steps in this development).

In September 2018, ECHA published, at the Commission's request, the results of an investigation on the use of lead shot in terrestrial environments other than wetlands, lead in other types of ammunition and lead in fishing tackle (ECHA 2018). The report concluded that there was sufficient evidence of risk from those other uses to justify additional regulatory measures. In July 2019, the Commission asked ECHA to prepare a proposal to restrict the marketing and use of lead in ammunition (gunshot and bullets) in all habitats and of lead in fishing tackle, conforming to the requirements of Annex XV to REACH. In

<sup>11</sup> <https://mim.dk/nyheder/2020/nov/danmark-vil-forbyde-bly-i-ammunition-til-jagt/>

<sup>12</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0057&from=EN>

February 2021, ECHA announced a restriction<sup>13</sup> on lead sold and used in hunting, sports shooting and other outdoor shooting including a ban on the sale and use of lead gunshot (with a five-year transition period) and a ban on the use of lead in bullets and other projectiles (small calibre: five-year; large calibre: 18-month transition periods). In March 2021, a public consultation was initiated based on an Annex XV restriction report<sup>14</sup>. This process is ongoing (at the time of writing), the provisional timetable is outlined in Thomas et al. (2021 (**Paper 26**)).

Several countries outside of Europe have introduced regulation of lead ammunition. In Australia, South Australia, Northern Territory, Queensland, Tasmania, New South Wales and Victoria have all partially banned the use of lead ammunition for hunting over wetlands, while some states have introduced bans on all recreational waterbird hunting. USA and Canada introduced a ban on waterbird/wetland hunting with lead shot in 1991 and 1997, respectively (Avery and Watson 2008). In Hokkaido, the northernmost island of Japan, a ban on the use of lead rifle bullets and shot for hunting Sika Deer *Cervus nippon* was introduced in 2000 and 2001, respectively, followed by prohibition of the use of any type of lead ammunition for hunting large animal species in 2004 and of the possession of lead ammunition during hunting in 2014 (Ishii et al. 2020). California is, since 2019, the only jurisdiction in the world to require use of non-lead ammunition for all categories and species of hunting, mainly to protect several avian scavenging species (Thomas et al. 2019 (**Paper 11**)). Most regulations apply to waterbird/wetland hunting with lead gunshot, primarily driven by the provisions established under the African Eurasian Waterbirds Agreement (Kanstrup et al. 2018 (**Paper 4**))

In addition to legal regulations, some countries have introduced voluntary programmes where hunters are recommended to use non-lead ammunition. Mateo and Kanstrup (2019 (**Paper 2**)) identified such a situation in a few European countries, including (for lead gunshot use in wetlands) the UK (Northern Ireland), and France, and (for lead rifle bullets) France and Austria where the promotion of a shift to non-lead bullets has been combined with incentives to hunters, for instance through the provision of free non-lead ammunition, together with free advice and gun cleaning by professionals. Voluntary schemes are also in place in several North American states (Schulz et al. 2020)

Mateo and Kanstrup (2019 (**Paper 2**)) conducted a review of the evidence for the degree of compliance with lead ammunition regulations and the subsequent benefits that these measures had created for susceptible species and for enhancing game meat safety. However, evidence for the levels of compliance was only available for three or four European countries, and the authors concluded that there was a general scarcity of information in the scientific literature on both the levels of compliance with regulations and the ultimate effects of regulation. Despite this scarcity, it has been established that levels of compliance are generally poor and that implementation of non-mandatory and partial regulations is a highly ineffective way of reducing the use of lead ammunition (Cromie et al. 2015; Cromie et al. 2010; Kanstrup and Thomas 2020 (**Paper 1**); Schulz et al. 2020; Widemo 2021). Even total legal bans on the import, trade and possession of lead ammunition have their shortcomings if the

<sup>13</sup> [Towards sustainable outdoor shooting and fishing – ECHA proposes restrictions on lead use - All news - ECHA \(europa.eu\)](#)

<sup>14</sup> Lead in outdoor shooting and fishing ANNEX XV report (europa.eu)

law is not properly enforced. Kanstrup (2012 (**Paper 12**)) showed the persistence of a certain degree of illegal use of lead shot in Pheasant hunting in Denmark, although later research (Kanstrup and Balsby 2019 (**Paper 15**)) has indicated much greater compliance with lead shot regulations for Pheasant and Mallard hunting in recent years, although this may not be the case for open sea hunting (Kanstrup and Balsby 2018 (**Paper 18**)). Such progress, however, must be viewed against the backdrop of the legislation that banned all use, trade and possession of lead gunshot cartridges in Denmark in 1996. Although more than 10 years have passed since the introduction of Japanese legislation on lead ammunition, including regulation of possession of all lead ammunition for deer hunting in Hokkaido, lead poisoning is still being reported from the Hokkaido region (Ishii et al. 2020).



Studies indicate that compliance with the Danish regulations on lead gunshot is high, but for some hunting forms it may not yet be complete.

## 7 Transition

To achieve transition within a user group from a traditional behavior undesirable to wider sections of society (in this case: the use of lead ammunition in hunting) to a new behavior (the use of non-lead ammunition) is a complex process. The decision to change behavior is ultimately that of the individual citizen, in this case the hunter's, so the successful transition from the use of lead to non-lead ammunition in hunting proceeds at the speed of the collective decision of individual hunters until the point of complete collective and societal transition. However, the hunters' choice of ammunition is a product of a complex web of drivers and barriers some of which are derived from the technical consequences of substituting lead with non-lead ammunition, but the majority of which has its origin in multi-faceted socio-economic and political discussions surrounding change, as seen in many other environmental and nature conservation issues.

The following sections discuss some key themes within this complex, emphasizing elements supported by new evidence from research presented in this dissertation that adds to existing knowledge and to the understanding of societal mechanisms influencing progress in wildlife and nature conservation.

### 7.1 Lead is not needed in ammunition

Although lead has been promulgated as an almost “perfect” material for ammunition, the preference for lead in ammunition is likely more the result of tradition shaping demand and subsequent economies of scale relating to commercial production than due to any true ballistic advantage to the use of the material (Kanstrup 2018 (**Paper 10**)). The technical aspects of changing from lead to non-lead have been well investigated (see section 6.5). The issue is also covered in several other dissertation papers: (Kanstrup 2006 (**Paper 20**); Kanstrup et al. 2016 (**Paper 13**); Kanstrup et al. 2018 (**Paper 4**); Kanstrup and Thomas 2020 (**Paper 1**); Kanstrup et al. 2016 (**Paper 8**); Thomas et al. 2015 (**Paper 9**); Thomas et al. 2016 (**Paper 19**)), all of which point to the conclusion that existing alternatives to lead ammunition largely fulfil the demands for safe and humane hunting at the same level as traditional lead ammunition. This applies in particular to shotgun ammunition for which alternatives have existed for more than fifty years, during which period these alternatives have been subjected to steady development and technical improvement by manufacturers in North America and Europe. Admittedly, the timeline for the development of alternatives to lead rifle hunting ammunition has been shorter than for shotgun ammunition, with the result that ammunition for some rifle applications still needs further refinement. This applies to small caliber weapons, including rim-fire types and air guns (caliber .22 and .17) that are used for hunting and population control of certain small game species including Rabbit *Oryctolagus cuniculus*, Corvidae and Columbidae (Hampton et al. 2020). Non-lead ammunition for such applications is now being manufactured and marketed. Although these products are generally recommended by manufacturers and other interest groups, there remains, however, a need to perform systematic testing of alternatives and invest in follow-up improvements to ammunition. Following rigorous systematic laboratory and field testing, as well as subsequent refinement, there is nothing to stop non-lead ammunition fulfilling all the demands for safe and humane hunting regardless of national tradition and application. Such a process will be stimulated by an increased demand as has been the case with transitioning to other

non-lead ammunition (Kanstrup and Thomas 2020 (**Paper 1**); Thomas et al. 2016 (**Paper 19**)).

All the combined evidence to date shows that, technically, non-lead ammunition fulfils the requirements for safe and humane hunting to the same level as does lead ammunition, this being supported by practical experiences from many countries that have introduced regulation of lead ammunition. Lessons learnt from some of these countries are briefly summarized in the following cases.

### 7.1.1 The Netherlands

In 1993, The Netherlands imposed a complete ban on the use of lead shot for hunting. The regulation was implemented due to the general awareness of lead shot contamination of waterbirds at the flyway level and specifically because of the high levels of prevalence of ingested shot in Dutch waterbird populations (Lumeij et al. 1989). Although hunters were skeptical in the beginning, they soon adapted to the use of non-lead shot. The new generations of hunters have never used lead shot, so this choice of ammunition is no longer an issue, and there has been no movement to question its regulation (Kanstrup 2018 (**Paper 10**)).

### 7.1.2 Norway

Norway introduced a complete ban on lead gunshot in hunting in 2005. Four years later, the general assembly of the Norwegian Association for Hunters and Anglers (NJFF) made a decision to work for the repeal of this regulation (outside wetlands). This led to a political process in the Norwegian parliament (Committee of Energy and Climate) including open hearings. During the process, the Directorate for the Environment made two statements, both recommending the ban not to be lifted. In February 2015, the Norwegian parliament decided to follow the proposal from the NJFF, and the Norwegian regulation was amended to allow use of lead shot for hunting outside wetlands (and at shooting ranges). It is widely established that the Norwegian process to lift the ban was (partially) driven by political incentives and not scientific facts (Arnemo 2016).

The Danish Hunters' Association (a sister organisation to NJFF), discussed this process and made a public statement concluding that: *"It is hard to see that Norway should have found 'the philosopher's Stone' and we wonder a little bit about the decision. We cannot see any good arguments and therefore we are not going to work for anything like it"* (Kanstrup 2018 (**Paper 10**)).

### 7.1.3 Denmark

In Denmark, lead shot was initially regulated for use in clay target shooting in the early 1980s, followed by a ban on the use of lead shot for hunting over Ramsar sites in 1986 and wider regulation in 1993. A total phase-out was initiated in 1996, including a ban on the trade and possession of lead shot cartridges (Kanstrup 2018 (**Paper 10**); Kanstrup and Balsby 2019 (**Paper 15**)). The lessons learnt from this process have been documented in several studies (e.g. Beintema 2004; Kanstrup 2006 (**Paper 20**); Kanstrup 2015 (**Paper 21**); Kanstrup and Andersen 2009; Pain 1992) and were summarised in a review in 2018 (Kanstrup 2018 (**Paper 10**)) as follows: *Hunters were initially negative towards the change. Resistance was driven by concern about the quality, safety issues, and expensive cost of non-toxic alternatives, compounded by lack of organizational leadership and ten-*

sions between stakeholders. As a result of the widening appreciation of the environmental effects of dispersed lead shot and the introduction of new generations of alternative shot types, hunter attitudes became positive and constructive. Change need not pose an obstruction to continued hunting opportunity. Introduction of steel shot for clay target shooting prompted many hunters to acquire good training experiences.

Contrary to many hunters' fears, the change was not an obstruction to continued hunting activity (Kanstrup 2015 (**Paper 21**)). During the last few years, the agenda has been set for a phase-out of lead rifle bullets, and approximately one fifth of Danish rifle hunters have voluntarily changed to use of non-lead bullets without the need for legislation (Kanstrup et al. 2021 (**Paper 6**)). Today, this process is supported by the Danish Hunters' Association, demonstrated by this statement made by a representative for the board of the association in September 2019 (authors' translation): "*We know that lead in nature and in our food is bad. Dispersing toxic heavy metals into our environment, and at the same time exposing lead to our game as a food source, is not acceptable. In other words: Time is right for the complete phasing out of lead in rifle ammunition*".<sup>15</sup> The Danish Hunters' Association also supported the legal regulation of lead in rifle hunting ammunition announced by the Danish Government in November 2020 intended to ban the use of all lead rifle ammunition for hunting purposes in 2023.

#### 7.1.4 Victoria, Australia

During the period 1992 to 1994, different Victorian bodies undertook a number of independent research projects investigating lead shot and their effects in waterbirds. Focus was placed upon shot pellet ingestion in gizzards and elevated lead levels in the liver tissue of *inter alia* Pacific Black Duck *Anas superciliosa*, a species considered to be vulnerable to lead poisoning, and Magpie Goose *Anseranas semipalmata* (Whitehead and Tschirner 1991). Other studies measured shot pellet densities in lake and swamp sediments, and accumulated lead in the wing bones of duck collected by hunters was studied. The results showed that 5% of the sampled Pacific Black Duck had ingested one or more pellets, and the same percentage exhibited elevated lead levels in their livers. It was found "... *certainly obvious that pellet ingestion and therefore poisoning, was occurring*" at an unacceptable level. To supplement these studies, it was estimated that 190 tonnes of lead were deposited in wetlands open to duck hunting in Victoria in the 1990 season and 235 tonnes in the 1991 season<sup>16</sup>.

Against this background, Victoria implemented a ban of the use of lead shot for duck hunting in 1993 and for hunting over wetlands from 1995. The regulation reinforced the hunters' sense of frustration over the way that hunting and firearm use were constantly under the political microscope and saw the move to non-toxic shot as a part of this process. However, the programme was supported by the leading hunting organisations and the Victorian Hunting Advisory Committee. Overall, it was recognised that hunting relies heavily on demonstrating to the community as a whole that it is undertaken with a

<sup>15</sup> <https://www.jaegerforbundet.dk/om-dj/dj-medier/nyhedsarkiv/2019/bly-i-riffelammunition-pa-vej-ud/>

<sup>16</sup> The Department of Conservation and Environment (DCE), Victoria.

very high degree of ethical and moral integrity among the participants<sup>17</sup> in order to justify its perpetuation.

### 7.1.5 Germany

During 2006-2007, the German Federal States of Brandenburg, Schleswig-Holstein and Bavaria launched investigations into the suitability of alternative materials to lead 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 2015). However, in 2008, the State of Brandenburg halted the field research on the use of non-lead bullets because of safety concerns about their ricochet characteristics. This led the Federal German Government to commission research into the ricocheting of rifle bullets, shotgun slugs and gunshot to compare the characteristics of non-lead versus traditional lead types and continued research into the terminal ballistics of hunting bullets (Gremse et al. 2014). These investigations proved non-lead ammunition to be just as safe and efficient as lead ammunition (see section 6.5.3.). The availability and costs of alternatives to lead ammunition helped to gain acceptance among the German hunters, and also the concurrent reporting of their experiences, showing that lead-free ammunition was just as safe and reliable today as lead ammunition was in the past, greatly assisted in successful transition (Gremse and Rieger 2015; Harmuth 2011; Spicher 2008). The regulation of lead rifle ammunition and the phase-in of non-lead types in many German states have been shown to have played an important role in the process of introducing non-lead ammunition to Danish hunters practicing hunting in Germany. It has been suggested that this is the most powerful contributing factor to the Danish transition to non-lead rifle ammunition, which, until now, has been achieved without legislative regulation in Denmark (Kanstrup et al. 2021 (**Paper 6**)).

### 7.1.6 North America

The introduction of non-lead gunshot for waterbird hunting in North America (USA by 1991 and Canada by 1997) provides a large disproportionate contribution to global experiences due to the long time series of the regulation and the magnitude of hunting in terms of wetland areas and waterbird harvest. Several studies have documented the process and outcome of the North American transition to non-lead gunshot and, directly or indirectly, demonstrated a high level of compliance among waterbird hunters and, consequently, reduced levels of lead poisoning of wild birds (Anderson et al. 2000; Friend and Thomas 2009; Havera et al. 1994; Simpson 1989; Stevenson et al. 2005). Despite this, the overall hunter experience and, in particular, the levels of contentment among the hunting community have been poorly documented in the scientific literature. Since the implementation of regulation in the 1990s, a whole new generation of hunters has been introduced to waterbird hunting during a period with no legal use of lead shot. Hence, the situation is likely similar to that in those European countries that made an early shift from lead to non-lead ammunition, for instance The Netherlands and Denmark, although these two countries made the transition through full regulation of lead shot. The further regulation of lead rifle ammunition culminating with the total ban on all lead ammunition for hunting in California in 2019 shows that

<sup>17</sup> <http://www.gma.vic.gov.au/education/fact-sheets/non-toxic-shot/why-has-the-change-been-made>

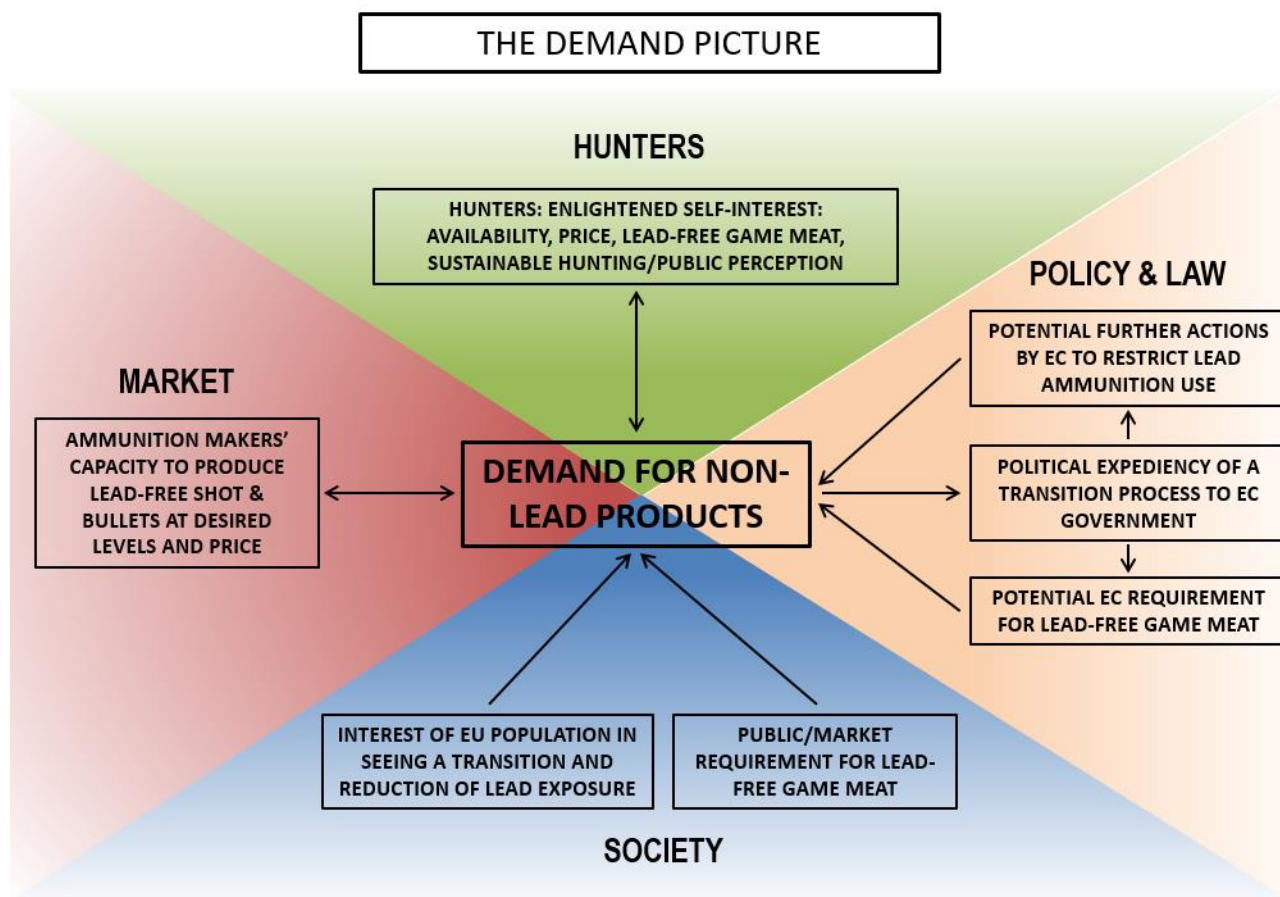
this option is possible. However, so far information on the success or lack of success of this step is not publically available.

## **7.2 Availability of alternative ammunition depends on the demand**

The availability of non-lead ammunition can be divided into two elements: “product availability” (the extent to which ammunition manufacturers produce non-lead ammunition) and “market availability” (the quantity of products available in retail gun and ammunition stores) (Kanstrup and Thomas 2019 (**Paper 7**); Thomas 2013). As already described in previous sections, product availability is now almost complete and only very few types of ammunition (e.g. those of small calibers) need further refinement to reach the same performance level as equivalent lead types. This is a simple question of technical development and the existing array of non-lead ammunition products that can replace lead is thus not limiting (Thomas et al. 2019 (**Paper 11**) **Paper 1**). The market availability is less complete. Kanstrup and Thomas (2019 (**Paper 7**)) concluded that lead-free shotgun cartridges were available in most European countries from retail shops offering online services, apart from countries without regulations, although the lead-free ammunition product range in countries with partial regulation of lead shot (e.g. restricted to wetlands/waterbirds) was very restricted compared to lead shot brands. Therefore, the stocks of non-lead ammunition held locally in retail shops tend to be limited in variety and quantity, specification and brand, such that, locally, hunters may not be able to purchase the ammunition best suited for their needs.

Both product and market availability are driven by demand. Although some products may be developed for a rather narrow and specialised market with no great promise of financial reward in terms of revenue, market availability is more often commercially and profit driven. The trade in hunting ammunition is highly competitive and there is little incentive among wholesale and retail outlets to stock products that are not subject to high levels of demand from customers. Kanstrup and Thomas (2019 (**Paper 7**)) found a clear correlation between national levels of regulation of lead gunshot ammunition, i.e. the demand, and the market availability of non-lead products. Furthermore, their study showed that low demand led to non-lead types being less prominently displayed on websites, often on the last page of several pages displaying lead products and frequently grouped under “special loads”.

Multiple factors relating to the users (hunters), policy, society interests and commercial market mechanisms regulate the demand and thereby the availability of non-lead ammunition, as illustrated by Kanstrup and Thomas (2020 (**Paper 1**)) and Figure 7.1. The single elements are thoroughly described in the original paper.



**Figure 7.1.** The four major components that interact to determine the demand for non-lead ammunition products. From Kanstrup and Thomas (2020 (**Paper 1**)).

The price of non-lead ammunition tends to be slightly higher than that of equivalent traditional lead types (see section 6.5.4). The price of ammunition is influenced by several elements roughly divided between production and market costs. The production cost depends primarily on the costs of basic materials and that of manufacturing the individual ammunition components and the assembly of cartridges. The latter is highly related to the production volume, so high demands for a given product will facilitate large-scale production as well as the manufacturing process, including the required quality testing, whereas a low production volume will make the single unit (cartridge) costs higher (Kanstrup and Thomas 2020 (**Paper 1**)). In the case of some lead alternative metals, such as bismuth- and tungsten-based gunshot, the raw materials are significantly more expensive than lead shot and as a result will never fall to price levels comparable to lead. On the other hand, steel shot – the most common alternative shot – could become cheaper due to lower material prices compared to traditional lead shot. Kanstrup and Thomas (2019 (**Paper 7**)) found that lead is 30 times more expensive than iron. In addition, the expiry of manufacturing patents will lower the future production costs of steel shot substantially (Kanstrup and Thomas 2020 (**Paper 1**)). Some of these mechanisms are today reflected in the Danish market price of steel versus lead shot for competition clay target shooting. Here, lead shot is still allowed at a few shooting ranges to enable shooters to train for international competitions (where lead shot is mandatory) to use lead shot. A personal communication

from Guntex (one of the large Danish importers and distributors of sport ammunition<sup>18</sup>) revealed that today's retail prices of clay shooting ammunition are DKK 1.2 (16 Eurocent) and DKK 1.6 (21 Eurocent) for a steel and lead cartridge, respectively, confirming that these lead cartridges are significantly more expensive than steel shot cartridges. This may be, primarily, due to the relatively low volume of lead shot cartridges imported and distributed for this special use but the lower material price of steel versus lead may also be an influence.

Kanstrup et al. (2021 (**Paper 6**)) demonstrated that prices of non-lead rifle cartridges on the Danish retail market were slightly higher than those of equivalent lead types, although this was not always the case. Furthermore, the study showed that for bulk bullets being offered in stores to hand loaders, there was a difference of 5.5% in favour of a non-lead type (lead: caliber 30, 11.7 g; non-lead: caliber 30, 10.1 g), and suggested that increased demand for non-lead products will stimulate production and availability and thus align lead versus non-lead prices also regarding loaded cartridges.

In relation to the overall costs to hunters of pursuing their sport, the cost of ammunition plays a minor role (Thomas 2015). However, several studies demonstrate that the price of non-lead alternatives is a primary concern for hunters (Kanstrup 2018 (**Paper 10**); Kanstrup et al. 2021 (**Paper 6**)) and even just slightly higher prices may inhibit an individual hunter's choice of non-lead products. American studies have demonstrated that barriers to using non-lead ammunition primarily were availability and its higher cost and that voucher programmes with free non-lead ammunition induced a higher rate of voluntary compliance (Chase and Rabe 2015). Furthermore, it was demonstrated that when free ammunition incentives were provided to big-game hunters in Wyoming, Bald Eagles *Haliaeetus leucocephalus* had significantly reduced levels of lead exposure (Bedrosian et al. 2012).

Economic incentive systems to support a shift from lead to non-lead ammunition have only been introduced in a few European countries (e.g. Austria) (Mateo and Kanstrup 2019 (**Paper 2**)), and the effect on sales volumes and use has been poorly documented. To the knowledge of the author of this dissertation, no jurisdictions have introduced broader state-organised tax incentive systems to facilitate the transition from lead to non-lead ammunition. Such systems were highly successful in the process of substituting leaded with unleaded petrol in the 1990s, where many countries – as an interim measure prior to taking regulatory steps – adopted a tax policy that assured the price of unleaded petrol was lower than that of leaded and thereby stimulated a rapid increase in unleaded sales. A number of European countries used this approach, for example Germany where leaded petrol was completely eliminated through tax incentives (OECD 1999). The viability and relevance of such an approach to facilitate transition from lead to non-lead ammunition in Europe is questionable. Firstly, the availability of non-lead ammunition is persistently increasing and prices are dropping, with the result that the cost of some common types of non-lead ammunition (e.g. steel shot) is already comparable or lower than that of lead types (Kanstrup et al. 2021 (**Paper 6**); Kanstrup and Thomas 2019 (**Paper 7**)). Secondly, the cost of ammunition plays a minor role in the hunter's overall budget; hence tax policies would need to create a substantial cost benefit of non-lead products to have an impact. Finally, many hunters may have accumulated large stocks of their own lead

<sup>18</sup> <https://guntex.dk/>

ammunition to be exhausted before a system of taxing products at purchase level would have effect. Here, regulation of the use and possession of lead ammunition, as anticipated in the forthcoming European Union restriction, would be more efficient if enforced and adhered to.

### 7.3 Lead ammunition is not sustainable

Kanstrup et al. (2018 (**Paper 4**)) dealt with all aspects of sustainability relating to the use of lead in hunting ammunition and concluded that use of lead ammunition is incompatible with the established principles for sustainable hunting. Adverse impacts on wildlife population processes and the potential for reductions in species population sizes, including rare and threatened taxa, mean that hunting with lead ammunition is not sustainable in ecological terms. Avoidable sub-lethal health and welfare impacts on large numbers of exposed wild animals are ethically unjustifiable. In political terms, continued use of lead ammunition undermines a broadly ambivalent public perception of hunting and thus creates obstacles to the long-term maintenance of hunting interests (also reflected in Arnemo et al. (2019 (**Paper 23**)); Kanstrup (2015 (**Paper 21**)); Kanstrup and Thomas (2020 (**Paper 1**)).

Lead ammunition leads to additional and avoidable dietary lead exposure for human consumers, which not only conflicts with public policy goals of removing all avoidable sources of exposure to lead but also creates objective and significant health risks for regular consumers, especially children and pregnant women. This element clearly poses a risk to the benign public perception of hunting (Kanstrup and Thomas 2020 (**Paper 1**)) but can also be related to the economic aspects of sustainability of the use of lead ammunition as described in Pain et al. (2019 (**Paper 3**)), who estimated that the consumption of lead-shot game by children within the European Union today may be linked to a potential loss of IQ estimated to be worth an annual cost of €40 million–€104 million to society each year if the use of lead shot and the rates of consumption of lead in game meat food persist at current levels. The study estimated minimum annual direct costs of continued use of lead ammunition across the European Union and Europe of c. €383–€960 million and €444–€1,300 million, respectively, and by using a willingness to pay approach, it estimated the value that society places on being able to avoid these losses was c. €2,200 million for waterbirds alone. The potential costs to mitigate the impacts of lead ammunition should, legally, be returned to the hunters and shooters based on the Polluter-pays Principle (e.g. European Union Treaty<sup>19</sup> Article 191 and European Union Directive 2004/35/<sup>20</sup>, Article 1) (Kanstrup et al. 2018 (**Paper 4**)). However, this principle has, in reality, not often been applied and societal costs are therefore likely to be externalised (Kanstrup and Thomas 2020 (**Paper 1**)).

A further assessment of the sustainability of the use of lead ammunition in hunting requires an evaluation of the levels of resistance and resilience (reversibility) as defined in section 6.1.3. This can be related to lead exposure in both biotic and abiotic systems.

<sup>19</sup> [https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uris-erv:OJ.C\\_2012.326.01.0001.01.ENG&toc=OJ:C:2012:326:TOC](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uris-erv:OJ.C_2012.326.01.0001.01.ENG&toc=OJ:C:2012:326:TOC)

<sup>20</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0035>

Although lead adversely affects physiological processes in living organisms (section 6.4.3.), organisms can exhibit varying degrees of resistance to exposure, for instance by immediate excretion or the ability of many organisms to physiologically lock lead away in inactive forms in tissues such as fat and bone. Lead may later be remobilised from these tissues, at which time it may become bioavailable and affect vital processes (Lam et al. 2020). However, this may be in limited doses with relatively low impact. Hence, many living organisms exhibit a certain level of resistance, as manifest in studies demonstrating fluctuating lead levels in blood and tissue according to exposure, as for example seen in raptors exposed to lead ammunition during hunting seasons (Bedrosian et al. 2012; Taggart et al. 2020). Such seasonal resistance indicates a possibility for potential recovery in the long term of the individual if the exposure terminates (resilience). This has been frequently demonstrated in the case of lead-poisoned animals brought in for treatment in rehabilitation centres, where such victims may show complete recovery following the termination of their exposure to lead (DOF 2020). Similar recovery has been demonstrated for human consumers after terminated dietary exposure to lead ammunition (Parry and Buenz 2020). On the contrary, effects of early life lead exposure (e.g. reduced IQ, cognitive abilities, intellectual disability and mental retardation) are permanent and irreversible (Lanphear et al. 2005).

In free-living animals in natural ecosystems, assessment of resilience in terms of physiological recovery after reduced exposure to lead and the subsequently reduced morbidity and mortality in individuals and populations is difficult. However, many studies have demonstrated a high degree of resilience based, indirectly, on indicators of lead exposure, including lead tissue levels and prevalence of ingested lead ammunition. Kanstrup et al. (2019 (**Paper 22**)) suggested that low concentrations of lead in Danish raptors compared to neighbouring countries were related to the phase-out of lead shot for hunting in Denmark since 1986. Kanstrup and Balsby (2019 (**Paper 16**)) supported the hypothesis that Mallards have switched from ingesting lead to steel shot due to the change of shot types used for hunting in their habitat, thereby indirectly demonstrating that the Danish phase-out of lead shot for hunting has led to decreased levels of waterbird poisoning, which is supported by studies elsewhere (Anderson et al. 2000; Mateo et al. 2014; Mondain-Monval et al. 2015; Samuel and Bowers 2000; Stevenson et al. 2005; Vallverdú Coll 2012).

Deposition of lead ammunition in soil and sediments may originate from (i) ammunition directly dispersed from hunting, i.e. shot and bullets penetrating or not hitting the target animal, (ii) ammunition ingested and later excreted by avifauna or (iii) embedded in non-retrieved target animals, which are introduced to the ecosystem after their death and natural decomposition. In particular, the contribution of the latter is poorly investigated. However, lead shot pellets transferred into ecosystems via wounded animals and ingestion by birds may not be a negligible source of lead as judged from the rates of wounding and ingestion recorded for multiple species. In contrast, regarding the direct contribution to ecosystems from ammunition penetrating through or not hitting the target animal, our state of knowledge is more advanced and demonstrates, in particular for gunshot, that high lead densities are accumulated in substrates in hunting hotspots. In such situations, this legacy of lead ammunition is evident. In some systems, abiotic parameters, including sediment accumulation and movement, may render the ammunition (periodically) unavailable to biological processes (e.g. due to deeper burial and function loss to surface layers). In some situations, however, dispersed lead ammunition can accumulate to very high densities and persist in places where it

remains highly accessible to birds for centuries, as demonstrated by Kanstrup et al. (2020 (**Paper 14**)). In this latter case, the level of resilience seems to be very limited and the dispersal of ammunition to be largely irreversible.

Judged against the background of the formal definitions of sustainability, in this case the Brundtland definition (section 6.1.3), the use of lead ammunition cannot be regarded as sustainable as it obstructs society from meeting the needs of the present, in terms of conserving wildlife and ecosystems and ensuring safe, humane hunting and maintaining a positive public perception. At the same time, the continued use of lead ammunition compromises the ability of future generations to meet their own needs because its continuation contributes a huge and accumulating legacy of spent toxic ammunition in natural ecosystems whose costs, measured either in the lost value of such systems or in the mitigation costs, are externalised to the community (Kanstrup and Thomas 2020 (**Paper 1**)).



Dispersed lead ammunition can accumulate to very high densities in hunting hotspots and can persist in places where it remains accessible to birds for centuries. In this case, the level of resilience seems to be very limited and the dispersal of ammunition to be largely irreversible.

#### **7.4 The precautionary principle applies**

In the face of reasonable grounds for concern that a particular activity may result in serious environmental harm, but where the risk has not been determined with certainty, the need to err on the side of caution and give the environment the benefit of the doubt is reflected in the precautionary principle. The application of the precautionary principle is, however, normally reserved for uncertain risks, and is only to be invoked where there is uncertainty about the relationship between the exposure to risk (in this case lead from ammunition) and the resultant harm to ecosystems, wildlife and humans. Since the historic work on lead toxicity presented here and elsewhere is overwhelming,

there is very little uncertainty about the relationships involved, rendering the precautionary principle arguably irrelevant. Nevertheless, any action needs to weigh the benefits and risks and any claim needs to carry a certain burden of proof. Both wild animals and humans can show variable overt responses to lead exposure as is the case with individual responses to many other pollutants. Here it may be necessary in some particular cases to evaluate lead exposure in the light of the precautionary principle.

The precautionary principle has been widely invoked by states in multiple non-binding and binding instruments relating to nature conservation, such as the 1992 Rio Declaration on Environment and Development<sup>21</sup> (Principle 15), stating: *“In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation”*, the Convention of Migratory Species’ Raptors Memorandum of Understanding<sup>22</sup> (para. 6) and the texts of numerous international treaties and national laws. For instance, a version of the principle appears in preambular text of the Convention of Biological Diversity’s<sup>23</sup> noting that: *“Where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat”*. Article II(2) of the AEWA Agreement Text<sup>24</sup> provides that parties *“should take into account the precautionary principle”* when implementing the conservation measures prescribed by the agreement, and Article 191(2) of the Treaty<sup>25</sup> on the Functioning of the European Union asserts that *“Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay.”* Following the European Commission’s issuance of a Communication on the precautionary principle (Commission of the European Communities 2000), the principle has come to inform much European Union policy, including areas other than the environment. Precise formulations differ, as do interpretations of their legal implications. In the wildlife conservation context the precautionary principle, at the very least, provides that scientific uncertainty should not be used to justify failures to act in the best interests of species’ conservation. However, some formulations are considerably more stringent. For instance, AEWA’s Conservation Guidelines<sup>26</sup> on the impacts of infrastructural developments define the principle as *“[p]rudent action which avoids the possibility of irreversible environmental damage in situations where the scientific evidence is inconclusive but the potential damage could be significant”*. Trouwborst (2006) argues that the principle has achieved the status of customary international law and that it should be defined in this context as encompassing both a right and a duty to take precautionary action: *“where there are reasonable grounds for concern that significant environmental harm may ensue,*

<sup>21</sup> [https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A\\_CONF.151\\_26\\_Vol.I\\_Declaration.pdf](https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf)

<sup>22</sup> <https://www.cms.int/raptors/en/page/agreement-text>

<sup>23</sup> <https://www.cbd.int/convention/articles/?a=cbd-00>

<sup>24</sup> [https://www.unep-awea.org/sites/default/files/basic\\_page\\_documents/agreement\\_text\\_english\\_final.pdf](https://www.unep-awea.org/sites/default/files/basic_page_documents/agreement_text_english_final.pdf)

<sup>25</sup> [https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.C\\_.2012.326.01.0001.01.ENG&toc=OJ:C:2012:326:TOC](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.C_.2012.326.01.0001.01.ENG&toc=OJ:C:2012:326:TOC)

<sup>26</sup> [https://www.unep-awea.org/sites/default/files/publication/cg\\_11\\_0.pdf](https://www.unep-awea.org/sites/default/files/publication/cg_11_0.pdf)

*states are deemed to have a customary right to do something about it. Where, however, the anticipated harm is not only significant but also serious or irreversible, states must be considered to also have an obligation to take action". Percival (2006) suggests that the precautionary principle cautions that regulatory policy should be proactive in ferreting out potentially serious threats to human health and the environment, as confirmed by the history of human exposure to substances including lead in other compounds than ammunition and asbestos.*

In summary, the specific risks of lead from ammunition in the environment are overwhelmingly documented and beyond uncertainty. It therefore could be argued that applying the precautionary principle is irrelevant. However, in the cases where there are elements of doubt about the specific risks of lead, the precautionary principle must apply. Communities must change the past approach to lead ammunition, i.e. shift from a stand point where "the absence of evidence of risk = evidence of the absence of risk" to "the absence of evidence of risk = a possibility of risk until proven otherwise", hence placing the burden of proof on those that claim that the future use of lead ammunition does not cause harm.

## **7.5 Role of stakeholders**

A successful transition is dependent of active involvement of citizens and their stakeholders. In the following sections, emphasis will be put on two of the most central groups, i.e. the manufacturers of ammunition and the users – the hunters.

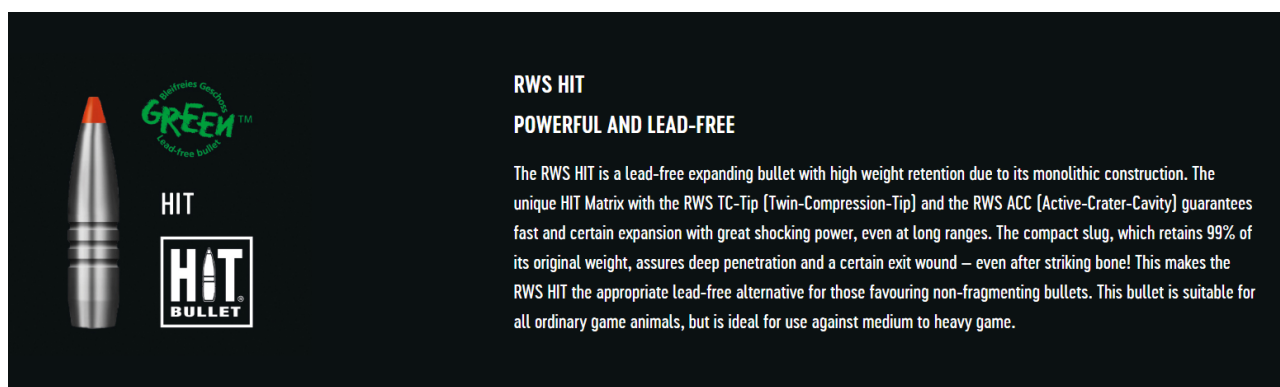
### **7.5.1 Manufacturers' interests**

The representative bodies of the ammunition and gun trades seek to protect their activities from change and unnecessary economic cost, though interestingly, individual businesses often seem well prepared to meet changing demands when/if the need arises, hence the present product and market availability of non-lead ammunition. Overall, business strategies to encourage the development of non-toxic hunting and sport shooting ammunition in order to sustain hunting and sport shooting interests in the long term have yet to be adopted by the ammunition manufactures and, in particular, their trade organisations. Indeed, those organisations have shown widespread resistance to change and keep arguing against any adverse impact of lead ammunition on the environment and human health. A search on the web page of the Association of European Manufacturers of Sporting Ammunition (AFEMS) in August 2020 revealed a special section dedicated to the lead ammunition debate<sup>27</sup>. In this section, a reference was made to 14 studies (claimed to be independent) presenting the common narrative that lead ammunition was of no relevance to human health or ecosystems, as for instance concluded in one presentation by the Hunters' Organisation from Schleswig-Holstein e.V. stating: "*Lead in lead ammunition is not relevant for consumer protection nor animal protection*"<sup>28</sup>. Of the studies presented here, only one was peer-reviewed (Meyer et al. 2016) (funded *inter alia* by AFEMS) and the majority was authored by people with rather obvious connections to the hunting and ammunition manufacturing communities. No reference was given to the massive legacy of scientific literature demonstrating both the severe adverse impact that lead ammunition can pose to wildlife,

<sup>27</sup> <https://www.afems.org/lead/>

<sup>28</sup> <https://www.afems.org/download/lead/independent-studies/Consumer-and-Animal-Protection.pdf>

ecosystems and humans, nor was reference made to the broad variety of existing suitable alternatives (e.g. Delahay and Spray (2015); Kanstrup et al. (2019); Watson et al. (2009)). Together with the World Forum on Shooting Activities (WFSA), AFEMS, in 2015, stated *inter alia* that metallic lead in ammunition had no significant impact on human health and the environment as compared to other forms of lead and that lead fragments in game meat, if ingested, cannot be directly absorbed by the human body because they are in metallic form. On this basis, AFEMS flagged the extraordinary and highly misleading headline “Lead makes you beautiful and HEALTHY” (see Kanstrup and Thomas 2020 (Paper 1)). Furthermore, the ammunition manufacturers’ representatives argue that the existing alternatives to lead ammunition are insufficient in terms of efficiency and safety despite the fact that members of these organisations, when advertising their non-lead products, commonly give their full recommendation of the general reliability of these products, see one example in Figure 7.2.



**Figure 7.2.** An example of a manufacturer’s recommendation of a “powerful and lead-free” rifle cartridge, in this case the German product RWS<sup>29</sup>.

This inconsistent and opportunistic approach taken by the ammunition industry reflects the real interest of this industry, i.e. to sustain existing production lines and, at the same time, develop new fields where there is a commercial potential. The industry’s approach to resist the phasing-out of lead ammunition is motivated by the wish to sustain a profitable, commercial trade of traditional lead products that have been the core of this industry for centuries. At the same time, the (mostly partial) regulation of lead shot in most European countries and the progressive phase-in of non-lead rifle ammunition either by regulation or voluntarily (Kanstrup et al. 2021 (Paper 6); Mateo and Kanstrup 2019 (Paper 2)) call for research and development to satisfy an increasing future demand for non-lead products. In other words, the ammunition industry resists the phase-out of lead ammunition for pure commercial reasons. If the industry’s postulated concern for animal welfare (the lethality question) and safety (ricocheting and damage to guns/shooters) by introducing non-lead ammunition were true, the industry could not stand behind the manufacturing, marketing and recommendation of any non-lead ammunition.

The commercial approach taken by the lead ammunition manufacturers and their organisations is fully understandable and predictable as this community is ingrained within a traditional, highly profit-oriented and competitive industry. Manufacturers are key players in the process of transitioning from lead to non-lead hunting ammunition and their concerns for a change to sustain their commercial interests should not and have not been disputed or dis-

<sup>29</sup> <https://rws-ammunition.com/en/infotainment/rws-bullets/rws-hit>

respected. However, the opportunistic approach leaves the information output from the ammunition producers resembling propaganda, in particular their information output concerning the risk of lead ammunition to ecosystems and human health. This contradicts the results and conclusions of more than half a century of scientific research reviewed, for example, by Arnemo et al. (2016) who found that more than 99% of 570 peer-reviewed papers published from 1975 to August 2016 raised grave concerns over the continued use of lead-based ammunition.

Despite the overwhelming evidence of negative impacts of lead in ammunition and the science-based documentation of the existence of suitable alternatives, AFEMS, in a 2019 press release, states: *"We believe that the ECHA investigation report cited by the Commission as the basis for their request, is not based on sound scientific information"*<sup>30</sup>. This attitude resembles that of previous industries campaigning for sustaining lead in products, for instance the addition of tetraethyl lead to petrol, where a *"show me the data"*-paradigm in the 1920s was established and led to a precedent-setting system of voluntary self-regulation by the lead industry as a model for environmental control. It implicitly signaled the level of industrial responsibility for lead pollution, and the stance was based on the rationale that there was no convincing published evidence of harm to humans (Needleman 1997; Nriagu 2009). Subsequent awareness and political responsibility led to the removal of lead from petrol (Needleman and Gee 2013).

The North American and European hunting and sport shooting ammunition industry has ensured the availability of an almost complete range of non-lead ammunition products. This is not due to any overall business strategy or defined target to support the long-term sustainability of hunting and shooting by supporting the transition to non-lead ammunition with products that meet toxicological criteria but rather due to the behaviour of individual businesses – often rather small companies – that have taken the lead and showed preparedness to meet changing demands driven by the hunters and the views of wider society (Kanstrup and Thomas 2020 (**Paper 1**)). Substituting lead with non-toxic alternatives in ammunition for recreational uses will cause short-term production and market changes. However, by acting on this opportunity, the ammunition manufacturing industry would demonstrate their ability to innovate and their sincere commitment to providing hunters and shooters with non-toxic products. By supporting such a transition, the ammunition manufacturing industry could make an essential, beneficial and necessary contribution to the long-term sustainability of hunting and shooting and thereby secure the long-term basis for their profitable business.

### 7.5.2 Hunters – representatives and citizens

Many national hunters' organisations and their international associates positively support the phase-out of lead shot – at the very least for hunting over wetlands (e.g. FACE 2020). However, they do not proactively campaign for such change and do not actively contribute to measures to improve enforcement where legislation is in place (Kanstrup et al. 2018 (**Paper 4**); Thomas et al. 2021 (**Paper 26**)). The intransigence of the hunting communities has inhibited progress at the socio-political level despite the widespread awareness of the consequences of lead ammunition use and a large and increasing body of literature emphasising the multiple benefits that would accrue from a transition to

<sup>30</sup> [https://gallery.mailchimp.com/068f43d6728c3bcee6f5c89ee/files/52636584-640d-4c8e-94d4-a246ad4f09c0/Press\\_Release\\_AFEMS\\_ECHA\\_restriction.pdf](https://gallery.mailchimp.com/068f43d6728c3bcee6f5c89ee/files/52636584-640d-4c8e-94d4-a246ad4f09c0/Press_Release_AFEMS_ECHA_restriction.pdf)

non-lead alternatives (Kanstrup and Thomas 2020 (**Paper 1**)). Although in some countries there may be a close relationship between the hunters' organisations and the national branches of the hunting ammunition industry, generally, the reactive strategy adopted by hunting organisations is not overtly motivated by short-term commercial interests but more likely by a fundamental hesitation to change. In general, hunters perceive and defend hunting as an established tradition and their self-perception is ingrained in this tradition that is conservative, resistant to change and not proactive (Cromie et al. 2015; Kanstrup et al. 2018 (**Paper 4**); Kanstrup and Thomas 2020 (**Paper 1**); Newth et al. 2015).

The question of lead in ammunition has often turned the discourse between stakeholders into a battlefield where the resistance to change is not driven by individual hunters but by a lack of political and organisational leadership. In many countries, different organisations represent different hunting interests. It is a common observation that such organisations do not think independently of each other, or indeed scientifically, and the competition between them is to be seen most forcefully to oppose change.

This was very evidently the case in Denmark in the 1980s when the public debate on the phase-out of lead gunshot was characterised by harsh mutual attacks, not only between traditionally opposing stakeholder groups (for example hunters and ornithologists) but also between different hunting organisations and hunters and scientists (Kanstrup 2018 (**Paper 10**)). A similar situation was evident later in the UK where hunting and field sport groups accused wildlife scientists of campaigning against lead in the media, for instance “*selectively withholding evidence...*” (CA 2013), while at the same time advocating strongly for sustaining the use of lead ammunition (Figure 7.3). However, the discourse has now changed – in some countries more rapidly than others. In Denmark, lead gunshot was phased out in the 1990s with the support of the hunters' organisations. In the UK, the same field sports organisations who in the 2010s campaigned strongly “*to fight the threat to lead ammunition*”, in a joint 2020 statement on the future of shotgun ammunition for live quarry shooting, said: “*In consideration of wildlife, the environment and to ensure a market for the healthiest game products, at home and abroad, we wish to see an end to [...] lead [...] in ammunition used by those taking all live quarry with shotguns within five years*” (GWCT et al. 2020).

**Figure 7.3.** An example of a British countryside and hunting stakeholder campaigning to fight the threat to lead.



At the international level, FACE is the main stakeholder representing the interests of hunters' organisations interests in Europe, just as CIC is an actor in Europe and worldwide. Both organisations have been involved in the lead ammunition issue since this discussion was initiated internationally during the 1980s. Both were invited to and actively participated in the adoption of the African-Eurasian Migratory Waterbird Agreement (AEWA) in 1995, which included an awareness of the dangers of lead gunshot, which was at that time well appreciated in Europe. This resulted in the AEWA adopting a firm policy that required the signatory parties to endeavour to phase out lead shot for hunting in wetlands before 2000 (Kanstrup et al. 2018 (**Paper 4**)). Since then, FACE and CIC have played different roles. In 2009, CIC held a workshop for experts (Kanstrup 2009). This workshop, "Sustainable Hunting Ammunition", was mandated by the CIC General Assembly 2009 and resulted in a workshop resolution (Figure 7.4) stating *inter alia* that risks from lead ammunition to wildlife, humans and the environment require urgent adoption of the use of nontoxic ammunition, that hunting organisations should be proactive rather than reactive on this issue and that they should act quickly.

## 8.2 Workshop Resolution

### Sustainable hunting ammunition

CIC Workshop, Aarhus, 5-7 November 2009

---

#### Resolution:

1. Lead is a poisonous material, and lead from ammunition causes preventable poisoning of wildlife and pollution of the environment, and poses a risk to consumers of game meat.
2. Ingestion of spent lead from ammunition kills waterfowl and terrestrial birds, including predators and scavengers and causes widespread sub-lethal effects. More recently it has been established that lead from spent ammunition contaminates game meat.
3. We encourage CIC and other hunting organizations to work with the appropriate food agencies to resolve the issues of lead contamination in game and we recommend the inclusion of game as a food product whereby the Maximum Limits of contamination are defined under EU Regulation 1881/2006.
4. Risks to wildlife, humans and the environment require urgent adoption of the use of non-toxic ammunition. It follows that hunting organisations should be proactive rather than reactive on this issue and that they should act quickly.
5. It is now technically feasible to phase out the use of lead ammunition for all hunting and shooting. However we recognise that while a wide range of non-toxic gunshot is currently available it may take longer for other types of non-toxic ammunition to be developed, e.g. some rifle bullets.
6. We recommend that a Road Map be developed by 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.
7. We recommend that a structured network be established to evaluate and disseminate information and provide advice, (e.g. based on the CONSEP model).
8. 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".

**Figure 7.4.** Resolution from the workshop "Sustainable Hunting Ammunition" arranged by the CIC 2009. See Kanstrup (2009) for more details.

Furthermore, the workshop recommended CIC to work for an inclusion of game as a food product, which would bring game meat into the same realms of control as farmed meat under the Maximum Limits of contamination, as defined under European Union Regulation 1881/2006, and that a Road Map be developed by CIC to implement the phase-in of non-toxic ammunition for all hunting and shooting as soon as practicable. Since then, CIC has shown very little initiative to follow these recommendations. In 2015, arranged a workshop (title: "What hunting rifle ammunition should I use?") together with FACE, AFEMS and the German ammunition manufacturer RWS. Seemingly, no general conclusion was reached at the meeting, although the full workshop can be viewed at the CIC video channel<sup>31</sup>. In August 2019, CIC made a comment on the European Commission's request to prepare a proposal to restrict all lead ammunition, underlining that CIC will continue to follow this issue very closely, acting together with FACE and other relevant parties in the best interests of the environment, the safety of hunters and the welfare of animals, concluding, however, that more work is still required to address all of the environmental and animal welfare shortcomings of a transition.

The challenge for hunting stakeholders to balance their different interests in the matter of lead ammunition can be further illustrated by the following examples.

The CIC "Sustainable Hunting Ammunition" workshop (Kanstrup 2009) was attended by a mixture of university scientists, private consultants, representatives of the ammunition industry and hunting stakeholders at both Nordic, European and Global level. The workshop report included a disclaimer concerning its outcome, including the resolution (Figure 7.4) saying: *"The outcome must [...] be regarded as an evaluation by experts and not stakeholders, and reservations by attendants having their formal platform in NGOs with a particular political interest in the issue must therefore be respected"*.

This disclaimer demonstrates that hunting NGOs have particular "political" interests regarding the issue of lead ammunition that do not necessarily align with the output given by experts. This is well-recognised and not necessarily controversial but underlines the fact that the role of stakeholders, and not least the information provided by them, should be understood and interpreted in this light and not necessarily be regarded as scientific facts or as reflecting the views and interests of the stakeholder grassroots, in this case the hunters (citizens). This observation is supported by an example from the European Union REACH approach to restrict hunting with lead gunshot in European wetlands by August 2020. In the final process before the vote in the REACH Committee on 3 September 2020, high-positioned expert employees as well as political (board) representatives in the Danish Hunters' Association were requested to sign the European Hunting Expert Fact Sheet (Hunting Experts 2020) to include the practical evidence of substituting lead shot with non-lead shot based also on 24 years' experience from the Danish hunting community. However, despite the fact that the Danish Hunters' Association often has advocated for a European phase-out of lead shot, the association abstained from this opportunity. This was not due to any disagreement with the content of the draft fact sheet but based on the reservation that the association thus would be inhibited from influencing international colleague organisations (e.g. FACE) to support a transition from lead to non-lead ammunition. This is an understandable and recognisable position and strategy from a central national NGO, resulting,

<sup>31</sup> <https://www.youtube.com/channel/UCaarm993sAqdiCC681egapw/playlists>

however, in an opposed stance to that of some colleague organisations and expressed in a FACE press release rejecting the REACH proposal of restricting lead shot in wetlands<sup>32</sup>. Interestingly, however, high ranking employees and board members of the Danish Hunters' Association have publically, but as private persons, expressed their support of the Expert Fact Sheet and, accordingly, the REACH Committee's decision (on 3 September 2020) to restrict lead shot in wetlands (Hunting Experts 2020). This example also shows the constraints of stakeholders to balance their roles in a process where a strategy to work internally and to demonstrate solidarity with other kindred organisations conflicts with the possibility of providing clear, science- and experience-based information. This was further demonstrated in a letter from 30<sup>th</sup> October 2018 to Ms. Elzbieta Bieńkowska, the European Union Commissioner for Internal Market, Industry, Entrepreneurship & SMEs, from three life-long hunters and former heads of national and European hunting organisations (hereof two former Secretary Generals of FACE)<sup>33</sup>. This letter expressed the firm opinion that lead shot requires complete restriction and replacement for the long-term good of wildlife, human health and hunting. The letter clearly stated that, quote: *We know and appreciate that lead is ballistically attractive, that hunters are familiar with it and that the gun and ammunition industry have built up to use and supply it. However, the wide availability of effective, safe and affordable alternatives means that it can no longer be acceptable from the perspective of ecological and human health and ultimately our collective vision for sustainability. [...] We therefore urge you not to succumb to suggestions that it is not possible to change. It is.*" This letter elegantly demonstrates how such former representatives of hunters with professional insight into the internal functioning of large stakeholder organisations and with particular knowledge of practical hunting were restricted in their ability to freely communicate their views, when in office.

Hunters' representatives at international and national level are regarded as representatives of the "stakeholders" and have, qua this position, been the official contacts for communication and consultation concerning the matter of regulating the use of lead ammunition. At European level, FACE is the key stakeholder representing national hunting organisations. In a few countries (e.g. France with 1.3 million hunters), these organisations have all hunters as members as membership is obligatory. However, in most countries membership of private organisations is voluntary. For example, in the UK, only 155,000 of an estimated 625,000 (25%) hunters are members of the British Association for Shooting and Conservation<sup>34</sup>. In Sweden, 195,000 of 29,000 hunters (67%) are members of the largest hunting organisation, Svenska Jägarförbundet, and in Belgium 13,000 of 20,000 hunters (65%) are members of a national hunting organisation<sup>35</sup>. In most countries, it is the norm that only a subset of hunters, and often only a minority, are members or affiliated with an organization; thus, they do not participate in membership activities including receipt of information or subject consultation about issues of societal importance. As a result, the lines of communication from global and European scientific bodies, regulatory authorities, management agencies and even hunters' organisations in the respective countries to the individual hunters are long and probably totally insufficient to ensure their effective participation in

<sup>32</sup> <https://www.face.eu/2020/08/phasing-out-lead-gunshot-over-wetlands-why-the-ec-proposal-is-unworkable/>

<sup>33</sup> <http://www.leadammunitiongroup.org.uk/wp-content/uploads/2019/12/Minutes-of-the-23rd-LAG-meeting-with-appendix.pdf>

<sup>34</sup> <https://basc.org.uk/about-us/>

<sup>35</sup> <https://www.face.eu/members/>

understanding the issues or participating in debates. In some cases the information may even be seen as biased as could, for instance, be the case in Denmark where food safety authorities have provided weak and misleading guidance on the subject of lead in game meat, leading to generally poor awareness of the adverse impacts of lead ammunition (Kanstrup et al. 2021 (**Paper 6**)).

In summary, hunters (as individuals, citizens and central players in the drama unfolding around them) seem only to be relatively poorly involved in the ongoing process of managing lead in ammunition, either at the European or national level. The issue is primarily managed through involvement of the hunters' representatives – the key stakeholders. These stakeholders often have complicated political and commercial agendas causing disruption of the lines of communication, which can easily result in either absent or biased information to and feedback from the grassroots. This has meant that the basic concerns of individual hunters are not necessarily included in the way that the risks from lead ammunition are recognised, discussed and ultimately managed. Inevitably, this not only weakens the power of the democratic process to deliver decisions, it also jeopardises the hunters' perception of regulations, thereby undermining the compliance with these.

The basic concerns of individual hunters are not necessarily included in the way that the risks from lead ammunition are recognised, discussed and ultimately managed.



## 7.6 An anti-hunting ploy?

Several studies have demonstrated that the two most common underlying causes for hunters resisting the change from lead to non-lead ammunition have been (i) the failure to recognize the adverse impact of lead ammunition on wildlife, ecosystems and human health and (ii) a fundamental inability to accept that non-toxic alternative ammunition could replace lead ammunition without jeopardizing common standards of efficiency and safety (Cromie et al. 2019; Kanstrup 2018 (**Paper 10**); Newth et al. 2019).

Over the last two decades, the accumulated legacy built upon the careful documentation of all of the adverse impacts of lead ammunition has been steadily growing, such that the core problem has become widely recognized and accepted, not only among a circle of scientists and conservationists, but increasingly in recent years also by some representatives of the hunting community (GWCT et al. 2020). Further recognition and understanding of the deleterious

impacts of the exposure of wildlife and humans to this source of lead will not be further progressed by the benefits of yet more continued scientific research. The current impediments to change are not associated with lack of available information, but resistance to change, which can now be regarded as purely socio-political (Arnemo et al. 2016). We find ourselves in a situation where the market for non-toxic, efficient and safe non-lead alternative ammunition has developed to the degree that the availability and supply of such products largely fulfils all the needs for any type of contemporary hunting and shooting application (Kanstrup et al. 2018 (**Paper 4**)). It is therefore evident that the grounds for all of the original and most fundamental reservations about the transition to lead to safe and reliable alternatives have all been refuted.

A third major force for resisting change in recent years has been the development of a perception among hunters and their representatives, the ammunition industry, and even by some governments, that regulation of lead in ammunition represents an attack on the basic right to hunt, *i.e.* that lead is being used as an anti-hunting ploy (*e.g.* Cromie et al. (2015); Kanstrup et al. (2021 (**Paper 6**)); Newth et al. (2019)). Newth et al. (2019) showed that hunters' perspectives were compounded by the feeling that opposition to lead shot is driven by a dislike of shooting. This stance has also been adopted by the ammunition industry, characterized by the statement from a representative of the Sporting Arms and Ammunition Manufacturers Institute (SAAMI) at a meeting arranged by CIC and FACE in February 2015, who considered that the approach taken by conservationists to restrict lead ammunition *"is not about lead – it is about hunting"*<sup>36</sup>. This opinion was addressed and balanced by the AEWA Executive Secretary, who in May 2020 made this statement: *"And let me be absolutely clear, no one here is trying to ban hunting – this is anti-poisoning, not anti-hunting. This is a misconception which keeps circulating like wildfire, refusing to die down. Hunters are a crucial part of AEWA and the wider conservation community. Countries such as the Netherlands and Denmark have shown us the way – they are proof that even the total phase-out of lead in ammunition is possible whilst keeping the hunting community strong and intact"*<sup>37</sup>. A representative from the British food market chain, Waitrose, at a October 2020 conference<sup>38</sup> arranged by GWCT stated *"...if we insist that the scientific case against lead is merely a device to ban shooting, we are lost"*.

In an attempt to undertake further analysis of this question, the author of this dissertation undertook an online survey (unpublished) among a group of 35 scientists from 11 countries (USA, Canada, Argentina, South Africa, New Zealand, UK, Germany, Switzerland, Norway, Sweden and Denmark) who regularly exchange information about lead in ammunition and who have jointly contributed several hundred scientific research papers on the topic. This group represents a broad spectrum of expertise in toxicology, wildlife health, wildlife management and nature conservation and the members are strong advocates for removing lead from hunting. Many of the group members contributed to the 2020 hunting expert fact sheet (Hunting Experts 2020) and the 2020 European scientists' open letter on the risks of lead ammunition (European Scientists 2020). However, the survey revealed that of the 35 (100%) respondents, 18 (51%) were in possession of a hunting licence or similar permit to hunt and of these, 13 (72%) hunted more than 5 days a

<sup>36</sup> <https://www.youtube.com/watch?v=PtPfn-24b64&index=15&list=PLFJWKcWN4Qf5XkZ99qPrI3tmDSJhy72HN>

<sup>37</sup> <https://www.unep-aewa.org/en/news/it-time-let-go-lead>

<sup>38</sup> <https://www.eventbrite.co.uk/e/game-2020-conference-tickets-90124582051#>

year. Twelve (34%) respondents were members of a hunting association, 17 (49%) were a member of a nature protection association, and 3 (9%) a member of an animal welfare/right organisation. Twenty-three (66%) regarded their attitude to hunting to be “Pro-hunting”, and twelve (34%) regarded it to be “Neutral to hunting”. None regarded their attitude to be “Anti-hunting” and none replied “Don’t know” to this question.

In conclusion, there is no convincing evidence that the initiative and movement to phase out lead in hunting ammunition is driven by a motivation to harm, reduce or ban hunting. On the contrary, many of the key people involved have accumulated a broad expertise based upon their own passion for, and practical experience of, hunting. On the basis of their first hand knowledge, they have documented the consequences of using lead ammunition through their own experiences but, more than that, have sought solutions and found ways to introduce non-lead ammunition to their own community. These ambitions have been motivated entirely by the wish to protect wildlife, ecosystems and humans from lead poisoning, but fundamentally also to sustain hunting.

## **7.7 Game meat**

The primary motivation for regulating lead in hunting ammunition has largely been to remove the very evident risk of poisoning our avifauna, either through birds ingesting lead shot as a direct contaminant or indirectly via secondary exposure of predatory and scavenging birds through consumption of birds that have been injured by or ingested lead gunshot. Poisoning may also be due to preying by such predatory and scavenging birds on un-retrieved game animals containing lead ammunition, either in the form of gunshot or residues of lead rifle ammunition (see section 3.4.6). In the US, initial concerns about lead shot stemmed from the risk to Bald Eagles (the national symbol of the States) from exposure to lead from predating waterbirds bearing ammunition lead in their bodies, which led to the regulation of lead shot over wetlands for waterbird hunting. Regulations in Europe (primarily over wetlands) have mostly been motivated from the perspective of waterbird conservation. The few regulations imposed on the use of leaded rifle bullets (e.g. in Germany, Japan, California and announced for Denmark) have been introduced primarily to protect wild scavengers from lead ingestion. However, in very recent years, a concern also for humans has come to the fore since the human species can be regarded as a predator or scavenger when consuming game meats. This concern has gained increasing importance for the argument to exclude lead from hunting ammunition in more countries including both Germany and the UK, though in the latter so far mostly articulated by private and commercial stakeholders (Barkham 2019; Gerofke et al. 2019). The European Commission is aware of the elevated lead levels found in game animals (EFSA 2010, 2012), and the food standards or safety agencies of a number of European Union nations have issued new advice intended to reduce or eliminate health risks associated with the consumption of lead-contaminated game meat.

The linkage between lead exposure levels and human health is intuitively an efficient contributory message to the discussions about removing lead from ammunition (Schulz et al. 2020) and, indeed, elimination of lead from game meat consumed by humans has, of late, become one of the strongest drivers for the transition from lead to non-lead ammunition in hunting. The food taste and demands of Europeans are rapidly changing, whether related to organic production or animal-free food products, or motivated by ethical concerns

about food production, environmental impacts of agriculture, climate and/or personal diet/health considerations (Kanstrup and Thomas 2020 (**Paper 1**)). There is a growing consumption of wild game meat in many European countries estimated to an annual value of 1.1 billion Euros (Thomas et al. 2020 (**Paper 17**)), and this expanding market appears to be readily sustained by abundant and increasing populations of European deer species and wild boar (BIOECO 2020; Massei et al. 2014). This market provides a great opportunity to support recreational hunting, especially if the game is taken with non-lead ammunition, thereby enhancing the pollution-free status of the meat.

Game is traded and exported with buried remains of ammunition. This deep-frozen “pot ready” Wood Pigeon *Columba palumbus* was purchased by the dissertation author in a Danish supermarket in 2020. It originated from the UK and was handled by a Danish game processing company. It contained three lead shot pellets of which one had fragmented into three particles (arrows). Of a sample of 5 purchased Pigeons, 4 had embedded lead shot (11 in total). This example shows that the regulation of lead shot for hunting in Denmark is no guarantee that Danish consumers will not have access to game meat containing lead.



Despite this opportunity, the pathway of exposure of humans to elevated levels of dietary lead derived from ammunition is absent from formal codes of practice on reducing exposure to lead in food, for instance the joint FAO and WHO standards for food Codex Alimentarius<sup>39</sup>, and no minimum levels of lead have been set for game meat within the European jurisdiction (Thomas et al. 2020 (**Paper 17**); Thomas et al. 2021 (**Paper 26**)).

Against this background, the total replacement of lead in hunting ammunition with available non-toxic alternatives would not only prevent exposure of humans and wildlife to ammunition-derived lead and allow depletion of the long-term environmental legacy of lead from spent ammunition, it would also make hunting more sustainable and socially acceptable (Kanstrup et al. 2021 (**Paper 6**); Kanstrup et al. 2018 (**Paper 4**); Kanstrup and Thomas 2020 (**Paper 1**)). A supplementary measure to such replacement is an amendment of the European Union Commission Regulation (EC) No 1881/2006 [of 19 December 2006], setting maximum levels for certain contaminants in foodstuffs to incorporate a maximum level also for game meats in order to harmonise food safety standards for lead in meats traded across and imported into the European Union, as proposed by Thomas et al. (2020 (**Paper 17**)). Continued use of lead ammunition, on the other hand, could mean the disposal of much shot game for human consumption is no longer possible, and an important means

<sup>39</sup> <http://www.fao.org/fao-who-codexalimentarius/about-codex/en/#c453333>

of providing economic and ethical underpinning for hunting and game management will be lost (Kanstrup et al. 2018 (**Paper 4**)).

## 7.8 Transition tools

Behavioural change may be achieved through legislation (“stick”), voluntary programmes building on the understanding and awareness of citizens or systems to reward the wanted behaviour (“carrot”) or combinations of these. Legislation will only be successful when combined with enforcement, compliance monitoring, necessary modifications to regulations (where required to achieve satisfactory behavioural change) and feedback to citizens to demonstrate the needs for, and the benefits from, the regulations and the subsequent changes in behaviour. Voluntary schemes also require monitoring of their effectiveness as well as feedback to citizens if the process is successful or where further adjustment is needed. In other words, any attempt to change citizen behaviour requires far more development, investment and monitoring than merely recommending or regulating for change (Mateo and Kanstrup 2019 (**Paper 2**); Thomas et al. 2021 (**Paper 26**)). In the case of lead ammunition, most administrative and statutory bodies have failed at all levels (until now) to recognise and include these important steps in their programmes, whether through legislation or voluntary mechanisms (Kanstrup and Thomas 2020 (**Paper 1**)).

### 7.8.1 Regulation

The phasing-out of the use of lead ammunition for hunting in Europe and elsewhere has, until very recently, been mostly targeted at the elimination of lead gunshot over wetlands through partial regulation. This has primarily been focused at prohibition of the use of lead shot over wetlands, without affecting the hunters’ right to possess and carry lead shot when hunting in wetlands. Very few European countries have a dedicated agency devoted to ensuring compliance with shooting regulations in the field and, to some extent, such regulations have been shown to be largely unsuccessful in achieving their desired aim (Cromie et al. 2010; Kanstrup 2018 (**Paper 10**); Thomas et al. 2021 (**Paper 26**); Widemo 2021).

Almost 40 years of attempting to phase-out the use of lead ammunition has revealed that in the early stages of any transition process, no matter under which jurisdiction, the majority of hunters will be unaware of the problems associated with lead ammunition or, if they are, remain unconvinced of the scale and nature of the problem (Kanstrup 2018 (**Paper 10**); Kanstrup et al. 2021 (**Paper 6**)). Use of lead ammunition, with which they are familiar, will continue for so long as possible, until such time as they are convinced of the need to change or are obliged to change by effectively enforced regulations. This common pattern of user inertia will always thwart the intent and effectiveness of regulations.

Vallverdú Coll (2012) found low levels of initial compliance (minimum non-compliance: 27%) with an imposed lead shot ban in the Ebro Delta (Spain). However, this improved (minimum noncompliance: 1%) after the local administration notified hunters that a total prohibition of hunting over protected wetlands would be enforced if the use of lead shot continued. In Denmark, enforcement of the 1986 partial regulation of lead shot in 26 wetlands achieved poor compliance, and it was not until 1996 (when complete regulation was imposed, including a ban on the trade and possession of lead shot)

that compliance improved (Kanstrup 2018 (**Paper 10**)). Despite this, evidence of subsequent illegal use appeared, but today compliance seems to be almost complete (Kanstrup and Balsby 2019 (**Paper 15**)) – albeit that this may vary between hunting types (Kanstrup and Balsby 2018 (**Paper 18**)).

Regulation of lead ammunition has been implemented at different levels, with contrasting legal impacts, either directly or indirectly. Until now, there has been no legal regulation at the European level. AEWA, The Bern Convention and other MEAs have led the way in recommending the removal of lead from ammunition, but such recommendations are not politically binding, and their implementation is, therefore, not mandatory for the contracting parties. However, in November 2020<sup>40</sup> the prohibition of the use of lead shot over wetlands agreed upon by the European Union was formally announced. This, together with an anticipated further restriction on lead ammunition in general, will be adopted as a formal European Union Regulation (REACH) that, if agreed, could be enacted as early as late 2022 (Thomas et al. 2021 (**Paper 26**)). This will set the conditions for the prohibition of manufacture, use, marketing and import of lead ammunition (Treu et al. 2020) and applies directly and legally to all member states and their citizens, although the individual member states will retain the formal responsibility to ensure enforcement and communication.

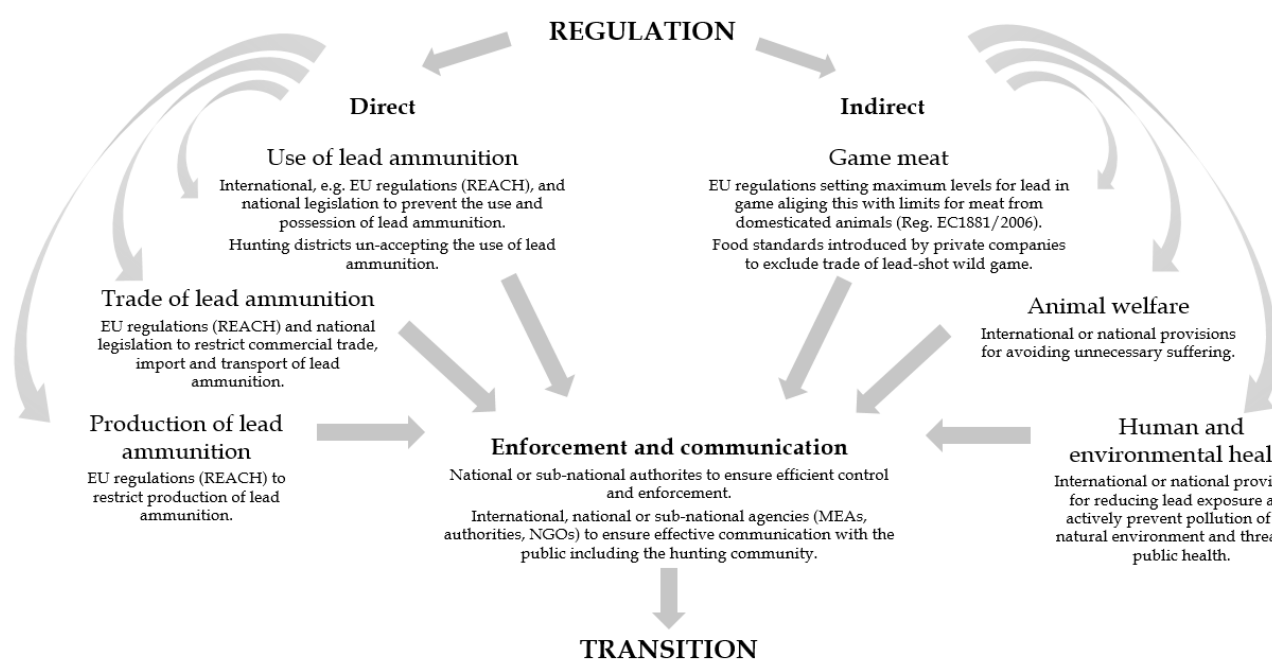
The present legal regulations of lead ammunition in Europe are established at national (federal) or, in some cases, subnational (states, departments) level. The most common restriction is a direct ban on the use of lead shot in particular geographical areas (e.g. wetlands) or for the hunting of particular species or groups of species (e.g. waterbirds), whereas wider regulation of possession, transport and trade is only applied in very few countries (Mateo and Kanstrup 2019 (**Paper 2**)). However, regulation may be achieved through indirect measures. The decision of the UK Waitrose supermarket chain to sell only game meat killed with lead-free ammunition as from 2020 (Barkham 2019), although not widely appreciated or set in place, indicates a preparedness of the private and commercial marketplace to intervene to eliminate the use of lead ammunition from the human food chain. Such interventions may well have significant impacts on the choice of ammunition used in hunting areas delivering game meat to the commercial market and have a direct effect upon the use of hunting ammunition. Setting of maximum levels for lead in game within the European Union Regulation 1881/2006, as suggested by Thomas et al. (2020 (**Paper 17**)), or by single member states (Kanstrup et al. 2016 (**Paper 8**)) would harmonise lead safety standards for traded domestic and game meats within the European Union and regulate this at the national level. The Waitrose initiative would impact the use of non-lead ammunition not only in the UK but also among game meat chains outside the UK because such indirect regulation would also apply to imported game meat.

Indirect regulation of lead ammunition may also arise from existing legislation that superficially appears irrelevant to the use of different ammunition types, with the result that it is neglected in the movement to prohibit lead. For instance, it is a widespread principle that hunting practices (including weaponry and ammunition) avoid all unnecessary animal suffering. This principle is encapsulated explicitly in internationally recognised codes and charters, and in some countries it is a legal requirement for hunters and hunting (Kanstrup et al. 2018 (**Paper 4**)). The consequences for animal welfare of lead ammunition use have been widely ignored because such consequences have

<sup>40</sup> [Comitology Register \(europa.eu\)](https://eur-lex.europa.eu/comitology-register/)

been a difficult and emotive topic. Nonetheless, the serious sub-lethal impacts on lead-poisoned bird individuals have been very well documented over many years and should not be regarded purely as an ethical problem. In countries with legislation that directly requires hunting not to cause avoidable suffering, lead ammunition use should be regarded as being in conflict with such provisions. In some countries, provisions apply to particular groups of people with special obligations. For example, in Poland, veterinarians are legally obliged to actively prevent pollution of the natural environment and threats to public health. They must abide by their ethical principles and not engage in (bird) hunting with lead ammunition and should actively oppose such forms of hunting on the grounds that they are harmful to the natural environment (Felsmann et al. 2020).

The mutual functionality, enforcement and communication of direct and indirect legal regulation of lead ammunition as described above, illustrated in Figure 7.5 and also addressed in Thomas et al. (2021 (Paper 26)), are complex. However, it is obvious that legal instruments must be applied. The recent (November 2020) decision of the European Union to regulate the use of lead gunshot over wetlands proves that European authorities have the capacity and are willing to establish such regulation. However, the efficiency of such regulation, i.e. the degree to which individual European hunters will shift from the use of lead to lead-free ammunition, depends upon the degree to which enforcement and communication of the regulation is rolled out in a cohesive strategy across all stakeholders, including the hunting community and the general public (Thomas et al. 2015 (Paper 9); Thomas et al. 2019 (Paper 11)). The latter publication suggested an in-depth examination of the regulations used by different governments to develop a powerful guide as to how to develop legislation that better serves the needs of wildlife and the environment.



**Figure 7.5.** Regulation may focus directly on the use, possession, trade and/or production of lead ammunition or indirectly through restrictions on the impacts of lead ammunition, including contamination of foods, unnecessary suffering of the hunted target animal or provisions for people in certain professions. Some supporting publications for the figure are: Kanstrup et al. (2018 (Paper 4)); Kanstrup and Thomas (2020 (Paper 1)); Kanstrup et al. (2016 (Paper 8)); Mateo and Kanstrup (2019 (Paper 2)); Thomas et al. (2019 (Paper 11)); Thomas et al. (2021 (Paper 26)); Thomas et al. (2020 (Paper 17)).

### 7.8.2 Voluntary systems

Segerson (2013) found three primary types of voluntary approaches in environmental protection programmes: 1) unilateral initiatives, where polluters voluntarily undertake actions to reduce pollution without any government involvement; 2) negotiated agreements, under which a regulatory agency negotiates with polluters over the terms of an agreement involving obligations on both sides, and 3) public voluntary programmes, whereby the government unilaterally determines both the rewards and obligations from participation and eligible polluters are encouraged to participate.

Although some voluntary approaches (mostly negotiated agreements according to Segerson's categorisation) to shift from lead to non-lead ammunition have been launched in Europe and North America (Chase and Rabe 2015; Mateo and Kanstrup 2019 (**Paper 2**)), they have largely been unsuccessful in terms of obtaining efficient transition (Cromie et al. 2015; Green et al. 2021; Kanstrup and Thomas 2020 (**Paper 1**); Schulz et al. 2020; Schulz et al. 2019). However, in some cases there has been a movement to change behaviour without direct legislative interference.

A study by Kanstrup et al. 2021 (**Paper 6**) showed that by 2019, approximately one fifth of Danish rifle hunters had changed to the use non-lead rifle ammunition instead of the classic lead bullets. This shift may have been influenced by legal regulations enforced in Germany in that some Danish hunters have been introduced to non-lead ammunition in Germany where lead bullets are prohibited in some regions. However, their study demonstrated that many Danish hunters were already aware of the adverse impacts of lead in rifle ammunition, including the potential negative influence of such ammunition on the long-term public perception of hunting and the impact on natural ecosystems, wildlife and human health. These elements functioned as drivers in the process to make a substantial number of hunters change their behaviour without recourse to legal force and with no involvement of the Danish governmental agencies. Hence, this process would fall within Segerson's first category, i.e. a unilateral initiative. However, the same study also identified a group of potential free-riders who, while well aware of the impacts of lead in rifle ammunition, have taken up a clear position against transition to lead ammunition, which they will continue to use for many years to come despite the voluntary ban. The same could apply to those hunters choosing to deplete their existing stock of lead ammunition before changing. Such sources of inertia to change represent serious barriers to successful transition, when based solely on voluntary approaches, which would remain the case even if this was extended to a negotiated agreement or a public voluntary programme.

The success of a voluntary programme therefore relies on the degree to which it is possible to reach out to the group of hunters who lack knowledge or concern in order to gradually raise awareness and, depending on attitude, eventually change individual behaviour. This is potentially a very large group of hunters of whom only a minority can be addressed via membership of a hunting association. Very few hunters are actively engaged in communication with the authorities as demonstrated, for example, in a survey among all 165,000 Danish hunters where only 27% of the recipients replied (Seismonaut 2019). It is therefore a huge, time-consuming and costly process to establish and run a reach-out programme to target and engage all hunters in the question of lead ammunition. Although Kanstrup et al. (2021 (**Paper 6**)) predicted a further shift from use of lead to non-lead ammunition among Danish rifle

hunters, they saw little prospect for such a shift to achieve a complete or almost complete transition. However, the fact that many rifle hunters were sufficiently open-minded to support or directly call for the banning of lead rifle ammunition indicates that the legal approach to phase out lead in rifle ammunition, as announced by the Danish Government in 2020 and supported by the Danish Hunters' Association, holds large potential to be successful.

In contrast to the general lack of success of voluntary programmes to ensure transition from lead to non-lead ammunition, a much more recent example shows that behavioural change in the hunting community can be driven more effectively by non-regulatory programmes and mainly by change of attitude among users. Since 2018, there has been increasing focus on the distribution of plastic debris from shotgun ammunition (both wads and cartridge shells) in the natural environment (see section 6.6.1 and Kanstrup and Balsby (2018 (Paper 18)). This problem has been addressed by hunting organisations in both the UK (GWCT et al. 2020) and Denmark<sup>41</sup>. The Danish government addressed this particular issue in its Plastic Action Plan (Regeringen 2018) that recommended regulation of the use of non-biodegradable shotgun wads. To prepare such a programme, the government in 2020 commissioned a work including *inter alia* mapping of existing cartridge products with biodegradable wads on the Danish market, field testing of such products, compilation of data on existing legislation and relevant standards, identification of suitable biodegradable materials and assessment of degradation mechanisms (Hansen et al. 2021).

Final conclusions about the technical and chemical aspects of the shift from traditional plastic wads to biodegradable types based on this work have (at the time of writing early 2021) not yet been drawn. However, an analysis of the existing market for cartridges (including a questionnaire and oral interviews of Danish ammunition importers and dealers) revealed that at by late 2020, at least 17 different brands of shotgun cartridges with biodegradable wads (a few also with biodegradable shells) were available to hunters on the Danish retail market. A similar range of products was available in other countries including the UK. In addition, the survey showed a substantial change in demand for these products over just a couple of years. In one gun store, c. 80 % of the 2020 hunting season sale of shotgun cartridges was comprised of cartridges with biodegradable wads. The same gun store expected an almost complete change to such types already by 2021. Other dealers reported a lesser rate of change, but all indicated a clear increase in the demand for non-lead cartridges (Hansen et al. 2021). Interestingly, the change seemed to be driven primarily by landowners and hunting outfitters who, in some places, required the use of biodegradable wads on their land, this being a condition in the contractual agreement between hunters and hunting providers. However, the survey indicated that many individual hunters had also voluntarily shifted to biodegradable products from a personal desire to reduce the dispersal of traditional plastic into the environment, which has become an essential element in the public discussion in the recent decades in Europe and elsewhere (Dilkes-Hoffman et al. 2019; EC 2014).

Plastic litter from ammunition is a visible and obvious polluter and its potential adverse impacts (e.g. the capability to disintegrate into micro-plastics and thereby cause a severe risk to ecosystems and human health) are intuitive to

<sup>41</sup> <https://www.jaegerforbundet.dk/om-dj/dj-medier/nyhedsarkiv/2018/slut-med-haglskale-i-plast/>

most people. The process to convert to biodegradable wad types is supported by the Danish Hunters' Association and the discourse in the hunters' community indicates no fundamental resistance to such change. This is not surprising seen in the light of the general change in the public attitude to plastic waste. However, it remains deeply perplexing (and should be subject to more thorough analysis) why so many hunters on a voluntary basis have so rapidly and positively engaged in reducing plastic pollution from hunting, while the same group of citizens historically and in many countries still resist or question the need and relevance of restricting the dispersal of a highly toxic metal as lead in the same ecosystem and from the same activity.

At present, the process to reduce plastic pollution from hunting ammunition in Denmark and similar countries can be categorised as a negotiated agreement according to Segerson (2013) with balanced interests and involvement from agencies and polluters. The replacement of traditional plastic (PE) components in shotgun cartridges with types having less impact on natural ecosystems could be enhanced by the establishment of regulations, as currently by the Danish government. However, there is a need to ensure that such regulation, if restricting the use of traditional plastic components (e.g. wads), also takes into account the environmental impact of alternative products in order not to substitute one problem with another and thereby confuse users and inhibit the present momentum for change.

## 7.9 Transition benefits all

To judge from the public discourse over the last 40 years and in particular the voices contributing to the debate from the community of hunters and ammunition makers, a transition from lead to non-lead hunting ammunition would be disadvantageous to society and hunting. The main arguments have been the potential for reduced efficiency and increased cost of hunting caused by the loss of lead and the introduction of alternative ammunition materials. The debate has included suggesting political motives of some nature protection groups to use the lead issue to slander hunting and ultimately to restrict or prohibit all hunting (see "this is not about lead, it is about hunting", see section 7.6). However, based on the present legacy of scientific evidence, this whole narrative can be inverted and formulated as a clear documentation of a transition which self-evidently contributes benefit to all branches and levels of society. This is most recently summarized by Arnemo et al. (2019 (**Paper 23**)) who emphasized the benefits in terms of (i) avoiding deaths of millions of wild animals from lead toxicosis, as this would bolster natural populations and prevent individuals from considerable suffering; (ii) eliminate risks from lead ammunition to the health of human consumers of game; and (iii) stop the annual increase in environmental contamination caused by the persistent accumulation of lead products, with its concomitant toxic legacy. These changes are beneficial for society in terms of not only enhancing conservation of wildlife and ecosystems and the continued improvement of public health but also by reducing the potential mitigation costs derived from lead ammunition—costs that are generally externalized to society (Kanstrup and Thomas 2020 (**Paper 1**); Pain et al. 2019 (**Paper 3**); Thomas et al. 2021 (**Paper 26**)).

These benefits to society should be regarded also as clear benefits to hunters as an integrated feature of society (Sonne et al. 2019 (**Paper 25**)). However, a transition would have some advantages being of more exclusive value to the hunting community and to the long-term sustainability of hunting interests. One is related to the hunters' role in supplying wild game meat as a quality

food product to meet the growing consumption, and in many European countries, this may place recreational hunting in a key role if the game is taken with non-toxic ammunition, enhancing the pollution-free status of the meat (Kanstrup and Thomas 2020 (**Paper 1**)). Another aspect of a phase-out of lead ammunition relating directly to the legitimacy of hunting is the legacy of steadily accumulating lead ammunition dispersed in natural ecosystems, often concentrated in sites of high conservation priority. Some sites hold densities of lead ammunition that would trigger an immediate recovery plan had they been former “brownfield” industrial sites monitored for pollution with regard to their after use (Kanstrup et al. 2020 (**Paper 14**); Thomas et al. 2021 (**Paper 26**)), and the costs of mitigating the impacts of accumulated lead could, legally, be returned to the hunters or their communities. However, it appears to be an even higher risk to hunting interests if hunting is excluded at such sites in future management plans if persistently associated with dispersal and accumulation of a toxic substance as lead.



It is a general conclusion that a transition from lead to non-lead hunting ammunition will benefit all, not least the hunters.

On 20 May 2020, the European Commission adopted a Communication<sup>42</sup> on a “EU Biodiversity Strategy for 2030 – Bringing nature back into our lives”, emphasising that biodiversity is suffering from the release of nutrients, chemical pesticides, pharmaceuticals, hazardous chemicals, urban and industrial wastewater and other waste, including litter and plastics, and that all of these pressures must be reduced. The strategy addresses identification of contami-

<sup>42</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380>

nated soil sites and set targets of strict protection of 10% land and 10% of European Union seas. While the strategy does not mention hunting explicitly, a draft technical note on criteria and guidance for designation of protected areas<sup>43</sup> issued in November 2020 defines strictly protected areas as sites that are occupied by naturally-occurring habitats and species where non-disturbance of natural processes is ensured and extractive activities, for instance hunting, are excluded. A complete EU-wide termination of hunting in all strictly protected areas as a consequence of such regulation and guidance would be a major blow to hunting rights of a dimension not hitherto seen, hence reactions from the hunting community have been prompt and aggressive. It is likely that many Europeans and their representative politicians in EU's institutions by intuition would not regard traditional hunting to be compatible with a level of strict protection of European nature areas and the success of the hunters' to campaign for the maintenance of their traditional rights would crucially depend on how hunting can be advocated as a sustainable activity supporting, and not jeopardising, conservation goals in strictly protected areas. In this context, the present and irreversible legacy of already dispersed lead hunting ammunition in many European nature areas would, to many people, be of primary concern. However, advocacy for the continued dispersal of lead in future management and resistance to change to non-toxic substitutes appears to be a direct route to permanently lose hunting rights in such sites.

Perhaps this complete narrative boils down to the conclusion made in a leading article by the author of this dissertation in the Danish hunting media in 2017: *"Lead is toxic, chemically speaking. Politically, it's probably even worse. Perhaps lead is most of all pure poison for the hunt itself"* (Kanstrup 2017). The benefits for the hunting community to terminate any connection between hunting and lead – a toxic substance that modern societies aim to exclude where possible – cannot be over-emphasised.

## 7.10 Target shooting

This dissertation has primarily focused upon the dispersal of ammunition from hunting into the natural environment and ecosystems where hunting takes place. However, in this section the focus will be changed to some of the common aspects of using weapons for hunting purposes and for target shooting whether the purpose for such target shooting is competition, training for competition or training simply to enhance hunting shooting skills. First, the weapons used are very much the same although the design of some types of competition weapons, in particular rifles, has developed to be too sophisticated for practical hunting use. Also, some small calibers used in competition are of limited relevance in practical hunting. Second, the ammunition is similar and traditionally based on lead. However, whereas hunting ammunition needs to balance both precision and impact, the main ballistic priority for target ammunition is to enhance precision, hence the common use of full jacketed rifle projectiles and small shot sizes (2.5 mm) – types that would be illegal or largely regarded to be insufficient to ensure proper terminal ballistic impacts in common hunting applications. Third, target shooting and hunting have some similarities in regard to the locations of practice, although the overlap in this respect seems to be less obvious. Most rifle target shooting is performed in closed and approved, and in many cases indoor, shooting ranges. In such cases, the risk of exposure of natural ecosystems to ammunition parts

<sup>43</sup> [https://www.jaegerforbundet.dk/media/16265/biodiversitetsstrategi\\_kommission\\_vejledning.pdf](https://www.jaegerforbundet.dk/media/16265/biodiversitetsstrategi_kommission_vejledning.pdf)

is low and recovery and recycling of ammunition material are a realistic option. Clay target shooting is commonly performed at closed and approved sites, in some cases at highly sophisticated ranges with proper recovery of shot and wads. Top-level competition shooting such as the Olympics is mostly organised at artificial and sophisticated shooting facilities with no or little exposure of nature areas. At some ranges, discharged lead shot may be recovered and recycled, but in reality this is rarely practised due to the difficulty and costs (Kanstrup and Thomas 2020 (**Paper 1**); Thomas and Guitart 2013). However, clay target shooting, aimed at low-level competition, initial qualification or simply training to enhance hunters' shooting skills, very often takes place at natural or semi-natural sites. Some extreme densities of lead shot have been recorded in wetlands close to shooting areas (Clausen and Wolstrup 1979; Mateo 2009) and the impact is documented for both ecosystems, vertebrate and invertebrate species (Hui 2002; Migliorini et al. 2004; Migliorini et al. 2005; Vyas et al. 2000). Some studies show that leaded rifle bullets in high densities at shooting ranges may cause pollution of the surrounding ecosystems (Okkenhaug et al. 2016; Okkenhaug et al. 2018). This may be mitigated by collection of lead bullets from backstop berms that are commonly a part of the construction of rifle shooting ranges. A fourth aspect of similarities between target shooting and hunting is the personnel. Some highly sophisticated and international disciplined competition shooting may be performed by people with no hunting background. However, regarding regional and local shooting arrangements, including competition shooting but in particular in common training, it appears that participants commonly have both a hunting and a shooting background. Such arrangements have the capacity to form the common ground for introducing behavioural change in, for example, the use of ammunition materials. Kanstrup (2018 (**Paper 10**)) found that the early regulation of lead shot for clay target shooting (1981) introduced many hunters to the practical use of steel shot, hence facilitating a relatively smooth transition to non-lead shot in hunting when initiated in 1986.

Training shooting skills, whether for hunting or competition, commonly takes place at ranges located in natural or semi-natural areas.



A complete change from lead ammunition to non-lead ammunition in target shooting, whether for competition or training, holds the potential to support and inspire the transition with regard to hunting ammunition. However, in certain sections of competition shooting such change appears to be less urgent. This includes primarily shooting disciplines, mostly rifle shooting, at facilities where ammunition parts can, at least theoretically, be recovered and recycled. For some of these disciplines (for example small caliber rifle target shooting), there are also some technical and ballistic challenges connected to a change from lead to other products. In contrast to this, there are no reported technical, ballistic or safety related concerns that justify the continued use of lead for any purpose of shotgun shooting, be that competition, training or hunting. Neither are there barriers in terms of costs as prices of non-lead shotgun ammunition over the last decades have become aligned with equivalent leaded products (Kanstrup and Thomas 2019 (**Paper 7**)), which is particularly evident for clay target shooting steel cartridges. Recipients of ammunition from such activities, including most target shooting, are natural or semi-natural areas with poor prospects of recovery.

Against this background, studies have suggested a complete and short-termed phase-out of all lead ammunition for clay target shooting (e.g. Kanstrup and Thomas 2020 (**Paper 1**)). The Olympic Games comprise an array of shotgun shooting disciplines and could be a powerful game changer in the course of substituting lead with steel shot in these disciplines as suggested by Thomas and Guitart (2013). The present rules actively prevent the use of steel shot. However, appropriate change of these rules to ensure all shotgun shooting disciplines to be performed with steel shot would not only instruct and inspire thousands of clay shooters to change and thereby halt lead contamination of shooting range environments world-wide, it would also send a powerful signal of the determination of the Games to fulfil its obligations under the Olympic Charter, in particular the defined mission and role of the Games to encourage and support a responsible concern for environmental issues (Olympic Charter 1.2.14<sup>44</sup>).

<sup>44</sup> [EN-Olympic-Charter.pdf](#)

## 8 Future perspectives

The toxic character of lead as a substance has been recognised for millennia, and over the last half century an overwhelming body of evidence of toxic impacts on people and related adverse consequences for the environment and society in general has led to comprehensive legislative and management actions to reduce or eliminate lead in almost any application where this is technically achievable.

Evidence for the serious adverse impacts of leaded hunting ammunition on wildlife reaches back to the 1800s, and during the last couple of decades it has become increasingly evident that lead ammunition also poses a direct and real risk to human consumers of game meat. Despite this, lead use in hunting ammunition continues. Discharge from hunting now constitutes the largest unregulated release of lead into all environments (Kanstrup and Thomas 2020 (**Paper 1**)). Due to increasing awareness, many countries across most continents have over the last 40 years or so regulated the use of lead ammunition for hunting. However, this has largely been implemented in partial, insufficient and poorly enforced programmes addressing only a subset of the problems associated with this type of lead use that directly contributes to the persistent poisoning of natural ecosystems and their associated wildlife and humans.

The proposal of the European Union to establish legal regulations to achieve a community-wide phase-out of lead ammunition is of crucial importance and recognised by a wide audience of practitioners and scientists (European Scientists 2020; Hunting Experts 2020). History shows that initiatives, including legal programmes, to regulate lead ammunition are slow and will only be successful if effectively controlled, monitored and enforced (Kanstrup 2018 (**Paper 10**); Thomas et al. 2021 (**Paper 26**)). However, the European strategy, supported by private initiatives to eliminate lead in hunting ammunition, for example the UK Waitrose initiative (Barkham 2019), will revitalise the efforts and establish a process to remove lead from hunting. Based on past evidence, no immediate success in terms of complete or almost complete phase-out should be anticipated, though.

Regardless of the success of the European Union initiative to exclude lead from hunting ammunition, it only addresses a subset of the problems connected to the use of lead ammunition in a wider global context. First, the geographical scale of the European approach is limited and does not apply to non-EU-countries, regions and continents, for example by not extending to those countries sharing flyways of millions of migratory birds within Europe, apart from a few European countries that are obliged to adhere to regulations under REACH (e.g. Norway). Second, the European approach to restrict the use of lead ammunition does not address the issue of contamination of game traded at a wider geographical scale, although the setting of minimum levels for lead in game, for instance within Regulation 1881/2006, as suggested by Thomas et al. (2020 (**Paper 17**)), would impact markets connected directly to the European Union through export and import. Further, this would alert other global jurisdictions to the need for health-protective international food safety standards. Third, the drawback of hunting in terms of the public perception caused by the association with lead as a toxic substance is only partly

addressed through the European Union's approach, and minimising its negative impact requires an initiative of much wider geographical and political scope than just Europe.

In the light of this, how do we enhance future efforts to meet more ambitious targets for ridding lead from hunting than those that have been made during the last 40 years? This wide and complex question touches on many aspects of nature management and socio-politics. Within the scope of this dissertation, two main and interconnected elements for highlighting appear: i) enhancement of interdisciplinary research and cross-sectional collaboration and ii) specific establishment of a new and much more ambitious strategy for communication across all sectors.

The persistent problems posed by lead in ammunition have so far been considered applying a limited uni- or intradisciplinary approach driven primarily by the nature and wildlife research sectors. For example, this was reflected in the contributions to the Special Issue published by *Ambio* in 2019 (Kanstrup et al. 2019). A survey among the 37 contributing authors revealed that most had their primary training in the disciplines of biology/ecology (23), veterinary medicine (11) and agriculture/forestry (2), while only one was trained in social sciences (1). Some had additional training in social sciences (1), engineering (1) and physics/mathematics (3). However, no one had a human medicine background and none had formal communications training. Hence, the Special Issue was authored largely by biologists and veterinarians, who mainly communicate among themselves.

The human health research sector has, for many years, provided evidence of the severe dangers to human health from lead in the environment and especially from lead in the human body, whereas it has been less effective at assessing the particular dangers posed by lead ammunition within the human food chain. For example, Mielke (2016) compiled 20 articles assessing the risk of lead in the environment and its effects on human health. Only one of those papers was related to the issue of lead in ammunition and there was no cross-reference to the multiple scientific papers demonstrating the clear linkage between lead ammunition and the specific risk that it poses to human health (Green and Pain 2019).

It seems that the researchers working in separate disciplines studying various different aspects of lead toxicity tend to work within specialised fields in the absence of interdisciplinary cross-fertilisation. With the benefit of hindsight, it is evident that finding ways to achieve a successful phase-out of lead in ammunition requires an extended use of interdisciplinary methods, including those from social sciences. This would, for example, provide a deeper understanding of the factors predicting and affecting compliance with the established regulations and acceptability of any future changes to practice (Newth et al. 2019).

The WHO One Health concept is a worldwide strategy for expanding interdisciplinary collaboration and communication in all aspects of health care for humans, animals and the environment. It is based on a vision of improving the lives of all species—human and animal—through forging co-equal, all-inclusive collaborations among human and veterinarian medicine, wildlife biology and other environmentally related disciplines (Buttke et al. 2015; Zinsstag et al. 2011). One of its pillars is environmental hazard exposure to humans and animals, which is an obvious platform for enhancing cross-sectoral research and

collaboration on the impacts of lead from ammunition, as also recognised by multiple studies (Arnemo et al. 2016; Hampton et al. 2018; Johnson et al. 2013; Pokras and Kneeland 2008). Although it is evident that our understanding of the impacts of lead ammunition on wildlife and humans will change little with further natural and health sciences research, there is still considerable benefit to come from interdisciplinary studies in documenting the impacts of lead across different species, ecosystems and environments. Addressing the lead ammunition issue within the framework of One Health appears to be crucial for such an approach and, therefore, for successful transition to non-lead ammunition.

A major obstacle to the phase-out of lead is the economic and market inertia that exists, inhibiting the replacement of the current lead-based ammunition with non-lead alternatives. Manufacture and trade in lead ammunition have traditionally been of great economic importance to many factories, exporters, importers and dealers. Few ammunition manufacturers have recognised the value of sustaining a long-term business strategy by supporting the sustainability of hunting and shooting through supplying the transition to non-lead ammunition with products that meet toxicological criteria (Kanstrup and Thomas 2020 (**Paper 1**)). Hence, there is an array of aspects including financial cost-benefits, traditions and cultural change associated with switching to alternatives, which lies beyond the realms of ecological, veterinarian and animal and human health issues.

The change to non-lead alternative ammunition also necessitates changes in people's perception at all levels in the supply chain and most especially down to the user on the ground (i.e. the individual hunter and consumer). Here too, we lack knowledge and understanding and there is a need to establish how current perceptions may impede the process and how to be proactive in changing these perceptions to phase-out lead ammunition in the most effective way.

Communication has already been mentioned in previous chapters but cannot be over-emphasized as a means to stimulate and ensure the efficiency of transition. The available knowledge of the problems of lead ammunition and the tools accessible to solve those problems is actually overwhelming and has been published at all levels. This includes some of the most reputable scientific journals (e.g. Sonne et al. (2019 (**Paper 25**))), in reviews and special issues of journals with specific focus at scientific, social, economic and cultural factors that influence the conditions of the human environment (e.g. Kanstrup et al. (2019)), in proceedings of several international gatherings (e.g. Delahay and Spray (2015); Kanstrup (2009); Pain (1992); Watson et al. (2009)) and in newsletters and special editions of central, international MEAs (e.g. AEWa (2009) and NGO, for instance CIC, see Kanstrup and Potts (2007)). Furthermore, the lead ammunition issue has been addressed at several practical workshops and clinics, for example in Bucharest in 2001 (AEWA workshop), Dakar in 2004 (ONCFS<sup>45</sup>, OMPO<sup>46</sup> and Wetlands International workshop) and Amman 2007 (Birdlife International workshop), and covered extensively in the national conservation and hunting media.

Cromie et al. (2019) demonstrated the increasing focus on lead ammunition over time by illustrating some of the key reviews of evidence, policy initiatives

<sup>45</sup> Office National de la Chasse et de la Nature

<sup>46</sup> Migratory Birds of the Western Palearctic

and publications. The mere fact that this dissertation includes almost 300 references, many of which are reviews of many more specific articles that are not directly referenced here, documents the legacy of evidence on the topic. So, there is no excuse for ignorance. The knowledge and evidence is documented and analysed, it has been synthesised and published and is therefore available to everybody. The question is whether it has been communicated effectively in the sense of it being truly appreciated and perceived by the relevant target audiences. The recent decision by the European Commission to restrict lead shot for hunting in wetlands and the prospects of the European Union to act further to phase out all lead ammunition indicate that the knowledge of problems and solutions has been communicated effectively to and perceived by the administrative and political institutions in Europe, or at least by the majorities needed to take institutional decisions. Furthermore, the regulations on the use of lead shot in wetlands established in many countries indicate a widespread recognition of the problem among national statutory authority bodies. However, the poor documentation of compliance with regulations, in some cases strong evidence of poor compliance (Cromie et al. 2010; Widemo 2021), indicated that existing knowledge has not yet led to sufficient recognition and acceptance among the users – the hunters. Together with the general lack of national authorities to police restriction (Thomas et al. 2021 (**Paper 26**)), this represents a very major block to transition.

Insufficient recognition of the need to change behaviour among the users - the hunters - together with a lack of authorities to police restriction is a major block to transition.



The British philosopher Nicholas Maxwell has devoted his professional and scientific career to advocate for changes to society to shift from being based on knowledge upon which to act to instead make change happen from a philosophy based on wisdom. This wisdom arises from the capacity to realise what is of value in life, both for oneself and others, and to include knowledge, understanding and technological know-how, and much else besides, in effecting change<sup>47</sup>. His suggested change of paradigm has created much dispute, not least in academia, and has by some been interpreted as “knowledge is

<sup>47</sup> <https://www.ucl.ac.uk/friends-of-wisdom/>

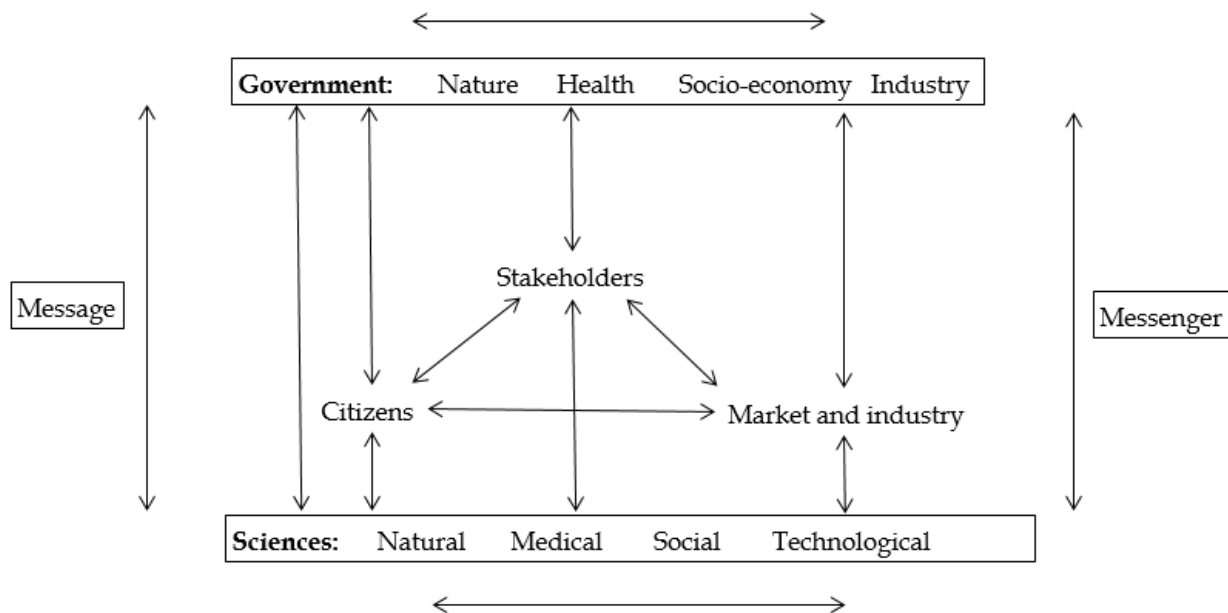
bad”, and “wisdom is good”. A broader and in-depth analysis of these more philosophical aspects of societal management lies beyond the scope of the present dissertation. However, the ideas of Maxwell lay out the foundation for suggesting that the strategy for transition from lead ammunition to non-lead alternatives needs, more fundamentally, to recognise the importance of wisdom – not that knowledge in itself is bad. It is both good and essential, but alone it is not enough. To extend knowledge to wisdom, communication is essential. And here, communication should be regarded in the broadest possible fashion, embracing not only the passive sharing of information but ensuring that information, its content of technical knowledge and the consequences of that knowledge are understood by, reflected on, debated and, where relevant, commented on by key target audiences.

Such communication must work horizontally among actors within the different levels of society, for example academia where enhancement of communication between relevant scientific sectors is a crucial element of a stronger interdisciplinary strategy. Also at the governmental level, where there is a need to stimulate cross-administrative communication, in particular between ministries with primary responsibility for nature conservation and ministries with responsibility for human and societal health. Communication also needs to work vertically, meaning, for example, that solid scientific evidence must be conveyed to governmental and citizen levels and *vice versa*. This process necessitates that reflections and criticisms from citizens and users are fed back to administrators and scientists in context. An essential part of communication is the message taken here to be the contextual standpoint/assertion articulated by the participant based on the given knowledge of this participant. The properties of the message are crucial, in particular when exchanged through the vertical communication where the composition, complexity and language must be adapted to enhance mutual perception and understanding. Globally, the scientific evidence for the need and the mechanisms necessary for a successful transition from lead to non-lead ammunition in hunting is available almost exclusively in English. At the same time, many technical reports and administrative and popular communications are released at national level in local languages, inaccessible elsewhere. Both elements create extensive limitations on the effectiveness of vertical communication given the present urgent priority to adapt the properties of the key messages to cross-national transfer. This impediment to effective communication represents a mutual responsibility. However, scientists have a particular responsibility and opportunity to enhance communication by including more sophisticated elements of dissemination in their project output. Too often, research projects terminate at the level of scientific publication. Popularisation of results and conclusions and proper communication at all relevant levels as an integrated part of project design and financing appear to be of crucial importance in the future if efforts to make a democratic and efficient behavioural change are to be successful.

Not only is the message and its properties of great importance for communication, so is the messenger. Most recently, this was studied in the USA by Schulz et al. (2020) in an interview and question survey demonstrating challenges related to having knowledgeable and credible spokespersons. The study emphasised the importance of such spokesmen to have hunting and shooting experience and be able to effectively communicate their experiences (expressed, for example, by one participant: “*Having somebody that cares about eagles is fine, but it is important that they’re a hunter*”). As to the personal experience of the author of this dissertation, this applies widely to the Danish and European situation

too. The impact of “*I have been there and done that – I have had your concerns but found solutions*” seems to be of crucial importance for the perception of messages connected to the lead to non-lead transition. The 2020 two-page factsheet released by 10 European scientists with extensive experience of and passion for hunting (Hunting Experts 2020) sent in November 2020 to a broad audience of European decision makers may have had much greater impact on the European Union decision to restrict lead gunshot in wetlands than the underlying and comprehensive evidence published in highly reputable journals by scientists who have great theoretical and academic credibility but perhaps lack personal insight into the many concerns relating directly to hunting. Danish success with phasing out lead shot has been linked to a few advocates within the hunting community who persuaded other hunters of the benefits using evidence from hunters-led research (Newth et al. 2015).

A tool to develop a future strategy to enhance government, research and communication by improving connections between levels and actors is illustrated in Figure 8.1.



**Figure 8.1.** Until today, the issue of lead in ammunition has been managed in more or less closed circles of government and science with poor interdisciplinary cross-fertilisation. Furthermore, the main public and citizens’ involvement has mostly been handled through representatives (stakeholders), who have often made the issue subject to internal political and commercial agendas, being counterproductive to transition. The success of a future strategy relies on the ability of actors to work across sectors and ensure that communication involves all levels. Formulating science-based and wise messages and stimulating key messengers by relevant messages is crucial.

The transition from lead to non-lead ammunition contains a number of aspects that could inspire an approach with adaptive management, which over time has been used in complicated wildlife management issues, especially where they cross borders and contain conflicts between different societal interests. In adaptive management, emphasis is placed on a shared learning process among scientists, managers and stakeholders, and successful programmes have been demonstrated for an array of species such as the flyway planning of the Svalbard Pink-footed Goose (Madsen et al. 2017). In countries with insufficient state

resources and financial instability, local bottom-up initiatives resembling adaptive management have shown some level of success in terms of regulating the use of lead ammunition in extensively hunted areas as, for example, in the Santa Fe and Córdoba provinces of Argentina (Uhart et al. 2019). However, more generally, and not least in a European context, eliminating poison from lead ammunition is not an inherently complex issue and the present transition approach of community-wide regulation orchestrated by a national commitment of enforcement and solid communication with all branches of society seems to be the most optimal and cost-beneficial one.

If successful, the result of such a transition would be to put an end to dispersal of lead ammunition into natural ecosystems and poisoning of wildlife and humans and thereby removal of a significant and unnecessary risk of adverse impacts at all levels. Furthermore, it would demonstrate that wildlife management has the capacity to adapt to challenges arising from trends in a rapidly developing modern society. Hunting is an integrated part of wildlife management and promotes good practice for management of harvestable species and controlling pests and for the conservation of habitats and ecosystems. Transitioning from lead to non-lead hunting ammunition is a necessary and possible next step in modern wildlife management that will bring significant conservation gains and create opportunities for improved constructive dialogue between hunting stakeholders and others engaged in enhancing biodiversity and nature conservation objectives. It thus holds the potential for revitalising strategies for nature conservation in which wildlife management and hunting are essential elements (Kanstrup et al. 2018 (**Paper 4**)).

The history of the movements to reduce and eliminate polluting sources of lead in society reveals that such changes have been slow, costly and divisive but ultimately successful, and in the process to remove lead from ammunition it would be wise to heed warnings from the past (Kanstrup et al. 2018 (**Paper 4**)). Case studies of how society has managed hazards to environmental and human health have been given by the European Environment Agency in two major compilations, one from 2001 (EEA 2001) and one from 2013 (EEA 2013), both with the title *"Late lessons from early warnings"*. One of the many cases described in the reports dealt with lead – not in ammunition but in petrol (Needleman and Gee 2013). However, there are strikingly many similarities between the scientific, public and economical responses to the rising need for substituting lead in petrol some decades ago and what we see today concerning lead in ammunition. The EEA reports list an array of key lessons for better decision-making drawn from these studies, experiences and reflections. Many of these apply directly to lessons learnt from the process of phasing out lead in hunting ammunition, some of which have been described in the literature and in this dissertation. The record of evidence of lead's adverse impact on human health reaches a couple of millennia back in history. The risk of lead ammunition to harm wildlife and the environment has been known for 150 years and in recent decades the risk of lead ammunition lead to adversely impact human health has been increasingly documented. Against this background, the issue of lead in hunting ammunition is now a candidate to become a valid and obvious case where the warnings have come early, but the lessons have come late, to the degree that we have to act sufficiently upon them. Multiple management actions have been suggested and discussed. Perhaps it all boils down to the very simple title of one of the papers behind this dissertation: *"Time to ban lead hunting ammunition"* (Sonne et al. 2019 (**Paper 25**)).

## 9 Conclusions

It is beyond any doubt that the dispersal of lead from hunting ammunition into the natural environment causes adverse, and in some cases irreversible, impacts on ecosystems and wildlife with the continued risk of ecosystem deterioration, including reductions in the size of populations of species of wild animals. Therefore, the practice jeopardizes international and national nature conservation goals.

Lead poisoning from this source causes death and severe suffering to millions of individuals of wildlife and poses a risk of poisoning to human consumers of game. Therefore, it contradicts ethical and food safety standards agreed by society.

Costs from lead dispersal from ammunition are significant and externalized to the community.

Use of lead in hunting ammunition is incompatible with sustainable and wise use in all senses and interpretations of these principles.

Lead remains the most widespread currently used ammunition material due to weak regulatory and communications effort by relevant authorities and due to a strong commercial lobby.

Non-lead, non-toxic, safe and efficient alternatives to lead ammunition are currently available on the market or, where locally absent, will be so once the demand for such products is ensured through the phase-out of lead ammunition through effective regulation.

Hunting can be practiced without lead in ammunition and adverse impacts from continued use are unnecessary and avoidable.

Successful transition from lead to non-lead hunting ammunition will only occur through direct and indirect regulatory actions backed by effective enforcement. Voluntary systems have proven ineffective.

Involvement of special interest NGOs, citizens and hunters in this process through direct and solid consultation and communication is essential to achieve an effective transition through effective legislation.

Efforts by some conservationists and scientists to promote this transition must be seen not as an attempt to harm hunting interests but, on the contrary, as a means to guide the perpetuation of sustainable hunting in a modern society.

Transition from lead to non-lead ammunition will benefit all by eliminating the continued risk of exposure to ecosystems, wildlife and humans. Not least, hunters will benefit through strengthening of the positive long-term public perception of hunting.

Strengthening research efforts across disciplines, including natural sciences, health, social sciences and technology is an essential prerequisite for ensuring an efficient, long-term and stable transition. The WHO initiative One Health is an obvious platform to promote such development.

A successful transition will demonstrate that nature and wildlife management has the capacity to adapt to new challenges as they arise as a result of trends in a modern society. It will bring significant benefits while creating the basis for an improved constructive dialogue between the stakeholders working to promote biodiversity and ensure nature conservation objectives.

Transition from lead to non-lead ammunition is not only essential but also eminently feasible.

## 10 References

Aebischer NJ, Wheatley CJ, Rose HR (2014). Factors associated with shooting accuracy and wounding rate of four managed wild deer species in the UK, based on anonymous field records from deer stalkers. *PloS one* 9:e109698-e109698 doi:10.1371/journal.pone.0109698

AEWA (2009). Phasing out the use of lead shot for hunting in wetlands. Experiences made and lessons learned by AEWA Range States. AEWA Report [https://www.unep-aewa.org/sites/default/files/publication/lead-shot-en\\_0.pdf](https://www.unep-aewa.org/sites/default/files/publication/lead-shot-en_0.pdf)

Ahamed M, Siddiqui MKJ (2007). Low level lead exposure and oxidative stress: Current opinions. *Clinica Chimica Acta* 383:57-64 doi:https://doi.org/10.1016/j.cca.2007.04.024

Ahrensens, Kayser (1848). Om Blykolik (Colica saturnina), About Lead Colic (Colica saturnina). *Ugeskrift for læger* 7:21

AMEC (2012) Abatement Costs of Certain Hazardous Chemicals. Lead in shot – Final Report December 2012. Report for European Chemicals Agency (ECHA). Contract No: ECHA 2011/140, Annankatu 18, 00121 Helsinki, Finland. [https://echa.europa.eu/documents/10162/13580/abatement+costs\\_report\\_2013\\_en.pdf/6e85760e-ec6d-4c8a-8fcf-e86a7ffd037d](https://echa.europa.eu/documents/10162/13580/abatement+costs_report_2013_en.pdf/6e85760e-ec6d-4c8a-8fcf-e86a7ffd037d)

Anderson SH (1991). *Managing our Wildlife Resources*. Prentice Hall

Anderson WL, Havera SP, Zercher BW (2000). Ingestion of Lead and Nontoxic Shotgun Pellets by Ducks in the Mississippi Flyway. *The Journal of Wildlife Management* 64:848-857 doi:10.2307/3802755

Andreotti A, Borghesi F, Aradis A (2016). Lead ammunition residues in the meat of hunted woodcock: a potential health risk to consumers. *Italian Journal of Animal Science* 15:22-29 doi:10.1080/1828051X.2016.1142360

Andreotti A, Guberti V, Nardelli R, Pirrello S, Serra L, Volponi S, Green RE (2018). Economic assessment of wild bird mortality induced by the use of lead gunshot in European wetlands. *Science of The Total Environment* 610-611:1505-1513 doi:https://doi.org/10.1016/j.scitotenv.2017.06.085

Apostoli P, Kiss P, Porru S, Bonde JP, Vanhoorne M (1998). Male reproductive toxicity of lead in animals and humans. ASCLEPIOS Study Group. *Occupational and Environmental Medicine* 55:364 doi:10.1136/oem.55.6.364

Archie EA, Chiyo PI (2012). Elephant behaviour and conservation: social relationships, the effects of poaching, and genetic tools for management. *Molecular Ecology* 21:765-778 doi:10.1111/j.1365-294X.2011.05237.x

Arnemo JM (2016). Blyhagsaken - tidenes miljøpolitiske farse. forskningno <http://forskning.no/meninger/kronikk/2016/09/blyhagsaken-tidenes-miljopolitiske-farse>

Arnemo JM, Andersen O, Stokke S, Thomas VG, Krone O, Pain DJ, Mateo R (2016). Health and Environmental Risks from Lead-based Ammunition: Science Versus Socio-Politics. *EcoHealth* 13:618-622 doi:10.1007/s10393-016-1177-x

Arnemo JM, Cromie R, Fox AD, Kanstrup N, Mateo R, Pain DJ, Thomas VG (2019 (**Paper 23**)). Transition to lead-free ammunition benefits all. *Ambio* 48:1097-1098 doi:10.1007/s13280-019-01221-x

Aronson AL (1971). Biological Effects of Lead in Domestic Animals. *J Wash, Acad Sci* 61, 2

Arrondo E, Navarro J, Perez-García JM, Mateo R, Camarero PR, Martín-Doimeadios RCR, Jiménez-Moreno M, Cortés-Avizanda A, Navas I, García-Fernández AJ, Sánchez-Zapata JA, Donázar JA (2020). Dust and bullets: Stable isotopes and GPS tracking disentangle lead sources for a large avian scavenger. *Environmental Pollution*:115022 doi:<https://doi.org/10.1016/j.envpol.2020.115022>

Arroyo B, Mateo R, García JT (2016). Trends in Wildlife Research: A Bibliometric Approach. In: Mateo R, Arroyo B, Garcia JT (eds) *Current Trends in Wildlife Research*. Springer International Publishing, Cham, pp 1-28. doi:10.1007/978-3-319-27912-1\_1

Assi MA, Hezmee MNM, Haron AW, Sabri MYM, Rajion MA (2016). The detrimental effects of lead on human and animal health. *Vet World* 9:660-671 doi:10.14202/vetworld.2016.660-671

Avery D, Watson R (2008). Regulation of Lead-based Ammunition Around the World. In Watson RT, Fuller M, Pokras M, Hunt WG (2009). *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*. The Peregrine Fund, Boise, Idaho, USA doi:10.4080/ilsa.2009.0115

Bailey JA (1984). *Principles of Wildlife Management*. John Wiley & Sons Inc:384

Barkham P (2019). Waitrose stops sale of birds shot with lead as experts call for UK ban. *The Guardian*  
<https://www.theguardian.com/business/2019/jul/29/experts-call-for-ban-on-lead-shot-as-waitrose-overhauls-sale-of-game>

Bassi E, Facchetti R, Ferloni M, Pastorino A, Bianchi A, Fedrizzi G, Bertolotti I, Andreotti A (2021). Lead contamination in tissues of large avian scavengers in south-central Europe. *Science of The Total Environment*:146130 doi:<https://doi.org/10.1016/j.scitotenv.2021.146130>

Bedrosian B, Craighead D, Crandall R (2012). Lead Exposure in Bald Eagles from Big Game Hunting, the Continental Implications and Successful Mitigation Efforts. *PLOS ONE* 7:e51978 doi:10.1371/journal.pone.0051978

Beintema N (2004). Non-toxic shot. A path towards sustainable use of the waterbird resource. *AEWA Technical Series* 3.  
[https://www.unep-aewa.org/sites/default/files/publication/ts3\\_non-toxic\\_shot\\_english\\_0.pdf](https://www.unep-aewa.org/sites/default/files/publication/ts3_non-toxic_shot_english_0.pdf)

Bellinger DC (2008). Neurological and Behavioral Consequences of Childhood Lead Exposure. *PLOS Medicine* 5:e115 doi:10.1371/journal.pmed.0050115

Bellinger DC (2013). Health Risks from Lead-Based Ammunition in the Environment - A Consensus Statement of Scientists. <https://escholarship.org/uc/item/6dq3h64x#main>

Bellrose FC (1959). Lead Poisoning as a Mortality Factor in Waterfowl Populations. *Illinois Natural History Survey Bulletin* 27:3 <https://www.ideals.illinois.edu/handle/2142/44086>

BIOECO (2020). European organic market grew to more than 37 billion euros in 2017. <https://www.bioecoactual.com/en/2019/02/18/european-organic-market/>

Bløtekjær K (2011). Bløtekjær, K. 2011. Haglballistik. Report Trondheim 1111

Boer HYd, Breukelen Lv, Hootsmans MJM, Wieren SEv (2004). Flight distance in roe deer (*Capreolus capreolus*) and fallow deer (*Dama dama*) as related to hunting and other factors. *Wildlife Biology* 10:35-41, 37 <https://doi.org/10.2981/wlb.2004.007>

Bro E, Deldalle B, Massot M, Reitz F, Selmi S (2003). Density dependence of reproductive success in grey partridge (*Perdix perdix*) populations in France: management implications. *Wildlife Biology* 9:93-102, 110 <https://doi.org/10.2981/wlb.2003.031>

Buekers J, Steen Redeker E, Smolders E (2009). Lead toxicity to wildlife: Derivation of a critical blood concentration for wildlife monitoring based on literature data. *Science of The Total Environment* 407:3431-3438 <https://doi.org/10.1016/j.scitotenv.2009.01.044>

Burrard MG (1944). The modern shotgun. Herbert Jenkins Ltd, London

Buttke DE, Decker DJ, Wild MA (2015). The role of one health in wildlife conservation: a challenge and opportunity. *J Wildl Dis* 51:1-8 doi:10.7589/2014-01-004

Büsselberg D, Evans ML, Haas HL, Carpenter DO (1993). Blockade of mammalian and invertebrate calcium channels by lead. *Neurotoxicology* 14: 249-58. <https://www.ncbi.nlm.nih.gov/pubmed/8247398>

CA (2013). The case for lead. Countryside Alliance leaflet <http://www.huntfortruth.org/wp-content/uploads/2014/05/Case-For-Lead-2013-Norway.pdf>

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

Cao X, Ma LQ, Chen M, Hardison DW, Jr., Harris WG (2003). Weathering of lead bullets and their environmental effects at outdoor shooting ranges. *Journal of environmental quality* 32:526-534 doi:10.2134/jeq2003.5260

Casas F, Mougeot F, Viñuela J, Bretagnolle V (2009). Effects of hunting on the behaviour and spatial distribution of farmland birds: importance of hunting-free refuges in agricultural areas. *Animal Conservation* 12:346-354 doi:10.1111/j.1469-1795.2009.00259.x

Ceracy J, Cottingham S (2010). *Lead Babies. How heavy metals are causing our children's autism, ADHD, learning disabilities, low IQ and behaviour problems.* Universe, Inc. New York, Bloomington.

Chandramouli K, Steer CD, Ellis M, Emond AM (2009). Effects of early childhood lead exposure on academic performance and behaviour of school age children. *Archives of Disease in Childhood* 94:844 doi:10.1136/ad.2008.149955

Chase L, Rabe MJ (2015). Reducing Lead on the Landscape: Anticipating Hunter Behavior in Absence of a Free Nonlead Ammunition Program. *PLOS ONE* 10:e0128355 doi:10.1371/journal.pone.0128355

Chin-Chia L, Chau-Hwa C, Shih-Ching Y, Jian-Nan L, Yu-Ten U, Chu-Lin K, Chun-Hao C, Pin-Huan Y (2020). Blood lead and zinc levels and their impact on health of free-living small carnivores in Taiwan, Republic of China. *Journal of Wildlife Diseases* 56:157-166 doi:10.7589/2018-11-273

Church ME, Gwiazda R, Risebrough RW, Sorenson K, Chamberlain CP, Farry S, Heinrich W, Rideout BA, Smith DR (2006). Ammunition is the Principal Source of Lead Accumulated by California Condors Re-Introduced to the Wild. *Environmental Science & Technology* 40:6143-6150 doi:10.1021/es060765s

Clausen B, Wolstrup C (1979). Lead poisoning in game from Denmark. *Danish Review of Game Biology* Vol. 11 no. 2

Clausen JL, Bostick B, Korte N (2011). Migration of Lead in Surface Water, Pore Water, and Groundwater With a Focus on Firing Ranges. *Critical Reviews in Environmental Science and Technology* 41:1397-1448 doi:10.1080/10643381003608292

Clausen KK, Holm TE, Haugaard L, Madsen J (2017). Crippling ratio: A novel approach to assess hunting-induced wounding of wild animals. *Ecological Indicators* 80:242-246 <https://doi.org/10.1016/j.ecolind.2017.05.044>

Cochrane RL (1976). Crippling effects of lead, steel, and copper shot on experimental mallards. *Wildlife Monographs* 51 [https://www.jstor.org/stable/3830469?casa\\_token=AvRfO4NZ1zkAAAAA%3AT0UGonEF95hS83m-BR-t\\_6JmAqf-R7DS-yyY2GMdQcM7ML09F4nCY4cSUDuhCkqv\\_KHH549rFLog\\_5nNasoXJCV\\_WvLy9ODIZ10BOecO7sdrYDJjhNLAYw&seq=1#metadata\\_info\\_tab\\_contents](https://www.jstor.org/stable/3830469?casa_token=AvRfO4NZ1zkAAAAA%3AT0UGonEF95hS83m-BR-t_6JmAqf-R7DS-yyY2GMdQcM7ML09F4nCY4cSUDuhCkqv_KHH549rFLog_5nNasoXJCV_WvLy9ODIZ10BOecO7sdrYDJjhNLAYw&seq=1#metadata_info_tab_contents)

Cromie R, Newth J, Reeves JP, O'Brien M, Beckmann K, Brown MJ (2015). The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult. In: Delahay, RJ & Spray, CJ (Eds) (2015) *Proceedings of the Oxford Lead Symposium Lead Ammunition: understanding and minimising the risks to human and environmental health* Edward Grey Institute, The University of Oxford,

UK [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/Papers/OLS\\_proceedings\\_cromie\\_newth\\_reeves\\_obrien\\_beckman\\_brown.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/Papers/OLS_proceedings_cromie_newth_reeves_obrien_beckman_brown.pdf)

Cromie R, Newth J, Strong E (2019). Transitioning to non-toxic ammunition: Making change happen. *Ambio* 46. doi:10.1007/s13280-019-01204-y

Cromie RL, Loram A, Hurst L, O'Brien M, Newth J, Brown MJ, Harradine JP (2010). Compliance with the Environmental Protection (Restrictions on Use of Lead Shot) (England) Regulations 1999.99 [file:///C:/Users/au85527/Downloads/WC0730\\_9719\\_FRP%20\(1\).pdf](file:///C:/Users/au85527/Downloads/WC0730_9719_FRP%20(1).pdf)

Cromsigt JPGM, Kuijper DPJ, Adam M, Beschta RL, Churski M, Eycott A, Kerley GIH, Mysterud A, Schmidt K, West K (2013). Hunting for fear: innovating management of human-wildlife conflicts. *Journal of Applied Ecology* 50:544-549 doi:10.1111/1365-2664.12076

de la Casa-Resino I, Hernández-Moreno D, Castellano A, Pérez-López M, Soler F (2014). Breeding near a landfill may influence blood metals (Cd, Pb, Hg, Fe, Zn) and metalloids (Se, As) in white stork (*Ciconia ciconia*) nestlings. *Ecotoxicology* 23:1377-1386 doi:10.1007/s10646-014-1280-0

Delahay RJ, Spray CJ (2015). Proceedings of the Oxford Lead Symposium: Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health. Oxford University: Edward Grey Institute. <http://oxfordleadsymposium.info/proceedings/>

Des Planches LT (1839). Traité des maladies de plomb ou saturnines. <https://gallica.bnf.fr/ark:/12148/bpt6k6365933m.texteImage>

Descalzo E, Camarero PR, Sánchez-Barbudo IS, Martínez-Haro M, Ortiz-Santaliestra ME, Moreno-Opo R, Mateo R (2021). Integrating active and passive monitoring to assess sublethal effects and mortality from lead poisoning in birds of prey. *Science of The Total Environment* 750:142260 <https://doi.org/10.1016/j.scitotenv.2020.142260>

DEVA (2011) Schlussbericht zum Forschungsvorhaben "Abprallverhalten von Jagdmunition". [https://www.seeadlerforschung.de/downloads/DEVA\\_Projektbericht\\_Ablenkverhalten.pdf](https://www.seeadlerforschung.de/downloads/DEVA_Projektbericht_Ablenkverhalten.pdf)

DEVA (2013a) Schlussbericht Flintenlaufgeschosse zum Forschungsvorhaben "Abprallverhalten von Jagdmunition" <https://www.deva-institut.de/files/userfiles/09HS001ABFlintenlaufgeschosse.pdf>

DEVA (2013b) Schlussbericht Schrote zum Forschungsvorhaben "Abprallverhalten von Jagdmunition" <https://www.deva-institut.de/files/userfiles/09HS001ABSchrote.pdf>

Dilkes-Hoffman LS, Pratt S, Laycock B, Ashworth P, Lant PA (2019). Public attitudes towards plastics. *Resources, Conservation and Recycling* 147:227-235 <https://doi.org/10.1016/j.resconrec.2019.05.005>

DOF (2020) For første gang i Danmark: Blyforgiftet kongeørn sat ud efter afgiftning. [https://www.dof.dk/om-dof/nyheder?nyhed\\_id=1765](https://www.dof.dk/om-dof/nyheder?nyhed_id=1765)

EC (2014). Attitudes of Europeans towards Waste Management and Resource Efficiency. Flash Eurobarometer 388. Eurobarometer [https://ec.europa.eu/commfrontoffice/publicopinion/flash/fl\\_388\\_en.pdf](https://ec.europa.eu/commfrontoffice/publicopinion/flash/fl_388_en.pdf)

ECHA (2017). ANNEX XV Restriction Report; Proposal for a Restriction; Lead. EC NUMBER: 231-100-4; CAS NUMBER: 7439-92-1 [https://echa.europa.eu/documents/10162/13641/restrictions\\_lead\\_shot\\_axv\\_report\\_en.pdf/6ef877d5-94b7-a8f8-1c49-8c07c894fff7](https://echa.europa.eu/documents/10162/13641/restrictions_lead_shot_axv_report_en.pdf/6ef877d5-94b7-a8f8-1c49-8c07c894fff7)

ECHA (2018). A review of the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle Version 1.4 [https://echa.europa.eu/documents/10162/13641/lead\\_ammunition\\_investigation\\_report\\_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a](https://echa.europa.eu/documents/10162/13641/lead_ammunition_investigation_report_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a)

Ecke F, Singh NJ, Arnemo JM, Bignert A, Helander B, Berglund ÅMM, Borg H, Bröjer C, Holm K, Lanzone M, Miller T, Nordström Å, Räikkönen J, Rodushkin I, Ågren E, Hörnfeldt B (2017). Sublethal Lead Exposure Alters Movement Behavior in Free-Ranging Golden Eagles. *Environmental Science & Technology* 51:5729-5736 doi:10.1021/acs.est.6b06024

EEA (2001). Late lessons from early warnings: the precautionary principle 1896–2000. Environmental issue Report No 22 European Environment Agency <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.418.1171&rep=rep1&type=pdf>

EEA (2013). Late lessons from early warnings: science, precaution, innovation. EEA Report No 1/2013 <https://www.eea.europa.eu/publications/late-lessons-2>

EFSA (2010). Scientific Opinion on Lead in Food. *EFSA Journal* 8:1570 doi:10.2903/j.efsa.2010.1570

Eisler R (1988). Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Laurel, MD <http://pubs.er.usgs.gov/publication/5200021>

Ertl K, Kitzner R, Goessler W (2016). Elemental composition of game meat from Austria. *Food Additives & Contaminants: Part B* 9:120-126 doi:10.1080/19393210.2016.1151464

European Scientists (2018). 2018 European Scientists' Open Letter on the Risks of Lead Ammunition. ECHA proposal under REACH Regulations. Restriction proposal on the use of lead gunshot in or over wetlands. <http://www.europeanscientists.eu/open-letter-2018/>

European Scientists (2020). 2020 European Scientists' Open Letter on the Risks of Lead Ammunition. ECHA proposal under REACH Regulations. Restriction proposal on the use of lead gunshot in or over wetlands. <http://www.europeanscientists.eu/open-letter-2020/>

FACE (2020). FACE statement on lead gunshots discussion in ENVI. [https://www.face.eu/wp-content/uploads/2020/02/FACE\\_statement\\_19\\_Feb\\_2020-3.pdf](https://www.face.eu/wp-content/uploads/2020/02/FACE_statement_19_Feb_2020-3.pdf)

Falk K, Merkel F, Kampp K, Jamieson SE (2006). Embedded lead shot and inflection rates in common eiders (*Somateria mollissima*) and king eiders (*S.*

- spectabilis) wintering in southwest Greenland. *Wildlife Biology* 12:257-265, 259 [https://doi.org/10.2981/0909-6396\(2006\)12\[257:ELSAIR\]2.0.CO;2](https://doi.org/10.2981/0909-6396(2006)12[257:ELSAIR]2.0.CO;2)
- Feierabend JS (1983). Steel shot and lead poisoning in waterfowl. An annotated bibliography of research 1976-1983 vol 8. National Wildlife federation Sci. & Tech. Series
- Felsmann M, Szarek J, Soltyszewski I, Karaźniewicz J (2020). Ethical and legal bird hunting duties by Polish veterinarians. [https://www.researchgate.net/publication/340298132\\_Ethical\\_and\\_legal\\_bird\\_hunting\\_duties\\_by\\_Polish\\_veterinarians](https://www.researchgate.net/publication/340298132_Ethical_and_legal_bird_hunting_duties_by_Polish_veterinarians)
- Fernández-Trujillo S, López-Perea JJ, Jiménez-Moreno M, Martín-Doimeadios RCR, Mateo R (2021). Metals and metalloids in freshwater fish from the floodplain of Tablas de Daimiel National Park, Spain. *Ecotoxicology and Environmental Safety* 208:111602 <https://doi.org/10.1016/j.ecoenv.2020.111602>
- Ferreyra H, Beldomenico PM, Marchese K, Romano M, Caselli A, Correa AI, Uhart M (2015). Lead exposure affects health indices in free-ranging ducks in Argentina. *Ecotoxicology* 24:735-745 doi:10.1007/s10646-015-1419-7
- Flora G, Gupta D, Tiwari A (2012). Toxicity of lead: A review with recent updates. *Interdiscip Toxicol* 5:47-58 doi:10.2478/v10102-012-0009-2
- Fox AD, Madsen J (1997). Behavioural and distributional effects of hunting disturbance on waterbirds in Europe: implications for refuge design. *Journal of Applied Ecology* 34, 1-13 <https://www.jstor.org/stable/pdf/2404842.pdf?refreqid=excelsior%3A4ec11ba2d23c58a4b280b7cb09d65034>
- Fox AD, Madsen J (2017). Threatened species to super-abundance: The unexpected international implications of successful goose conservation. *Ambio* 46:179-187 doi:10.1007/s13280-016-0878-2
- Franklin B (1786). Famous Letter On Lead Poisoning. <https://www.historyofinformation.com/detail.php?id=4759>
- Friend M, Franson JC (1988). Field Manual of Wildlife Diseases. [https://pubs.usgs.gov/itr/1999/field\\_manual\\_of\\_wildlife\\_diseases.pdf](https://pubs.usgs.gov/itr/1999/field_manual_of_wildlife_diseases.pdf)
- Friend M, Thomas VG (2009). Pitfalls Encountered in the Transition to Non-lead Ammunition Use in North America and How They Were/ Are Being Addressed. **Paper** presented at the CIC Sustainable Hunting Ammunition. [http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC\\_Sustainable\\_Hunting\\_Ammunition\\_Workshop\\_Report\\_low\\_res.pdf](http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC_Sustainable_Hunting_Ammunition_Workshop_Report_low_res.pdf)
- Fäth J, Göttlein A (2019). Assessing the leaching behavior of different gunshot materials in natural spring waters. *Environmental Sciences Europe* 31:57 doi:10.1186/s12302-019-0249-2
- Gabrielson IN (1951). *Wildlife Management*. The Macmillan Co. 274 p.

- Gangoso L, Álvarez-Lloret P, Rodríguez-Navarro AAB, Mateo R, Hiraldo F, Donázar JA (2009). Long-term effects of lead poisoning on bone mineralization in vultures exposed to ammunition sources. *Environmental Pollution* 157:569-574 <https://doi.org/10.1016/j.envpol.2008.09.015>
- Garvin JC, Slabe VA, Cuadros Díaz SF (2020). Conservation Letter: Lead Poisoning of Raptors. *Journal of Raptor Research* 54:473-479, 477 <https://doi.org/10.3356/0892-1016-54.4.473>
- Garwood RL (1994). Gough Thomas's gun book: shotgun lore for the sportsman. The Gunnerman Press: Auburn Hills, Michigan, USA
- Gerofke A, Martin A, Schlichting D, Gremse C, Müller-Graf C (2019). Heavy metals in game meat. *Chemical hazards in foods of animal origin*:585 - 609 <https://doi.org/10.3920/978-90-8686-877-3>
- Gidlow DA (2015). Lead toxicity. *Occupational Medicine* 65:348-356 doi:10.1093/occmed/kqv018
- Gil-Jiménez E, Mateo R, de Lucas M, Ferrer M (2020). Feathers and hair as tools for non-destructive pollution exposure assessment in a mining site of the Iberian Pyrite Belt. *Environmental Pollution* 263:114523 <https://doi.org/10.1016/j.envpol.2020.114523>
- Gil-Sánchez JM, Molleda S, Sánchez-Zapata JA, Bautista J, Navas I, Godinho R, García-Fernández AJ, Moleón M (2018). From sport hunting to breeding success: Patterns of lead ammunition ingestion and its effects on an endangered raptor. *Science of The Total Environment* 613-614:483-491 <https://doi.org/10.1016/j.scitotenv.2017.09.069>
- Gordon JN, Taylor A, Bennett PN (2002). Lead poisoning: case studies. *Brit J Clin Pharmacol* 53:451-458 doi:10.1046/j.1365-2125.2002.01580.x
- Goyer RA, Clarkson TW (1996). Toxic effects of metals. the Basic Science of Poisons [https://www.biologicaldiversity.org/campaigns/get-the-lead-out/pdfs/health/Goyer\\_1996.pdf](https://www.biologicaldiversity.org/campaigns/get-the-lead-out/pdfs/health/Goyer_1996.pdf)
- Grandjean P (2010). Even low-dose lead exposure is hazardous. *The Lancet* 376:855-856 [https://doi.org/10.1016/S0140-6736\(10\)60745-3](https://doi.org/10.1016/S0140-6736(10)60745-3)
- Grandjean P (2013). Only One Chance. How Environmental Pollution Impairs Brain Development -- and How to Protect the Brains of the Next Generation. *Environmental Ethics and Science Policy Series*
- Grandjean P, Landrigan PJ (2014). Neurobehavioural effects of developmental toxicity. *The Lancet Neurology* 13:330-338 [https://doi.org/10.1016/S1474-4422\(13\)70278-3](https://doi.org/10.1016/S1474-4422(13)70278-3)
- Green A, Mateo R, Guitart R (2000). Determinants of Lead Shot, Rice, and Grit Ingestion in Ducks and Coots. *Journal of Wildlife Management* 64:939-947 doi:10.2307/3803202
- Green RE, Pain DJ (2016). Possible effects of ingested lead gunshot on populations of ducks wintering in the UK. *Ibis* 158:699-710 doi:10.1111/ibi.12400

Green RE, Pain DJ (2019). Risks to human health from ammunition-derived lead in Europe. *Ambio* doi:10.1007/s13280-019-01194-x

Green RE, Taggart MA, Pain DJ, Clark NA, Clewley L, Cromie R, Elliot B, Green RMW, Huntley B, Huntley J, Leslie R, Porter R, Robinson JA, Smith KW, Smith L, Spencer J, Stroud DA (2021). Effect of a joint policy statement by nine UK shooting and rural organisations on the use of lead shotgun ammunition for hunting common pheasants *Phasianus colchicus* in Britain. *Conservation Evidence Journal* 18, 1-9 <https://conservationevidencejournal.com/reference/pdf/8858>

Gremse C, Rieger S (2012). Ergänzende Untersuchungen zur Tötungswirkung bleifreier Geschosse. HNE Eberswalde. [https://www.hnee.de/\\_obj/85DD11C1-35B5-4435-B044-4F6B7B6975F0/inline/FWWJ\\_Endbericht\\_09HS023\\_25.02.14.pdf](https://www.hnee.de/_obj/85DD11C1-35B5-4435-B044-4F6B7B6975F0/inline/FWWJ_Endbericht_09HS023_25.02.14.pdf)

Gremse C, Rieger S (2015). Lead from Hunting Ammunition in Wild Game Meat: Research Initiatives and Current Legislation in Germany and the EU. In *Proceedings of the Oxford Lead*. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/Papers/OLS\\_proceedings\\_gremse\\_reiger.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/Papers/OLS_proceedings_gremse_reiger.pdf)

Gremse F, Krone O, Thamm M, Kiessling F, Tolba RH, Rieger S, Gremse C (2014). Performance of lead-free versus lead-based hunting ammunition in ballistic soap. *PloS one* 9:e102015-e102015 doi:10.1371/journal.pone.0102015

Grinnell GB (1894). Lead poisoning. *Forest & Stream* 42

Group of Scientists (2014). Wildlife and human health risks from lead-based ammunition in Europe: A consensus statement by scientists. . <https://www.zoo.cam.ac.uk/system/files/documents/European-Statement.pdf>

Gunnarsson G, Elmberg J, Pöysä H, Nummi P, Sjöberg K, Dessborn L, Arzel C (2013). Density dependence in ducks: a review of the evidence. *European Journal of Wildlife Research* 59:305-321 doi:10.1007/s10344-013-0716-9

Gupte PR, Koffijberg K, Müskens GJDM, Wikelski M, Kölzsch A (2019). Family size dynamics in wintering geese. *Journal of Ornithology* 160:363-375 doi:10.1007/s10336-018-1613-5

GWCT, BGA, BASC, CA, CLA, MA, NGO, SLE, SACS (2020) A joint statement on the future of shotgun ammunition for live quarry shooting. <https://basc.org.uk/a-joint-statement-on-the-future-of-shotgun-ammunition-for-live-quarry-shooting/>

Hampton JO, DeNicola AJ, Forsyth DM (2020). Assessment of Lead-Free .22 LR Bullets for Shooting European Rabbits. *Wildlife Society Bulletin n/a* doi:10.1002/wsb.1127

Hampton JO, Eccles G, Hunt R, Bengsen AJ, Perry AL, Parker S, Miller CJ, Joslyn SK, Stokke S, Arnemo JM, Hart Q (2021). A comparison of fragmenting lead-based and lead-free bullets for aerial shooting of wild pigs. *PLOS ONE* 16:e0247785 doi:10.1371/journal.pone.0247785

Hampton JO, Laidlaw M, Buenz E, Arnemo JM (2018). Heads in the sand: public health and ecological risks of lead-based bullets for wildlife shooting in Australia. *Wildlife Research* 45:287-306.

<https://doi.org/10.1071/WR17180>

Hampton JO, Arnemo JM, Barnsley R, Cattet M, Daoust P-Y, DeNicola AJ, Eccles G, Fletcher D, Hinds LA, Hunt R, Portas T, Stokke S, Warburton B, Wimpenny C (2021). Animal welfare testing for shooting and darting free-ranging wildlife: a review and recommendations. *Wildlife Research*:

<https://doi.org/10.1071/WR20107>

Hansen NML, Sommer-Larsen P, Ma N, Pallesen BE, Andersen M, Vestbø AP, Kanstrup N (2021). Kortlægning af markedet for bionedbrydelige haglskåle. Miljøstyrelsen <https://www2.mst.dk/Udgiv/publikationer/2021/03/978-87-7038-281-6.pdf>

Harmuth J (2011). Erfahrungen mit bleifreier Munition im Jagdbetrieb des Stadtförstamtes Rostock. In: Krone O, (Editor) Bleivergiftungen bei Greifvögeln. Ursachen, Erfahrungen, Lösungsmöglichkeiten. Der Seeadler als Indikator. Proceeding of the Conference „Bleivergiftungen bei Seeadlern: Ursachen und Lösungsansätze“ from April 16th 2009 in Berlin, Free University, 127 pages

Havera SP, Hine CS, Georgi MM (1994). Waterfowl Hunter Compliance with Nontoxic Shot Regulations in Illinois. *Wildlife Society Bulletin* (1973-2006) 22:454-460 [www.jstor.org/stable/3783388](http://www.jstor.org/stable/3783388)

Hernberg S (2000). Lead poisoning in a historical perspective. *American Journal of Industrial Medicine* 38:244-254 doi:10.1002/1097-0274(200009)38:3<244::Aid-ajim3>3.0.Co;2-f

Holm TE, Madsen J (2013). Incidence of embedded shotgun pellets and inferred hunting kill amongst Russian/Baltic barnacle geese *Branta leucopsis*. *European Journal of Wildlife Research* 59:77-80 doi:10.1007/s10344-012-0649-8

Hui CA (2002). Lead distribution throughout soil, flora, and an invertebrate at a wetland skeet range. *Journal of toxicology and environmental health Part A* 65:1093-1107 doi:10.1080/152873902760125246

Hunt WG, Watson RT, Oaks JL, Parish CN, Burnham KK, Tucker RL, Belthoff JR, Hart G (2009). Lead Bullet Fragments in Venison from Rifle-Killed Deer: Potential for Human Dietary Exposure. *PLOS ONE* 4:e5330 doi:10.1371/journal.pone.0005330

Hunting Experts (2020). Alternatives to lead ammunition. Sorting fact from fiction. <https://europeanhuntingexperts.org/>

Haas GH (1977). Unretrieved shooting loss of mourning doves in north-central South Carolina. *Wildlife Society Bulletin* 5:123-125 <http://pubs.er.usgs.gov/publication/5220971>

ILA (2019). Lead Production & Statistics. International Lead Association webpage, visited December 2019 <https://www.ila-lead.org/lead-facts/lead-production--statistics>

Iqbal S, Blumenthal W, Kennedy C, Yip FY, Pickard S, Flanders WD, Loring K, Kruger K, Caldwell KL, Jean Brown M (2009). Hunting with lead: Association between blood lead levels and wild game consumption. *Environmental Research* 109:952-959 <https://doi.org/10.1016/j.envres.2009.08.007>

Ishii C, Ikenaka Y, Nakayama SMM, Kuritani T, Nakagawa M, Saito K, Watanabe Y, Ogasawara K, Onuma M, Haga A, Ishizuka M (2020). Current situation regarding lead exposure in birds in Japan (2015–2018); lead exposure is still occurring. *Journal of Veterinary Medical Science* advpub doi:10.1292/jvms.20-0104

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L. (2015). Plastic waste inputs from land into the ocean. *Science*. 347(6223): p. 768-771. doi:10.1126/science.1260352

Janiszewski P, Daszkiewicz T, Cilulko J (2015). The effect of wintering conditions on the body weight and carcass quality of farm-raised fallow deer (*Dama dama*). *Bulgarian Journal of Agricultural Science* 21:668-673

Johansen P, Pedersen HS, Asmund G, Riget F (2006). Lead shot from hunting as a source of lead in human blood. *Environmental Pollution* 142:93-97 <https://doi.org/10.1016/j.envpol.2005.09.015>

Johnson CK, Kelly TR, Rideout BA (2013). Lead in Ammunition: A Persistent Threat to Health and Conservation. *EcoHealth* 10:455-464 doi:10.1007/s10393-013-0896-5

Juberg DL (2000). Lead and Human Health. American Council on Science and Health, [https://books.google.dk/books?id=eh\\_sGdXtPrC&pg=PT8&dq=lead+goyer+1996&hl=da&sa=X&ved=0ahUKEwj4qpxh5zmAhUE-NOwKHSc6CWUQ6AEIKDAA#v=onepage&q=lead%20goyer%201996&f=false](https://books.google.dk/books?id=eh_sGdXtPrC&pg=PT8&dq=lead+goyer+1996&hl=da&sa=X&ved=0ahUKEwj4qpxh5zmAhUE-NOwKHSc6CWUQ6AEIKDAA#v=onepage&q=lead%20goyer%201996&f=false)

Kanstrup N (1987). Jernhaglpatroners anvendelighed (1). Jagt&Fiskeri November 1987

Kanstrup N (2006 (**Paper 5**)). Sustainable harvest of waterbirds. a global review. *Waterbirds around the world*:98-106 [http://archive.jncc.gov.uk/PDF/pub07\\_waterbirds\\_part2.2.7.pdf](http://archive.jncc.gov.uk/PDF/pub07_waterbirds_part2.2.7.pdf)

Kanstrup N (2006 (**Paper 20**)). Non-toxic shot - Danish experiences. *Waterbirds around the world*:861 <https://www.amazon.com/Waterbirds-Around-World-Conservation-Management/dp/0114973334>

Kanstrup N (2009) (Ed.) Sustainable Hunting Ammunition. CIC, Aarhus, Denmark [http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC\\_Sustainable\\_Hunting\\_Ammunition\\_Workshop\\_Report\\_low\\_res.pdf](http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC_Sustainable_Hunting_Ammunition_Workshop_Report_low_res.pdf)

Kanstrup N (2012 (**Paper 12**)). Lead in game birds in Denmark: Levels and sources. *Danish Academy of Hunting* <https://www.scribd.com/document/475251831/Kanstrup-2012-Lead-in-Danish-Game-Birds>

Kanstrup N (2015). Non-lead rifle ammunition – availability in Danish gun stores vol 1508-02. Danish Academy of Hunting, OneDrive\DNA-D26313\150820\_Blyfri\_riffelammunition\_forhandlerundersogelse\_RAPPORT.pdf

Kanstrup N (2015 (**Paper 21**)). Practical and social barriers to switching from lead to non-toxic gunshot – a perspective from the EU. In: Delahay R, Spray C (eds) Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, The University of Oxford. pp 98-103. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/Papers/OLS\\_proceedings\\_kanstrup.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/Papers/OLS_proceedings_kanstrup.pdf)

Kanstrup N (2017). Blypatroner er gift for jagtens fremtid. Jagt, vildt og våben 2017/10 <https://jvv.dk/bly-gift-jagtens-fremtid/>

Kanstrup N (2018 (**Paper 10**)). Lessons learned from 33 years of lead shot regulation in Denmark. Ambio 48:999,1008 doi:10.1007/s13280-018-1125-9

Kanstrup N, Andersen LT (2009). 25 years' experience of hunting without lead shot in Denmark. Sustainable Hunting Ammunition [http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC\\_Sustainable\\_Hunting\\_Ammunition\\_Workshop\\_Report\\_low\\_res.pdf](http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC_Sustainable_Hunting_Ammunition_Workshop_Report_low_res.pdf)

Kanstrup N, Andersen LTA (2003). Forbud mod dårlige haglpatroner. Jæger 5/2003 <https://www.jaegerforbundet.dk/media/10312/j%C3%A6ger-2003-maj-forbud-mod-d%C3%A5rlige-patroner.pdf>

Kanstrup N, Balsby TJS (2015). Blyfri riffelammunition - effektivitet under praktisk jagt. (with an English summary) Dansk Jagtakademi 1506-01 <https://www.scribd.com/document/475251146/150615-Blyfri-Riffelammunition-RAPPORT>

Kanstrup N, Balsby TJS (2018 (**Paper 18**)). Plastic litter from shotgun ammunition on Danish coastlines - Amounts and provenance. Environmental Pollution 237:601-610 doi:10.1016/j.envpol.2018.02.087

Kanstrup N, Balsby TJS (2019 (**Paper 15**)). Danish pheasant and mallard hunters comply with the lead shot ban. Ambio 48:1009-1014 doi:10.1007/s13280-019-01152-7

Kanstrup N, Balsby TJS (2019 (**Paper 16**)). Ingested shot in mallards (Anas platyrhynchos) after the regulation of lead shot for hunting in Denmark. European Journal of Wildlife Research 65 doi:10.1007/s10344-019-1278-2

Kanstrup N, Balsby TJS, Thomas VG (2016 (**Paper 13**)). Efficacy of non-lead rifle ammunition for hunting in Denmark. European Journal of Wildlife Research 62:333-340 doi:10.1007/s10344-016-1006-0

Kanstrup N, Chriel M, Dietz R, Sondergaard J, Balsby TJS, Sonne C (2019 (**Paper 22**)). Lead and Other Trace Elements in Danish Birds of Prey. Archives of Environmental Contamination and Toxicology 77:359-367 doi:10.1007/s00244-019-00646-5

Kanstrup N, Fox AD, Balsby TJS (2020 (**Paper 14**)). Toxic lead gunshot persists accessible to waterbirds after a 33-year ban on their use. *Science of The Total Environment*:136876 <https://doi.org/10.1016/j.scitotenv.2020.136876>

Kanstrup N, Hansen HP, Balsby TJS, Møllerup KA (2020). Bly i riffelammunition: danske jægers kendskab og holdning. DCE, Videnskabelig rapport nr 381 <https://dce2.au.dk/pub/SR381.pdf>

Kanstrup N, Hansen HP, Balsby TJS, Møllerup KA (2021 (**Paper 6**)). Non-lead rifle ammunition: Danish hunters' attitudes. *Environmental Sciences Europe* doi:10.1186/s12302-021-00485-z

Kanstrup N, Hartmann P (1991). Plastikfri jernhaglpatroner. En undersøgelse af våbenslitage, skudeffektivitet m.v. ved brug af jernhaglpatroner med filtforladning og paphylster. *GameConsult*, April 1991

Kanstrup N, Haugaard L (2020). Krav til projektilvægt, anslagsenergi m.v. for riffelammunition, der anvendes til jagt og regulering. Fagligt notat nr. 36. DCE. Aarhus Universitet, [https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet\\_2020/N2020\\_36.pdf](https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet_2020/N2020_36.pdf)

Kanstrup N, Potts D (2007) Lead Shot: New developments with relevance to all hunters. *CIC Newsletter* vol 2007/4

Kanstrup N, Swift J, Stroud DA, Lewis M (2018 (**Paper 4**)). Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47:846-857 doi:10.1007/s13280-018-1042-y

Kanstrup N, Thomas VG (2019 (**Paper 7**)). Availability and prices of non-lead gunshot cartridges in the European retail market. *Ambio* 48:1039-1043 doi:10.1007/s13280-019-01151-8

Kanstrup N, Thomas VG (2020 (**Paper 1**)). Transitioning to lead-free ammunition use in hunting: socio-economic and regulatory considerations for the European Union and other jurisdictions. *Environmental Sciences Europe* 32:91 doi:10.1186/s12302-020-00368-9

Kanstrup N, Thomas VG, Fox AD (2019). (Eds.) Lead in hunting ammunition: Persistent problems and solutions vol 48 Springer, *Ambio* <https://link.springer.com/journal/13280/48/9>

Kanstrup N, Thomas VG, Fox AD (2019 (**Paper 24**)). Foreword. *Ambio* 48:923-924 doi:10.1007/s13280-019-01220-y

Kanstrup N, Thomas VG, Krone O, Gremse C (2016 (**Paper 8**)). The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations. *Ambio* 45:621-628 doi:10.1007/s13280-016-0780-y

Kay RNB, Sharman GAM, Hamilton WJ, Goodall ED, Pennie K, Coutts AGP (1981). Carcass characteristics of young red deer farmed on hill pasture. *The Journal of Agricultural Science* 96:79-87 doi:10.1017/S0021859600031890

Kenntner N, Tataruch F, Krone O (2001). Heavy metals in soft tissue of white-tailed eagles found dead or moribund in Germany and Austria from 1993 to

2000. Environ Toxicol Chem 20:1831-1837 doi:10.1897/1551-5028(2001)020<1831:hmisto>2.0.co;2

Knott J, Gilbert J, Green RE, Hoccom DG (2009). Comparison of the lethality of lead and copper bullets in deer control operations to reduce incidental lead poisoning; field trials in England and Scotland. Conservation Evidence 6:71-78

Knudsen NV (2020). Blyfri Riffelammunition: Den store test. Jæger 4/2020:118-127. <https://www.jaegerforbundet.dk/om-dj/dj-medier/dj-online/test-af-blyfri-ammunition/>

Knutsen HK, Brantsæter AL, Alexander J, Meltzer HM (2015). Associations between consumption of large game animals and blood lead levels in humans in Europe: the Norwegian experience. In: Delahay, RJ & Spray, CJ (Eds) (2015) Proceedings of the Oxford Lead Symposium Lead Ammunition: understanding and minimising the risks to human and environmental health Edward Grey Institute, The University of Oxford, UK. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_knutsen\\_brantsaeter\\_alexander\\_meltzer.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_knutsen_brantsaeter_alexander_meltzer.pdf)

Kollander B, Widemo F, Ågren E, Larsen EH, Loeschner K (2017). Detection of lead nanoparticles in game meat by single particle ICP-MS following use of lead-containing bullets. Analytical and Bioanalytical Chemistry 409:1877-1885 doi:10.1007/s00216-016-0132-6

Koller K, Brown T, Spurgeon A, Levy L (2004). Recent developments in Low-Level Lead Exposure and Intellectual Impairment in Children. Environmental Health Perspectives. <https://doi.org/10.1289/ehp.6941>

Kosnett MJ, Wedeen RP, Rothenberg SJ, Hipkins KL, Materna BL, Schwartz BS, Hu H, Woolf A (2007). Recommendations for medical management of adult lead exposure. Environmental health perspectives 115:463-471 doi:10.1289/ehp.9784

Kovacs KM, Aars J, Lydersen C (2014). Walruses recovering after 60+ years of protection in Svalbard, Norway. Polar Research 33:26034 doi:10.3402/polar.v33.26034

LAG (2015). Lead Ammunition, Wildlife and Human Health. A report prepared for the Department for Environment, Food and Rural Affairs and the Food Standards Agency, United Kingdom. <http://www.leadammunitiongroup.org.uk>

Lam SS, McPartland M, Noori B, Garbus S-E, Lierhagen S, Lyngs P, Dietz R, Therkildsen OR, Christensen TK, Tjørnløv RS, Kanstrup N, Fox AD, Sørensen IH, Arzel C, Krøkje Å, Sonne C (2020). Lead concentrations in blood from incubating common eiders (*Somateria mollissima*) in the Baltic Sea. Environment International 137:105582 <https://doi.org/10.1016/j.envint.2020.105582>

Lampel W, Seitz G (1983). "Jagdballistik – Die Lehre vom jagdlichen Schuss". Verlag J Neumann-Neudamm, 1983

Lanphear BP, Hornung R, Khoury J, Yolton K, Baghurst P, Bellinger DC, Canfield RL, Dietrich KN, Bornschein R, Greene T, Rothenberg SJ, Needleman HL,

Schnaas L, Wasserman G, Graziano J, Roberts R (2005). Low-Level Environmental Lead Exposure and Children's Intellectual Function: An International Pooled Analysis. *Environmental Health Perspectives* 113:894-899 doi:doi:10.1289/ehp.7688

Leopold A (1933). *Game Management*. C. Scribner's Sons. 481 p.

Lessler AM (1988). Lead and Lead Poisoning from Antiquity to Modern Times. *Ohio J Sci* 88(3): 78-84

<https://pdfs.semanticscholar.org/61a3/22cfe7c1622aaf7576512b881f9352fb4913.pdf>

Lindboe M, Henrichsen EN, Høgåsen HR, Bernhoft A (2012). Lead concentration in meat from lead-killed moose and predicted human exposure using Monte Carlo simulation. *Food Additives & Contaminants: Part A* 29:1052-1057 doi:10.1080/19440049.2012.680201

Lindbohm ML, Sallmen M, Anttila A, Taskinen H, Hemminki K (1991). Paternal occupational lead exposure and spontaneous abortion. *Scandinavian journal of work, environment & health* 17:95-103 doi:10.5271/sjweh.1721

Linden MA, Manton WI, Stewart RM, Thal ER, Feit H (1982). Lead poisoning from retained bullets. Pathogenesis, diagnosis, and management. *Ann Surg* 195:305-313 doi:10.1097/00000658-198203000-00010

Lone K, Loe LE, Meisingset EL, Stamnes I, Mysterud A (2015). An adaptive behavioural response to hunting: surviving male red deer shift habitat at the onset of the hunting season. *Animal Behaviour* 102:127-138 <https://doi.org/10.1016/j.anbehav.2015.01.012>

Lowry ED (1974). Shotgun efficiency: the real facts *Sports Afield* March 1974: 35-35, 148-153

Lumeij JT, Hendriks H, Timmers A (1989). The prevalence of lead shot ingestion in wild mallards (*Anas platyrhynchos*) in the Netherlands. *Veterinary Quarterly* 11:51-55 doi:10.1080/01652176.1989.9694196

Madry MM, Kraemer T, Kupper J, Naegeli H, Jenny H, Jenni L, Jenny D (2015). Excessive lead burden among golden eagles in the Swiss Alps. *Environmental Research Letters* 10:034003 doi:10.1088/1748-9326/10/3/034003

Madsen HHT, Skjødt T, Jørgensen PJ, Grandjean P (1988). Blood lead levels in patients with lead shot retained in the appendix. *Acta Radiol* 29:745-746 doi:10.1080/02841858809171977

Madsen J (1998). Experimental refuges for migratory waterfowl in Danish wetlands. II. Tests of hunting disturbance effects. *Journal of Applied Ecology* 35:398-417 doi:10.1046/j.1365-2664.1998.00315.x

Madsen J (2010). Age bias in the bag of pink-footed geese *Anser brachyrhynchus*: influence of flocking behaviour on vulnerability. *European Journal of Wildlife Research* 56:577-582 doi:10.1007/s10344-009-0349-1

Madsen J, Williams JH, Johnson FA, Tombre IM, Dereliev S, Kuijken E (2017). Implementation of the first adaptive management plan for a European migratory waterbird population: The case of the Svalbard pink-footed goose *Anser brachyrhynchus*. *Ambio* 46:275-289 doi:10.1007/s13280-016-0888-0

Mariano González L, Oria J, Sánchez R, Margalida A, Aranda A, Prada L, Caldera J, Ignacio Molina J (2008). Status and habitat changes in the endangered Spanish Imperial Eagle *Aquila adalberti* population during 1974–2004: implications for its recovery. *Bird Conservation International* 18:242-259 doi:10.1017/S0959270908000245

Markowitz M (2000). Lead Poisoning. *Pediatrics in Review* 21 (10) 327-335 <https://doi.org/10.1542/pir.21-10-327>

Martin A, Gremse C, Selhorst T, Bandick N, Müller-Graf C, Greiner M, Lahrssen-Wiederholt M (2017). Hunting of roe deer and wild boar in Germany: Is non-lead ammunition suitable for hunting? *PLOS ONE* 12:e0185029 doi:10.1371/journal.pone.0185029

Massei G, Kindberg J, Licoppe A, Dragan G, Sprem N, Kamler J, Baubet E, Hohmann U, Monaco A, Ozolins J, Cellina S, Podgórski T, Fonseca C, Markov N, Pokorny B, Rosell C, Náhlik A (2014). Wild boar populations up, numbers of hunters down? A review of trends and implications for Europe. *Pest Management Science* 71 doi:10.1002/ps.3965

Mateo R (2009). Lead poisoning in wild birds in Europe and the regulations adopted by different countries. Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans [https://www.peregrinefund.org/subsites/conference-lead/2008PbConf\\_Proceedings.htm](https://www.peregrinefund.org/subsites/conference-lead/2008PbConf_Proceedings.htm)

Mateo R, Belliure J, Dolz JC, Aguilar Serrano JM, Guitart R (1998). High Prevalences of Lead Poisoning in Wintering Waterfowl in Spain. *Archives of Environmental Contamination and Toxicology* 35:342-347 doi:10.1007/s002449900385

Mateo R, Guitart R (2000). The effects of grit supplementation and feed type on steel-shot ingestion in mallards. *Preventive Veterinary Medicine* 44:221-229 [https://doi.org/10.1016/S0167-5877\(00\)00101-X](https://doi.org/10.1016/S0167-5877(00)00101-X)

Mateo R, Kanstrup N (2019 (**Paper 2**)). Regulations on lead ammunition adopted in Europe and evidence of compliance. *Ambio* 48:989-998 doi:10.1007/s13280-019-01170-5

Mateo R, Vallverdú-Coll N, López-Antia A, Taggart MA, Martínez-Haro M, Guitart R, Ortiz-Santaliestra ME (2014). Reducing Pb poisoning in birds and Pb exposure in game meat consumers: The dual benefit of effective Pb shot regulation. *Environment International* 63:163-168 <https://doi.org/10.1016/j.envint.2013.11.006>

Mateo R, Vallverdú-Coll N, Ortiz-Santaliestra ME (2013). Intoxicación por munición de plomo en aves silvestres en España y medidas para reducir el riesgo. *Ecosistemas* 22(2):61-67 doi:10.7818/ECOS.2013.22-2.10

Mayhew AL, Keat WW (2003). *A Concise Dictionary of Middle English*.

- McAuley C, Ng C, McFarland C, Dersch A, Koppe B, Sowen D (2018). Lead exposure through consumption of small game harvested using lead-based ammunition and the corresponding health risks to First Nations in Alberta, Canada. *Cogent Environmental Science* 4 doi:10.1080/23311843.2018.1557316
- McCann B, Whitworth W, Newman R (2016). Efficacy of non-lead ammunition for culling elk at Theodore Roosevelt National Park. *Human-Wildlife Interactions* 10:268-282 doi:10.26077/8gma-q214
- McDowell PK, Conway WC, Haukos DA, Moon JA, Comer CE, Hung I-K (2015). Blood lead exposure concentrations in mottled ducks (*Anas fulvigula*) on the upper Texas coast. *J Southeastern Assoc Fish Game Agencies* 2:221-228 <http://www.seafwa.org/33%20McDowell%20et%20al%20221-228.pdf>
- Menzel A-C, Krone O (2021). Using Regurgitated Pellets From White-Tailed Sea-Eagles as Noninvasive Samples to Assess Lead Exposure Caused by Hunting in Germany. *Journal of Raptor Research* doi:10.3356/jrr-20-52
- Meyer CB, Meyer JS, Francisco AB, Holder J, Verdonck F (2016). Can Ingestion of Lead Shot and Poisons Change Population Trends of Three European Birds: Grey Partridge, Common Buzzard, and Red Kite? *PLOS ONE* 11:e0147189 doi:10.1371/journal.pone.0147189
- Mielke HW (2016). (Ed.) Lead Risk Assessment and Health Effects. *International Journal of Environmental Research and Public Health* 13 doi:10.3390/ijerph13060587
- Migliorini M, Pigino G, Bianchi N, Bernini F, Leonzio C (2004). The effects of heavy metal contamination on the soil arthropod community of a shooting range. *Environmental Pollution* 129:331-340 <https://doi.org/10.1016/j.envpol.2003.09.025>
- Migliorini M, Pigino G, Caruso T, Fanciulli PP, Leonzio C, Bernini F (2005). Soil communities (Acari Oribatida; Hexapoda Collembola) in a clay pigeon shooting range. *Pedobiologia* 49:1-13 <https://doi.org/10.1016/j.pedobi.2004.06.009>
- Monclús L, Shore RF, Krone O (2020). Lead contamination in raptors in Europe: A systematic review and meta-analysis. *Science of The Total Environment* 748:141437 <https://doi.org/10.1016/j.scitotenv.2020.141437>
- Mondain-Monval J-Y, Defos du Rau P, Guillemain M, Olivier A (2015). Switch to non-toxic shot in the Camargue, France: effect on waterbird contamination and hunter effectiveness. *European Journal of Wildlife Research* 61:271-283 doi:10.1007/s10344-014-0897-x
- Needleman H, Gee D (2013). Lead in petrol 'makes the mind give way'. Chapter 3 in *Late Lessons from early warnings: science, precaution, innovation European Environment Agency, Copenhagen* [file:///C:/Users/au85527/Downloads/Late%20lessons%20Vol%20II\\_chapter3.pdf](file:///C:/Users/au85527/Downloads/Late%20lessons%20Vol%20II_chapter3.pdf)

Needleman HL (1997). Clair Patterson and Robert Kehoe: Two Views of Lead Toxicity. Environmental Research, Section A 78, 79–85 (1998), Article No ER973807 University of Pittsburgh, School of Medicine, 100 N Bellefield Avenue, Pittsburgh, Pennsylvania 15213 Received November 4, 1997 <https://www.sciencedirect.com/science/article/abs/pii/S001393519793807X>

Nevin R (2007). Understanding international crime trends: The legacy of pre-school lead exposure. Environmental Research 104:2007) 2315–2336 <https://pic.plover.com/Nevin/Nevin2007.pdf>

Newth JL, Brown MJ, Rees EC (2011). Incidence of embedded shotgun pellets in Bewick's swans *Cygnus columbianus bewickii* and whooper swans *Cygnus cygnus* wintering in the UK. Biological Conservation 144:1630-1637 <https://doi.org/10.1016/j.biocon.2011.02.014>

Newth JL, Cromie RL, Kanstrup N (2015). Lead shot in Europe: conflict between hunters and conservationists. In: Conflicts in Conservation: Navigating towards Solutions. [https://www.researchgate.net/publication/281233846\\_Conflicts\\_in\\_Conversation\\_navigating\\_towards\\_solutions](https://www.researchgate.net/publication/281233846_Conflicts_in_Conversation_navigating_towards_solutions)

Newth JL, Lawrence A, Cromie RL, Swift JA, Rees EC, Wood KA, Strong EA, Reeves J, McDonald RA (2019). Perspectives of ammunition users on the use of lead ammunition and its potential impacts on wildlife and humans. People and Nature 1:347-361 doi:10.1002/pan3.30

Noer H, Hartmann P, Madsen J, Christensen TK, Kanstrup N, Simonsen NH (2001). Crippling of game animals. Status for research 2001. Faglig rapport fra DMU, nr. 367. [https://www.dmu.dk/1\\_viden/2\\_Publikationer/3\\_fagrappporter/rapporter/fr367.pdf](https://www.dmu.dk/1_viden/2_Publikationer/3_fagrappporter/rapporter/fr367.pdf)

Nriagu JO (1983a). Lead and Lead Poisoning in Antiquity. New York: Wiley. <https://www.worldcat.org/title/lead-and-lead-poisoning-in-antiquity/oclc/8931502>

Nriagu JO (1983b). Saturnine gout among Roman aristocrats. Did lead poisoning contribute to the fall of the Empire? N Engl J Med 308: 660-663. <https://www.nejm.org/doi/full/10.1056/NEJM198303173081123>

Nriagu JO (2009). History in lead and lead poisoning in history. Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans doi:DOI 10.4080/ilsa.2009.0102

OECD (1999). Phasing Lead out of Gasoline: An Examination of Policy Approaches in Different Countries. <http://www.oecd.org/chemicalsafety/risk-management/1937036.pdf>

Okkenhaug G, Grasshorn Gebhardt K-A, Amstaetter K, Lassen Bue H, Herzel H, Mariussen E, Rossebø Almås Å, Cornelissen G, Breedveld GD, Rasmussen G, Mulder J (2016). Antimony (Sb) and lead (Pb) in contaminated shooting range soils: Sb and Pb mobility and immobilization by iron based sorbents, a field study. Journal of Hazardous Materials 307:336-343 <https://doi.org/10.1016/j.jhazmat.2016.01.005>

Okkenhaug G, Smebye AB, Pabst T, Amundsen CE, Sævarsson H, Breedveld GD (2018). Shooting range contamination: mobility and transport of lead (Pb), copper (Cu) and antimony (Sb) in contaminated peatland. *Journal of Soils and Sediments* 18:3310-3323 doi:10.1007/s11368-017-1739-8

Orfila M (1817). A General System of Toxicology. <https://collections.nlm.nih.gov/catalog/nlm:nlmuid-2566014R-bk>

Pain DJ (1992). Lead poisoning in waterfowl. International Waterfowl and wetlands Research Bureau. Proceedings of an IWRB Workshop, Brussels, Belgium, 13-15 June 1991. IWRB Special Publication 16, Slimbridge, UK

Pain DJ, Cromie RL, Newth J, Brown MJ, Crutcher E, Hardman P, Hurst L, Mateo R, Meharg AA, Moran AC, Raab A, Taggart MA, Green RE (2010). Potential Hazard to Human Health from Exposure to Fragments of Lead Bullets and Shot in the Tissues of Game Animals. *PLOS ONE* 5:e10315 doi:10.1371/journal.pone.0010315

Pain DJ, Dickie I, Green RE, Kanstrup N, Cromie R (2019 (**Paper 3**)). Wildlife, human and environmental costs of using lead ammunition: An economic review and analysis. *Ambio* 48:969-988 doi:10.1007/s13280-019-01157-2

Pain DJ, Mateo R, Green RE (2019). Effects of lead from ammunition on birds and other wildlife: A review and update. *Ambio* doi:10.1007/s13280-019-01159-0

Parry G, Buenz EJ (2020). Including eating lead-shot meat in the differential diagnosis of non-specific symptoms. *Internal Medicine Journal* 50:1293-1294 <https://doi.org/10.1111/imj.15024>

Pattee O, Pain DJ (2003). Lead in the environment. Handbook of ecotoxicology, eds DJ Hoffman, BA Rattner, GA Burton Jr, and J Cairns Jr, Second ed, pp 373-408 Boca Raton, Florida, USA: CRC Press [https://books.google.dk/books?hl=da&lr=&id=6U3MBQAAQBAJ&oi=fnd&pg=PA373&dq=Pattee+and+pain+2003&ots=lvY-fxYk80&sig=6HnDqDipQHjOBy-zHhBwOqbJv74&redir\\_esc=y#v=onepage&q&f=false](https://books.google.dk/books?hl=da&lr=&id=6U3MBQAAQBAJ&oi=fnd&pg=PA373&dq=Pattee+and+pain+2003&ots=lvY-fxYk80&sig=6HnDqDipQHjOBy-zHhBwOqbJv74&redir_esc=y#v=onepage&q&f=false)

Paulsen P, Bauer F, Sager M, Schuhmann-Irschik I (2015). Model studies for the release of metals from embedded rifle bullet fragments during simulated meat storage and food ingestion. *European Journal of Wildlife Research* 61:629-633 doi:10.1007/s10344-015-0926-4

Paulsen P, Sager M (2017). Nickel and copper residues in meat from wild artiodactyls hunted with nickel-plated non-lead rifle bullets. *European Journal of Wildlife Research* 63:63 doi:10.1007/s10344-017-1123-4

Pay JM, Katzner TE, Hawkins CE, Koch AJ, Wiersm JM, Brown WE, Mooney NJ, Cameron EZ (2020). High Frequency of Lead Exposure in the Population of an Endangered Australian Top Predator, the Tasmanian Wedge-Tailed Eagle (*Aquila audax fleayi*). *Environmental Toxicology and Chemistry* n/a doi:10.1002/etc.4914

Percival R (2006). Who's Afraid of the Precautionary Principle? All Faculty Publications 23

Pierce BL, Roster TA, Frisbie MC, Mason CD, Roberson JA (2015). A comparison of lead and steel shot loads for harvesting mourning doves. *Wildlife Society Bulletin* 39:103-115 doi:10.1002/wsb.504

Pokras MA, Kneeland MR (2008). Lead Poisoning: Using Transdisciplinary Approaches to Solve an Ancient Problem. *EcoHealth* 5:379-385 doi:10.1007/s10393-008-0177-x

Putman RJ, Langbein J, M. Hewison AJ, Sharma SK (1996). Relative roles of density-dependent and density-independent factors in population dynamics of British deer. *Mammal Review* 26:81-101 doi:10.1111/j.1365-2907.1996.tb00148.x

Ramazzini B (1713). *Diseases of Workers*. Hafner Publishing Company

Regeringen (2018). Plastik uden spiold - Regeringen plastikhandlingsplan. Miljø- og Fødevareministeriet [https://en.mfvm.dk/fileadmin/user\\_upload/ENGLISH\\_FVM.DK/Regeringens\\_plastikhandlingsplan\\_UK.pdf](https://en.mfvm.dk/fileadmin/user_upload/ENGLISH_FVM.DK/Regeringens_plastikhandlingsplan_UK.pdf)

Reuben A, Caspi A, Belsky DW, Broadbent J, Harrington H, Sugden K, Houts RM, Ramrakha S, Poulton R, Moffitt TE (2017). Association of Childhood Blood Lead Levels With Cognitive Function and Socioeconomic Status at Age 38 Years and With IQ Change and Socioeconomic Mobility Between Childhood and Adulthood. *JAMA* 317:1244-1251 doi:10.1001/jama.2017.1712

Rooney CP, McLaren RG, Condron LM (2007). Control of lead solubility in soil contaminated with lead shot: Effect of soil pH. *Environmental Pollution* 149:149-157 <https://doi.org/10.1016/j.envpol.2007.01.009>

Rutishauser E (1932). Experimentelle Studien über die bei chronischer Bleivergiftung vorkommenden Knochenveränderungen von der Art der Ostitis fibrosa von Recklinghausen und dabei nachweisbarer Epithelkörpervergrößerung. *Archiv für Gewerbepathologie und Gewerbehygiene* 3:300-324 doi:10.1007/BF02125071

Sachdeva C, Thakur K, Sharma A, Sharma KK (2018). Lead: Tiny but Mighty Poison. *Indian J Clin Biochem* 33:132-146 doi:10.1007/s12291-017-0680-3

Sakai T (2000). Biomarkers of Lead Exposure. *INDUSTRIAL HEALTH* 38:127-142 doi:10.2486/indhealth.38.127

Samuel MD, Bowers EF (2000). Lead Exposure in American Black Ducks after Implementation of Non-Toxic Shot. *The Journal of Wildlife Management* 64:947-953 doi:10.2307/3803203

Sanderson GC, Bellrose FC (1986). A review of the problem of lead poisoning in waterfowl. *Ill Nat Hist Surv Spec Pub* 4

Sanderson WL, Havera SP (1989). Lead poisoning in Illinois Waterfowl (1977-1988) and the Implementation of nontoxic shot Regulations. *Illinois Natural history Survey Biological notes* 133 <https://www.ideals.illinois.edu/bitstream/handle/2142/17301/leadpoisoningini133ande.pdf?sequence=1>

- Saxena G, Flora SJS (2004). Lead-induced oxidative stress and hematological alterations and their response to combined administration of calcium disodium EDTA with a thiol chelator in rats. *Journal of Biochemical and Molecular Toxicology* 18:221-233 doi:10.1002/jbt.20027
- Scheuhammer AM, Norris SL (1996). The ecotoxicology of lead shot and lead fishing weights. *Ecotoxicology* 5:279-295 doi:10.1007/bf00119051
- Schulz J, Wilhelm Stanis S, Hall D, Webb E (2020). Until It's a regulation It's not my fight: Complexities of a voluntary nonlead hunting ammunition program. *Journal of Environmental Management* 277:111438. doi:10.1016/j.jenvman.2020.111438
- Schulz JH, Wilhelm Stanis SA, Webb EB, Li CJ, Hall DM (2019). Communication strategies for reducing lead poisoning in wildlife and human health risks. *Wildlife Society Bulletin* 43:131-140 <https://doi.org/10.1002/wsb.955>
- Schupp T, Damm G, Foth H, Freyberger A, Gebel T, Gundert-Remy U, Hengstler JG, Mangerich A, Partosch F, Röhl C, Wollin K-M (2020). Long-term simulation of lead concentrations in agricultural soils in relation to human adverse health effects. *Archives of Toxicology* doi:10.1007/s00204-020-02762-x
- Segerson K (2013). Voluntary Approaches to Environmental Protection and Resource Management. *Annual Review of Resource Economics* 5:161-180 doi:10.1146/annurev-resource-091912-151945
- Seismonaut (2019). Evaluering af formidling og efteruddannelse inden for jagt og vildtforvaltning. <https://mst.dk/media/189149/evaluering-af-formidling-og-efteruddannelse-inden-for-jagt-og-vildtforvaltning-rapport.pdf>
- Sevillano-Caño J, Cámara-Martos F, Zamora-Díaz R, Sevillano-Morales JS (2021). Lead concentration in game migratory upland bird meat: Influence of ammunition impacts and health risk assessment. *Food Control* 124:107835 <https://doi.org/10.1016/j.foodcont.2020.107835>
- Simpson SG (1989). Compliance by Waterfowl Hunters with Nontoxic Shot Regulations in Central South Dakota. *Wildlife Society Bulletin* (1973-2006) 17:245-248 [www.jstor.org/stable/3782378](http://www.jstor.org/stable/3782378)
- Sogbohossou EA, Bauer H, Loveridge A, Funston PJ, De Snoo GR, Sinsin B, De Iongh HH (2014). Social Structure of Lions (*Panthera leo*) Is Affected by Management in Pendjari Biosphere Reserve, Benin. *PLOS ONE* 9:e84674 doi:10.1371/journal.pone.0084674
- Sonne C, Alstrup AKO, Ok YS, Dietz R, Kanstrup N (2019 (**Paper 25**)). Time to ban lead hunting ammunition. *Science* 366:961 doi:10.1126/science.aaz8150
- Spicher V (2008). Erfahrungen mit bleifreier Kugelmunition in der jagdlichen Praxis. In: Krone O (Editor) *Bleivergiftungen bei Seeadlern: Ursachen und Lösungsansätze – Anforderungen an bleifreie Büchsenengeschosse. Zusammenfassung der naturwissenschaftlichen Vorträge des Fachgesprächs vom 05. Mai 2008 im Henry-Ford-Bau der Freien Universität Berlin*, 95 p.

Stevenson AL, Scheuhammer AM, Chan HM (2005). Effects of Nontoxic Shot Regulations on Lead Accumulation in Ducks and American Woodcock in Canada. *Archives of Environmental Contamination and Toxicology* 48:405-413 doi:10.1007/s00244-004-0044-x

Stokke S, Arnemo JM, Brainerd S (2019). Unleaded hunting: Are copper bullets and lead-based bullets equally effective for killing big game? *Ambio* 48:1044-1055 doi:10.1007/s13280-019-01171-4

Stokke S, Botten L, Arnemo JM (2010). Lead fragments from hunting bullets in game meat - a health risk for consumers? *Norsk Veterinærtidsskrift* 122:407-410

Stokke S, Brainerd S, Arnemo JM (2017). Metal deposition of copper and lead bullets in moose harvested in Fennoscandia. *Wildlife Society Bulletin* 41:98-106 doi:10.1002/wsb.731

Strand J, Tairova Z, Danielsen J, Hansen JW, Magnusson K, Naustvoll L-J, Sørensen TK (2015). Marine Litter in Nordic Waters. . Nordic Council of Ministers <http://norden.diva-portal.org/smash/get/diva2:824655/FULLTEXT01.pdf>

Strandgaard H (1993). Untersuchungen zur tötenden Wirkung von Eisen- und Bleischroten. *Zeitschrift für Jagdwissenschaft* 39:34-45 doi:10.1007/bf02310215

Stretesky PB, Lynch MJ (2004). The relationship between lead and crime. *Journal of health and social behavior* 45:214-229 doi:10.1177/002214650404500207

Stroud D (2015). The regulation of lead in the environment: a brief review. Oxford Lead Symposium: Lead Ammunition: understanding and minimising the risks to human and environmental health [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_stroud.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_stroud.pdf)

Sullivan T, Gottel N, Basta N, Jardine P, Schadt C (2012). Firing range soils yield a diverse array of fungal isolates capable of organic acid production and Pb mineral solubilization. *Applied and Environmental Microbiology* 78(17), 6078-6086

Taggart MA, Shore RF, Pain DJ, Peniche G, Martinez-Haro M, Mateo R, Homann J, Raab A, Feldmann J, Lawlor AJ, Potter ED, Walker LA, Braidwood DW, French AS, Parry-Jones J, Swift JA, Green RE (2020). Concentration and origin of lead (Pb) in liver and bone of Eurasian buzzards (*Buteo buteo*) in the United Kingdom. *Environmental Pollution* 267:115629 <https://doi.org/10.1016/j.envpol.2020.115629>

Tammone A, Caselli AE, Condorí WE, Fernandez V, Estein SM, Vanstreels RET, Sosa C, Delaloye A, Uhart MM (2021). Lead exposure in consumers of culled invasive alien mammals in El Palmar National Park, Argentina. *Environmental Science and Pollution Research* doi:10.1007/s11356-021-13654-7

Thomas V (2018). Chemical compositional standards for non-lead hunting ammunition and fishing weights. *Ambio* 48 doi:10.1007/s13280-018-1124-x

Thomas VG (2013). Lead-Free Hunting Rifle Ammunition: Product Availability, Price, Effectiveness, and Role in Global Wildlife Conservation. *Ambio* 42:737-745 doi:10.1007/s13280-012-0361-7

Thomas VG (2015). Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In: Delahay, RJ & Spray, CJ (Eds) (2015) Proceedings of the Oxford Lead Symposium Lead Ammunition: understanding and minimising the risks to human and environmental health Edward Grey Institute, The University of Oxford, UK [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_thomas.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_thomas.pdf)

Thomas VG, Friend M, Kanstrup N, Mateo R, Pain DJ (2009). Nontoxic Ammunition: Criteria of Nontoxicity and their Application. Paper presented at the CIC Sustainable Hunting Ammunition. [http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC\\_Sustainable\\_Hunting\\_Ammunition\\_Workshop\\_Report\\_low\\_res.pdf](http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC_Sustainable_Hunting_Ammunition_Workshop_Report_low_res.pdf)

Thomas VG, Gremse C, Kanstrup N (2015 (**Paper 9**)). Key questions and responses regarding the transition to use of lead-free ammunition. Oxford Lead Symposium: Lead Ammunition: understanding and minimising the risks to human and environmental health [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_thomas\\_kanstrup\\_gremse.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_thomas_kanstrup_gremse.pdf)

Thomas VG, Gremse C, Kanstrup N (2016 (**Paper 19**)). Non-lead rifle hunting ammunition: issues of availability and performance in Europe. *European Journal of Wildlife Research* 62:633-641 doi:10.1007/s10344-016-1044-7

Thomas VG, Guitart R (2005). Priority contribution. Role of international conventions in promoting avian conservation through reduced lead toxicosis: progression towards a non-toxic agenda. *Bird Conservation International* 15:147-160 doi:10.1017/S0959270905000110

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

Thomas VG, Kanstrup N, Fox AD (2019 (**Paper 11**)). The transition to non-lead sporting ammunition and fishing weights: Review of progress and barriers to implementation. *Ambio* 48:925-934 doi:10.1007/s13280-018-1132-x

Thomas VG, Pain DJ, Kanstrup N (2021 (**Paper 26**)). Restrictions on the use of lead ammunition in the European Union: Issues of enforcement and compliance. *Environmental Policy and Law*. Submitted after revision.

Thomas VG, Pain DJ, Kanstrup N, Green RE (2020 (**Paper 17**)). Setting maximum levels for lead in game meat in EC regulations: An adjunct to replacement of lead ammunition. *Ambio* doi:10.1007/s13280-020-01336-6

Thompson LJ (2018). Chapter 29 - Lead. *Veterinary Toxicology* (Third Edition):439-443 <https://doi.org/10.1016/B978-0-12-811410-0.00029-5>

Treu G, Drost W, Stock F (2020). An evaluation of the proposal to regulate lead in hunting ammunition through the European Union's REACH regulation. *Environmental Sciences Europe* 32:68 doi:10.1186/s12302-020-00345-2

Trinogga A, Fritsch G, Hofer H, Krone O (2013). Are lead-free hunting rifle bullets as effective at killing wildlife as conventional lead bullets? A comparison based on wound size and morphology. *443:226-232* doi:10.1016/j.scitotenv.2012.10.084

Trouwborst A (2006). *Precautionary Rights and Duties of States*. Martinus Nijhoff Publishers 2006. <https://ssrn.com/abstract=2556393>

Tscherkess, A. Experimentelle Beiträge zur Pathologie des Gefäßsystems bei Bleivergiftung. *Archiv f. experiment. Pathol. u. Pharmakol* 108, 220–229 (1925). <https://doi.org/10.1007/BF01862856>

Tukker A, Buist H, van Oers L, van der Voet E (2006). Risks to health and environment of the use of lead in products in the EU. *Resources, Conservation and Recycling* 49:89-109 <https://doi.org/10.1016/j.resconrec.2006.03.005>

TWS (2008). Sources and Implications of Lead Ammunition and Fishing Tackle on Natural Resources. Technical Review 08-01 <https://wild-life.org/wp-content/uploads/2014/05/Lead08-1.pdf>

Uhart M, Ferreyra HDV, Romano M, Muchiutti A, Alzuagaray S, Santiago M, Caselli A (2019). Lead pollution from hunting ammunition in Argentina and current state of lead shot replacement efforts. *Ambio* 48:1015-1022 doi:10.1007/s13280-019-01178-x

Vajas P, Calenge C, Richard E, Fattebert J, Rousset C, Saïd S, Baubet E (2020). Many, large and early: Hunting pressure on wild boar relates to simple metrics of hunting effort. *Science of The Total Environment* 698:134251 <https://doi.org/10.1016/j.scitotenv.2019.134251>

Vallverdú-Coll N, López-Antia A, Martínez-Haro M, Ortiz-Santaliestra ME, Mateo R (2015). Altered immune response in mallard ducklings exposed to lead through maternal transfer in the wild. *Environmental Pollution* 205:350-356 <https://doi.org/10.1016/j.envpol.2015.06.014>

Vallverdú-Coll N, Mateo R, Mougeot F, Ortiz-Santaliestra ME (2019). Immunotoxic effects of lead on birds. *Science of The Total Environment* 689:505-515 <https://doi.org/10.1016/j.scitotenv.2019.06.251>

Vallverdú Coll N (2012). Compliance with the ban of lead ammunition in a Mediterranean wetland, the Ebro delta MSc:41 <http://digital.csic.es/bitstream/10261/146711/1/TFMVALLVERDU.pdf>

van den Heever L, Smit-Robinson H, Naidoo V, McKechnie AE (2019). Blood and bone lead levels in South Africa's Gyps vultures: Risk to nest-bound chicks and comparison with other avian taxa. *Science of The Total Environment* 669:471-480 <https://doi.org/10.1016/j.scitotenv.2019.03.123>

Veit HP, Kendall RJ, Scanlon PF (1983). The effect of lead shot ingestion on the testes of adult ringed turtle doves (*Streptopelia risoria*). (Article). *Avian dis-*

eases, Volume 27, Issue 2, 1983 Apr-Jun, Pages 442-452 <https://www.scopus.com/record/display.uri?eid=2-s2.0-0020740967&origin=inward&txGid=7005523c768e44cb985200f61ccf6a2f>

Vyas NB, Spann JW, Heinz GH, Beyer WN, Jaquette JA, Mengelkoch JM (2000). Lead poisoning of passerines at a trap and skeet range. *Environmental Pollution* 107:159-166 [https://doi.org/10.1016/S0269-7491\(99\)00112-8](https://doi.org/10.1016/S0269-7491(99)00112-8)

W.S. (1919). Wetmore on Lead Poisoning in Waterfowl. *The Auk* 36:605 <https://doi.org/10.2307/4073410>

Wani AL, Ara A, Usmani JA (2015). Lead toxicity: a review. *Interdiscip Toxicol* 8:55-64 doi:10.1515/intox-2015-0009

Watson RT, Fuller M, Pokras M, Hunt WG (2009). Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, Idaho, USA doi:DOI 10.4080/ilsa.2009.0102

WCED (1987). Our Common Future. Oxford University Press <https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf>

Wetmore A (1919). Lead poisoning in waterfowl. United States Department of Agriculture Bulletin 793:1-12

Whitehead PJ, Tschirner K (1991). Lead shot ingestion and lead poisoning of magpie geese *Anseranas semipalmata* foraging in a Northern Australian hunting reserve. *Biological Conservation* 58:99-118. [https://doi.org/10.1016/0006-3207\(91\)90047-D](https://doi.org/10.1016/0006-3207(91)90047-D)

Widemo F (2021). Shooting habits and habitats – effects of education and legislation on the phasing out of lead shot. *Environmental Science & Policy* 118:56-62 <https://doi.org/10.1016/j.envsci.2021.01.010>

Willebrand T, Hörnell M (2001). Understanding the effects of harvesting willow ptarmigan (*Lagopus lagopus*) in Sweden. *Wildlife Biology* 7:205-212, 208 <https://doi.org/10.2981/wlb.2001.025>

Wilson WA, Harper RG, Alexander G, Perara M, Fraker M (2020). Lead Contamination in Ground Venison from Shotgun-Harvested White-Tailed Deer (*Odocoileus virginianus*) in Illinois. *Bulletin of Environmental Contamination and Toxicology* doi:10.1007/s00128-020-02967-x

Winneke G, Lilienthal H, Kramer U (1996). The neurobehavioural toxicology and teratology of lead. *Archives of toxicology Supplement = Archiv für Toxikologie Supplement* 18:57-70 doi:10.1007/978-3-642-61105-6\_7

Zinsstag J, Schelling E, Waltner-Toews D, Tanner M (2011). From "one medicine" to "one health" and systemic approaches to health and well-being. *Preventive veterinary medicine* 101:148-156 doi:10.1016/j.prevetmed.2010.07.003

Aasebø U, Kjær KG (2009). Lead poisoning as possible cause of deaths at the Swedish House at Kapp Thordsen, Spitsbergen, winter 1872-3. *BMJ* 339:b5038 doi:10.1136/bmj.b5038

# Annex 1. Dissertation papers

## References

This annex contains the 26 papers referred to as **Paper x** in the text. Except **Paper 26** (which is resubmitted after revision), all papers are published and available at the internet in many cases as open access articles. References are provided with doi and/or URL. The papers are also referenced in the dissertation reference list.

## Rights

For papers not published with open access, rights to use the papers connected to this dissertation were provided by the relevant journals. Licenses to this particular use are inserted for each paper.

## Authors' contributions

In cases where papers are the result of a group work, a statement from co-authors on the dissertation author's contribution to the work has been inserted before each article, cf. section 5 (1) of the Executive Order on Doctoral Degrees<sup>48</sup>.

<sup>48</sup> <https://www.retsinformation.dk/eli/lta/1996/750>

### List of dissertation papers.

Nr	Reference	Titel
1	Kanstrup and Thomas 2020	Kanstrup N, Thomas VG (2020). Transitioning to lead-free ammunition use in hunting: socio-economic and regulatory considerations for the European Union and other jurisdictions Environmental Sciences Europe 32:91 doi:10.1186/s12302-020-00368-9
2	Mateo and Kanstrup 2019	Mateo R, Kanstrup N (2019). Regulations on lead ammunition adopted in Europe and evidence of compliance. Ambio 48:989-998 doi:10.1007/s13280-019-01170-5
3	Pain et al. 2021	Pain DJ, Dickie I, Green RE, Kanstrup N, Cromie R. (2019). Wildlife, human and environmental costs of using lead ammunition: an economic review and analysis. Ambio 48(9): 969-988. Special Issue: LEAD USE IN HUNTING. Online 16 March 2019. DOI: 10.1007/s13280-019-01157-2
4	Kanstrup et al. 2018	Kanstrup N, Swift J, Stroud DA, Lewis M (2018). Hunting with lead ammunition is not sustainable: European perspectives Ambio 47:846-857 doi:10.1007/s13280-018-1042-y
5	Kanstrup 2006	Kanstrup N (2006). Sustainable harvest of waterbirds: a global review. <i>Waterbirds around the world</i> . Eds. G.C. Boere, C.A. Galbraith & D.A. Stroud. The Stationery Office, Edinburgh, UK. pp. 98-106.
6	Kanstrup et al. 2021	Kanstrup N, Hansen HP, Balsby TJS, Møllerup KA (2021). Non-lead rifle ammunition: Danish hunters' attitudes. Environmental Sciences Europe 33, 41. <a href="https://doi.org/10.1186/s12302-021-00485-z">https://doi.org/10.1186/s12302-021-00485-z</a>
7	Kanstrup & Thomas 2019	Kanstrup N, Thomas VG (2019). Availability and prices of non-lead gunshot cartridges in the European retail market Ambio 48:1039-1043 doi:10.1007/s13280-019-01151-8
8	Kanstrup et al 2016	Kanstrup N, Thomas VG, Krone O, Gremse C (2016). The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations Ambio 45:621-628 doi:10.1007/s13280-016-0780-y
9	Thomas et al. 2015	Thomas VG, Gremse C, Kanstrup N (2015). Key questions and responses regarding the transition to use of lead-free ammunition. In: Delahay RJ, Spray CJ (eds) Oxford Lead Symposium: Lead Ammunition: understanding and minimising the risks to human and environmental health, 2015. Edward Grey Institute.
10	Kanstrup 2019	Kanstrup N (2018). Lessons learned from 33 years of lead shot regulation in Denmark Ambio 48:999,1008 doi:10.1007/s13280-018-1125-9
11	Thomas et al. 2019	Thomas VG, Kanstrup N, Fox AD (2019). The transition to non-lead sporting ammunition and fishing weights: Review of progress and barriers to implementation Ambio 48:925-934 doi:10.1007/s13280-018-1132-x
12	Kanstrup 2012	Kanstrup N (2012). Lead in game birds in Denmark: Levels and sources. Danish Academy of Hunting. Article 2012-02-1
13	Kanstrup et al. 2016	Kanstrup N, Balsby TJS, Thomas VG (2016). Efficacy of non-lead rifle ammunition for hunting in Denmark European Journal of Wildlife Research 62:333-340 doi:10.1007/s10344-016-1006-0
14	Kanstrup et al 2020	Kanstrup N, Fox AD, Balsby TJS (2020). Toxic lead gunshot persists accessible to waterbirds after a 33-year ban on their use Science of The Total Environment:136876 <a href="https://doi.org/10.1016/j.scitotenv.2020.136876">https://doi.org/10.1016/j.scitotenv.2020.136876</a>
15	Kanstrup and Balsby 2019	Kanstrup N, Balsby TJS (2019). Danish pheasant and mallard hunters comply with the lead shot ban. Ambio 48, 1009-1014 (2019). <a href="https://doi.org/10.1007/s13280-019-01152-7">https://doi.org/10.1007/s13280-019-01152-7</a>
16	Kanstrup and Balsby 2019	Kanstrup N, Balsby TJS (2019). Ingested shot in mallards ( <i>Anas platyrhynchos</i> ) after the regulation of lead shot for hunting in Denmark European Journal of Wildlife Research 65 doi:10.1007/s10344-019-1278-2
17	Thomas et al. 2020	Thomas VG, Pain DJ, Kanstrup N, Green RE (2020). Setting maximum levels for lead in game meat in EC regulations: an adjunct to replacement of lead ammunition Ambio <a href="https://doi.org/10.1007/s13280-020-01336-6">https://doi.org/10.1007/s13280-020-01336-6</a>

18	Kanstrup & Balsby 2018	Kanstrup N, Balsby TJS (2018). Plastic litter from shotgun ammunition on Danish coastlines - Amounts and provenance <i>Environmental Pollution</i> 237:601-610 doi:10.1016/j.envpol.2018.02.087
19	Thomas et al. 2016	Thomas VG, Gremse C, Kanstrup N (2016.) Non-lead rifle hunting ammunition: issues of availability and performance in Europe <i>European Journal of Wildlife Research</i> 62:633-641 doi:10.1007/s10344-016-1044-7
20	Kanstrup 2006	Kanstrup N (2006). Non-toxic shot - Danish experiences. <i>Waterbirds around the world</i> . Eds. G.C. Boere, C.A. Galbraith & D.A. Stroud. The Stationery Office, Edinburgh, UK. P. 861.
21	Kanstrup 2015	Kanstrup N (2015). Practical and social barriers to switching from lead to non-toxic gunshot – a perspective from the EU. In: Delahay R, Spray C (eds) <i>Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health</i> . Edward Grey Institute, The University of Oxford. pp 98-103. 2015. <a href="http://oxfordleadsymposium">http://oxfordleadsymposium</a> .
22	Kanstrup et al. 2019	Kanstrup N, Chriel M, Dietz R, Søndergaard J, Balsby TJS, Sonne C (2019). Lead and Other Trace Elements in Danish Birds of Prey <i>Archives of Environmental Contamination and Toxicology</i> 77:359-367 doi:10.1007/s00244-019-00646-5
23	Arnemo et al 2019	Arnemo JM, Cromie R, Fox AD, Kanstrup N, Mateo R, Pain DJ, Thomas VG (2019). Transition to lead-free ammunition benefits all <i>Ambio</i> 48:1097-1098 doi:10.1007/s13280-019-01221-x
24	Kanstrup et al. 2019	Kanstrup N, Thomas VG, Fox AD (2019). Foreword <i>Ambio</i> 48:923-924 doi:10.1007/s13280-019-01220-y
25	Sonne et al. 2019	Sonne C, Alstrup AKO, Ok YS, Dietz R, Kanstrup N (2019). Time to ban lead hunting ammunition <i>Science</i> 366:961 doi:10.1126/science.aaz8150
26	Thomas et at. 2021	Thomas VG, Pain DJ, Kanstrup N (2021). Restrictions on the use of lead ammunition in the European Union: Issues of enforcement and compliance <i>Environmental Policy and Law</i> . Resubmitted after revision.

# PAPER 1

## TITLE:

Kanstrup N, Thomas VG (2020). Transitioning to lead-free ammunition use in hunting: socio-economic and regulatory considerations for the European Union and other jurisdictions Environmental Sciences Europe 32:91 doi:10.1186/s12302-020-00368-9

**RIGHTS:** Open access

## AUTHORS' CONTRIBUTIONS

Described in the paper and approved by both authors.

Confirmed, March 2021

A handwritten signature in black ink, appearing to read 'Niels Kanstrup', with a stylized, flowing script.

Niels Kanstrup

POLICY BRIEF

Open Access



# Transitioning to lead-free ammunition use in hunting: socio-economic and regulatory considerations for the European Union and other jurisdictions

Niels Kanstrup<sup>1\*</sup>  and Vernon G. Thomas<sup>2</sup>

## Abstract

**Background:** Hunting throughout the European Union (EU) has left an accumulating legacy of spent lead ammunition that has deleterious toxic effects upon the environment, wildlife, and humans who consume hunted game meat. Non-toxic lead substitutes for both rifle and shotgun ammunition have been developed and are required in some EU jurisdictions. Within the EU, at least 28 companies make or distribute non-lead shotgun ammunition, and a further 14 companies distribute non-lead rifle ammunition. However, a broad transition to the use of these products has been resisted by the hunting and ammunition-making communities.

**Results and conclusions:** It is in the self-interest of these communities to recognize the consequences of externalizing the effects of spent lead ammunition to society, and to make hunting more sustainable and socially acceptable. The paper endorses the ongoing process under the European Commission (EC) to introduce wide and fundamental restrictions on the use, trade and possession of lead ammunition for all types of hunting within 3 years, and within 5 years for clay target shooting. This would align EC regulations on lead from ammunition with lead from other anthropogenic sources, and EC regulations that protect the natural environment, especially the conservation of wild birds. Simultaneous EC regulation of lead in marketed game meats would provide extra health protection and assure a safe source of game meat products for consumers.

**Keywords:** European Commission, Hunter resistance, Non-lead substitutes, Product demands, Pollution externalization, Game food standards

## Introduction

Hunters comprise a small minority (less than 2%) of the European society, but have for centuries externalized the problems associated with discharged ammunition to the environment and its inhabitants [1]. The cumulative body of evidence that spent lead ammunition from recreational hunting poses a toxic risk to waterbirds, non-wetland/upland birds, scavengers, and humans who eat

hunted game meat is incontrovertible [2, 3] and demonstrates the unsustainable use of such ammunition [1, 2, 4–6]. Discharge of spent lead hunting ammunition now constitutes the largest unregulated release of lead to environments [7]. Despite the long-term recognition of this toxic risk to wildlife in particular, and the availability of lead-free non-toxic substitutes for shotgun and rifle ammunition, a regulated transition to the use of these substitutes is slow, and until now almost exclusively for wetland hunting [8].

There is no consistent pattern to the phase-out of lead ammunition use in the European Union and beyond, and a wide range of regulative actions exists. While Denmark

\*Correspondence: nk@bios.au.dk

<sup>1</sup> Department of Bioscience, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark

Full list of author information is available at the end of the article

and The Netherlands have made most progress in restricting lead shotgun ammunition use, Poland, Ireland and Greece have enacted no restriction. Only Germany requires the use of lead-free rifle ammunition in some jurisdictions [8]. The decision of the UK Waitrose supermarket chain to sell only game meat killed with lead-free ammunition [9] indicates a preparedness of the marketplace to intervene on the issue of lead ammunition use, mainly out of concern about risks to human health from ingested lead and liability.

Given the enormous body of scientific evidence of the toxic effects of lead on humans and wildlife [1], it is paradoxical that lead ammunition use in hunting has eluded much regulation. This is due to lead effects on humans and wildlife being regulated via human health agencies and wildlife agencies, respectively, and the disconnect between them. Not even the United Nations Environment Program has prioritized this recognized issue in its current lead reduction initiatives [10–12]. However, lead used for hunting is now known to have major health implications for consumers of game [13, 14] and is regarded to be a One Health issue [1].

The European Green Deal [15] defines a zero pollution ambition for a toxic-free environment to protect Europe's citizens and ecosystems, and sets ambitions for the EU to better monitor, report, prevent, and remedy pollution from air, water, soil, and consumer products. Accordingly, the European Chemicals Agency (ECHA), mandated by the European Commission (EC), has proposed a restriction of lead shot over wetlands to be agreed in 2020, and currently prepares a restriction on lead ammunition in general (including lead shot in terrestrial habitats), with the earliest adoption if agreed by member states by end of 2022 [16, 17]. These actions by the European Commission, based on ECHA [16], may result in wide and fundamental restrictions on the use, trade and possession of lead ammunition, especially if maximum levels of lead in game meat are introduced and harmonized with those for domesticated animal meat products, as advised by Thomas et al. [18].

Any new EC-level regulation must be based on thorough analysis of the best pathway towards a complete transition to lead-free hunting ammunition. This paper rests on the premise that a regulated transition to the use of lead-free ammunition is warranted and inevitable, especially given existing EC restrictions on other anthropogenic sources of lead. The paper provides a partial framework for the regulation of lead ammunition in the EU from a socio-economic and legal perspective for consideration by EC policy makers and regulators. These same considerations are then applied to other jurisdictions in which reductions in lead ammunition use are possible.

### The hunting and shooting communities

In the EU and other Western regions, hunting over the past half century has developed almost exclusively as a leisure activity performed by a small minority of people. European hunters comprise c. 1.8% of the population, ranging from less than 0.2% in Belgium and the Netherlands to almost 6% in Finland and Cyprus: Ireland has the highest level (8.3%) [19]. However, hunters' numbers are declining in most European countries [20]. Many hunters perceive and defend hunting as an established tradition, and hunters' self-perception is ingrained in this tradition. This tradition is conservative, resistant to change, and not proactive [5, 21, 22]. This makes hunting vulnerable when the surrounding community values are changing rapidly in directions that make hunting more difficult to integrate and sustain politically.

The practice of hunting in Europe has not been subjected to much environmental regulation in terms of setting limits for release of deleterious chemicals. However, there are some specific areas where it is in the hunters' clear self-interest to show a greater adaptability to changing social attitudes, as in the issue of lead from hunting ammunition. The original purpose of hunting was to provide food for the community, and this remains intuitive for many Europeans, including people with no immediate connection to hunting. In some consumer groups, the trend is towards changing traditionally farmed foods with organic products, or wild-harvested products. This is motivated by ethical concerns for animal welfare in traditional agriculture and low-fat quality foods. The issue of food and consumer health affords hunters the opportunity to act constructively with society. This opportunity to supply Europeans with uncontaminated food is in the hunters' unconditional self-interest and a powerful argument for maintaining hunting.

Although the public supply of game meat appears limited in quantity, the annual tonnage of marketed game meat is significant. Recently, 10 European–Scandinavian–Eurasian nations reported an annual import of game meat exceeding 270,000 tonnes [23], despite several nations that have large game markets, such as the UK, France, Austria, and Hungary not being included in the data. Thomas et al. [18] estimated that European hunters shoot over 5.3 million large game mammals and over 80 million birds that support a game meat market supplying 5 million citizens. Hence, the hunters' opportunity to promote their image as suppliers of a valuable food is clear. However, it is crucial that hunters as primary producers<sup>1</sup> and the subsequent processing chain fully

<sup>1</sup> "REGULATION (EC) No. 853/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2004 on the hygiene of foodstuffs" link <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32004R0852>, which declares hunters as these primary producers and further outlines their collective responsibilities towards food safety of their products.

guarantee the quality and health safety of such food. This warrants a lead-free and otherwise safe content of game meat on the part of hunters and food processors in light of consumers' increasing interest in health-safe foods. Lead is of major concern because its presence in game meat can be traced back directly to contamination from lead ammunition, and verified using isotope analysis [24].

That lead causes adverse impacts on human health has been known for millennia. Concerns about lead from hunting ammunition negatively impacting wildlife, ecosystems and human health has become more evident during the last century [2]. It is paradoxical that hunters, their national and international organizations, and responsible governments have not played a more pronounced and proactive role to require the use of existing, non-toxic, and effective alternatives. Although some governments partly regulated some lead ammunition use, there is only poor documentation of the enforcement and compliance with such regulations. The general picture is poor progress, especially since several European countries have taken no initiative to limit this source of contamination [8].

The intransigence of the hunting communities has inhibited progress at the socio-political level [25] despite awareness of the consequences of lead ammunition use [26]. However, a large and increasing body of literature has emphasized the multiple benefits that would accrue from a transition [2]. Nevertheless, there remains a need to persistently document and communicate such benefits to the hunters and their communities to enlighten the apparent related self-interest. Sparing millions of wild animals from death from lead toxicosis is in the self-interest of a community whose activity is based on the sustainable harvest of wildlife populations [25]. Preventing suffering of wild animals from sub-lethal lead intoxication is also in the direct interest of hunters, not least by complying with legal provisions and the public expectation of hunting to not cause unnecessary suffering.

Continued use of lead ammunition constitutes an irreversible contamination of natural habitats. Such type of environmental damage is addressed potentially by EU Directive 2004/35/(April 2004) on environmental liability with regard to the prevention and remedying of environmental damage, which is based on the "polluter-pays principle" (Article 1). Should hunters be identified as "polluters", they risk the costs of remediation. If not, such externalized costs fall on society [5], thus risking further loss of favourable public perception of hunting. Not least, the elimination of risks of lead exposure among human consumers of game meat could promote the interests of hunters in sustaining their role of supplying society with a unique food and documented to be pivotal in sustaining the public perception of hunting [27]. This single

argument manifests the hunters' undisputable self-interest in substituting toxic with non-toxic ammunition.

Non-lead ammunition is regarded by many hunters with scepticism due to many years of biased information campaigns led mostly by the lead manufacturing industry [1]. For example, the Association of European Manufacturers of Sporting Ammunition (AFEMS) and the World Forum on Shooting Activities (WFSA) stated that "...metallic lead in ammunition has no significant impact on human health and the environment as compared to other forms of lead. Lead fragments in game meat, if ingested, cannot be directly absorbed by the human body because they are in metallic form"<sup>2</sup>—a statement that made AFEMS flag the headline "Lead makes you beautiful and HEALTHY"<sup>3</sup> Competing hunters' organizations have also circulated biased information on non-lead ammunition performance and price [5, 22]. All these claims have been studied and refuted [28]. Thus, non-lead shot cartridges and rifle ammunition are available for purchase in most European countries [29–31], but the product range of lead-free shotgun ammunition in countries with partial regulations is restricted compared to lead shot brands [31]. These studies concluded that availability of non-lead ammunition is not limited by production, but by demand at the national, regional, and local levels. Some alternative types, including bismuth and tungsten based, gunshot are significantly more expensive than lead shot cartridges. However, in terms of the overall budget of hunters, the cost of ammunition plays a minor role [29]. Furthermore, steel shot—the most common alternative shot—could become significantly cheaper than traditional lead shot when an end to present manufacturing patents will lower production costs substantially. This favours the interest of hunters by lowering potential costs of a transition and indicates that some non-lead ammunition in the long term will become significantly cheaper than traditional lead types.

In order to promote change, hunters should regard the transition to lead-free ammunition as advantageous, not disadvantageous to their self-interest. Once the transition is established, the greater demand for non-lead ammunition will stimulate development and production, thus increasing product diversity and availability. This process will be self-reinforcing, and an economy of scale will further moderate prices. The main obstacle to realization of this socio-economic mechanism is the unwillingness of governments to act on regulation, and apparent lack of

<sup>2</sup> AFEMS/WFSA 2015. Symposium, "The sustainable use of lead ammunition in hunting and sports shooting: Facts and emotions" press release. [http://www.leadsymposium.eu/en/the\\_symposium/press\\_release.aspx](http://www.leadsymposium.eu/en/the_symposium/press_release.aspx).

<sup>3</sup> <https://www.euractiv.com/section/health-consumers/opinion/lead-makes-you-beautiful-and-healthy/>.

awareness in the hunters' communities. A Danish questionnaire 2020 survey (Kanstrup, unpublished) revealed that 82% of Danish rifle hunters ( $n=2679$ ) had "no" or "little" concern about the risks connected to lead in rifle ammunition, whereas about half had "some" or "comprehensive" knowledge of the non-lead rifle ammunition that is widely available in Denmark [32]. There is a need via education and extension to emphasize advantages to hunters from reduced environmental pollution and reduced lead exposure to wildlife and humans through a transition from lead to non-lead rifle ammunition.

### The ammunition industry and trade

The industries supplying European hunters with ammunition comprise a national and international complex. Few, if any, produce all ammunition components themselves. Most assemble ammunition from components purchased from suppliers specialized in production of single components, i.e. primed case/shells, propellants, shot, bullets, and cartridge wads. Most manufacturers make a wide selection of ammunition, including types of ammunition for both hunting and sport shooting and competition. Additionally, many factories supply ammunition for the police, security services and/or the military. The share of ammunition for hunting comprises for most manufacturers a minor part of their production, especially compared with ammunition for clay target shooting.

Many European countries with well-established hunting have no national ammunition manufacture and rely on specialized export/import businesses to supply retail markets. Agencies handling the transfer of ammunition from production to consumption are mostly organized in groups to stimulate trade, and thus achieve monopoly and discount advantages on certain brands. However, despite such systems, ammunition may be traded in parallel routes, and in some cases, directly from the manufacturer to the consumer. The whole system of production, handling, transport, trade and sale of ammunition is highly complex and primarily commercial, thus rather steered by strategies to optimize profit than to sustain hunting and nature conservation. Only a few ammunition manufacturers have recognized their clear self-interest in sustaining a long-term business strategy by supporting the sustainability of hunting and shooting through supplying the transition to non-lead ammunition with products that meet toxicological criteria.

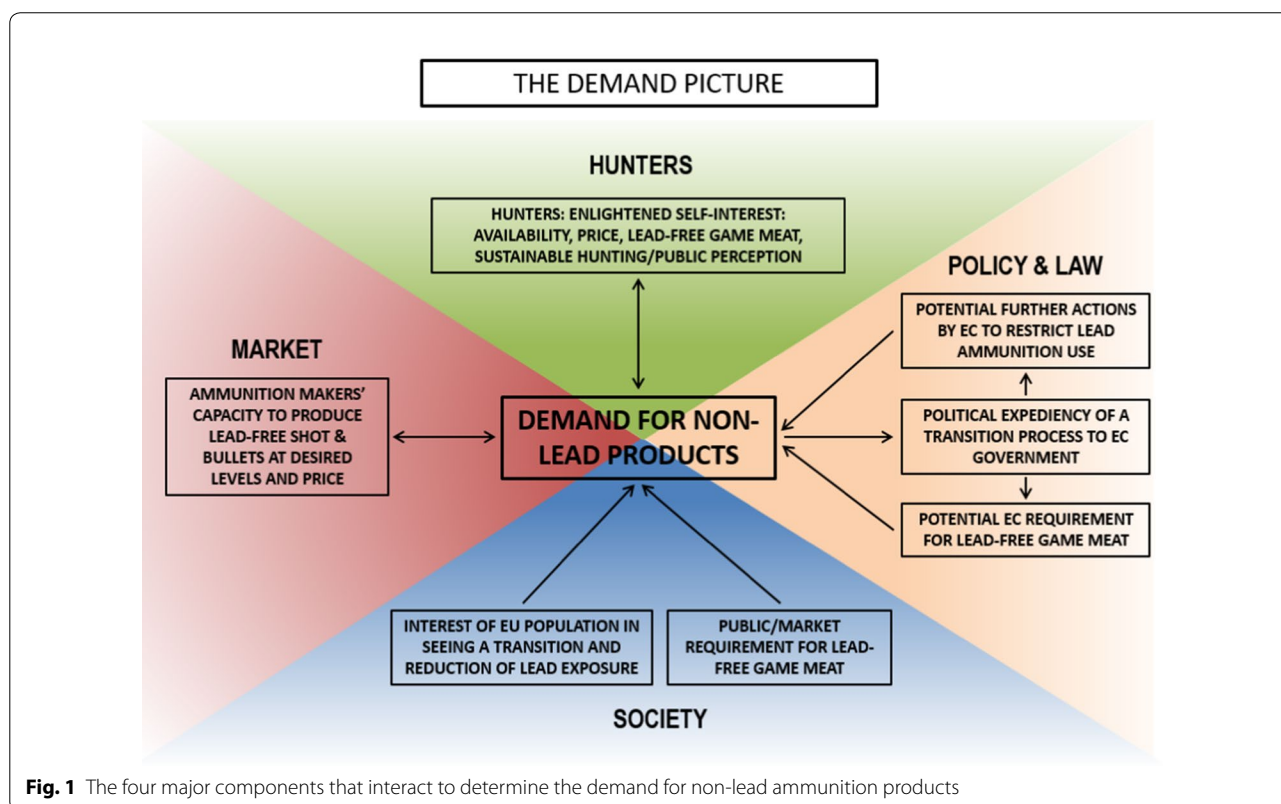
North American and European national and regional regulative demands for the use of non-lead shotgun and rifle ammunition in hunting from the mid-1980s to the present [33], have forced industry to develop substitutes for lead-based ammunition. Manufacturers have been successful in this quest, and there is now a range of non-lead types of shotgun and rifle ammunition suited for all

categories of European hunting and target shooting [29, 31].<sup>4</sup> It is important to note that any species of game that may be hunted with lead-based shotgun or rifle ammunition can be hunted successfully with non-lead equivalents. The availability of these non-lead products is crucial for a successful transition. A wide "product availability" exists, meaning that the ammunition industry has already created effective lead ammunition substitutes that are effective and cost-competitive [29, 31, 34]. However, industry produces only according to assured market demands (Fig. 1). Thus "market availability", i.e. the diversity and volume of products offered at the consumer/retail level, may be limited, as concluded by Kanstrup and Thomas [31] who found that stocks of non-lead ammunition held in local European retail shops may be limited in variety, quantity, specification, and brand.

From the industry's perspective, the demand issue is central to a successful transition. It stimulates competition among producers, product development, and competitive pricing. Large-scale demands for a given product facilitate a producer's changing the assembly process from one cartridge gauge/calibre to another; including the quality testing that is required. A partial requirement (only certain areas/taxa), and voluntary adoption of non-lead ammunition by hunters, offer no assurance of product demand [35], an assurance that only regulation and enforcement can provide (Fig. 1). In spite of the prevailing European "patchwork" regulation of lead ammunition, 28 companies already market non-lead shotgun ammunition in Europe [31], and 14 companies market non-lead rifle ammunition in a wide range of calibres and bullet types [30].

The manufacture of steel shot has occurred mainly in China and is more expensive to produce than traditional lead shot. However, a patented US method for manufacturing small steel gunshot (especially 2–3 mm diameter) by atomization provides a cheaper product. This patent expired in 2019 thus enabling other manufacturers to make steel shot cartridges at lower costs, especially those designed for clay target shooting. Acting on this opportunity would demonstrate the European ammunition manufacturers' innovation and sincere interest in providing hunters and shooters with non-toxic products.

<sup>4</sup> Non-lead rifle ammunition is produced using the same brass cartridge cases, primers, and propellants as those used for lead-based ammunition. Only the bullets are made from non-lead material, usually pure copper, or a 95% copper–5% zinc alloy. Steel shot shotgun cartridges require different propellants, and different shot wads than their lead shot equivalents. However, non-lead shotgun cartridges using shot made from bismuth–tin shot or tungsten plastic shot are produced using identical components as equivalent lead shot cartridges.



### Role of the European Commission

The European Union is a political body that has the tradition and power authority to establish policies and laws to benefit the European community's economy, business, social welfare, health, food safety, and conservation of the natural environment. Until recently, the EU has not acted on the issue of lead in ammunition, despite the Union's ratification of, or being party to, several Multinational Environmental Agreements that have taken proactive steps to support the phase-out of lead ammunition, e.g. the United Nations Convention on Migratory Species (CMS), and the African Eurasian Waterbird Agreement (AEWA). While such agreements could stimulate EC policy development, they lack regulatory authority.

In 2017, the European Commission requested the European Chemicals Agency (ECHA) to prepare an Annex XV report to propose a restriction on lead gunshot in wetlands under the EU REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) Regulation [17]. The Commission initiative to restrict lead in ammunition in EU derives from the European Green Deal [15] which defines a zero pollution ambition for a toxic-free environment to protect Europe's citizens and ecosystems, and sets ambitions for the EU to better monitor, report, prevent and remedy pollution from air, water, soil, and consumer products. The Annex XV report was adopted

by ECHA's scientific committees (including the Committee for Socio-Economic Analysis) in June, 2018, prior to being considered by the REACH Committee (comprising Member State representatives). In September 2018, ECHA concluded that additional measures were needed to regulate the use of lead ammunition in terrestrial environments and lead fishing weights [16]. The need for this extension was motivated by several arguments including that it would: limit additional pollution with lead and improve the quality of the environment; reduce the mortality of an estimated 1 to 2 million birds, such as pheasants and partridges and scavenging and predator species that consume lead-poisoned birds; and reduce health risks to hunters and their families who frequently eat game meat killed with lead shot or bullets. In October, 2019, the extended proposal was published in a call for evidence with a deadline at December, 2019. The present status is that two REACH restrictions are on their way: (1) the restriction of lead shot over wetlands to be agreed by member states, which cannot be amended anymore; and (2) the restriction on lead ammunition in general including lead shot in terrestrial habitats (and also including lead in fishing gear) currently being developed by ECHA, which will be commented by REACH committees and the public by January 2022 with the earliest adoption if agreed by member states by end of 2022.

All EC regulations apply directly at the national level. Thus, when any EU-level approved regulation enters into force, it becomes directly and immediately applicable within all 27 member countries, including their government, administration, businesses, and citizens. Should an EC initiative to regulate lead ammunition and fishing weights under the REACH come into force, a process to begin the transition would begin across all 27 member states, including non-EU countries that have ratified REACH, i.e. Norway, Iceland and Liechtenstein.

Countries do not need to create their own legislation to bring such EU legal act into force. However, the single countries hold the formal responsibility to ensure enforcement. Therefore, each EU Member State (and Norway, Iceland and Liechtenstein) must establish an official system of controls and identify legislation specifying penalties for non-compliance with the provisions of REACH. The ECHA hosts the Forum for Exchange for Information on Enforcement (Forum) composed of representatives of national enforcement authorities to coordinate the enforcement of REACH.

Approximately 18,000–21,000 tonnes of lead gunshot have been added to European natural ecosystems annually and have accumulated over the past 1–2 centuries. This lead becomes solubilized in lower pH waters and sediments and constitutes a permanent source of pollution [36, 37]. A regulated transition to non-lead ammunition use in the EU would complement related EU environmental initiatives such as the EU Water Framework Directive, the EU Birds Directive, and other agreements (the Bonn Convention, the Ramsar Convention and the AEWA) to which it is a party [38, 39].

The European Commission has other legal instruments that could support the transition at the EU level. EC Regulation No 1881/2006 of 19 December, 2006, sets maximum levels for certain contaminants in foodstuffs. This act sets maximum levels of lead allowed in traded meat from bovine animals, sheep, pigs and poultry, wild cephalopods, and bivalve molluscs, but not from wild game animals. Setting maximum levels of lead game meat in harmony with EC regulations on lead in domestic meats and offal is important as a complementary measure to the regulation of the trade and use of lead ammunition because it would harmonize health protection standards for traded game meat across the EU and protect people who consume game meat. Maximum levels would also provide a mechanism for measuring compliance with regulations of the use of lead ammunition through the enforcement, inspection, and monitoring programmes conducted by Member States [18].

### **Proposed EC regulated phase-in schedule for non-lead ammunition**

Assuming that the EC will enforce a REACH restriction on all lead ammunition, a realistic schedule for implementation has to be developed, based on awareness of existing regulations and how they can develop into a permanent EU-wide transition. The greatest need is for lead shotgun ammunition to be phased out for hunting in all habitat types, and for all lead rifle ammunition to be phased out in all hunting applications. The rationales are the same for both categories of hunting: preventing lead exposure from spent ammunition ingestion, preventing lead exposure in humans who consume hunted game animals, and preventing lead accumulation in hunted environments, especially those subject to shotgun shooting [2].

Lead hunting gunshot should be the first because it has the longest record of adverse impacts on wildlife and ecosystems and, therefore, has been subject to multiple international and national regulatory initiatives. In terms of tonnage, the dispersal of lead gunshot in natural ecosystems exceeds by far other sources and causes an irreversible accumulation of lead that constitutes a long-term and uncertain environmental risk [40] and should therefore stop as soon as possible. Safe and efficient alternatives to lead gunshot and rifle bullets are available at prices comparable to traditional lead types and in quantities that will keep pace with increasing market demands [31]. Use of lead shot is already restricted in 23 European countries, and lead rifle ammunition is currently state-wide restricted in three states in Germany, where several more states have introduced partial regulation of lead rifle ammunition, e.g. in state forests [8, 41].

We therefore fully endorse the ongoing REACH procedure including the restriction of lead shot over wetlands to be agreed by member states in 2020, and the further restriction on lead ammunition in general currently being developed by ECHA with the earliest adoption by end of 2022. In both cases, a phase-in period of maximum 3 years from the formal adoption of the restrictions is proposed as this would allow for education and awareness programmes for EU hunters through their national and EU-level organizations. These same programmes would address both rifle and shotgun hunters, emphasizing the need for, and benefits of, the transition. This length of time would allow ammunition makers to increase their existing production of non-lead products, and to increase availability within the EU. The amount of rifle ammunition used annually is likely much less than the volume of shotgun cartridges due largely to the nature of each type of hunting (although more than 150 tonnes of lead is dispersed annually into the environment in the EU by hunting with lead bullets [16]). This should

facilitate the transition to the use of non-lead rifle ammunition within 3 years. The EC would also be advised to set a maximum lead level (ML) in marketed game meat products in harmony with that set for domestic meats under EC Regulation 1881/2006 [42]. This should be an essential complement to the regulation of lead gunshot and rifle bullets [17]. The rationale for the dual regulation is that wild game meat is imported into the EU from non-EU countries (e.g. the United Kingdom and New Zealand) and should comply with an EU regulation allowing access to EU markets. Regulating the use of non-lead ammunition by all hunters would ensure that game would not contain lead, whether consumed by them or entered into retail markets.

Clay target shooting accounts for the largest segment of lead cartridge production, and the transition to non-lead ammunition for this sport has received little consideration [43]. Given the larger amount of non-lead ammunition (i.e. with smaller diameter steel shot) that would need to be produced, and that such competitive shooting is also an Olympic sport, it is proposed that a 5-year transition period (i.e. 2020–2025) be applied to this category of shotgun ammunition. Competition shooting with small and full-bore rifle calibres at shooting ranges where remediation programs are documented and lead residues of ammunition are recycled could proceed without restriction.

An EC regulation per se makes no transition. Although an EU restriction will automatically prohibit imports, enforcement is necessary to ensure compliance at the trade and user level as long as stocks of lead ammunition are available. The construction of the regulation is critical. If the regulation were only partial, and hunters were allowed to transport lead ammunition to, and be in possession of lead ammunition inside hunting areas where only the *use* of such ammunition is prohibited, enforcement would be difficult and compliance equally poor. Evidence from countries with partial prohibitions of lead shows a low level of compliance [44, 45]. However, a national ban on the possession of lead shot cartridges would promote compliance, as in Denmark [45].

#### European society and its position on hunting and lead pollution

The non-hunting segment of the European population exceeds 98%. In a democratic society where formal political decisions are based on simple majorities, the hunting community needs allies among non-hunters to favour decisions that preserve hunting. The public acceptance of hunting has been investigated in very general terms which demonstrate great variation among countries. In a questionnaire, EORG [46] found that national respondents were “Very worried” about hunting and shooting in a

range from 5% (Sweden) to 38% (Greece). It appears that most national populations are split into three groups: some are generally positive to hunting, some are neither positive nor negative, and some are generally negative. In Denmark, 43% of the general public had a positive attitude, 31% were indifferent, and 26% had a negative attitude to recreational hunting [47]. However, for many people, the attitude toward hunting depends on what the attitude is about. Some of the conditions under which hunting occurs affect attitudes. For instance, hunting of farm-reared and released game birds, hunting organized as a group hunt, and single day leases of hunting grounds have less acceptance than other types of hunting [47]. In a US study, 87% of respondents agreed that it was acceptable to hunt for food. However, only 37% agreed that it was acceptable to hunt for a trophy [48]. Heberlein and Willebrand [49] found that over 90% of Swedes supported hunting by native people, but this dropped when hunting was for meat and recreation. Only one third of the Swedes supported hunting when only recreation and sport were given as reasons. This reflects the large majority of non-hunting European public not having a clear overall attitude to hunting, but can be regarded to be highly ambivalent and impressionable.

Changing social attitudes and behaviours may be insensitive to, and conflict with, the interests of hunters. As an example, Europe has regulated an end to the many uses of anthropogenic lead, an environmental action that is well-supported by society because of the understood risks posed by lead to humans. Against this backdrop, it is difficult to reconcile the continued release of many tonnes of un-reclaimed ammunition lead each year, especially in the interests of sport, and the known persistent and adverse impacts on ecosystems, wildlife, and humans who consume game. Changes in types of foods demanded by Europeans are occurring quickly, whether related to organically produced foods, or animal-free foods. The European retail market has recorded a significant growth rate of organic food, and consumer attitudes to meat are changing showing a rise in the number of vegetarians, vegans and flexitarians, with more people now opting for meat-free days [50, 51]. The changes arise out of ethical concerns about food production, environmental impacts of agriculture, and personal diet/health considerations. It is relevant, here, to note that despite the declining demand for farmed meat there is a growing consumption of wild game meat in many European countries, e.g. Germany and the UK [52, 53] largely because such food is seen to have lived a better life than domestic animals, and its comparative nutritional value [54]. This growing market appears to be readily sustained by abundant and increasing populations of European deer species and wild boar (*Sus scrofa*) [20, 55]. This market provides a

great opportunity to support recreational hunting, especially if game is taken with non-lead ammunition, thereby enhancing the pollution-free status of the meat.

Hunting and clay target shooting have the inevitable consequence that gunshot, wads and bullets are unavoidably dispersed into the environment. This amounts, annually, to over 40,000 tonnes lead in EU. Limited documentation exists on the costs of clean-up of spent ammunition parts (lead shot, plastic wads, and cartridge cases) from hunting and sport shooting. As to the latter, Kajander and Parri [56] presented available techniques for the management of environmental impacts at shooting ranges, including maintenance measures, remediation and design features for new ranges. Such management activities may be very costly, especially at the level of the individual shooter. Few estimates exist for complete clean-up costs. However, were all lead contamination from the 10,000–20,000 tonnes of gunshot used annually by sports shooters in the EU to be mitigated, annual costs would be in the region of 81–162 million Euros [14]. This estimate was based on a per tonne figure for clean-up of rifle bullets. Gunshots are more dispersed than bullets and clean-up of gunshot is likely to be considerably more costly than the above estimate. Clean-up of shooting ranges is practised in some places and private services have developed techniques to assist. Clean-up of the 21,000 tonnes of lead shot used annually for hunting would not be practical or economically feasible. To reduce the risks in the most contaminated hunting areas such as regular fixed blinds, Pain et al. [14] assumed that expenditures at least similar to the cost of cleaning up shooting ranges would likely be required.

The potential costs to mitigate impacts of accumulated lead ammunition contamination should, legally, be returned to the hunters and shooters based on the Polluter-pays Principle (e.g. EU Directive 2004/35/, Article 1) although this principle has, in reality, not often been applied. However, few, if any, European hunting or shooting system includes direct charging of the costs for such mitigation, and costs are externalized to the community. In a Danish example, 7000 tonnes of contaminated soil were removed from a surface areas of 0.6 ha at a shotgun shooting range after 50 years' shooting in Langstrup Bog (Fredensborg) in 2019 [57]. The costs (about 1 mil. Euros) were paid by the local municipality because the shooting club responsible was dissolved.

European society is increasingly aware of the importance of recycling metals, driven by concerns over, inter alia, supply, market prices, sustainable resource management, and climate change. That hunting and shooting cause ammunition parts to be dispersed into the environment, with no or little possibility of retrieval and recycling, makes these sports un-aligned with common social

concerns. This applies to all metals used in ammunition (lead, steel, bismuth, copper, zinc, and tungsten), and society could criticize hunting and shooting for being wasteful of these valuable resources. Consequently, there is need for the hunting and shooting society in cooperation with the ammunition industry to minimize wastage of valuable metals. Lead gunshot comprises the largest tonnage of ammunition, and a transition to steel shot would be the cornerstone in this strategy.

The externalization of costs of remediating dispersal of spent toxic and polluting ammunition from shooting and hunting is poorly recognized by the public. When better documented, and used strategically by non- or anti-hunting groups, this may become a tremendous obstacle to hunters and their interests. The fact that the accumulated pool of a toxic substance that poses a potential threat to wildlife, ecosystems, and humans originates from a small percentage of society, and from a purely recreational activity, only makes the case much more difficult. In societal terms, continued use of lead ammunition undermines a broadly ambivalent public perception of responsible hunting [5]. Society would likely favour a lead ammunition ban, given EU-wide bans on other lead products. Moreover, the existing European capacity to produce non-lead substitutes would favour legislation that would prevent lead problems and their associated costs from being externalized to the public.

### Considerations for other international jurisdictions

Most jurisdictions in the EU and internationally requiring use of non-lead hunting ammunition have acted over concerns with wetland species hunting rather than hunting across all habitats. Although Denmark and The Netherlands have banned use of lead shotgun ammunition, lead rifle ammunition is still allowed in these countries. In North America, hunters are required, nation-wide, to use non-lead ammunition to hunt only migratory waterfowl (the USA since 1991; Canada, since 1999) [33]. California is, since 2019, the only jurisdiction to require non-lead ammunition use for all categories and species of hunting, mainly to protect several avian scavenging species [33]. Globally, no national-level jurisdiction has linked regulation of lead ammunition to public health concerns, although several German states require non-lead rifle ammunition use for this reason [4].

The sale of hunted wild game is a largely European phenomenon. However, hunting with lead-based ammunition for personal consumption is a common practice in many non-European countries, and native and non-native people who rely on wild game for their principal food intake are especially at risk from dietary lead exposure. This is the case in Alaska, USA [58], Canada [59–61], and Greenland [62]. In Alaskan children, the cause

of high blood lead levels could be attributed to consumption of lead-contaminated game meat and hunting households in over half of cases examined [58]. Large numbers of birds (species of doves and ducks) shot in high-volume hunts (1000–2000 birds/hunter/day) are also given to local communities in Argentina who are subsequently exposed to ingested lead [63]. The remains of trophy animals killed in African countries are routinely distributed to nearby communities, together with the residues of lead in the carcasses [64]. These examples of lead exposure are entirely preventable by the use of non-lead ammunition, but few of the jurisdictions listed above have taken any action on this issue. Large numbers of animals are killed as pests by culling operations in various countries. The carcasses may be eaten by people or left for consumption by scavengers, which are also subjected to lead exposure and subsequent mortality [65]. Avian scavengers and predators that consume the remains of hunted animals are, globally, frequently exposed to lead from spent ammunition [6]. A transition to non-lead ammunition use by hunters would, simultaneously and immediately, benefit the health of these birds besides the humans who consume game.

There is clear need to regulate the transition to use of non-lead products for all types of hunting to protect not only human and wildlife health, but also to reduce aquatic and soil pollution. It is in the socio-political interests of all hunting communities to do so [5]. Should the EC regulate lead ammunition use, international hunting agencies such as the European Federation for Hunting and Conservation (FACE) and the International Council for Game and Wildlife Conservation (CIC) could facilitate the adoption of non-toxic lead ammunition among member states, especially given their focus on the sustainability and value of hunting, and the endorsement of the CIC by various United Nations agencies. The recent declaration by the British Association for Shooting and Conservation [66], and its endorsement by related United Kingdom associations, that a transition to non-lead shotgun ammunition is now justified, is an important step in facilitating this process.

## Conclusions

Lead from spent ammunition affects adversely the health of the environment, its wildlife, and humans. Effective non-lead substitutes exist for both shotgun and rifle shooting and are becoming increasingly available. Their voluntary adoption by hunters has been resisted, and it will require regulation at the EU level to effect the transition to non-lead ammunition use and to prevent further externalization to society of the problems and costs of accumulated lead. It is in the enlightened self-interest of hunters to respond, thereby

increasing demands for non-lead products that industry can provide, to make hunting be more socially responsible and sustainable, and to provide game meat products that are safe for consumers. The ongoing EC regulation under a REACH restriction of lead gunshot in wetlands (2020) and all other types of ammunition in any habitats (2022) should take effect within a maximum of 3 years from the adoption of the restrictions, although within a of maximum 5 years for clay target shotgun shooting at ranges. The amendment of EC Regulation 1881/2006 to require mandatory lead MLs for all game meats would be a vital complement to the regulated transition to non-lead ammunition. This dual regulation would prevent lead-contaminated game meat from entering the European Union from both within the Union and imports from non-EU countries. The regulatory proposals advanced in this paper for the EU have direct relevance to other international jurisdictions where hunting is practised, and especially where people are at risk from lead ingestion by frequent consumption of game meats, and scavenging species are exposed to lead in the remnants of shot animals. These proposals are entirely consistent with, and complement, the environmental ambitions of the EU for a non-toxic environment and the United Nations 2030 Agenda for Sustainable Development [12, 15].

## Abbreviations

AEWA: African Eurasian Waterbird Agreement; AFEMS: Association of European Manufacturers of Sporting Ammunition; CIC: International Council for Game and Wildlife Conservation; CMS: United Nations Convention on Migratory Species; EC: European Commission; ECHA: European Chemicals Agency; EU: European Union; FACE: European Federation for Hunting and Conservation; ML: Maximum level; REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals; WFSA: World Forum on Shooting Activities.

## Acknowledgements

We thank the three peer reviewers for their diligent reviews and helpful comments on an earlier draft.

## Authors' contributions

Both authors contributed equally to the concept of the paper, the research behind it, its composition, and submission. Both authors read and approved the final manuscript.

## Funding

Funding was provided by the personal financial resources of the authors. Aarhus University, Department of Bioscience, kindly funded the Open Access publication.

## Availability of data and materials

Not applicable.

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Competing interests

The authors declare that they have no competing interests.

# Author details

<sup>1</sup> Department of Bioscience, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark. <sup>2</sup> Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, ON N1G 2W1, Canada.

Received: 17 March 2020 Accepted: 15 June 2020

Published online: 24 June 2020

# References

1. Arnemo JM, Andersen O, Stokke S, Thomas VG, Krone O, Pain DJ, Mateo R (2016) Health and environmental risks from lead-based ammunition: science versus socio-politics. *EcoHealth* 13:618–622. <https://doi.org/10.1007/s10393-016-1177-x>
2. Kanstrup N, Thomas VG, Fox AD (2019) Lead in hunting ammunition: persistent problems and solutions. Special Issue. *Ambio* 48(9):923–1098
3. Pain DJ, Swift J, Green R, Cromie R (2020) The tide is turning for lead ammunition. *Br Birds* 113:110–118
4. Gerofoke A, Martin A, Schlichting D, Gremse C, Müller-Graf C (2019) Heavy metals in game meat. In: Rietjens IMCM, Rose MD, Smulders FJM (eds) Chemical hazards in foods of animal origin. Food safety assurance and veterinary public health, No. 7. Wageningen Academic Publishers, Wageningen, pp 585–609. [https://doi.org/10.3920/978-90-8686-877-3\\_24](https://doi.org/10.3920/978-90-8686-877-3_24)
5. Kanstrup N, Swift J, Stroud DA, Lewis M (2018) Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47(8):846–857. <https://doi.org/10.1007/s13280-018-1042-y>
6. Krone O (2018) Lead poisoning in birds of prey. In: Sarasola JH, Grande JM, Negro JJ (eds) Birds of prey: biology and conservation in the XXI century. Springer, Cham, pp 251–272. [https://doi.org/10.1007/978-3-319-73745-4\\_11](https://doi.org/10.1007/978-3-319-73745-4_11)
7. ECHA (2019) ECHA newsletter November 2019–February 2020. <https://newsletter.echa.europa.eu/home/-/newsletter/entry/terrestrial-environments-also-being-polluted-with-lead-ammunition>. Accessed 1 Dec 2019
8. Mateo R, Kanstrup N (2019) Regulations on lead ammunition adopted in Europe and evidence of compliance. *Ambio* 48:989–998. <https://doi.org/10.1007/s13280-019-01170-5>
9. Barkham P (2019) Waitrose stops sale of birds shot with lead as experts call for UK ban. *The Guardian*. <https://www.theguardian.com/business/2019/jul/29/experts-call-for-ban-on-lead-shot-as-waitrose-overhauls-sale-of-game>. Accessed 17 Dec 2019
10. Thomas VG, Guitart R (2016) Exposure to lead through ammunition—need to revise strategies. *Environ Policy Law* 46:127–131. <https://doi.org/10.3233/EPL-46202>
11. UNEP (2017) Towards a pollution-free planet. Background report. Nairobi. <https://www.unenvironment.org/resources/report/towards-pollution-free-planet-background-report>. Accessed 4 Mar 2020
12. UNEP (2019) Global chemicals outlook II. From legacies to innovative solutions. Implementing the 2030 agenda for sustainable development. Geneva
13. Green RE, Pain DJ (2019) Risks to human health from ammunition-derived lead in Europe. *Ambio* 48:954–968. <https://doi.org/10.1007/s13280-019-01194-x>
14. Pain DJ, Dickie I, Green RE, Kanstrup N, Cromie R (2019) Wildlife, human and environmental costs of using lead ammunition: an economic review and analysis. *Ambio* 48:969–988. <https://doi.org/10.1007/s13280-019-01157-2>
15. EC (2019) The European Green Deal. Communication from the Commission to the European Parliament, The European Council, The Council, The European Economic and Social Committee and the Committee of Regions. The European Commission, COM 640. [https://ec.europa.eu/info/sites/info/files/european-green-deal-communication\\_en.pdf](https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf). Accessed 20 Dec 2019
16. ECHA (2018) A review of the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle. [https://echa.europa.eu/documents/10162/13641/lead\\_ammunition\\_investigation\\_report\\_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a](https://echa.europa.eu/documents/10162/13641/lead_ammunition_investigation_report_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a). Accessed 17 Dec 2019
17. Treu G, Drost W, Stock F (2020) An evaluation of the proposal to regulate lead in hunting ammunition through the European Union's REACH regulation. *Environ Sci Eur* 32:68. <https://doi.org/10.1186/s12302-020-00345-2>
18. Thomas VG, Pain DJ, Kanstrup N, Green RE (2020) Setting maximum levels for lead in game meat in EC regulations: an adjunct to replacement of lead ammunition. *Ambio*. <https://doi.org/10.1007/s13280-020-01329-5>
19. FACE (2020) Web page. <https://www.face.eu>. Accessed 17 Jan 2020
20. Massei G, Kindberg J, Licoppe A, Găcić D, Šprem N, Kamler J, Baubet E, Hohmann U, Monaco A, Ozolinš J et al (2014) Wild boar populations up, numbers of hunters down? A review of trends and implications for Europe. *Pest Manage Sci* 71:492–500. <https://doi.org/10.1002/ps.3965>
21. Newth JL, Lawrence A, Cromie RL, Swift JA, Rees EC, Wood KA, Strong EA, Reeves J, McDonald RA (2019) Perspectives of ammunition users on the use of lead ammunition and its potential impacts on wildlife and humans. *People Nat* 1:347–361. <https://doi.org/10.1002/pan3.30>
22. Cromie R, Newth J, Reeves J, O'Brien M, Beckmann K, Brown M (2015) The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult. In: Delahay RJ, Spray CJ (eds) Proceedings of the oxford lead symposium: lead ammunition: understanding and minimizing the risks to human and environmental health. Edward Grey Institute: Oxford University, pp 104–124. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_cromie\\_newth\\_reeves\\_obrien\\_beckman\\_brown.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_cromie_newth_reeves_obrien_beckman_brown.pdf)
23. FAO (2018) Game meat. production and trade in the ENECE region. Food and Agricultural Organization of the United Nations. Rome, Italy. <https://www.unece.org/fileadmin/DAM/timber/meetings/2018/20180321/game-meat-draft-2018-03.pdf>. Accessed 17 Jan 2020
24. Tsuji LJS, Wainman BC, Martin ID, Sutherland C, Weber J-P, Dumas P, Nieboer E (2008) The identification of lead ammunition as a source of lead exposure in first nations: the use of lead isotope ratios. *Sci Total Environ* 393:291–298. <https://doi.org/10.1016/j.scitotenv.2008.01.022>
25. Arnemo JM, Cromie R, Fox AD, Kanstrup N, Mateo R, Pain DJ, Thomas VG (2019) Transition to lead-free ammunition benefits all. *Ambio* 48(9):1097–1098. <https://doi.org/10.1007/s13280-019-01221-x>
26. Kanstrup N (2009) (ed) Sustainable hunting ammunition. In: Proceedings of workshop sustainable hunting ammunition, Aarhus 2009. Aarhus, Denmark. [http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC\\_Sustainable\\_Hunting\\_Ammunition\\_Workshop\\_Report\\_low\\_res.pdf](http://www.cic-wildlife.org/wp-content/uploads/2013/04/CIC_Sustainable_Hunting_Ammunition_Workshop_Report_low_res.pdf). Accessed 1 Dec 2019
27. Ljung PE, Riley SJ, Heberlein TA, Ericsson G (2012) Eat, prey, and love: game meat consumption and attitudes towards hunting. *Wildl Soc Bull* 36:669–675. <https://doi.org/10.1002/wsb.2008>
28. Thomas VG, Kanstrup N, Gremse C (2015). Key questions and responses regarding the transition to use of lead-free ammunition. In: Delahay RJ, Spray CJ (eds) Proceedings of the Oxford lead symposium. lead ammunition: understanding and minimising the risks to human and environmental health, Edward Grey Institute, University of Oxford, UK, pp 125–133. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_thomas\\_kanstrup\\_gremse.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_thomas_kanstrup_gremse.pdf)
29. Thomas VG (2015) Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In: Delahay RJ, Spray CJ (eds) Proceedings of the Oxford lead symposium. Lead ammunition: understanding and minimising the risks to human and environmental health, Edward Grey Institute, University of Oxford, UK, pp 85–97. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_thomas.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_thomas.pdf)
30. Thomas VG, Gremse C, Kanstrup N (2016) Non-lead rifle hunting ammunition: issues of availability and performance in Europe. *Eur J Wildl Res* 62:633–641. <https://doi.org/10.1007/s10344-016-1044-7>
31. Kanstrup N, Thomas VG (2019) Availability and prices of non-lead gun-shot cartridges in the European retail market. *Ambio* 48(9):1039–1043. <https://doi.org/10.1007/s13280-019-01151-8>
32. Kanstrup N, Haugaard L (2020) Krav til projektilvægt, anlagsenergi m.v. for rifellammunition, der anvendes til jagt og regulering. bind 36, Fagligt notat fra DCE – Nationalt Center for Miljø og Energi. [https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet\\_2020/N2020\\_36.pdf](https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet_2020/N2020_36.pdf) (With an English summary)
33. Thomas VG, Kanstrup N, Fox AD (2019) The transition to non-lead sporting ammunition and fishing weights: review of progress and barriers to implementation. *Ambio* 48:925–934. <https://doi.org/10.1007/s13280-018-1132-x>

34. Thomas VG (2013) Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. *Ambio* 42:737–745. <https://doi.org/10.1007/s13280-012-0361-7>
35. Thomas VG, Owen M (1996) Preventing lead toxicosis of European waterfowl by regulatory and non-regulatory means. *Environ Conserv* 23:358–364. <https://doi.org/10.1017/S0376892900039229>
36. Miglioni M, Pigino G, Bianchi N, Bernini F, Leonzio C (2004) The effects of heavy metal contamination on the soil arthropod community of a shooting range. *Environ Pollut* 129:331–340. <https://doi.org/10.1016/j.envpol.2003.09.025>
37. Sullivan T, Gottle N, Basta N, Jardine P, Schadt C (2012) Firing range soils yield a diverse array of fungal isolates capable of organic acid production and Pb mineral solubilization. *Appl Environ Microbiol* 78(17):6078–6086. <https://doi.org/10.1128/aem.01091-12>
38. Thomas VG, Guitart R (2005) Role of international conventions in promoting avian conservation through reduced lead toxicosis: progression towards a non-toxic agenda. *Bird Conserv Int* 15:147–160. <https://doi.org/10.1017/s0959270905000110>
39. Brack W, Ait-Aissa S, Backhaus T, Birk S, Barceló D, Burgess R, Cousins I, Dulio V, Escher BI, Focks A et al (2019) Strengthen the European collaborative environmental research to meet European policy goals for achieving a sustainable, non-toxic environment. *Environ Sci Eur* 31:63. <https://doi.org/10.1186/s12302-019-0232-y>
40. Kanstrup N, Fox AD, Balsby TJS (2020) Toxic lead gunshot persists accessible to waterbirds after a 33-year ban on their use. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.136876>
41. Gremse C, Rieger S (2015) Lead from hunting ammunition in wild game meat: research initiatives and current legislation in Germany and the EU. In: Delahay RJ, Spray CJ (eds) *Proceedings of the Oxford lead symposium. Lead ammunition: understanding and minimising the risks to human and wildlife health*, Edward Grey Institute, University of Oxford, UK, pp 51–57. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_gremse\\_reiger.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_gremse_reiger.pdf)
42. EC (2006) European Commission Regulation EC 1881/2006. Setting maximum levels for certain contaminants in foodstuffs. *Official Journal of the European Union* EC 1881/2006 (20.12.2006), L364/365–L364/324. <http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1442063437890&uri=CELEX:32006R1881>
43. Thomas VG, Guitart R (2013) Transition to non-toxic gunshot use in Olympic shooting: policy implications for IOC and UNEP in resolving an environmental problem. *Ambio* 42:746–754. <https://doi.org/10.1007/s13280-013-0393-7>
44. Cromie R, Loram A, Hurst L, O'Brien M, Newth J, Brown M, Harradine J (2010) Compliance with the environmental protection (restrictions on use of lead shot) (England) Regulations 1999. DEFRA, Bristol, UK. <http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=16075>
45. Kanstrup N (2018) Lessons learned from 33 years of lead shot regulation in Denmark. *Ambio* 48:999–1008. <https://doi.org/10.1007/s13280-018-1125-9>
46. EORG (2002) The attitudes of Europeans towards the environment. [https://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs\\_180\\_en.pdf](https://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_180_en.pdf). Accessed 17 Jan 2020
47. Gamborg C, Jensen FS (2017) Attitudes towards recreational hunting: a quantitative survey of the general public in Denmark. *J Outdoor Recreat Tour* 17:20–28. <https://doi.org/10.1016/j.jort.2016.12.002>
48. Byrd E, Lee JG, Widmar NJO (2017) Perceptions of hunting and hunters by U.S. respondents. *Animals* 7(11):83–98. <https://doi.org/10.3390/ani7110083>
49. Heberlein TA, Willebrand T (1998) Attitudes toward hunting across time and continents: The United States and Sweden. *Game Wildl* 15:1071–1080. <http://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=1777661>
50. BIOECO (2020) European organic market grew to more than 37 billion euros in 2017. <https://www.bioecoactual.com/en/2019/02/18/european-organic-market/>. Accessed 17 Dec 2019
51. EC (2018) EU Agricultural Outlook. For markets and income 2018–2030. [https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/medium-term-outlook-2018-report\\_en.pdf](https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/medium-term-outlook-2018-report_en.pdf). Accessed 16 Jan 2020
52. DJV (2018) Jäger haben mehr Wildbret geliefert. <https://www.jagdverband.de/content/jäger-haben-mehr-wildbret-geliefert>. Accessed 10 Jan 2020
53. Mintel (2016) Unprocessed poultry and red meat—UK—October 2016. <https://store.mintel.com/unprocessed-poultry-and-red-meat-uk-october-2016>. Accessed 20 Jan 2020
54. Straziņa V, Jemeljanovs A, Šterna V (2013) Nutrition value of wild animal meat. *Proc Latvian Acad Sci Sect B* 67(4/5):373–377. <https://doi.org/10.2478/prolas-2013-0074>
55. Burbaitė L, Csányi S (2010) Red deer population and harvest changes in Europe. *Acta Zool Lituonica* 20:179–188. <https://doi.org/10.2478/v10043-010-0038-z>
56. Kajander S, Parri A (2014) Management of the environmental impact of shooting ranges. [https://www.ecde.info/sites/default/files/docs/sy\\_4\\_2014\\_en.pdf](https://www.ecde.info/sites/default/files/docs/sy_4_2014_en.pdf). Accessed 10 Jan 2020
57. NIRAS (2019) Karlebo Skydebane. Dokumentationsrapport. Fredensborg Kommune December 2019. Projekt ID: 10401296. Document ID: XTAX-EUDDNY4W-75177900-785. Fredensborg Municipality, Denmark
58. Bressler JM, Yoder S, Cooper S, McLaughlin J (2019) Blood lead surveillance and exposure sources among Alaska children. *J Public Health Manag Pract* 25(1Suppl):S71–S75. <https://doi.org/10.1097/phh.0000000000000877>
59. Levesque B, Duchesne J-F, Gariépy C, Rhainds M, Dumas P, Scheuhammer AM, Proulx J-F, Déry S, Muckle G, Dallaire F, Dewailly É (2003) Monitoring of umbilical cord blood lead levels and sources assessment among the Inuit. *Occup Environ Med* 60:693–695. <https://doi.org/10.1136/oem.60.9.693>
60. Liberda EN, Tsuji LJS, Martin ID, Ayotte P, Robinson E, Dewailly E, Nieboer E (2018) Source identification of human exposure to lead in nine Cree Nations from Quebec, Canada (*Eeyou Istchee* territory). *Environ Res* 161:409–417. <https://doi.org/10.1016/j.envres.2017.11.023>
61. Couture A, Levesque B, Dewailly É, Muckle G, Déry S, Proulx J-F (2012) Lead exposure in Nunavik: from research to action. *J Circumpolar Health* 71:18591. <https://doi.org/10.3402/ijch.v71i0.18591>
62. Johansen P, Pedersen HS, Asmund G, Riget F (2006) Lead shot from hunting as a source of lead in human blood. *Environ Pollut* 142:93–97. <https://doi.org/10.1016/j.envpol.2005.09.015>
63. Uhart M, Ferreyra HdV, Romano M, Muchiutti A, Alzuagaray S, Santiago M, Caselli A (2019) Lead pollution from hunting ammunition in Argentina and current state of lead shot replacement efforts. *Ambio* 48:1015–1022. <https://doi.org/10.1007/s13280-019-01178-x>
64. Bodeau-Livinec F, Glorennec P, Cot M, Dumas P, Durand S, Massougbedji A, Ayotte P, Le Bot B (2016) Elevated blood lead levels in infants and mothers in Benin and potential sources of exposure. *Int J Environ Res Public Health* 13:316. <https://doi.org/10.3390/ijerph13030316>
65. Hampton JO, Laidlaw M, Buenz E, Arnemo JM (2018) Heads in the sand: public health and ecological risks of lead-based bullets for wildlife shooting in Australia. *Wildl Res* 45:287–306. <https://doi.org/10.1071/WR17180>
66. BASC (2020) British Association for Shooting and Conservation. A joint statement on the future of shotgun ammunition for live quarry shooting. <https://basc.org.uk/a-joint-statement-on-the-future-of-shotgun-ammunition-for-live-quarry-shooting/>. Accessed 24 Feb 2020

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

# PAPER 2

## TITLE:

Mateo R, Kanstrup N (2019). Regulations on lead ammunition adopted in Europe and evidence of compliance. Ambio 48:989-998 doi:10.1007/s13280-019-01170-5

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

### Order Summary

Licensee:	Aarhus University
Order Date:	Feb 27, 2020
Order Number:	4776980807936
Publication:	AMBIO
Title:	Regulations on lead ammunition adopted in Europe and evidence of compliance
Type of Use:	Thesis/Dissertation
Order Ref:	Mateo and Kanstrup 2019
Order Total:	0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

## AUTHORS' CONTRIBUTIONS:

Dear Niels,

I state that our contribution in the paper "Mateo R, Kanstrup N (2019) Regulations on lead ammunition adopted in Europe and evidence of compliance. Ambio 48:989-998 doi:10.1007/s13280-019-01170-5" was as follows:

Conceptualization: RM, NK.

Formal analysis: RM, NK

Writing - Original Draft: RM

Writing - Review & Editing: RM, NK

Visualization: RM, NK

RM: Rafael Mateo

NK: Niels Kanstrup

Best regards

Rafael Mateo Soria, DVM, PhD

Group of Wildlife Toxicology

Instituto de Investigación en Recursos Cinegéticos (IREC) - Institute for Game and Wildlife Research

CSIC-UCLM-JCCM

Ronda de Toledo 12

13005 Ciudad Real

Spain

Tel: +34 926 295450 / +34 926 295300 + 90321

Fax: +34 926295451

Web <http://www.irec.es>

[https://www.researchgate.net/profile/Rafael\\_Mateo](https://www.researchgate.net/profile/Rafael_Mateo)

Confirmed, March 2021



Niels Kanstrup

# Regulations on lead ammunition adopted in Europe and evidence of compliance

Rafael Mateo , Niels Kanstrup

Received: 24 November 2018 / Revised: 28 February 2019 / Accepted: 6 March 2019

**Abstract** The transition to non-lead ammunition has been enforced by regulations on use and possession of lead shot and rifle bullets. Here we review the scientific and technical literature about this regulatory process in Europe and give some notes of its effectiveness to reduce this source of lead contamination in aquatic and terrestrial environments. Presently, lead shot use has been legally restricted in 23 European countries. Two, Denmark and The Netherlands, have a total ban of lead gunshot use in all types of habitats, 16 countries have a total ban in wetlands and/or for waterbird hunting, and 5 have a partial ban implemented only in some wetlands. The legal regulation of lead bullets is limited to some German regions. This review also highlights the need to know the level of compliance with the ban on lead ammunition and the subsequent benefits for the susceptible species and for game meat safety.

**Keywords** Bullet · Compliance · Contamination · Game meat · Lead poisoning · Shot pellet

## INTRODUCTION

Lead is a relatively abundant and cheap metal with good ballistic properties for hunting that has not been replaced by other materials for several centuries despite the technological advances and the development of new materials as occurred with other lead uses (Oltrogge 2009), possibly because the evidence of the toxicological impact of this use has not been known until recent times (Pain et al. 2015).

There is a huge amount of information about lead toxicity and the health and environmental impacts associated with its uses since antiquity (Stroud 2015). The balance

between the benefits of the use of this metal and its risk for life has led to its substitution by other materials (ECHA 2017). Such replacement was overcome for uses in plumbing or as a component of paints, petrol and even fishing weights, but many users and manufacturers are still opposed to the substitution of lead in ammunition despite the accumulated evidence of its negative environmental impacts (Thomas et al. 2015; Kanstrup et al. 2019). The introduction of new generations of non-lead shot types has been a driver for the advance in the regulation and elimination of lead in ammunition, as well as the wider understanding of the risks of dispersed of lead shot in ecosystems (Oltrogge 2009; Thomas 2013, 2015; Kanstrup 2019). The non-toxic properties of both the new materials and the final commercial products are another important issue that must be considered for the regulation of the new types of ammunition (Thomas 2016, 2019).

Here we summarize the status of the regulation of the use of lead ammunition for hunting in the different European countries and their compliance and effectiveness. In this review, we have updated previous reviews of the regulations adopted in Europe (Mateo 2009; Stroud 2015) with the most recent regulatory changes adopted in different European countries (AEWA 2018; ECHA 2018; VCF 2018) and other decisions made within with the framework of international agreements (UNEP/CMS 2014; IUCN/WCC 2016). The aim of this review is to compile the information about this regulation in order to highlight the differences between countries and the need of harmonization as ECHA (2017) proposed for the countries within the European Union (EU). We also want to highlight the scarcity of information in the scientific literature about the compliance with regulations or about the effects of these bans on the reduction of lead exposure in the vulnerable avian species.

## ROLE OF INTERNATIONAL AGREEMENTS IN THE REGULATORY PROCESS

Individual European countries have implemented national regulations based on the evidence of the environmental impact of lead ammunition in their territories and/or because of the ratification of international treaties that have obligated the parties to make progress in the ban of lead ammunition (Stroud 2015; Kanstrup et al. 2019). However, the effect of these international policy statements has not yet been translated into effective regulations in many countries.

As a summary of the international instruments concerning lead poisoning and wildlife, in 1991 the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) was the first to recommend phasing out lead shot use in wetlands or for waterfowl hunting. By the time of the adoption of the UN-African-Eurasian Migratory Waterbird Agreement (AEWA) in 1995, awareness of the dangers of lead gunshot was well appreciated. As a result, the AEWA Action Plan contained a firm obligation for Parties to endeavour to phase out lead shot for hunting in wetlands by 2000. Insufficient implementation in the majority of Contracting Parties in 2008 resulted in a resolution to establish a new deadline for 2017, and this resolution included the need to 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 (AEWA 2012). This is an important aspect because the information about the compliance of these regulations will help the countries to decide policy measures and requirements to enforce the law (Mateo et al. 2014; Cromie et al. 2015; Kanstrup and Balsby 2018; Kanstrup 2019). Parties to the more global Convention on the Conservation of Migratory Species of Wild Animals (UNEP/CMS; Bonn Convention), the “mother” convention to AEWA, adopted in 2014 a resolution whose appended guidelines requested a phase out of the use of lead ammunition across all habitats (wetlands and terrestrial) by 2017 (UNEP/CMS 2014). While this target has not yet been met, various steps have been made towards this, including the establishment of the UNEP/CMS Lead Task Group in 2017. More recently, the World Conservation Congress adopted a resolution in 2016 that calls for action from the IUCN Director General and Commissions along with governments and all IUCN member organizations to work towards the phase out of lead ammunition following the guidelines of the 2014 UNEP/CMS Resolution (IUCN/WCC 2016). In the same line, the United Nations Environment Assembly adopted in 2017 a resolution on Environment and Health which calls for member States and the Executive Director to raise awareness of the dangers to the environment of lead

in ammunition, and to encourage research regarding alternatives (UNEA 2017).

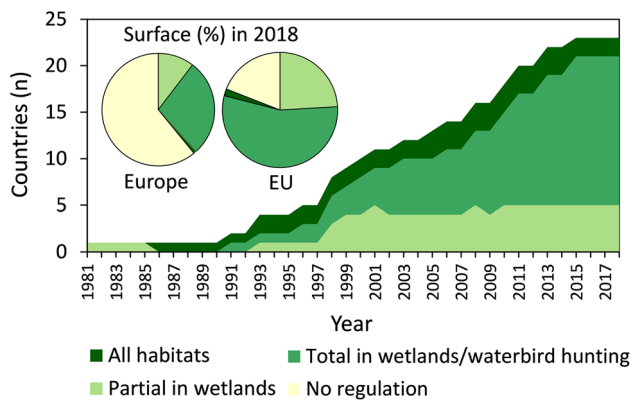
Within the EU, the directive on the conservation of wild birds aimed member states to phase out lead shot in wetlands by 2009 (Stroud 2015). More recently, the process of Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) in the EU by means the European Chemicals Agency (ECHA) has offered the appropriate framework to adopt the necessary regulatory actions on lead ammunition. This has led to propose a restriction of the use of lead gunshot in or over wetlands (ECHA 2017). This proposal states that (1) lead and lead compounds shall not be used in gunshot for shooting with a shot gun within a wetland or where spent gunshot would land within a wetland, and (2) lead gunshot shall not be in the possession of persons in wetlands. At the time of writing this review, the European Commission must adopt a decision about the support to this restriction. In 2018, ECHA also published an investigation report “reviewing the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle” (ECHA 2018). This report concluded that (1) lead gunshot in terrestrial areas poses a risk to both human health and the environment, and (2) the consumption of game shot with lead-based ammunition (including lead-rifle bullets) can result in exposure to consumers and as lead is considered a non-threshold toxicant, this consumption results in risks to humans. Also, dispersal of lead from fishing tackle was included in this additional ECHA (2018) initiative. A wider restriction proposal based on this report is anticipated in time and following this report, a group of 54 European scientists from 17 countries have already encouraged the European Commission to prepare a proposal for further measures to restrict the use of all lead ammunition and anglers’ lead weights (European Scientists 2018).

## CURRENT REGULATION OF LEAD AMMUNITION IN EUROPE

By 2018, the regulation of lead ammunition has been already adopted by 23 European countries as detailed in the following section. Figure 1 shows the increase in the number of countries with regulations of lead ammunition since the first partial regulation was implemented in Denmark in 1981.

### Lead shot

There are at present 23 countries in Europe in which lead shot has been totally or partially banned (Fig. 2). All these countries, except Norway and Switzerland, are within the EU, but there are still six EU countries without any



**Fig. 1** Trend over time of the number of European countries with a ban on the use of lead shot in wetlands and/or for waterbird hunting (partial in specific wetlands or total) and also including terrestrial habitats (all habitats). Pie charts based on the total surface (area) of countries with and without regulations. The total surface of the left pie (Europe) includes the European parts of Azerbaijan, Kazakhstan, Russia and Turkey

regulation of lead ammunition according to the information submitted to international agreements (i.e. Greece, Ireland, Lithuania, Poland, Romania and Slovenia) (AEWA 2015, 2018; ECHA 2017). The regulations adopted in the European countries varied from those with a total ban in all the territory and habitats (i.e. Denmark and Netherlands) to those with a national ban on the use in all wetlands or for waterbird hunting (16 countries) or in some specific wetlands of international importance (5 countries) (Fig. 2). Another four countries (i.e. Albania, Malta, Moldova, Lithuania) have implemented a ban on waterbird hunting or a moratorium in important areas for waterbirds. The outcome of ECHA/REACH restriction proposal is currently awaited but would seek to harmonize regulation across the EU, which would eliminate these differences among countries (ECHA 2017).



**Fig. 2** Lead shot regulations in Europe. Regulations are partial in some specific wetlands of international importance (Ramsar sites, Special Protection Areas for Birds), total in all wetlands or total in all types of habitats

## Lead bullets

The use of lead bullets has been banned only in some regions, sites or National Parks in Germany, Italy and Spain in order to avoid contamination of game meat and/or to protect raptors from lead poisoning (ECHA 2017; Martin et al. 2017; VCF 2018). In Germany, the white-tailed eagle (*Haliaeetus albicilla*) has been found to be affected by lead poisoning due to the ingestion of lead bullet fragments present in carcasses and offal left by large-game hunters (Krone et al. 2009). The adoption of this measure in Germany to protect the white-tailed eagle from lead poisoning contrasts with the lack of regulation in other countries where lead poisoning in this species has been also detected, e.g. Sweden (Heller et al. 2009), Finland (Isomursu et al. 2018) and Poland (Kitowski et al. 2017). Similarly, the regulation of the use of lead bullets is practically absent in countries in Southern and Central Europe where lead poisoning has been detected in griffon vulture (*Gyps fulvus*) (Carneiro et al. 2016; Mateo-Tomás et al. 2016), cinereous vulture (*Aegypius monachus*) (Rodríguez-Ramos et al. 2009), bearded vulture (*Gypaetus barbatus*) (Berny et al. 2015) and Egyptian vulture (*Neophron percnopterus*) (Gangoso et al. 2009). There are only a few sites where the protection of the bearded vulture has promoted local regulations. In Italy, the use of lead bullets has been restricted in Sondrio Province since the season 2012/13; lead bullets can still be used provided that hunters bury the offal of killed ungulates (Bassi et al. 2014; ECHA 2018; VCF 2018). In Stelvio National Park and in many other protected areas where hunting is not allowed, the use of lead-free bullets is mandatory in case of interventions to control wild ungulates. A regional regulation made in 2017 by Emilia-Romagna region established the use of lead-free ammunition when the game meat is intended for market sale (ECHA 2018), but this regulation was withdrawn later in 2018. In Spain, the region of Valencia has recently banned the use of lead bullets in the Maestrazgo mountains, where a reintroduction project of bearded vultures is being carried out (VCF 2018). In Austria, the use of non-lead bullets is being promoted in the Hohe Tauern National Park with some incentivations for hunters (i.e. free check of the calibre and weapon as well as free advice from the rifle master, free chemical cleaning of the weapon by the rifle master, 1 free pack of lead-free ammunition and 25% discount on purchase of each additional package (up to a maximum of 5) of lead-free ammunition) (VCF 2018). In France, similar pilot voluntary initiatives are being developed in the Cévennes National Park, the French Alps in Haute Savoie and the French Pyrenees (VCF 2018).

## REGULATION OF LEAD AMMUNITION BY EUROPEAN COUNTRIES: COMPLIANCE, EFFECT ON HUNTING BAGS AND OBSERVED BENEFITS FOR BIRDS AND GAME MEAT SAFETY

- *Albania (non-EU member)* A 2-year hunting moratorium in wetlands was imposed between March 2014 and March 2016, and a further five-year hunting moratorium was imposed for 2016–2021, but there is no regulation of lead shot use (AEWA 2018).
- *Andorra (non-EU member)* Without regulation of lead ammunition.
- *Armenia (non-EU member)* Without regulation of lead ammunition.
- *Austria (EU member)* Lead shot is not permitted for hunting waterfowl wherever they occur (ECHA 2017). The use of non-lead bullets is being encouraged with some incentives for hunters (VCF 2018).
- *Azerbaijan (non-EU member)* Without regulation of lead ammunition.
- *Belarus (non-EU member)* Without regulation of lead ammunition.
- *Belgium (EU member)* In Flanders, lead shot has been banned for waterfowl hunting in Ramsar sites since 1993, and in 1998 this ban was extended to all EU Bird Directive areas (Beintema 2001). A total ban on the use of lead shot over wetlands in Flanders was adopted in 2003 (AEWA 2005) and the use of lead shot also outside wetlands was banned in 2005 (ECHA 2018). In Wallonia, the restriction applied initially to hunting in wetlands, although coated lead pellets ('cartouches à plomb nickelés') were allowed (AEWA 2008). The total ban of lead shot for waterfowl hunting at less than 50 m from wetlands in Wallonia was established in 2005 (AEWA 2018).
- *Bosnia-Herzegovina (non-EU member)* Without regulation of lead ammunition.
- *Bulgaria (EU member)* The ban of lead shot in wetlands and 200 metres around has been in place since 2008 (MoEW 2007). The prohibition is enforced by the Executive Forestry Board and covers all existing wetlands across the country (AEWA 2015).
- *Croatia (EU member)* A provision forbidding the use of lead shot in wetlands throughout the Republic of Croatia became law when this country entered the EU in 2013 (AEWA 2015).
- *Cyprus (EU member)* Lead shot was banned in wetlands in Cyprus in 2003 with the law on the protection and conservation of game and wild birds (AEWA 2008, 2015).
- *Czech Republic (EU member)* The use of lead shot for waterfowl hunting was banned on 31 December 2010 (AEWA 2015).

- Denmark (EU member)** This was the first country in the world that implemented a ban on the use of lead shot, with the exception of the ban in some specific areas of the Mississippi Flyway in USA since 1976 (Anderson et al. 1987). This ban on lead shot use in Denmark was implemented for clay target shooting over wetlands in 1981, for hunting in Ramsar areas and for shooting over ponds with rearing and release of mallards (*Anas platyrhynchos*) for hunting and for clay target shooting in all habitats in 1986 (Kanstrup 2006). Moreover, from 1986, trade of cartridges containing more than 28.5 g of lead was banned (Clausen 1992). Denmark enforced a total ban on the use, trade and possession of lead shot in 1996 (Kuivenhoven et al. 1998, Kanstrup 2006), but there is still no regulation of lead bullets used for large-game hunting (Kanstrup et al. 2016). In Greenland, the use of all lead shot was not banned until 2012. In Denmark, compliance of the ban has recently been investigated. Kanstrup and Balsby 2018 found that the majority of shotgun plastic debris collected on Danish shorelines originated from non-lead types. In samples from 2016 and 2017 of pheasants with embedded shot ( $N = 447$ ), Kanstrup and Balsby 2019 found that 1.8% (in 2016) and 2.2% (in 2017) were killed with lead shot, the remaining with non-lead types, mainly steel shot. The same study showed that among 148 mallards bagged in 2017, 3.1% had lead shot. The high compliance is due to strict regulation of use of lead shot in all habitats combined with a ban of trade and possession of lead shot cartridges. Furthermore, the wide availability of high-quality non-lead ammunition types is a driver for the compliance (Kanstrup 2019). Regarding the impact of this regulation on the hunting activity, the number of hunters, the long-term popularity of hunting and the annual hunting bag in Denmark have not been affected by the implementation of lead shot regulations (Kanstrup 2015, 2019). Prevalence of ingested shot is at present subjected to investigation. A sample of 690 mallard gizzards showed a prevalence of ingested shot at c.10%. Of this, the majority was steel shot (Kanstrup, unpublished).
- Estonia (EU member)** The use of lead shot for hunting in wetlands was banned in 2013 (AEWA 2015).
- Finland (EU member)** Lead shot was banned for waterfowl hunting (except in Åland Islands) in 1996 (AEWA 2018).
- France (EU member)** In Tour du Valat Biological Station estate, a 2500-ha natural wetland in the Camargue (Rhône Delta), lead shot was voluntarily banned in 1994 for both terrestrial game and waterbirds (Mondain-Monval et al. 2015). A nation-wide ban on lead shot for hunting in wetlands has been implemented since 2006 (AEWA 2018). Voluntary initiatives by hunters to use non-lead bullets are being developed in the Cévennes National Park, the French Alps in Haute Savoie and the French Pyrenees (VCF 2018). Regarding the effect of the regulation, the prevalence of lead shot ingestion in waterfowl in Tour du Valat did not decrease between the period 1995–1999 ( $n = 297$ , 13.5%) and the period 2003–2005 ( $n = 179$ , 12.3%), but there was a significant increase in the prevalence of steel shot ingestion from 2% to 7.8%, respectively (Mondain-Monval et al. 2015). These authors concluded that the voluntary ban on lead shot in Tour du Valat had avoided the contamination of 8% of the ducks foraging in that area during the 11 years of the study.
- Georgia (non-EU member)** Without regulation of lead ammunition.
- Germany (EU member)** At a national scale, the German Federal Government and hunter's associations made in 1993 a recommendation to use non-toxic shot for waterfowl hunting in wetlands (Beintema 2001). Presently, several regions of Germany have banned lead shot for hunting waterfowl in waterbodies in line with AEWa resolutions (Gremse and Rieger 2015). The Federal States of Baden-Württemberg, Bavaria, Berlin, Brandenburg, Hesse, Lower Saxony, Mecklenburg-Western Pomerania, North Rhine-Westphalia, Rhineland-Palatinate, Saarland, Saxony-Anhalt, Schleswig-Holstein, and Thuringia have implemented a ban on lead shot for waterbird hunting, comprising 94.5% of Germany's total area (AEWA 2005, 2015). Saxony has banned lead shot use in all types of habitats since 2014. Moreover, the Government of Brandenburg was the first to introduce regulations of the use of any lead ammunition, including lead bullets for game hunting in the federal forests in 2005 (AEWA 2005, Kenntner et al. 2007). Specifically, 3 of 16 German Federal States (Schleswig-Holstein, Baden-Württemberg and Saarland) have totally banned the use of lead-core bullets for hunting. In Schleswig-Holstein, the use of lead bullets and shotgun slugs for hunting was banned first in State Forests in 2013 and then state-wide in 2015. In Baden-Württemberg, the use of lead bullets has been banned for hunting ungulates in the State Forests since 2014 and the rest of the region since 2016. In Saarland, the ban on lead-rifle ammunition was implemented in State Forests in 2011 and became state-wide since 2014, with a grace period granted to phase out their use by 2017. The Federal State of North Rhine-Westphalia is in the process of passing legislation to restrict the use of lead bullets and shotgun slugs in hunting, but there is already a ban on lead ammunition for rifles in State

Forests since 2013. Other German regions have also banned lead-rifle ammunition in State Forests since 2013 (Berlin, Brandenburg, Lower Saxony and Rhineland-Palatinate), 2014 (Mecklenburg-Vorpommern) and 2015 (Hesse) (Gremse and Rieger 2015).

In terms of the effect of the regulation on game meat safety, Martin et al. (2017) found that median concentrations of lead in red deer (*Cervus elaphus*) meat did not differ significantly between lead shot and non-lead shot animals, but the highest concentrations were found in edible parts of animals shot with lead ammunition.

- *Greece (EU member)* Without regulation of lead ammunition.
- *Hungary (EU member)* Lead shot was banned for hunting in Ramsar sites and other wetlands in 2005 (AEWA 2005).
- *Iceland (non-EU member)* Without regulation of lead ammunition.
- *Ireland (EU member)* Without regulation of lead ammunition.
- *Italy (EU member)* The use of lead shot was banned in wetlands under the category of Special Protection Areas (SPAs) and within 150 m from their shores in 2008, which covers about 45% of the overall wetland surface area. However, the possession of lead ammunition inside the SPA wetlands is still allowed, making enforcement of the ban problematic. The use of lead shot is still allowed in wetlands outside SPAs (AEWA 2015). The use of lead bullets has been banned for hunting in Stelvio National Park and Sondrio Province (ECHA 2018; VCF 2018).
- *Kosovo (non-EU member)* Without regulation of lead ammunition.
- *Latvia (EU member)* Lead shot was banned for waterfowl hunting at the Natural Park Lake Engure in 1998 and this was later extended to other nature reserves in 2004 (Beintema 2001; AEWA 2018).
- *Liechtenstein (non-EU member)* Without regulation of lead ammunition.
- *Lithuania (EU member)* Hunting is forbidden in most important wetlands of the country (ECHA 2018), but there is no specific regulation of lead ammunition.
- *Luxemburg (EU member)* The use of lead shot for hunting in wetlands and 30 m around them has been banned since 2011 (AEWA 2015).
- *North Macedonia (non-EU member)* Without regulation of lead ammunition.
- *Malta (EU member)* There are no wetlands where hunting is permitted (ECHA 2018), but there is no specific regulation of lead ammunition.
- *Moldova (non-EU member)* Waterfowl hunting was prohibited during 2014–2015 in the state protected areas, including Ramsar sites where most of the SPAs are located. Hunting of migratory birds was prohibited during 2015–2017. A lead shot ban for hunting in all wetlands of international importance was also implemented during 2014–2016 according to the Association Agreement between Moldova and the EU (AEWA 2015, 2018). Without specific regulation of lead ammunition.
- *Monaco (non-EU member)* Without regulation of lead ammunition, but hunting is banned in all the territory.
- *Montenegro (non-EU member)* Without regulation of lead ammunition.
- *Netherlands (EU member)* The use of lead shot was banned nation-wide in 1993, and possession has been illegal since 1998: enforcement is carried out by the police (Kuivenhoven et al. 1998; Beintema 2001; AEWA 2015). Together with Denmark, it is the only European country with a total ban on lead shot for game. The Netherlands also regulate clay target shooting with lead shot (Thomas and Guitart 2013).
- *Norway (non-EU member)* Lead shot was banned for waterfowl hunting in 1991 (Beintema 2001) and this was extended to all types of hunting in 2005, but in 2015 the Norwegian parliament voted to permit again the use of lead shot for hunting non-wetland species (Knutsen et al. 2015; Arnemo et al. 2016).
- *Poland (EU member)* Without regulation of lead ammunition.
- *Portugal (EU member)* Lead shot has been partially banned for hunting in wetlands since 2010 (AEWA 2018).
- *Romania (EU member)* Without regulation of lead ammunition.
- *Russia (non-EU member)* Without regulation of lead ammunition.
- *San Marino (non-EU member)* Without regulation of lead ammunition.
- *Serbia (non-EU member)* Without regulation of lead ammunition.
- *Slovakia (EU member)* Lead shot has been banned for hunting in wetlands since 2015 (AEWA 2015).
- *Slovenia (EU member)* Without regulation of lead ammunition.
- *Spain (EU member)* The use and possession of lead shot was banned in Ramsar sites and other protected wetlands in 2001, and this was extended in 2007 to all the Natura 2000 wetlands. Before that, the use of lead shot for hunting in wetlands was banned in the regions of the Balearic Islands in 1995 and Castilla-La Mancha in 1999 (Mateo 2009). The use of lead bullets has been banned in Maestrazgo mountains in the region of Valencia (VCF 2018).

The effect of the ban on lead shot was monitored in the Ebro Delta, where lead shot ingestion in waterbirds had

been studied before the ban (Mateo et al. 2014). After effective ban starting in the Ebro Delta in 2003, the examination of the gizzards of 937 waterbirds harvested by hunters between 2007 and 2012 revealed a decrease in the prevalence of lead shot ingestion in 4 out of the 9 species studied with respect to the prevalence observed before the ban in 1991–1996. In particular, lead shot ingestion in mallards decreased significantly from a pre-ban value of 30.2% to 15.5% in the post-ban period (Mateo et al. 2014). These results can be explained by the good compliance by hunters of the lead shot ban. Hunted birds with only embedded Pb shot declined from 26.9% in 2007–2008 to < 2% over the following three hunting seasons after ban reinforcement implemented by Environmental Officers by controlling the ammunition carried by hunters in the wetlands. It was also probably important to undertake random monitoring of shot game via X-ray and retrieval and identification of the ammunition used to kill it, the result of which would have consequences for obtaining hunting permits in subsequent years. The partial ban facilitates the focus of enforcement in these important wetlands, but also leaves out of the regulation some important feeding areas around natural wetlands (i.e. rice fields in the case of the Ebro Delta). Regarding other effects of this regulation, there was a benefit in the reduction of the lead concentrations in the meat of hunted waterfowl. Only 2.5% of mallard muscle tissue had Pb levels above European Union regulations for meat (0.1 µg/g wet weight) in the 2008–09 season, when the prevalence of lead shot ingestion was also lowest (5.1%) (Mateo et al. 2014). The hunting bag of waterfowl in the Ebro Delta was similar before and after the ban on lead shot (Mateo et al. 2013).

- *Sweden (EU member)* Lead shot was banned first in Sweden for waterfowl hunting within Ramsar sites, and for all geese and ducks in 1998. In 2002, the Swedish government introduced a ban on lead ammunition intended to be fully implemented in 2008 (for wetlands in 2002, for lead shot everywhere in 2006, and for bullets in 2008) (AEWA 2005), but only the ban on the use of lead shot for hunting in wetlands was implemented on the expected date (AEWA 2018). Clay target shooting with lead shot is regulated (Thomas and Guitart 2013).
- *Switzerland (non-EU member)* A ban on the use of lead shot in shallow water areas and other wetlands was introduced in 1998 (Beintema 2001). In 2012, lead shot use was banned for the hunting of waterfowl in general, and is enforced by cantonal authorities (AEWA 2018).

- *Turkey (non-EU member)* Without regulation of lead ammunition.
- *Ukraine (non-EU member)* There is no regulation of lead ammunition, but a draft law has been prepared for the banning of lead shot use when hunting in wetlands of international importance (i.e. Ramsar sites), and has been submitted to the Ukrainian Parliament (Verkhovna Rada) for adoption (AEWA 2018).
- *United Kingdom (EU member)* Different regulations have been adopted by the different regions. In 1999, England banned shooting with lead shot on or over any area below high-water mark of ordinary spring tides, specific Sites of Special Scientific Interest, for certain waterbird species. The same regulation was adopted by Wales in 2002. Scotland banned lead shot for shooting on or over wetland areas in 2005. In Northern Ireland, there was initially a voluntary ban, but a statutory ban similar to the Scottish model was implemented in 2009 (AEWA 2008, 2015; Stroud 2015).

The compliance with the ban on lead shot for hunting over wetlands in England has been studied with hunted waterfowl purchased from game dealers between 2002 and 2014. Non-compliance, measured by the presence of embedded Pb shot in the purchased waterfowl during this period, varied between 68 and 77%, denoting low compliance with the ban (Cromie et al. 2015).

## CONCLUSIONS

Current regulations on lead ammunition in Europe differ between countries. For EU countries this may be partially reversed by future regulations under REACH. However, the migratory flyways of many of the avian species affected by lead poisoning (primarily waterbirds and raptors) are continental in range. Figures 1 and 2 indicate that protection of birds against lead poisoning from lead shot is limited to a small part of Europe. For wetland species, the regulations are more widespread, but there is a particular lack of protection in several countries of Eastern Europe, where migrating birds of the Black Sea/Mediterranean flyway pass and stage. In the case of lead bullets, regulation is limited to some German Federal States and some specific sites in Italy and Spain, which gives only a partial protection to some large eagles and avian scavengers. Finally, the international agreements (i.e. AEWA and UNEP/CMS) and supranational authorities (i.e. REACH/ECHA) are moving countries to regulate lead ammunition in all forms and for all types of hunting, but the way this ban on lead ammunition is produced (i.e. partial or total) can be a determinant for the compliance and success of the ban. Moreover, in most of the countries the use of lead shot is

still allowed for hunting waterbirds in their feeding sites out of wetlands, which may not reduce the risk of exposure to spent shot. Recent experience in Europe has shown how important is to improve the knowledge about the compliance with bans on lead ammunition, especially in those countries where both non-lead and lead ammunition are available in the market. Compliance can be monitored by direct examination of killed animals to check the type of ammunition used, but it can be also performed by monitoring the reduction of the lead exposure in the vulnerable species. Regulation, by itself, does not secure the protection of birds from lead poisoning unless there is strict law enforcement and a continuous field monitoring to confirm that lead poisoning is no longer an issue.

**Acknowledgements** We thank Anna Mazzolini, Alessandro Andreotti, Oliver Krone and Jovan Andevski their help with the information about the current regulations in some EU countries. We also thank two anonymous reviewers their comments and suggestions to improve this review.

## REFERENCES

- AEWA. 2005. Third Session of the Meeting of the Parties to the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA), 23–27 October 2005, Dakar, Senegal. [www.unep-awea.org](http://www.unep-awea.org). Accessed 23 Nov 2018.
- AEWA. 2008. 8th Meeting of the Technical Committee, 3–5 March 2006, Bonn, Germany. [www.unep-awea.org](http://www.unep-awea.org). Accessed 23 Nov 2018.
- AEWA. 2012. Resolution 5.231. AEWA's Contribution to Delivering the Aichi 2020 Biodiversity Targets. 5th Session of the Meeting of the Parties 14–18 May 2012, La Rochelle, France. [http://www.unep-awea.org/meetings/en/mop/mop5\\_docs/mop5\\_final\\_res.htm](http://www.unep-awea.org/meetings/en/mop/mop5_docs/mop5_final_res.htm). Accessed 23 Nov 2018.
- AEWA. 2015. Resolution 6.15. AEWA's Contribution to Delivering the Aichi 2020 Biodiversity Targets and Relevance of the Sustainable Development Goals. 6th Session of the Meeting of the Parties 9–14 November 2015, Bonn, Germany. [http://www.unep-awea.org/sites/default/files/document/awea\\_mop6\\_res15\\_cnr\\_aichi\\_en\\_0.pdf](http://www.unep-awea.org/sites/default/files/document/awea_mop6_res15_cnr_aichi_en_0.pdf). Accessed 23 Nov 2018.
- AEWA. 2018. 7th Session of the Meeting of the Parties (MOP7). National Reports. <https://www.unep-awea.org/en/meeting/7th-session-meeting-parties-awea>. Accessed 23 Nov 2018.
- Anderson, W.L., S.P. Havera, and R.A. Montgomery. 1987. Incidence of Ingested Shot in Waterfowl in the Mississippi Flyway, 1977–1979. *Wildlife Society Bulletin* 15: 181–188.
- Armeno, J.M., O. Andersen, S. Stokke, V.G. Thomas, O. Krone, D.J. Pain, and R. Mateo. 2016. Health and Environmental Risks from Lead-based Ammunition: Science Versus Socio-Politics. *Eco-Health* 13: 618–622.
- Bassi, E., M. Ferloni, A. Gugiatti, L. Pedrotti, M. Di Giancamillo, and G. Grilli. 2014. Il rischio di saturnismo negli uccelli necrofagi in relazione alle attuali modalità di caccia degli ungulati. In *Atti XVI Convegno Italiano di Ornitologia. Cervia (RA), 22–25 settembre 2011*, eds. R. Tinarelli, A. Andreotti, N. Baccetti, L. Melega, F. Roscelli, L. Serra, and M. Zenatello, 335–336. Scritti, Studi e Ricerche di Storia Naturale della Repubblica di San Marino.
- Beintema, N. 2001. *Lead Poisoning in Waterbirds. International Update Report 2000*. Wageningen, The Netherlands: Wetlands International.
- Berny, P., L. Vilagines, J.M. Cugnasse, O. Mastain, J.Y. Chollet, G. Joncour, and M. Razin. 2015. VIGILANCE POISON: Illegal Poisoning and Lead Intoxication are the Main Factors Affecting Avian Scavenger Survival in the Pyrenees (France). *Ecotoxicology and Environmental Safety* 118: 71–82.
- Carneiro, M.A., P.A. Oliveira, R. Brandão, O.N. Francisco, R. Velarde, S. Lavín, and B. Colaço. 2016. Lead Poisoning Due to Lead-Pellet Ingestion in Griffon Vultures (*Gyps fulvus*) from the Iberian Peninsula. *Journal of Avian Medicine and Surgery* 30: 274–279.
- Clausen, B. 1992. Lead Poisoning Control Measures in Denmark. In *Lead Poisoning in Waterfowl*, ed. D.J. Pain, 68–70. Slimbridge, UK: International Waterfowl and Wetland Research Bureau.
- Cromie, R., J. Newth, J. Reeves, M.O'Brien, K. Beckmann, and M. Brown. 2015. The Sociological and Political Aspects of Reducing Lead Poisoning from Ammunition in the UK: Why the Transition to Non-toxic Ammunition is so Difficult. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 104–124. Oxford, UK: Edward Grey Institute, The University of Oxford.
- ECHA. 2017. Adopted Opinions on Restriction Proposals. Lead compounds – Shot. EC Number: 231-100-4; CAS Number: 7439-92-1. Restriction Report, Opinions of ECHA Committees and Consultation Responses. European Chemicals Agency. <https://echa.europa.eu/previous-consultations-on-restriction-proposals/-/substance-rev/17005/term>. Accessed 23 Nov 2018.
- ECHA. 2018. The European Chemicals Agency (ECHA) Recommends that Measures are Needed to Regulate the Use of Lead Ammunition in Terrestrial Environments in Addition to Those Proposed for Wetlands. <https://echa.europa.eu/-/echa-identifies-risks-to-terrestrial-environment-from-lead-ammunition>. Accessed 23 Nov 2018.
- European Scientists. 2018. An Open Letter from European Scientist on the Risks on Lead Ammunition. <http://www.europeanscientists.eu/>. Accessed 20 Feb 2019.
- Gangoso, L., P. Alvarez-Lloret, A.A. Rodríguez-Navarro, R. Mateo, F. Hiraldo, and J.A. Donazar. 2009. Long-Term Effects of Lead Poisoning on Bone Mineralization in Vultures Exposed to Ammunition Sources. *Environmental Pollution* 157: 569–574.
- Gremse, C., and S. Rieger. 2015. Lead from Hunting Ammunition in Wild Game Meat: Research Initiatives and Current Legislation in Germany and the EU. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 51–56. Oxford, UK: Edward Grey Institute, The University of Oxford.
- Helander, B., J. Axelsson, H. Borg, K. Holm, and A. Bignert. 2009. Ingestion of Lead from Ammunition and Lead Concentrations in White-Tailed Sea Eagles (*Haliaeetus albicilla*) in Sweden. *Science of the Total Environment* 407: 5555–5563.
- Isomursu, M., J. Koivusaari, T. Stjernberg, V. Hirvelä-Koski, and E.R. Venäläinen. 2018. Lead Poisoning and Other Human-Related Factors Cause Significant Mortality in White-Tailed Eagles. *Ambio* 47: 858–868. <https://doi.org/10.1007/s13280-018-1052-9>.
- IUCN/WCC. 2016. International Union for the Conservation of Nature/World Conservation Congress 2016. Resolution 82. [https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC\\_2016\\_RES\\_082\\_EN.pdf](https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_082_EN.pdf). Accessed 20 Feb 2019.
- Kanstrup, N. 2006. Non-toxic Shot-Danish Experiences. In *Waterbirds Around the World*, eds. C.G. Boere, C.A. Galbraith, and D.A. Stroud, 861. Edinburgh, UK: The Stationery Office.

- Kanstrup, N. 2015. Practical and Social Barriers to Switching from Lead to Non-toxic Gunshot—A Perspective from the EU. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 98–102. Oxford, UK: Edward Grey Institute, The University of Oxford.
- Kanstrup, N. 2019. Lessons Learned from 33 Years of Lead Shot Regulation in Denmark. In *Lead in Hunting Ammunition: Persistent Problems and Solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. <https://doi.org/10.1007/s13280-018-1125-9>.
- Kanstrup, N., and T.J.S. Balsby. 2018. Plastic Litter from Shotgun Ammunition on Danish Coastlines—Amounts and Provenance. *Environmental Pollution* 237: 601–610.
- Kanstrup, N., and T.J.S. Balsby. 2019. Danish Pheasant and Mallard Hunters Comply with the Lead Shot Ban. In *Lead in Hunting Ammunition: Persistent Problems and Solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. <https://doi.org/10.1007/s13280-019-01152-7>.
- Kanstrup, N., V.G. Thomas, O. Krone, and C. Gremse. 2016. The Transition to Non-lead Rifle Ammunition in Denmark: National Obligations and Policy Considerations. *Ambio* 45: 621–628. <https://doi.org/10.1007/s13280-016-0780-y>.
- Kanstrup, N., J. Swift, D.A. Stroud, and M. Lewis. 2019. Hunting with Lead Ammunition is Not Sustainable: European Perspectives. *Ambio* 47: 846–857. <https://doi.org/10.1007/s13280-018-1042-y>.
- Kenntner, N., Y. Crettenand, H.-J. Fünfstück, M. Janovsky, and F. Tataruch. 2007. Lead Poisoning and Heavy Metal Exposure of Golden Eagles (*Aquila chrysaetos*) from the European Alps. *Journal of Ornithology* 148: 173–177.
- Kitowski, I., D. Jakubas, D. Wiącek, and A. Sujak. 2017. Concentrations of Lead and Other Elements in the Liver of the White-Tailed Eagle (*Haliaeetus albicilla*), a European Flagship Species, Wintering in Eastern Poland. *Ambio* 46: 825–841. <https://doi.org/10.1007/s13280-017-0929-3>.
- Knutsen, H.K., A.L. Brantsæter, J. Alexander, and H.M. Meltzer. 2015. Associations Between Consumption of Large Game Animals and Blood Lead Levels in Humans in Europe: The Norwegian Experience. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, C.J., 44–50. Oxford, UK: Edward Grey Institute, The University of Oxford.
- Krone, O., N. Kenntner, A. Trinogga, M. Nadjafzadeh, F. Scholz, J. Sulawa, K. Totschek, P. Schuck-Wersig, and R. Zieschank. 2009. Lead Poisoning in White-Tailed Sea Eagles: Causes and Approaches to Solutions in Germany. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 289–301. Boise, Idaho, USA: The Peregrine Fund.
- Kuivenhoven, P., J. van Vessel, and E. van Maanen. 1998. Saturnisme des oiseaux d'eau. Rapport d'actualisation internationale 1997. *Bulletin Mensuel de l'Office National de la Chasse* 229: 28–31.
- Martin, A., C. Gremse, T. Selhorst, N. Bandick, C. Müller-Graf, M. Greiner, and M. Lahrssen-Wiederholt. 2017. Hunting of Roe Deer and Wild Boar in Germany: Is Non-lead Ammunition Suitable for Hunting? *PLoS ONE* 12: e0185029.
- Mateo, R. 2009. Lead Poisoning in Wild Birds in Europe and the Regulations Adopted by Different Countries. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 71–98. Boise, Idaho, USA: The Peregrine Fund.
- Mateo, R., N. Vallverdú-Coll, A. López-Antia, M.A. Taggart, M. Martínez-Haro, R. Guitart, and M.E. Ortiz-Santaliestra. 2014. Reducing Pb Poisoning in Birds and Pb Exposure in Game Meat Consumers: The Dual Benefit of Effective Pb Shot Regulation. *Environment International* 63: 163–168.
- Mateo, R., N. Vallverdú-Coll, and M.E. Ortiz-Santaliestra. 2013. Intoxicación por munición de plomo en aves silvestres en España y medidas para reducir el riesgo. *Ecosistemas* 22: 61–67.
- Mateo-Tomás, P., P.P. Olea, M. Jiménez-Moreno, P.R. Camarero, I.S. Sánchez-Barbudo, R.C.R. Martín-Doimeadios, and R. Mateo. 2016. Mapping the Spatio-Temporal Risk of Lead Exposure in Apex Species for More Effective Mitigation. *Proceedings of the Royal Society B* 283: 20160662.
- MoEW (Ministry of Environment and Water). 2007. Biological Diversity Act. State Gazette. No.94/2007. National Assembly. Sofia, Bulgaria.
- Mondain-Monval, J.-Y., P. Defos du Rau, M. Guillemain, and A. Olivier. 2015. Switch to Non-Toxic Shot in the Camargue, France: Effect on Waterbird Contamination and Hunter Effectiveness. *European Journal of Wildlife Research* 61: 271–283.
- Oltrogge, V. 2009. Success in Developing Lead-Free, Expanding-Nose Centerfire Bullets. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 310–315. Boise, Idaho, USA: The Peregrine Fund.
- Pain, D.J., R.L. Cromie, and R.E. Green. 2015. Poisoning of Birds and Other Wildlife from Ammunition-Derived Lead in the UK. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 58–84. Oxford, UK: Edward Grey Institute, The University of Oxford.
- Rodríguez-Ramos, J., V. Gutiérrez, U. Höfle, R. Mateo, L. Monsalve, E. Crespo, and J.M. Blanco. 2009. Lead in Griffon and Cinereous Vultures in Central Spain: Correlations between Clinical Signs and Blood Lead Levels. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 235–236. Boise, Idaho, USA: The Peregrine Fund.
- Stroud, D.A. 2015. Regulation of Some Sources of Lead Poisoning: A Brief Review. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 8–26. Oxford, UK: Edward Grey Institute, The University of Oxford.
- Thomas, V.G. 2013. Lead-Free Hunting Rifle Ammunition: Product Availability, Price, Effectiveness, and Role in Global Wildlife Conservation. *Ambio* 42: 737–745. <https://doi.org/10.1007/s13280-012-0361-7>.
- Thomas, V.G. 2015. Availability and Use of Lead-Free Shotgun and Rifle Cartridges in the UK, with Reference to Regulations in Other Jurisdictions. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 85–97. Oxford, UK: Edward Grey Institute, The University of Oxford.
- Thomas, V.G. 2016. Elemental Tungsten, Tungsten–Nickel Alloys and Shotgun Ammunition: Resolving Issues of Their Relative Toxicity. *European Journal of Wildlife Research* 62: 1–9.
- Thomas, V.G. 2019. Chemical Compositional Standards for Non-lead Hunting Ammunition and Fishing Weights. In *Lead in Hunting Ammunition: Persistent Problems and Solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. <https://doi.org/10.1007/s13280-018-1124-x>.
- Thomas, V.G., and R. Guitart. 2013. Transition to Non-toxic Gunshot Use in Olympic Shooting: Policy Implications for IOC and UNEP in Resolving an Environmental Problem. *Ambio* 42: 746–754. <https://doi.org/10.1007/s13280-013-0393-7>.

- Thomas, V.G., N. Kanstrup, C. Gremse. 2015. Key Questions and Responses Regarding the Transition to Use of Lead-Free Ammunition. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and Minimizing the Risks to Human and Environmental Health*, eds. R.J. Delahay, and C.J. Spray, 125–134. Oxford, UK: Edward Grey Institute, The University of Oxford.
- UNEA. 2017. Third Meeting of the UN Environment Assembly (UNEA)—Resolution UNEP/EA.3/Res.4. <https://papersmart.unon.org/resolution/uploads/k1800154.english.pdf>. Accessed 20 Feb 2019.
- UNEP/CMS 2014. UN Convention on Migratory Species (CMS) Resolution 11.15—Preventing Poisoning of Migratory Birds. [https://www.cms.int/sites/default/files/document/cms\\_cop12\\_res.11.15%28rev.cop12%29\\_bird-poisoning\\_e.pdf](https://www.cms.int/sites/default/files/document/cms_cop12_res.11.15%28rev.cop12%29_bird-poisoning_e.pdf). Accessed 20 Feb 2019.
- VCF. 2018. Lead Ammunition Banned from Maestrazgo—Significant Breakthrough in Our Most Recent Bearded Vulture Reintroduction Project. Vulture Conservation Foundation. <https://www.4vultures.org/lead-ammunition-banned-in-valencia>. Accessed 20 Feb 2019.

### Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

### AUTHOR BIOGRAPHIES

**Rafael Mateo** (✉) is a doctor in Veterinary Medicine from the University of Barcelona (UAB). He is a wildlife toxicologist at the Institute for Game and Wildlife Research (IREC) and has been the director of this institute since 2015. His research is focused on the study of the effect of toxic substances of diverse origin on wildlife. *Address:* Instituto de Investigación en Recursos Cinegéticos (IREC), CSIC-UCLM-JCCM, Ronda de Toledo 12, 13005 Ciudad Real, Spain  
e-mail: rafael.mateo@uclm.es

**Niels Kanstrup** is a Danish biologist, scientist and hunter. He has been working with the Danish Hunters' Association and has been the President of the CIC Migratory Bird Commission and a member of the AEWA technical Committee, and during his whole career worked with sustainability of hunting and focused particularly on the issue of lead in hunting ammunition. He is an independent consultant in nature management and an adjunct senior scientist connected to Aarhus University, Department of Bioscience at Kalø. *Address:* Department of Bioscience, Institute for Bioscience – Kalø, Aarhus University, Grenåvej 12, 8410 Rønde, Denmark.  
e-mail: nk@bios.au.dk

# PAPER 3

## TITLE:

Pain, DJ, Dickie I, Green, RE, Kanstrup N, Cromie R (2019). Wildlife, human and environmental costs of using lead ammunition: an economic review and analysis. *Ambio* 48(9): 969-988. Special Issue: LEAD USE IN HUNTING. Online 16 March 2019. DOI: 10.1007/s13280-019-01157-2

**RIGHTS:** Open access

## AUTHORS' CONTRIBUTIONS:

To whom it may concern,

This is just to confirm that the contribution of Niels Kanstrup to the paper listed below, of which I am first author, was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Pain, D.J., Dickie, I., Green, R. E., Kanstrup, N. & Cromie, R. 2019. Wildlife, human and environmental costs of using lead ammunition: an economic review and analysis. *Ambio* 48(9): 969-988. Special Issue: LEAD USE IN HUNTING. Online 16 March 2019. DOI: 10.1007/s13280-019-01157-2

Yours sincerely

Deborah Pain

Professor Deborah Pain

[dp596@cam.ac.uk](mailto:dp596@cam.ac.uk)

<https://www.zoo.cam.ac.uk/directory/debbie-pain>

This is just to confirm that the contribution of Niels Kanstrup to the paper listed below, of which I am an author, was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Pain, D.J., Dickie, I., Green, R. E., Kanstrup, N. & Cromie, R. 2019. Wildlife, human and environmental costs of using lead ammunition: an economic review and analysis. *Ambio* 48(9): 969-988. Special Issue: LEAD USE IN HUNTING. Online 16 March 2019. DOI: 10.1007/s13280-019-01157-2

Sincerely,

Ian

Ian Dickie

**eftec**

Economics For The Environment Consultancy

3<sup>rd</sup> Floor, 4 City Road

London EC1Y 2AA

tel: 44(0)2075805383

mob: 44(0)7740512593

[www.eftec.co.uk](http://www.eftec.co.uk)

*Conservation Science Group, Downing Street, Cambridge CB2 3EJ, UK*

email: [reg29@cam.ac.uk](mailto:reg29@cam.ac.uk)

Web: <http://www.zoo.cam.ac.uk/zoostaff/green.htm>

Phone: 01223 762840 (direct line) Fax: 01223 336676

---

13 April 2021

Aarhus University  
Denmark

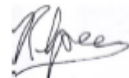
To Whom it may Concern

This letter is to confirm that Niels Kanstrup made substantial contributions to this paper, of which I am a co-author.

Pain, D.J., Dickie, I., Green, R. E., Kanstrup, N. & Cromie, R. 2019. Wildlife, human and environmental costs of using lead ammunition: an economic review and analysis. *Ambio* 48(9): 969-988. Special Issue: LEAD USE IN HUNTING.  
Online 16 March 2019. DOI: 10.1007/s13280-019-01157-2

Niels Kanstrup contributed to this publication by discussing and planning the paper in advance and by reviewing and editing drafts by critical review and commentary.

Yours sincerely



Professor Rhys E. Green

To Whom it may Concern

This letter is to confirm that Niels Kanstrup made substantial contributions to this paper, of which I am a co-author.

Pain, D.J., Dickie, I., Green, R. E., Kanstrup, N. & Cromie, R. 2019. Wildlife, human and environmental costs of using lead ammunition: an economic review and analysis. *Ambio* 48(9): 969-988. Special Issue: LEAD USE IN HUNTING. Online 16 March 2019. DOI: 10.1007/s13280-019-01157-2

Niels contributed to this publication by discussing and planning the paper in advance and by reviewing and editing drafts by critical review and commentary.

Yours faithfully,



**Dr. Ruth Cromie,**  
Research Fellow

**Wildfowl & Wetlands Trust (WWT)**  
Slimbridge, Glos GL2 7BT, UK

**M** 07866 942999  
**E** [ruth.cromie@wwt.org.uk](mailto:ruth.cromie@wwt.org.uk)  
**W** [wwt.org.uk](http://wwt.org.uk)

Confirmed, April 2021



Niels Kanstrup

# Wildlife, human and environmental costs of using lead ammunition: An economic review and analysis

Deborah J. Pain , Ian Dickie, Rhys E. Green, Niels Kanstrup, Ruth Cromie

Received: 27 November 2018 / Revised: 29 January 2019 / Accepted: 4 February 2019

**Abstract** A proposed European Union (EU)-wide restriction on the use of lead gunshot for shooting in and over wetlands estimated that the societal benefits of a restriction outweighed costs, despite few identified benefits being quantified economically. A subsequent Annex XV Investigation Report on the evidence of impacts of lead ammunition in terrestrial environments concluded that additional measures to control its use are warranted, although to date this has not been further evaluated. To help inform this process, we review the literature and undertake new analyses to estimate the costs of continued use of lead ammunition associated with impacts on wildlife, people and the environment. We estimate minimum annual direct costs across the EU and Europe of c. €383 million–€960 million and €444 million–€1.3 thousand million respectively. The value that society places on being able to avoid these losses, estimated using a ‘willingness to pay’ approach, was c. €2.2 thousand million for wildfowl alone. Our estimated costs of the continued use of lead ammunition across the EU appear to be considerably greater than the likely costs of switching to non-toxic alternative ammunition types, although these have not been formally estimated in full.

**Keywords** Birds · Bullets · Evaluation · Financial · Gunshot · Society

## INTRODUCTION

Due to the high toxicity of lead and the public and environmental health problems it causes, most releases of lead

into the environment are strictly regulated in Europe (e.g. see AMEC 2012). However, shooting continues to release tens of thousands of tonnes of lead ammunition (gunshot and bullets) into the European environment annually, contaminating soil and water and putting at risk the health of wild birds that ingest spent ammunition directly, and both wildlife and people that eat lead ammunition or fragments of it in their food. While limited regulations exist requiring the replacement of lead with non-toxic ammunition in some parts of the world and for certain types of shooting, these do not adequately control the risks (see Green and Pain 2012, 2015; Pain et al. 2015, 2019). In Europe, a few countries banned the use of lead gunshot decades ago (e.g. Denmark and the Netherlands), but in most EU Member States, controls are partial, piecemeal, and not always complied with (Cromie et al. 2015). Based on the overwhelming evidence of the toxic effects of lead from ammunition in wildlife and the risks to human health, scientists (Bellinger et al. 2013; Group of Scientists 2014) and Multilateral Environmental Agreements (AEWA 1999; CMS 2014; IUCN 2016), have called for the replacement of lead ammunition with non-toxic alternatives. The European Commission requested the European Chemicals Agency (ECHA) to prepare an Annex XV report proposing a restriction on lead gunshot in wetlands under the EU REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) Regulation. The report was reviewed and adopted by ECHA’s expert scientific committees (including the Committee for Socio-Economic Analysis) in June 2018, prior to being considered by the REACH Committee (comprising Member State representatives) before adoption into law.<sup>1</sup> Concurrently, ECHA published an Annex XV Investigation Report on the

<sup>1</sup> This process was still underway February 2019.

evidence of impacts of lead ammunition in terrestrial environments (ECHA 2018a) which recommends that additional measures are needed to regulate the use of lead ammunition in terrestrial environments and lead fishing weights. While the costs of replacing lead gunshot with non-toxic alternatives have been widely considered (e.g. AMEC 2012), there have been only a few incomplete attempts at quantifying the costs of continued use of lead ammunition (e.g. Andreotti et al. 2018). Hence, the net costs/benefits of restriction remain uncertain.

In this paper, we review cost estimates in the peer-reviewed and grey literature, including consultation responses to the ECHA restriction proposal (ECHA 2017b, 2018c) and add new analyses of the costs to society of continued use of lead ammunition. New analyses include replacement costs of four species of raptors in the EU and Europe, replacement costs of several species of terrestrial birds in the UK, and costs of potential reductions in IQ in children in the EU, resulting from frequent consumption of wild game shot with lead. We also highlight other as yet unquantified costs. This paper is not exhaustive but aims to give an indication of the types and magnitudes of some of the main costs of continued use of lead ammunition to society.

## ASSESSMENT OF COSTS ASSOCIATED WITH THE USE OF LEAD-BASED AMMUNITION

### Costs associated with impacts on wildlife

Lead poisoning from ammunition sources affects a wide range of different species, but most research has involved birds. This has been reviewed by numerous authors, updated by Pain et al. (2019). Wildfowl (ducks, geese and swans) ingest spent lead gunshot while feeding, mistakenly for food items or the grit that they deliberately ingest and retain in a muscular part of their stomach, the gizzard, to help break down their food. Other birds that directly ingest spent gunshot include other waterbird species (e.g. cranes and flamingos) and terrestrial birds including gamebirds like partridges and pheasants, pigeons and doves. Another route of exposure occurs in predatory or scavenging birds, whose food includes species that are shot as pests or for food or sport. Raptors and scavenging birds can eat shot, bullets or fragments thereof in shot animals that have been wounded and survived (and thus may be more vulnerable to being taken by a predator) or unretrieved carcasses. As a common practice, parts of carcasses of large game animals, like deer viscera, are removed and left in the countryside when the animal is retrieved. These may contain fragments of ammunition. Recent evidence indicates that mammalian predators and scavengers may similarly be exposed to

dietary lead derived from ammunition (reviewed in Pain et al. 2019), but this has not been widely investigated. Finally, some birds with lead ammunition shot into their bodies are not killed by it immediately, but their subsequent welfare and survival may be adversely affected. In addition to the wildlife killed directly by lead poisoning, several times more animals suffer welfare effects from sublethal poisoning (Andreotti et al. 2018) and may have increased susceptibility to other diseases or accidents (Kelly and Kelly 2005; Ecke et al. 2017).

The costs to society of sublethal poisoning and mortality of wildlife are difficult to evaluate, but the question can be approached in a variety of ways. These ways include estimating the

- Costs of *replacing* birds that have died. This could be through captive breeding and release or other means of increasing the populations.
- Costs of *treating* poisoned birds.
- Costs of *losing the services* provided by the wildlife, including tourism, hunting for food or sport and improvement of environmental health.
- Willingness of society to pay* to avoid these impacts—a way of estimating the value of wildlife to people.

These approaches are described below.

### Replacement costs

(i) *Wildfowl* For 16 of species of wildfowl for which sufficient information was available, Andreotti et al. (2018) estimated that about 700 000 individuals die from acute lead poisoning annually in the EU (6.1% of the wintering population) and one million across Europe (7.0%). Three times more birds were estimated to suffer sublethal effects. These authors estimated the economic loss of the acute mortality by calculating the replacement costs through buying and releasing captive-bred birds, taking account of the high mortality rate of captive birds (72.7%) in the months following release into the wild. This was estimated at an annual cost of €105 million in the EU and €142 million across Europe. These figures are for 16 species only and do not include species for which there were insufficient data. Deaths caused indirectly by lead poisoning and effects on reproduction were excluded and if included would increase the estimated losses.

It is notable that of the 150 migratory waterbird species listed under the African-Eurasian Waterbird Agreement (AEWA) which regularly occur within the EU, two thirds (100 species) are considered to be vulnerable to lead poisoning from spent lead shot based upon research and surveillance (where available) and knowledge of feeding behaviour and habits (AEWA 2017). Lead poisoning is a threat to 23 wildfowl species with unfavourable

**Table 1** Estimated replacement costs of common pheasants and red-legged partridges affected by lead shot from ammunition sources in the UK

	% hunter shot birds with ingested shot	Number of shot ingested <sup>a</sup>	Hunting bias correction <sup>b</sup>	Percentage with ingested gunshot after hunting bias correction	Percentage with ingested shot corrected for turnover <sup>c</sup>	Increase in annual mortality for birds with ingested shot <sup>d</sup>	Percentage of population estimated as dying <sup>e</sup>	Population <sup>f</sup>	Number of birds estimated as dying	Cost of replacement	References
Pheasant	3.0	1	1.5	2.00	12.4	0.045	0.558	37 800 000	210 924	€3.132 million	Butler et al. (2005)
Red-legged partridge	1.4	1	1.5	0.93	7.2	0.045	0.323	6 665 000	21 478	€0.319 million	Butler (2005)
Total									232 402	€3.451 million	

Assumptions:

<sup>a</sup>As we do not know how many shot are ingested, we assume that only one shot is ingested

<sup>b</sup>We assume that the increased likelihood of a hunter killing a terrestrial gamebird that has ingested a lead gunshot is the same as a mallard that has ingested a lead gunshot. If terrestrial gamebirds are less sensitive to the effects of lead, then hunters will be less likely to kill a pheasant that has ingested lead

<sup>c</sup>We use a hunting season of 124 days in the UK for pheasant (1 Oct–1 Feb) and 154 days for red-legged partridge (1 September–1 February) and a turnover rate of shot in the gizzard of 20 days—i.e.  $124/20 = 6.2$  for pheasant;  $154/20 = 7.7$  for red-legged partridge

<sup>d</sup>Due to the possibility of decreased sensitivity of terrestrial gamebirds to lead-shot impacts, we have used an arbitrary increase in annual mortality caused by lead-shot ingestion of 50% of that calculated for mallard (Bellrose 1959)

<sup>e</sup>Percentage with ingested shot corrected for hunting bias and turnover multiplied by increase in annual mortality

<sup>f</sup>Assumes that 35 million pheasants and 6.5 million red-legged partridges are released each year (PACEC 2006), although this is likely to be an underestimate as numbers of released birds are reported to have increased (Aebischer 2013). We added on breeding numbers from Musgrove et al. (2013) assuming a ratio of male to breeding female pheasants of 1:4.6 and that each red-legged partridge territory equalled 2 birds. We multiplied by the production cost of each pheasant released of €14.85 (£12.55; Savills 2017), and assumed that this was similar for red-legged partridges

conservation status for which single species action plans have been written (Kanstrup et al. 2018). Replacement costs for all affected waterbird species would therefore be considerably higher than these estimates.

(ii) *Terrestrial gamebirds* Although terrestrial gamebirds ingest shot, suffer sublethal effects and can die of lead poisoning, it is more difficult to estimate numbers that die of lead poisoning each year. This is primarily because little information exists on their sensitivity to lead poisoning and fewer studies have been conducted on them. However, of these, several suggest that some terrestrial gamebirds may be less sensitive to the effects of lead poisoning than wildfowl (Gasparik et al. 2012; Runia and Solem 2017). In the UK, sufficient information exists to calculate, in broad terms, potential gamebird mortality from lead poisoning and how much it would cost to replace birds lost, based upon levels of shot ingestion and production costs of reared and released pheasants (*Phasianus colchicus*). Table 1 outlines our calculation of replacement costs. Our estimates of mortality are based on a method used by Bellrose (1959) to estimate lead poisoning mortality in wildfowl. Due to the uncertainties mentioned above, and because some gamebirds that might otherwise die from lead poisoning are shot before they can do so, we have been conservative in our terrestrial gamebird mortality estimates in several ways (Table 1). For example, we have assumed that gamebirds ingest only one shot (while pheasants are known to frequently ingest multiple shot, for

example, Runia and Solem 2016) and that mortality from lead poisoning following shot ingestion is an arbitrary 50% of that estimated for mallards (*Anas platyrhynchos*). Consequently, while terrestrial bird mortality could still be smaller than our estimate, it is perhaps more likely to be greater. In contrast, a bias that would result in our estimate of lead poisoning mortality being too high results from the substantial non-shooting mortality of captive-bred birds in the first few weeks post-release (Madden et al. 2018); this would result in many fewer birds surviving to be exposed to lead poisoning. Ideally, we would wish to estimate lead poisoning mortality based upon numbers of birds that survive for different periods post release, and would also correct for the fact that not all pheasants are released simultaneously. These biases in both directions highlight that our estimate should be considered only as a very broad indicator of the possible magnitude of lead-poisoning-related costs. We estimate that, in the UK, 232 402 pheasants and red-legged partridges (*Alectoris rufa*) may die as a direct result of lead poisoning each year. We multiplied this by the cost of producing and releasing a pheasant to arrive at an estimated annual replacement cost of over €3 million in the UK (Table 1). This is a broad approximate estimate rather than a precise estimate and does not include the contribution of sublethal lead poisoning to increased levels of mortality from other causes. We have been unable to find EU-wide figures for numbers of terrestrial gamebirds released and rearing costs.

**Table 2** Estimated replacement costs of selected raptor species killed by lead poisoning from ammunition sources in the European Union and throughout Europe

Species	Population (pairs) EU; Europe <sup>a</sup>	Annual adult survival <sup>b</sup>	Numbers of adults (individuals) estimated to die annually EU; Europe	Percentage of mortality estimated from lead poisoning <sup>c</sup>	Numbers of adults estimated to die annually from lead poisoning EU; Europe	Replacement cost (€48 108 per adult) EU; Europe	Replacement cost (€661 284 per adult) EU; Europe	References
White-tailed eagle	4202; 10 650	0.90–0.95	420–840; 1066–2130	22	92–184; 234–468	€4.4–8.9 million; €11.3–22.5 million	€61.1–122.3 million; €154.9–309.9 million	Isomursu et al. (2018) [Finland], Krone et al. (2009) [Germany], Nadjafzadeh et al. (2013) [Germany], Helander et al. (2009) [Sweden]
Golden eagle	5300; 10 800	0.87	1378; 2808	5–10	69–138; 140–281	€3.3–6.6 million; €6.8–13.5 million	€45.6–91.1 million; €92.8–185.7 million	Ganz et al. (2018) [Swiss Alps], Ecke et al. (2017) [Sweden], Russel and Fransson (2014) [USA], Langner et al. (2015) [USA]
Griffon vulture	32 350; 33 400	0.97 (released—long-term estimate)	1941; 2004	2.5	49; 50	€2.3 million; €2.4 million	€32.1 million; €33.1 million	Berny et al. (2015) [French Pyrenees]
Red kite <i>Milvus milvus</i>	27 950; 29 300	0.92 (3rd year in absence of illegal killing)	4472; 4688	7.15	320; 335	€15.4 million; €16.1 million	€211.4 million; €221.7 million	Molenaar et al. (2017) [England], Berny et al. (2015) [French Pyrenees]
Total—EU; Europe					530–691; 760–1135	€25.4–33.2 million; €36.6–54.5 million	€350.2–456.9 million; €502.5–750.4 million	

<sup>a</sup>Adult populations (pairs) from BirdLife International (2015). The European Red List of Birds Supplementary Material. Adults are given as no or limited information is available for immature birds. However, total population sizes, estimates of numbers of birds that will die of lead poisoning, and replacement costs would be considerably larger

<sup>b</sup>Recent survival estimates used where possible. Where possible, these are for stable or increasing populations. This will result in an underestimate of mortality and costs

<sup>c</sup>For white-tailed eagles, 22% of 740 dead birds is the average from four large studies in Finland, Germany and Sweden. For golden eagles, 9% of 55 birds in the Swiss Alps had liver Pb > 6 mg/kg (up to 80 mg/kg), and 30% of 46 birds had bone Pb > 20 mg/kg. We use a range of 5–10%, as has been found in the USA. For griffon vultures, a recent surveillance programme (French Pyrenees) reported 2.5% of 119 dead birds as lead poisoned. For red kites, 5.5% of 110 red kites (England) and 8.8% of 34 dead birds in the French Pyrenees died from lead poisoning (midpoint of 7.15%). Both immature and adult birds are included in these estimates

<sup>d</sup>These are minimum costs because of the assumptions above<sup>a,b</sup>. Costs are based on an analysis of what are considered to be cost-effective (supplementary feeding and translocation) and more costly (breeding and reintroduction) methods of replacing birds lost. These are based on Ferrer et al. (2017) who calculated that for a standard reintroduction programme of bearded vultures, releasing 10 young per year during 10 years, each one of the released young bred in captivity costs around €146 805 compared with €10 680 for each young bird that originated from a food-supplemented wild population. The activities undertaken to reintroduce or supplement populations of many raptor species, and thus their costs, are broadly similar. The proportion of fledgling birds that survive to reproductive age has been shown to be relatively constant in wild bird populations (Ricklefs 2000; see also Fig. 7.1 of Green 2002), with a mean value of 0.222. To obtain the cost of replacing one dead adult, we therefore divided the cost of producing an immature by 0.222 to give replacement costs per adult of €661 284 and €48 108, respectively

(iii) *Predatory and scavenging raptors* Table 2 gives our minimum estimated annual costs of replacing individuals of four of the 16 species of raptor (Pain et al. 2019—Table 2) known to be susceptible to lead poisoning in Europe. While many more raptor species die of lead poisoning, insufficient data were available to estimate replacement costs in other species. Estimates of numbers of individuals that die from lead poisoning annually were based on EU or European population size of breeding pairs, mean annual adult survival, and the percentage of mortality estimated to be from lead poisoning taken from relevant studies. Replacement costs were based on an analysis of the costs of releasing immature raptors to the wild for reintroduction or population supplementation (Ferrer et al. 2017) and range from what are considered to be very cost effective (supplementary feeding and translocation) and more costly (breeding and reintroduction) methods. These figures were then scaled to account for the proportion of fledgling birds that survive to reproductive age.

We estimate annual replacement costs to be €25–457 million in the EU and €37–750 million in Europe for these four species alone. The wide range takes into account different approaches to replacing wild birds, from supplementary feeding and translocation (€48 108 per adult bird) to captive breeding and reintroduction (€661 284 per adult bird). Minimum costs are likely to be between the middle and upper ends of this range because even the costs of the generally cheaper population supplementation method can fall in the middle of this range, as illustrated by a recent golden eagle (*Aquila chrysaetos*) population supplementation project in Scotland (Pinkstone 2017). Notably, it is not always possible to supplementary feed wild birds to increase productivity and translocate additional young.

Our estimates should also be considered as minima because immature birds as well as adults die from lead poisoning and survival estimates used tended to be for stable/increasing populations and may underestimate overall mortality.

#### Treatment costs

An alternative to replacing wildfowl lost to lead poisoning would be to find and treat all poisoned birds. For wildfowl, treatment costs would be approximately €1 000<sup>2</sup> a bird covering an anaesthetic and X-ray, blood test for diagnosis, five days of hospitalisation with lead-chelation therapy and one more accompanying blood test. This is likely to be a minimum level of treatment. Treating the 1 million wildfowl estimated to die in Europe each year would therefore cost c. €1 thousand million a year and with the additional 3 million wildfowl that

suffer sublethal effects would cost €4 thousand million a year. However, finding, catching and treating all such birds is not a practical proposition even were financial resources available as it would only be possible to find a small proportion of poisoned birds in a condition that would allow for their treatment prior to death. It is difficult to estimate with any precision the proportion of birds potentially treatable, so in order to generate indicative costs, we assume here that 1% of all lead-poisoned birds could be treated. Assuming 1% of the estimated 1 million wildfowl dying every winter in Europe could be treated, this equates to avoided costs of €10 million per year. Treatment costs for 1% of the million birds that die plus 1% of the 3 million additional birds estimated to suffer welfare effects from lead poisoning would be €40 million per year (€28 million a year for wildfowl in the EU). Treating and thus potentially avoiding the deaths of 1% of all poisoned wildfowl would be largely additional to replacement costs as welfare organisations would treat sick and dying birds irrespective of replacement.

These figures are substantial underestimates as the costs of finding sick birds are likely to be greater than treatment costs and these have not been included. We have not estimated costs of treating raptors, other scavengers or terrestrial birds.

#### Costs of services lost

Wild birds provide a large number of services to society, some of which are outlined below.

(i) *Birdwatching* Many people across Europe enjoy birdwatching. In the UK alone, six million people were reported to enjoy birdwatching every couple of weeks (Kellaway 2009). People benefit physically and mentally from walking in greenspaces of high natural value and from exposure to birds and other nature (e.g. Barton et al. 2009; Cox et al. 2017, 2018), and many industries benefit economically from birdwatching including optics (binoculars, telescopes and cameras), publishing, bird food, tourism and associated industries. While it is difficult to quantify the economic impact on human health and well-being of the reduction in quality of the natural environment caused by the avoidable loss of birds due to lead poisoning, other economic values are more readily quantified. For example, white-tailed eagles (*Haliaeetus albicilla*) were driven to extinction in Scotland at the beginning of the twentieth century largely as a result of persecution, and were first reintroduced to Scotland in 1975. Surveys on the Scottish Isle of Mull conducted in 2010 found that up to £5 million (€5.9 million<sup>3</sup>) of tourist spend was attracted every

<sup>2</sup> Based on €60 for vet examination, €315 for anaesthetic and X-ray, 2 × €126 for blood test, €315 for 5 day hospitalisation and €88 for chelation therapy.

<sup>3</sup> Throughout the paper, figures have been presented in £ when this was the currency of the original publication cited, with a € conversion given using an exchange rate of £1 = €1.18 (November 2018).

year by the (at the time) 14 pairs of white-tailed eagles that had recolonised the island; 110 jobs were supported by this spend each year, and £1.4 million (€1.65 million) of local income was supported each year (Molloy 2011). In many parts of the white-tailed eagle's range, lead poisoning is an important mortality factor (Table 2). Applying the average figures for annual adult survival and loss to lead poisoning for white-tailed eagles across Europe (Table 2) would give an estimated loss to the local economy of the Isle of Mull, with a population of just 3000 people, of £82 500 (€97 350) (annual survival of 0.925, 22% of mortality from lead poisoning equates to 0.462 adult breeding birds lost to lead poisoning annually, with a value of £5 million (€5.9 million) for 28 adult breeding birds). This figure is simply illustrative, as average survival and lead-poisoning figures from across Europe do not necessarily apply to the eagle population on the Isle of Mull, but gives an indication of the potential value of even small numbers of raptors to local communities.

Specific birdwatching opportunities and general interest in birds also generate revenue. Examples are goose-watching in Scotland, estimated at £1.5 million (€1.77 million) a year more than 20 years ago (Rayment et al. 1998). More generally, in 2015, there were around 2.2 million individuals and family members of BirdLife partner-organizations in the EU, Norway, Iceland and Liechtenstein (BirdLife International 2018). Members of the 10 EU BirdLife partner-organisations with the most members spend a total of €126 million a year in fees (BirdLife International 2018). In addition, there are many other conservation organisations across Europe members of which have an interest in birds. While it is not easy to use these figures to ascribe a value to the loss of birds to lead poisoning, it highlights some of the value that people place upon birds—further reinforced by a 'willingness to pay' (WTP) study—illustrated below.

(ii) *Hunting for sport or food* Game species of wetland and terrestrial birds provide leisure hunting opportunities and harvest opportunities for meat or for feathers. Andreotti et al. (2018) estimated the annual cost of the opportunities lost for hunting caused by mortality in the 16 wildfowl species to be €129 million in the EU and €185 million across Europe. In the 2017/18 season, about 38% of pheasants and red-legged partridges released in the UK were shot and the average income per bird shot was c. £36 (€42.5—Savills 2017). Therefore, income lost in the UK as a result of lead-poisoning deaths of an estimated 232 402 pheasants and partridges (see above) would be an estimated £3.18 million (€3.75 million).

(iii) *Environmental and human health* Wild birds support environmental health in variety of ways, a clear example being that of scavenging raptors, which remove potentially biohazardous material from our environment

(summarised by Birdlife International 2018). Vultures, as scavengers, are particularly vulnerable to the ingestion of lead from ammunition in the carcasses of dead large game animals, and losing their services comes at a cost. As an example, following an outbreak of bovine spongiform encephalopathy (BSE) in 2001 and the detection of Creutzfeldt–Jakob disease in humans, sanitary legislation (Regulation EC 1774/2002) was passed in the EU requiring that domestic animal carcasses be collected from farms and transformed for use for industrial purposes or destroyed in authorised plants. This reduced the food supply for the vultures that had traditionally relied in part on the flesh of domestic livestock for their food, consequently providing an important environmental health service. Morales-Reyes et al. (2015) estimated that in Spain (which holds 90% of European vultures—BirdLife International 2015), carcass collection and transport to processing plants resulted in additional emissions of 77 344 metric tons of CO<sub>2</sub> eq. to the atmosphere per year, plus payments by farmers and regional/national administrations ca. \$50 million (€44 million)<sup>4</sup> to insurance companies for livestock carcass removal and processing in 2012. Although new legislation (Regulation EC 142/2011) in 2011 allowed for disposal of carcasses in set areas where vultures could feed, this analysis illustrates the economic value of the disposal service and avoided CO<sub>2</sub> emissions provided by vultures. In France, it is estimated that livestock carcass removal by 900 pairs of griffon vultures (*Gyps fulvus*) saves the public purse €440 000 a year (Orabi 2011). In India, massive population declines in three species of *Gyps* vulture were estimated to have associated human health costs (resulting from increases in feral dogs, dog bites and human rabies cases) of US\$ 34 thousand million (€29.92 thousand million) between 1993 and 2006 (> \$2 thousand million—€1.76 thousand million—a year; Markandya et al. 2008).

(iv) *Other Services* Many species help with the dispersal of plants and lower organisms supporting ecosystem functioning. Waterbirds alone provide a range of key services via their roles in many aquatic ecosystems (Green and Elmberg 2014). These include as predators (including of 'pest' species), herbivores and vectors of seeds, invertebrates and nutrients. Many species can be effective sentinels of potential disease outbreaks and bioindicators of ecological conditions. While we have not attempted to estimate the value of the services lost as a result of lead

<sup>4</sup> Throughout the paper, figures have been presented in \$ when this was the currency of the original publication cited, with a € conversion given using an exchange rate US\$1 = €0.88 (November 2018).

**Table 3** Value transfer—comparing policy good context and study good context(s)

Selection criteria	Hanley et al. (2001)	ECHA policy site and good	Conclusion
I. Similarity of the study good and policy good	Avoided loss of goose populations	Avoided loss in all species of wildfowl populations (due to decrease in lead poisoning mortality)	Similar
II. Similarity of the change in provision of the study good and policy good	10% population decrease	6.1% population decrease	Adjust values for different % level of loss
III. Similarity of the sites where the study good and policy good are found	Goose habitats across Scotland, UK	Wildfowl habitats across EU Member States	Similar
IV. Similarity of the affected human populations	Scotland population (households) 2001	EU population (households) 2017	Sites are similar, but adjust for number of households, and disposable income per household
V. Similarity of the number and quality of substitutes for the study good and policy good	Substitutes (other wildfowl and bird species are conserved)	Some substitutes (other bird species are conserved)	Similar
VI. Similarity of the study good and policy good market constructs	Public good	Public good	Similar
VII. Study quality	A robust study with a full account of validity and potential biases in estimates	N/A	Good quality

poisoning, Green and Elmer (2014) suggest some methodologies for calculating value of waterbirds.

#### *Willingness to pay (WTP)*

It is estimated that in the EU, about 700 000 wildfowl die every winter as a direct result of lead poisoning (Andreotti et al. 2018), representing 6.1% of the wintering population. This is a minimum as additional birds that suffer sublethal poisoning are likely to die from other causes, exacerbated by the sublethal poisoning. A WTP study in Scotland found that on average, people were willing to pay an estimated £10.99 (€16.50 in 2017 prices)<sup>5</sup> per household per year for avoided losses of 10% in all goose species (Hanley et al. 2001).

In the absence of better valuation evidence, the Scottish value can be extrapolated to the number of EU households in 2017 (~ 221 million—Eurostat 2018),<sup>6</sup> calibrated for the avoided losses of 6.1% of all species of wildfowl in the EU (see WWT 2018).

<sup>5</sup> WTP values were converted from 2001 GBP to 2017 Euros using the 2001 to 2017 Consumer price index <https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/d7g7/mm23> and the Bank of England's exchange rate (Bank of England, 2018) <https://www.bankofengland.co.uk/boeapps/database/Rates.asp?Travel=N1xASx&into=EUR> (for 21/11/2018) and the ratio between EU and UK average household disposable income per capita.

<sup>6</sup> Eurostat number of private households [http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfst\\_hnnhtych&lang=en](http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfst_hnnhtych&lang=en)

There is uncertainty involved in applying WTP values from one country and environmental 'good' to another. Value transfer guidelines (eftec 2009) have been considered regarding the calculation of these values, and the key criteria to be considered in assessing the suitability of a study good (the geese valued in Hanley et al. 2001) to the policy good (the impacts on wildfowl of lead shot) are outlined in Table 3. As shown, the differences in the species being addressed within the study good and policy good, and the location and affected populations, are key areas of uncertainty for this value transfer. The indicative value in the EU for the avoided losses in wildfowl populations obtained from this value transfer may be €2.2 thousand million per year. This transfer from Scotland to the rest of the EU, and the fact that the WTP study only valued geese populations, introduces significant uncertainty. It is possible that values are significantly under- or over-estimated and the estimate should be regarded as a broad indicative value. Further adjustments to this transfer (e.g. to account for different rates of environmental NGO membership) could be made, but doing so would not counter the main sources of uncertainty—around whether households in the rest of the EU hold similar views to households in Scotland, and whether public preferences have changed between 2001 and 2018. Despite this uncertainty, this value transfer illustrates that households in the EU are likely to hold a very significant positive value for avoiding wildfowl deaths caused by lead poisoning from gunshot ingestion.

The costs estimated in this section deal only with those relating to wildfowl. The WTP value of avoiding declines of other species would be considerable. People also appear willing to pay a considerable amount to avoid declines of threatened species (Hanley et al. 2001). Many species considered to be regionally threatened in Europe and the EU are at risk from lead poisoning (e.g. Egyptian vulture (*Neophron percnopterus*), bearded vulture (*Gypaetus barbatus*), Spanish imperial eagle (*Aquila adalberti*), common pochard (*Aythya ferina*) and many other wildfowl species (see Pain et al. 2015, 2019; and Leronymidou et al. 2015 for species status). Avoiding lead poisoning in these species is certainly desirable from a population perspective, and the costs of their recovery would be substantial and long term.

### Cost associated with impacts on people

Fragments of lead derived from the ammunition used to kill game birds and mammals are often present in their edible tissues and are a potentially significant source of dietary exposure to bioavailable lead in groups of people who frequently consume the meat of game animals (EFSA 2010; Pain et al. 2010; Green and Pain 2012). The Panel on Contaminants in the Food Chain (CONTAM Panel) of the European Food Safety Authority (EFSA) produced a scientific opinion on lead in food (EFSA 2010) at the request of the European Commission, and for their risk assessment identified critical effects in humans as being developmental neurotoxicity in young children and cardiovascular effects and nephrotoxicity in adults. Their reference points for characterising increased risk from dietary lead were Benchmark Dose Limits (BMDLs), being the 95th percentile lower confidence limit of the Benchmark Dose—BMD—of extra risk derived from blood lead levels in  $\mu\text{g/L}^{-1}$ . There is evidence that the developing brains of children are especially susceptible to the effects of chronic lead exposure, even at low concentrations (Lanphear et al. 2005; Budtz-Jørgensen 2010; EFSA 2010). The EFSA CONTAM Panel concluded from their risk assessment that the possibility of adverse effects on chronic kidney disease and systolic blood pressure could not be excluded in some adults that are high consumers of game (e.g. one 200 g meal per week), i.e. they could be at risk of cardiovascular effects and nephrotoxicity. Some children in average consumer groups across the EU (that did not frequently ingest wild shot game) may already be at risk of reduced IQ. Any consumption of foodstuffs with elevated lead levels, such as game shot with lead, would amplify this risk in this particularly vulnerable group. While all of these health effects, on IQ, systolic blood pressure and chronic kidney

disease have associated economic costs, we have estimated only the costs of IQ reduction in children, the most vulnerable group.

### Costs of estimated reductions in IQ in children

Several estimates exist of the number of children under eight years old in the UK at risk of incurring a one point or more reduction in IQ as a result of their current levels of exposure to ammunition-derived dietary lead from game. Green and Pain (2015) estimated this to be thousands of children in the UK (calculated to be in the range 4 000—48 000) at risk from lead exposure via gamebird meat alone. An unpublished British Association for Shooting and Conservation/Countryside Alliance (BASC/CA) game meat consumption survey estimated that 9 000 (midpoint of 5 500—12 500) children (it is unclear whether these were under eight years old or less than eight years in age so we have assumed the latter) from the shooting community consume at least one game meal per week averaged over the year (reported in LAG 2014). A human health assessment of the risks associated with consumption of game shot with lead (LAG 2015) indicates that 11 000 children (ages unspecified) from the shooting community eat at least one game meal per week. Both of the latter two estimates exclude high-level consumers of game meat outside the shooting community and refer to all types of game, but it is likely that the vast majority of it was wild game killed using lead ammunition. These estimates are for the live-quarry shooting community only and for children eating one or more game meals a week. This level of consumption generally exceeds the amount of game required to give the BMD for neurodevelopmental effects (Green and Pain 2012; Green and Pain 2015). Hence (and noting the BMD is less conservative than BMDL as described above), it seems probable that the population of children of 8 years old or younger at potential neurodevelopmental risk from ammunition-derived lead in game meat in the live-quarry shooting community in the UK may be more than 10 000.

The implication of this exposure to lead (to the BMD) has been estimated as a 1 point or more decrease in IQ in children (EFSA 2010), which can have a significant cost to society. This cost could be calculated for the EU by estimating the number of children across the EU that consume enough game to potentially have a negative impact on their IQ, and applying relevant valuations for the costs associated with that IQ reduction.

The actual amount of wild game consumed in all EU countries is not known, but can be estimated approximately for children by scaling the number of UK children exposed to high dietary levels of ammunition-derived lead by the

number of hunters in other EU countries, relative to the UK. This approach is not expected to be completely accurate because we do not know how much per capita game consumption by hunters and their families varies among EU countries. The total number of hunters in the EU28 is estimated to be over 6 667 770 in 2009 (based on a survey reported by FACE 2010). Based on these data, and applying the UK hunter to child game consumption ratio (800 000 hunters and 10 000 children estimated to be at neurodevelopmental risk), around 83 000 or more children across the EU27 may be at risk of a potential reduction in IQ of 1 point.

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). In the EU, although they use different methods, two different studies have valued a reduction in 1 point in IQ (per child) based upon reviews of the literature, at around €8 000 and €10 000 (ECHA 2011; Bierkens et al. 2012). More recently, Monahan et al. (2015) estimated the discounted lifetime monetary value of the loss of one IQ point as being considerably lower at £3 297 (€3 882 in 2018 prices<sup>7</sup>). This corresponds to the cost of a 1 point decrease in IQ to a child across their lifetime. Using this range of values (€3 882–10 000), the consumption of lead-shot game by children within the EU today may be linked to a potential loss in IQ estimated to be worth €322 million to €830 million. This is a cost to the cohort of children 8 years old or younger. If we divide by 8 we have an annualised cost of €40 million—€104 million, i.e. the recurring (i.e. ongoing and cumulative) cost to society for every year in which use of lead shot and rates of consumption of lead in game meat food persist at current levels. Historic impacts prior to the generation considered here are not evaluated but are additional.

This calculation is conservative in several ways. Firstly, some children will eat more than one meal of game a week, with risk of a greater reduction in IQ. Secondly, recent studies suggest that high-level consumers of game may be more numerous, relative to the national number of hunters, in some other EU countries than in the UK. In the UK, with 800 000 hunters, one survey estimated that 27 000–62 000 adults eat game more than once a week and 5500–12 500 children eight years old or younger eat game once a week (cited in LAG 2014). These 32 500–74 500 people of all ages amount to only about 10% of the population of

hunters. Studies conducted in other EU countries suggest that about 2–3 times the population of hunters may be potential high consumers of game. For example, in Italy, Ferri et al. (2017) surveyed 766 Italian shooters and found that an average of four servings per month (of 100–200 g game per serving) was consumed and that game mammals and birds were consumed regularly with friends and relatives in 83% and in 60% of cases, respectively. Accounting for an inventoried population of 751 876 shooters in Italy, these authors estimated that there is regular consumption of mammalian and feathered wild game in around 1.65 million and 2 million people, respectively—equating to 2.2–2.7 times the number of hunters in Italy. In Germany, Geroefke et al. (2018) found, from a representative survey conducted on game meat consumption of the German population, that about 1.5% ate large game (red Deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*)) once a week or more and an additional 2.4% one to three times a month. With a population of 82.8 million (in 2017—Eurostat online), the 1.5% of at least weekly consumers of game meat represents 1.24 million people, which is over three times the population of hunters (in 2016/17—c. 384 000; DJV 2017). It therefore seems likely that in some other EU countries high-level consumers of game may be much more numerous, relative to the total number of hunters, than in the UK. Thus, our estimate of costs of IQ reduction across the EU, which is based upon UK proportions, could be too low. Game consumption could also be higher than that in the UK, relative to the number of hunters, in Sweden and France (Livsmedelsverket undated; ANSES 2018).

We have not considered the cost contribution that increased blood lead levels may potentially make to increased crime rates (e.g. see Campbell et al. 2018). Criminality has costs to the criminal justice system and to victims, including in health care, lost earnings, stolen/damaged property and loss of quality and duration of life. While there is compelling evidence linking childhood lead exposure and antisocial behaviour in childhood and later adolescence (Sampson and Winter 2018), this area is understudied and we have not attempted to monetise potential economic costs.

#### Other health costs

Reduced IQ in children is only one of the health effects associated with chronic low-level exposure to lead, as can occur through the frequent consumption of game animals shot with lead ammunition. EFSA (2010) considered that the possibility of adverse effects on chronic kidney disease and systolic blood pressure could not be excluded in adults with high levels of wild game consumption, and we have not attempted to evaluate the costs to adult health. A large scale

<sup>7</sup> Converted from 2015 GBP to 2017 Euros using money GDP deflators at Market Prices (HM Government, 2018) <https://www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-october-2018-budget-2018>) and the Bank of England's exchange rate for 21/11/2018 (2018 <https://www.bankofengland.co.uk/boeapps/database/Rates.asp?Travel=NIxASx&into=EUR>).

longitudinal study from the USA has recently reported that many more adult deaths appear to be associated with low level lead exposure than previously considered. Results suggest that low-level environmental lead exposure is an important and largely overlooked risk factor for death, particularly from cardiovascular disease, in the USA (Lanphear et al. 2018). In the EU, approaching 49 million people were living with cardiovascular disease, with an estimated to cost the economy of €210 thousand million a year (Wilkins et al. 2017)—averaging €4286 per person per year. While increased systolic blood pressure in frequent consumers of game may only contribute a small proportion to this, the economic costs may nonetheless be substantial (e.g. a totally hypothetical contribution of 0.1% increase in cardiovascular disease contributed by increased lead consumption from among the 7 million hunters and c. 21 million associated game consumers would cost €120 million a year).

Also, ingestion is only one route of exposure to lead from ammunition, albeit possibly the most significant in many exposed people such as hunters and their families. Elevated blood lead levels are also associated with hunting activity per se, whether by subsistence hunting communities or target shooters (e.g. Fillion et al. 2014; Laidlaw et al. 2017). This is likely associated with inhalation of lead fume or the transfer of lead dust (e.g. when handling lead ammunition) (reviewed in Green and Pain 2015). While use of non-toxic shot would prevent exposure to lead dust (due to the abrasion of lead shot), it would not prevent exposure to lead fume resulting from the use of lead compounds in the chemical mixture of the primer.

### Costs associated with environmental impacts

Lead from ammunition is a significant and largely unregulated source of environmental contamination across Europe. Most emissions are strictly regulated and controls exist on lead levels in the ambient air, ground water, surface water, drinking water, soils, battery disposal, landfill, petrol and other sources (see AMEC 2012). As an example of the significance of ammunition emissions, in Norway in 2005, ammunition and fishing equipment (weights etc.) were considered to constitute 90% (66% and 24%, respectively) of the total of 240 tonnes of Norwegian lead emissions (Heier et al. 2009) with industrial deposits contributing only 3%.

According to industry figures, annually approximately 21 000 tonnes of lead from shotgun cartridges used in hunting is dispersed into the environment in the EU (27) with an additional 10 000–20 000 tonnes used by sports shooters (ECHA 2018a<sup>8</sup> based on a variety of

figures including AMEC 2012). This reflects the suggestion by the Association of European Manufacturers of Sporting Ammunition (AFEMS—as reported in AMEC 2012) that approximately half of all lead shot consumed in the EU is used for target shooting and the other half is used for hunting. Lead from bullets is additional with an estimated 350 + tonnes dispersed into the environment by hunting in 2004 (ECHA 2018a). Lead from ammunition is unevenly distributed in the environment. Highest concentrations are found where shooting occurs consistently in limited areas, e.g. at static target shooting ranges (like military ranges), moving target ranges (like clay pigeon shooting sites) and where live game are shot from static blinds (e.g. Andreotti and Borghesi 2012). Other types of live target shooting, including driven gamebird shooting, disperse lead ammunition more widely across large parts of the countryside.

Once deposited, a high proportion of lead from shot usually stays in the upper soil layers and generally breaks down slowly, with some lead being leached to the surrounding environment. In areas of high ammunition deposition, soil concentrations can be up to hundreds of times higher than in uncontaminated control sites (summarised in LAG 2015). In certain situations, some of the lead from deposited shot can be taken up by plants resulting in plant lead levels that are significantly higher than those found in plants from control soils and exceed acceptable limits for animal or human foodstuff (LAG 2015).

As long as lead ammunition continues to be used (and when it is not cleaned up), it will accumulate and associated risks to human and environmental health will increase. For example, in Finland, several thousand outdoor shooting ranges exist and they were considered one of the most common causes of soil contamination, with almost a third of them considered to have the potential to cause a risk of groundwater pollution (Sorvari et al. 2006). Soil, discharge, subsurface and groundwater lead concentrations can be high in areas of repeated ammunition deposition (e.g. Mariussen et al. 2017a; Okkenhaug et al. 2017) and put at risk soil biota, small mammals and aquatic organisms including fish (Sorvari 2007; Heier et al. 2009; Mariussen et al. 2017b).

While relatively little appears to have been done to remediate environmental lead contamination from wild game shooting, contaminated soil is treated at some firing ranges. High soil lead concentrations occur in impact berms at fixed target ranges, and more broadly across sites where there is a moving target, such as at clay pigeon shoots. Metal-contaminated soil, particularly at abandoned shooting ranges, is sometimes dealt with either by removal to approved landfill sites or treatment to stabilise the lead and reduce the amount of lead and other metals that is leachable (e.g. Kajander and Parri 2014; Mariussen et al.

<sup>8</sup> Other estimates of annual releases of lead gunshot indicate the tonnage is probably significantly higher (see ECHA 2018a).

2015). However, remediation can be challenging and costly, especially with shooting ranges on mires where large volumes of peat may need to be removed, the availability of disposal sites for this type of material is limited, and some mires also have high conservation value and can take decades to restore (Mariussen et al. 2017a). High levels of contamination at shooting ranges may necessitate costly cleanup and/or restrict subsequent land uses, e.g. limiting potential for agricultural use, or uses that could potentially put at risk human health, domestic stock or wildlife. Such risk could result from: elevated plant lead levels (particularly in root crops); the risk of grazing domestic or wild animals ingesting either soil or plants with high lead concentrations while feeding, or shot close to the soil surface; and risks presented by silage made from plants from shot fall-out areas, that could contain lead pellets. Health risks resulting from redeployment of shot-over land may not become apparent for some time. For example, Urrutia-Goyes et al. (2017) found a high (non-carcinogenic) health risk due to Pb pollution, with ingestion as the main exposure pathway, at an urban public park on the redeveloped site of a historic military shooting range in Athens, Greece.

There is no register of shooting clubs and ranges across Europe, and these vary in size from large establishments used on a daily basis to small parts of shooting clubs that are used only occasionally. In Finland, Kajander and Parri (2014) estimated that between 600 and 1000 shooting ranges existed. If the ratio between the proportion of hunters and shooting ranges in Finland holds across the EU, this would suggest that approximately 17 000 shooting ranges exist across the EU (using numbers of hunters from FACE 2010). Kajander and Parri (2014) produced a detailed analysis of the best available techniques for the management of environmental impact at shooting ranges. These include design features for new ranges, maintenance measures and remediation. Some of these can be very costly, but due to the variation in the types of shooting activities at ranges and the environments in which they are situated, site-specific studies are needed to identify appropriate management methods and a single best available technique cannot be identified for all situations.

Costs of clean-up will be associated with individual situations, and few estimates exist based upon a cost per tonne of lead ammunition contaminating the land. However, it was recently reported in the press in the USA (Kays 2018) that the clean-up costs of an estimated 60 tons of lead bullets (54.4 tonnes) was US \$500 000 (€440 000). Extrapolating this to the 10 000–20 000 tonnes of lead gunshot used by sports shooters in the EU annually would suggest that, were all lead contamination to be mitigated, annual costs would be in the region of 92 million to 184

million \$US (€81–162 million). This estimate is for bullets and clean-up of gunshot is likely to require that larger areas be treated as gunshot are more dispersed than bullets. Furthermore, there is a large margin of error associated with this estimate as it is based on just one recent decontamination example, but it gives a very broad indication of hypothetical annual costs. While it would not be practical or economically feasible to clean-up the 21 000 tonnes of shot used annually for hunting, it seems reasonable to assume that at least a similar cost would likely be required to reduce risks in the most contaminated areas, such as regular blinds.

## Other costs

### *Surveillance and research*

Surveillance and research on the impacts of lead poisoning (including monitoring the efficacy of regulations where they occur) is time consuming and costly. The evidence which has then driven policy on this issue has come mainly from scientists from universities and the conservation NGO sector. Scientists have been required to demonstrate that

**Table 4** Estimated costs of research over a 5-year period (Feb 2013–Jan 2018) related to the impacts lead ammunition on humans, domestic and wild animals and the environment in Europe

Type of study	Number of studies (Feb 2013–Jan 2018)	Indicative cost (€) per type of study	Total cost (€)
Desk-based studies	5	14 000	70 000
Lab/fieldwork-based studies	49	44 000	2 156 000
Large studies with metadata analysis	4	57 000	228 000
Total	55	–	2 454 000

1. The total number of studies is limited to just published peer reviewed European studies carried out over the last 5 years. Studies have been gathered from Web of Science (23.08.18) and limited to research on (i) wildlife populations, (ii) domestic animals, (iii) human health, and (iv) environmental contamination. Search terms used were: lead and shot and bird; lead and bullet and bird; lead and ammunition and bird; lead and ammunition and human; blood and lead and domestic/livestock; blood and lead and game; lead and ammunition and pollution. It also excludes research on non-toxic alternatives to lead shots (i.e. focuses on the problem rather than studies on the solution)

2. The indicative cost per type of study (2016 prices) was determined using expert judgement by calculating the number of days required per type of resource required (e.g. fieldworkers, technician, research associates, senior researchers, veterinarians/medics), lab equipment and lab analysis required and a standard full cost recovery university overhead factor. The results have been verified through informal consultation with those who carry out such fieldwork and lab analysis

lead from ammunition presents unacceptable risks to wildlife, human health and the environment rather than for the shooting users (the polluters) to demonstrate its safety. In order to develop an indicative cost of this research, peer-reviewed studies conducted over a 5-year period (Feb 2013–Jan 2018) in Europe were identified using Web of Science (Table 4). The estimated research cost over this period was €2.45 million. This does not include studies that have been published but not peer-reviewed, including many government reports and risk analyses conducted by government agencies. These can be extremely costly, for example in the UK, the Lead Ammunition Group (LAG) was set up to advise the UK Government's Department for the Environment, Food and Rural Affairs (DEFRA) and the Food Standards Agency (FSA) on the risks of lead ammunition to wildlife and human health, and potential mitigation measures. The LAG conducted a series of risk assessments (LAG 2015) running to > 400 pages and held 18 meetings between February 2013 and January 2018. This process alone (funded by the individual members and their supporting organisations rather than government) is likely to have cost in the region of £200 000–£300 000 (€236 000–€354 000) in staff time over a 5 year period. In addition, several other research reports were conducted by or commissioned by UK Statutory agencies over this period (i.e. the Food Standards Agency and FSA Scotland). Human health risk assessments were also conducted in a variety of other European countries, including Spain, France, Germany, Norway and Sweden (AESAN 2012; VKM 2013; SNFA 2014; ANSES 2018; Gerofke et al. 2018). It would therefore not be unreasonable to suggest that the total annual cost of research into this issue, including university, NGO and government scientists, is likely to be in the region of €1 million or more annually. This does not include the substantial amount of work conducted by the European Chemicals Agency (ECHA) in the preparation of a dossier for restriction proposal for the use of gunshot over wetlands, nor the many individuals and organisations that have contributed to this process.

### Enforcement

At present, legislation regarding the use of lead ammunition across the EU and Europe is variable. With respect to gunshot, a few EU member states have introduced legislation banning the use of lead gunshot (irrespective of species shot or habitat) across all or much of their territory (Belgium, Denmark, The Netherlands, Croatia), five have no legislation (Greece, Ireland, Poland, Romania, Slovenia) while the remaining member states have partial restrictions, e.g. for shooting certain species and/or in certain places (ECHA 2017a). Regulations should be followed in those countries that have them, but enforcement is

variable. For example, in the UK where there are partial restrictions, there is little if any statutory enforcement of the regulations and very low compliance (c. 30%—Cromie et al. 2015). Were enforcement to be effective under such situations of partial regulation it would be very costly. This is a cost that should currently be incurred by governments, but is not (at least in the UK) due to a lack of enforcement and ineffectiveness of current partial regulations. A total ban on all use of lead gunshot is far simpler in terms of practicality and enforcement as acknowledged by ECHA (2018b). A total ban would be simple to police by existing enforcement organisations, and responsibility for compliance would sit with the producers and retailers of lead gunshot rather than the individual shooter. Enforcement costs would likely be far lower for a total ban compared to partial restrictions.

### Collision

Another area of cost not previously considered is that of increased risk of collision of large birds, such as swans, with infrastructure like power lines which has been found to be related to elevated blood lead level (Kelly and Kelly 2005; Ecke et al. 2017); this is probably related to the disorientation and physical impediment created by sub-lethal lead levels. Associated economic impacts result from interruptions of power and damage to power lines (and potentially to road traffic). Lack of coordination resulting from lead poisoning was also suspected when an Imperial Eagle (*Aquila heliaca*) crashed into a car in Hungary in 2017 (Pannon Eagle 2018). Bird strikes with aircraft present an ongoing safety and economic risk (Pfeiffer et al. 2018). While no data are available, it seems probable that effects of sublethal lead poisoning on flight behaviour might increase the likelihood of aircraft strikes. The potential effects and costs of such strikes would be greatest for large-bodied birds such as swans, geese and eagles.

### Food production

Contamination of land by lead from ammunition occasionally results in pollution issues for domestic animals or food production. For example, incidents of lead poisoning from ingested lead gunshot (deposited by target shooting) occasionally occur in small numbers of domestic poultry and cattle in the UK causing suffering and mortality (Payne et al. 2013; APHA 2016); this has sometimes created potential food safety incidents, illustrated by a supermarket recall of eggs from chickens that had ingested lead shot (BBC 2008). In Italy, a police operation in 2016 reportedly seized about 3000 packs of meat sauce and sauce based on game meat, due to the detection of lead levels that exceeded legally permissible limits (Piuweb 2016). A brand of

sea salt produced at a salt pan in France and distributed was recalled from supermarkets due to elevated lead concentrations, apparently caused by contamination from lead ammunition (Colin 2018). While such cases of food contamination are reported relatively infrequently, they can have a serious economic impact for the farmers and food producers and distributors concerned.

The use of lead ammunition also results in considerable loss of otherwise useable meat due to the need to remove and discard meat within a large radius of the wound canal of bullets in large game animals. Fragments from bullets and elevated tissue lead concentrations have been found as far as 20–30 cm from the wound canal so considerable meat loss is associated with attempting to eliminate lead fragments (e.g. VKM 2013). Several food safety agencies recommend discarding meat in proximity to the wound canal (SNFA 2014) including a radius of 30 cm from the bullet tract (Knutsen et al. 2015). In Norway, efforts to avoid lead in venison by discarding meat close to wound channels causes the discard of 200 tonnes of contaminated meat annually,<sup>9</sup> representing an economic loss equivalent to €3 million (Kanstrup et al. 2018).

### *Risk to dogs*

It is common practice for hunters of large game animals to leave offal and sometimes trimmings of meat from around the wound canal in nature, and sometimes trimmings from the wound canal are fed to dogs (e.g. VKM 2013). Chronic exposure to lead through feeding wound trimmings to dogs presents a risk of lead poisoning (VKM 2013; Høgåsen et al. 2016), with associated welfare costs and costs to the animal's owners.

## DISCUSSION

ECHA (2017a) estimated the total annual societal costs of restricting the use of lead shot over wetlands (including peatlands) in the EU to be €35–61 million. This takes account of the costs to hunters (including costs for necessary testing, technical adaptations to shotguns, premature replacement of shotguns, and the incremental cost of more expensive alternative ammunition) and the share of this cost that goes either as tax revenue to governments or as mark-ups to retailers and manufacturers of shotguns and ammunition. ECHA used a figure of total societal benefits of > €105 million comprising the avoided opportunity cost associated with the annual mortality in the EU of approximately 700 000 wildfowl from 16 wetland bird species

known to ingest lead shot (Andreotti et al. 2018). None of the other societal use, non-use or existence benefits (e.g. mortality of scavengers and predators, human health impacts, impacts on leisure activities, protection of ecosystem services and rare bird species) were quantified.

The proposed restriction covers wetlands, and ECHA (2017a) used the Ramsar definition of wetlands which includes peatlands. They assumed that 8% of shooting was in the narrower definition of wetlands (i.e. largely wetlands with open water where wildfowl shooting takes place) and that the collateral impact occurring due to the wider wetland definition affected the 53% of hunting by shooters of 'fowl-like' birds (e.g. grouse, partridges, quail, pheasant, dove and pigeons) that could occur over peatland. ECHA acknowledged that it is possible that the numbers of hunters over peatland may be lower than this, and therefore their estimate of costs to hunters may be an overestimate. However, as ECHA found costs of €35–61 million for 61% of hunters (using shotguns), we can broadly assume a cost of €57–100 million for all hunters who use shotguns, although this may be higher or lower. This would not include costs of restricting lead ammunition to sports (target) shooters and to large game hunters using rifles, or target shooters using bullets. However, it is considered that steel shot types available could be readily used in the types of guns used, and target shooting practiced at, the Olympics (Thomas and Guitart 2013) and by extension in most target shooting clubs.

Some non-lead alternatives like steel shot may over time become cheaper than equivalent lead shot, hence transition to non-lead includes the potential for reducing hunter's annual [running] cost (Kanstrup and Thomas 2019). The transition to non-lead bullets would also incur a cost, but volumes are low compared with lead shot (AMEC 2012) and alternatives are available in the EU and already widely used in some places, e.g. several German States have regulations requiring the use of non-lead bullets (Thomas et al. 2016) and Forest Enterprise England wildlife rangers transitioned to using lead-free bullets for killing deer (FEE 2017). While we have not attempted to estimate the costs of complete transition to non-toxic ammunition in this paper, these factors suggest that it is unlikely to be much more than double the €57–100 million estimated for all hunters that use shotguns.

A range of benefits of banning lead ammunition, relating to avoiding costs that its use currently imposes on society, are identified. For the EU, minimum replacement (€133–565 million) and treatment (€28 million) costs for a limited selection of bird species known to die of lead poisoning are estimated at, on average, around €377 million annually. An extrapolation of a WTP study for avoided lead-poisoning losses of wildfowl alone gave an indicative value of c. €2.2 thousand million per year. Uncertainty in

<sup>9</sup> <http://www.hegmar.no/Nyheter/Naeringsliv/2016/09/Maa-kaste-200-tonn-viltkjoett>.

**Table 5** Summary of selected additive cost estimates of continued use of lead ammunition across the EU and Europe

Cost Area	Description	Annual cost (€) EU	Annual cost (€) Europe	References
Wildlife				
Replacement costs—direct mortality	Replacement of 700 000 wildfowl (EU) or 1 million (Europe) of 16 species	€105 million	€142 million	Andreotti et al. (2017)
	Replacement of 4 species of raptor in the EU (530–691 individuals) and Europe (765–1139 individuals)	€25–457 million	€37–750 million	This paper, Table 2
	Replacement of 232 402 released pheasants and red-legged partridges in the UK	Costs for UK only—€3.4 million Not estimated for EU	Not estimated but > €3.4 million	This paper, Table 1
	Replacement of an additional 11 wildfowl species; 12 raptor species, 11 other waterbird and wading species and 2 terrestrial gamebirds known to suffer lead poisoning but for which insufficient information was available to estimate replacement costs	Not estimated	Not estimated	Andreotti et al. (2018), Pain et al. (2015), (2019)
Replacement costs—indirect mortality	Birds that die as a result of sublethal lead poisoning increasing susceptibility to disease and accidents	Not estimated	Not estimated	e.g. Kelly and Kelly (2005), Ecke et al. (2017)
Treatment costs	Costs for treating 1% of 700 000 lead-poisoned wildfowl in the EU and 1 million in Europe, plus 1% of an additional 2.1 (EU) and 3 million (Europe) that suffer sublethal welfare effects	€28 million	€40 million	This paper; ECHA (2017b)
	Costs of treating raptors and terrestrial birds that suffer lead poisoning	Not estimated	Not estimated	
People				
Reduced IQ in children	Minimum annual costs of risk of reduced IQ in children in the EU that frequently consume game shot with lead. Surveys from other countries suggest that this may be an underestimate, possibly by an order of magnitude	€40–104 million	Not estimated but > €40–104 million	This paper
Increased incidence of CKD and SBP in adults		Not estimated	Not estimated	
Environment				
Clean-up	Ammunition at shooting ranges—broad estimate	€81–162 million	Not estimated but > €81–162 million	This paper
	Ammunition at hunting blinds with greatest contamination—broad estimate	c. €100 million	Not estimated but > c. €100 million	This paper
Other costs				
Research	Investigating lead poisoning: monitoring and surveillance	€ 1 million	Not estimated but > € 1 million	This paper, Table 4
Advocacy		Not estimated	Not estimated	
Enforcement		Not estimated	Not estimated	
Collision	Collision of poisoned birds with power lines, other infrastructure and vehicles due to weakened state	Not estimated	Not estimated	Kelly and Kelly (2005), Pannon Eagle (2018)
Food production	Poisoning of poultry and livestock exposed to lead shot or feed contaminated with lead shot; other food products (e.g. salt) contaminated with shot; wastage of meat around the wound channel of large mammals killed with lead bullets	Not estimated	Not estimated	Payne et al. (2013), APHA (2016), Colin (2018)
Health of domestic dogs	Risks to dogs fed trimmings from shot game animals	Not estimated	Not estimated	VKM (2013), Högäsen et al. (2016)
Total		€383 million–€960 million	€444 million–€1.30 thousand million	

extrapolating WTP values from Scotland across EU member states, and the limited number of species for which data enabled replacement and treatment cost estimates to be made suggest an annual cost of those birds lost to lead poisoning of at least several hundreds of millions and possibly several thousand million euros. Costs to human health are likely to be associated primarily with reduced IQ in children and increased cardiovascular and chronic kidney disease in adults. Minimum annual costs of reduced IQ in children are estimated at €40 million–€104 million but these could be higher, possibly substantially higher. Health costs in adults have not been estimated but could be of a similar order of magnitude taking account of the potential numbers of high consumers of game and the costs of healthcare. The costs of environmental clean-up of shooting ranges have only been estimated in the broadest terms but, based on clean-up of the tonnage of lead estimated to be used at shooting ranges, could hypothetically be €81–162 million for shooting ranges and it seems reasonable to suspect may be similar or higher at heavily contaminated sites of wild game shooting such as hunting blinds.

Table 5 summarises estimated additive costs to wildlife, human health and the environment and lists additional costs that would also be additive but that we have not been able to estimate. Those un-estimated costs likely to be most substantially are human health costs of frequent exposure to lead from game in adults (chronic kidney disease and systolic blood pressure) and replacement and treatment costs of those bird species known to be affected by lead poisoning but for which insufficient data were available to make estimates. Estimates of numbers of people that frequently consume game in some EU countries also suggest that our estimate of the costs of reduced IQ in children associated with frequent game consumption may be low. Our estimates of several of the costs of continued use of lead ammunition have involved a large number of assumptions, as laid out in Tables 1, 2, 3, 4 and 5 and the accompanying text. However, except in the hypothetical case of environmental clean-up, our estimates have tended to be conservative, and may have underestimated costs as described. Nonetheless, the margins of error are likely to be large and the estimates should be considered to give an indication of the likely magnitude of costs rather than a precise evaluation. For additive direct costs, we estimate a minimum annual cost across the EU and Europe of c. €383–960 million and €444 million to €1.3 thousand million per year, respectively. Using a WTP approach, the value that society places on being able to avoid these losses is likely to be far higher, and was estimated to be €2.2 thousand million per year for wildfowl in the EU alone. The combined value that society would place on being able to avoid the combined wildlife, human health and environmental costs of continued use of lead

ammunition would be far greater. Regardless of the methods used, our estimated costs of the continued use of lead ammunition across the EU are many times, and possibly an order of magnitude greater than the estimated annual total societal costs of switching to non-toxic alternative ammunition types.

**Acknowledgements** The authors would like to thank Rohit Mistry of eftec and Léa Badoz and Barbara Herrero of BirdLife International for useful information provided in various reports and/or submissions to ECHA consultations that we accessed for our paper.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

## REFERENCES

- Aebischer, N.J. 2013. National Gamebag Census: Released game species. *Game & Wildlife Conservation Trust Annual Review of* 2012: 34–37.
- AESAN. 2012. Report of the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN) in relation to the risk associated with the presence of lead in wild game meat in Spain. AESAN-2012-002. Retrieved November, 2018, from, [http://www.aecosan.msssi.gob.es/AECOSAN/docs/documentos/seguridad\\_alimentaria/evaluacion\\_riesgos/informes\\_cc\\_ingles/LEAD\\_GAME.pdf](http://www.aecosan.msssi.gob.es/AECOSAN/docs/documentos/seguridad_alimentaria/evaluacion_riesgos/informes_cc_ingles/LEAD_GAME.pdf).
- AEWA. 1999. African-Eurasian Migratory Waterbirds Agreement – Resolution 1.14. UNEP/AEWA/MOP1/RES. 1.14. <http://www.unep-aewa.org/en/document/phasing-out-lead-shot-wetlands>.
- AEWA. 2017. Response to public consultation on ECHA restriction report #1873. EC Number 231-100-4, CAS Number 7439-92-1. Retrieved November, 2018, from, <https://echa.europa.eu/previous-consultations-on-restriction-proposals/-/substance-rev/17005/term>.
- AMEC Environment & Infrastructure UK Limited. 2012. European Chemicals Agency. Abatement Costs of Certain Hazardous Chemicals. Lead in shot—Final Report December 2012. Report for European Chemicals Agency (ECHA). Contract No: ECHA 2011/140, Annankatu 18, 00121 Helsinki, Finland.
- Andreotti A., and F. Borghesi. 2012. Il piombo nelle munizioni da caccia: Problematiche e possibili soluzioni. Rapporti ISPRA, 158/2012.
- Andreotti, A., V. Guberti, R. Nardelli, S. Pirrello, L. Serra, S. Volponi, and R.E. Green. 2018. Economic assessment of wild bird mortality induced by the use of lead gunshot in European wetlands. *Science of the Total Environment* 610–611: 1505–1513. <https://doi.org/10.1016/j.scitotenv.2017.06.085>.
- ANSES. 2018. AVIS de l'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail relatif au “risque sanitaire lié à la consommation de gibier au regard des contaminants chimiques environnementaux (dioxines, polychlorobiphényles (PCB), cadmium et plomb)”. Avis de l'ANSES Saisine n° 2015-SA-0109. ANSES 14 rue Pierre et Marie Curie, 94701 Maisons-Alfort Cedex. [www.anses.fr](http://www.anses.fr).
- APHA. 2016. Disease surveillance in England and Wales. *Veterinary Record* 178: 37–40. <https://doi.org/10.1136/vr.h6863>.

- Barton, J., R. Hine, and J. Pretty. 2009. The health benefits of walking in green spaces of high natural and heritage value. *Journal of Integrative Environmental Sciences* 6: 61–278. <http://www.julespretty.com/wp-content/uploads/2013/09/3.-Barton-et-al-The-health-benefits-of-walking-2009.pdf>.
- BBC. 2008. Waitrose egg recall on lead fears. Retrieved November, 2018, from, <http://news.bbc.co.uk/1/hi/uk/7393600.stm>.
- Bellinger, D.C., A. Bradman, J. Burger, T.J. Cade, D.A. Cory-Slechter, D. Doak, M. Finkelstein, A.R. Flegel, et al. 2013. Health risks from lead-based ammunition in the environment: A consensus statement of scientists. <https://escholarship.org/uc/item/6dq3h64x>.
- Bellrose, F.C. 1959. Lead poisoning as a mortality factor in waterfowl populations. *Illinois Natural History Survey Bulletin* 27: 235–288.
- Berny, P., L. Vilagines, J.M. Cugnasse, O. Mastain, J.Y. Chollet, G. Joncour, and M. Razin. 2015. Vigilance poison: Illegal poisoning and lead intoxication are the main factors affecting avian scavenger survival in the Pyrenees (France). *Ecotoxicology and Environmental Safety* 118: 71–82. <https://doi.org/10.1016/j.ecoenv.2015.04.003>.
- Bierkens, J., J. Buekers, M. Van Holderbeke, and R. Torfs. 2012. Health impact assessment and monetary valuation of IQ loss in pre-school children due to lead exposure through locally produced food. *Science of the Total Environment* 414: 90–97. <https://doi.org/10.1016/j.scitotenv.2011.10.048>.
- BirdLife International. 2015. European Red List of Birds. Luxembourg. Office for Official Publications of the European Communities. <http://datazone.birdlife.org/info/euroredlist> including supplementary material information for individual species.
- BirdLife International. 2018. BirdLife Europe and Central Asia General comments on the Public consultation on the draft opinion of the Committee of Socio-economic Analysis (SEAC) Restriction on the use of lead and its compounds in shot in wetlands. Retrieved December, 2018, from, <https://echa.europa.eu/previous-consultations-on-restriction-proposals/-/substance-rev/17005/term>.
- Budtz-Jørgensen, E. 2010. An international pooled analysis for obtaining a benchmark dose for environmental lead exposure in children. Scientific technical report submitted to EFSA. <https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/sp.efsa.2010.EN-47>.
- Butler, D.A. 2005. Incidence of lead shot ingestion in red-legged partridges (*Alectoris rufa*) in Great Britain. *Veterinary Record* 157: 661–662.
- Butler, D.A., R.B. Sage, R.A.H. Draycott, J.P. Carroll, and D. Potts. 2005. Lead exposure in ring-necked pheasants on shooting estates in Great Britain. *Wildlife Society Bulletin* 33: 583–589.
- Campbell, P.M., E. Corneau, D. Nishimura, E. Teng, and D. Ekoualla. 2018. Cost-benefit analysis for a lead wheel weight phase-out in Canada. *Science of the Total Environment* 637: 79–90. <https://doi.org/10.1016/j.scitotenv.2018.04.414>.
- CMS. 2014. UN Convention on Migratory Species (CMS) Resolution 11.15—Preventing Poisoning of Migratory Birds. Adopted at COP11 in 2014. [https://www.cms.int/sites/default/files/document/cms\\_cop12\\_res.11.15%28rev.cop12%29\\_bird-poisoning\\_e.pdf](https://www.cms.int/sites/default/files/document/cms_cop12_res.11.15%28rev.cop12%29_bird-poisoning_e.pdf).
- Colin, G. 2018. Du plomb découvert dans le sel de Guérande. l'édition du soir POLÉMIQUE Vendredi 2 Mars 2018. Retrieved November, 2018, from, <https://www.ouest-france.fr/leditiondusoir/data/20000/reader/reader.html#:~:preferred=1/package/20000/pub/28744/page/12>.
- Cox, D.T.C., D.F. Shanahan, H.L. Hudson, R.A. Fuller, K. Anderson, S. Hancock, and K.J. Gaston. 2017. Doses of nearby nature simultaneously associated with multiple health benefits. *International Journal of Environmental Research and Public Health* 14: 172. <https://doi.org/10.3390/ijerph14020172>.
- Cox, D.T.C. 2018. Nature in the City. Retrieved 27 January, 2019, from, <http://valuing-nature.net/news/nature-city-birds-and-mental-health>.
- Cromie, R., J. Newth, J. Reeves, M. O'Brien, K. Beckmann, and M. Brown. 2015. The sociological and political aspects of reducing lead poisoning from ammunition in the UK: Why the transition to non-toxic ammunition is so difficult. In *The Oxford Lead Symposium. Lead Ammunition: Understanding and minimising the risks to human and environmental health*, eds. R.J. Delahay, C.J. Spray, pp. 27–43. Edward Grey Institute, The University of Oxford, UK. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_cromie\\_newth\\_reeves\\_obrien\\_beckman\\_brown.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_cromie_newth_reeves_obrien_beckman_brown.pdf).
- DJV. 2017. Jagdscheinhaber in Deutschland. Retrieved November, 2018, reported in <http://predatordown.com/more-hunters-in-germany-german-hunting-newspaper/>.
- ECHA. 2011. Committee for Risk Assessment Committee (RAC) for Socio-economic Analysis (SEAC), background document to the opinions on Annex XV dossier proposing restrictions on lead and its compounds in jewellery. Retrieved November, 2018, from, <http://echa.europa.eu/documents/10162/ab0baa9c-29f8-41e2-bcd9-42af796088d2>.
- ECHA. 2017a. Annex XV restriction report proposal for a restriction substance name: Lead IUPAC name: Not Applicable EC Number: 231-100-4 CAS Number: 7439-92-1. European Chemicals Agency Annankatu 18, Helsinki, Finland. Committee. 96 pp. <https://echa.europa.eu/documents/10162/6ef877d5-94b7-a8f8-1c49-8c07c894ff77>.
- ECHA. 2017b. Adopted Opinions on Restriction proposals. EC Number: 231-100-4. CAS Number: 7439-92-1. Comments submitted on restriction report updated 21/12/17. <https://echa.europa.eu/previous-consultations-on-restriction-proposals/-/substance-rev/17005/term>.
- ECHA. 2018a. Annex XV Investigation Report (ECHA/PR/18/14). 17 September 2018. A review of the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle. [https://echa.europa.eu/documents/10162/13641/lead\\_ammunition\\_investigation\\_report\\_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a](https://echa.europa.eu/documents/10162/13641/lead_ammunition_investigation_report_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a).
- ECHA. 2018b. Committee for Risk Assessment (RAC) Committee for Socio-economic Analysis (SEAC) Opinion on an Annex XV dossier proposing restrictions on LEAD IN GUNSHOT Compiled version prepared by the ECHA Secretariat of RAC's opinion (adopted 9 March 2018) and SEAC's opinion (adopted 14 June 2018). <https://echa.europa.eu/documents/10162/b092e670-3266-fb5d-6296-544eacbb5d4a>.
- ECHA. 2018c. Adopted Opinions on Restriction proposals. Comments submitted to date on SEAC draft opinion. Updated 21/05/2018. <https://echa.europa.eu/previous-consultations-on-restriction-proposals/-/substance-rev/17005/term>.
- Ecke, F., N.J. Singh, J.M. Arnemo, A. Bignert, B. Helander, Å.M.M. Berglund, H. Borg, C. Bröjer, et al. 2017. Sub-lethal lead exposure alters movement behavior in free-ranging golden eagles. *Environmental Science and Technology* 51: 5729–5736. <https://doi.org/10.1021/acs.est.6b06024>.
- eftec. 2009. Valuing environmental impacts: Practical guidelines for the use of value transfer in policy and project appraisal. Report for the Department for Environment, Food and Rural Affairs. Retrieved May, 2018, from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/182376/vt-guidelines.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/182376/vt-guidelines.pdf).
- EFSA Panel on Contaminants in the Food Chain (CONTAM). 2010. Scientific opinion on lead in food. *EFSA Journal* 8: 1570.
- Eurostat. 2018. Number of private households by household composition, number of children and age of youngest child (1000) Last update: 26-04-2018 [http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfst\\_hhnhtych&lang=en](http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfst_hhnhtych&lang=en).

- FACE. 2010. Hunters in Europe in FACE Annual Report 2009-2010.
- FEE. 2017. Forest Enterprise England Annual Report and Accounts 2016-17. Presented to the House of Commons pursuant to Section 7(3) of the Government Resources and Accounts Act 2000. [https://www.forestry.gov.uk/pdf/60334HC183FEE\\_Web.pdf/\\$FILE/60334HC183FEE\\_Web.pdf](https://www.forestry.gov.uk/pdf/60334HC183FEE_Web.pdf/$FILE/60334HC183FEE_Web.pdf).
- Ferrer, M., V. Morandini, G. Baguena, and I. Newton. 2017. Reintroducing endangered raptors: A case study of supplementary feeding and removal of nestlings from wild populations. *Journal of Applied Ecology* 2017: 1–8. <https://doi.org/10.1111/1365-2664.13014>.
- Ferri, M., L. Baldi, S. Cavallo, R. Pellicanò, and G. Brambilla. 2017. Wild game consumption habits among Italian shooters: Relevance for intakes of cadmium, perfluorooctanesulphonic acid, and 137cesium as priority contaminants. *Food Additives and Contaminants Part A Chemistry Analysis Control Exposure and Risk Assessment* 34: 832–841. <https://doi.org/10.1080/19440049.2017.1293303>.
- Fillion, M., J.M. Blais, E. Yumvihoze, M. Nakajima, P. Workman, G. Osborne, and H.M. Chan. 2014. Identification of environmental sources of lead exposure in Nunavut (Canada) using stable isotope analyses. *Environment International* 71: 63–73. <https://doi.org/10.1016/j.envint.2014.06.004>.
- Ganz, K., L. Jenni, M.M. Madry, T. Kraemer, H. Jenny, and D. Jenny. 2018. Acute and chronic lead exposure in four avian scavenger species in Switzerland. *Archives of Environmental Contamination and Toxicology*. <https://doi.org/10.1007/s00244-018-0561-7>.
- Gasparik, J., J. Venglarčík, J. Slamečka, R. Kropil, P. Smehyl, and J. Kopecký. 2012. Distribution of lead in selected organs and its effect on reproduction parameters of pheasants (*Phasianus colchicus*) after an experimental per oral administration. *Journal of Environmental Science and Health: Part A* 47: 1267–1271. <https://doi.org/10.1080/10934529.2012.672127>.
- Gerofke, A., E. Ulbig, A. Martin, C. Müller-Graf, T. Selhorst, C. Gremse, M. Spolders, H. Schafft, et al. 2018. Lead content in wild game shot with lead or non-lead ammunition - Does “state of the art consumer health protection” require non-lead ammunition? *PLoS ONE* 13: e0200792. <https://doi.org/10.1371/journal.pone.0200792>.
- Green, R.E. 2002. Diagnosing causes of population declines and selecting remedial action. In *Conserving bird biodiversity: General principles and their application*, ed. K. Norris and D.J. Pain, 139–156. Cambridge: Cambridge University Press.
- Green, A.J., and J. Elmberg. 2014. Ecosystem services provided by waterbirds. *Biological Reviews* 89: 105–122. <https://doi.org/10.1111/brev.12045>.
- Green, R.E., and D. Pain. 2012. Potential health risks to adults and children in the UK from exposure to dietary lead in gamebirds shot with lead ammunition. *Food and Chemical Toxicology* 50: 4180–4190. <https://doi.org/10.1016/j.fct.2012.08.032>.
- Green R.E., and D.J. Pain. 2015. Risks of health effects to humans in the UK from ammunition-derived lead. In *The Oxford Lead Symposium. Lead Ammunition: Understanding and minimising the risks to human and environmental health*, eds. R.J. Delahay, and C.J. Spray, pp. 27–43. Edward Grey Institute, The University of Oxford, UK. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_green\\_pain.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_green_pain.pdf).
- Grosse, S.D., T.D. Matte, J. Schwartz, and R.J. Jackson. 2002. Economic gains resulting from the reduction in children's exposure to lead in the United States. *Environmental Health Perspectives* 110: 563–569. <https://doi.org/10.1289/ehp.02110563>.
- Group of Scientists. 2014. Wildlife and Human Health Risks from Lead-Based Ammunition in Europe: A Consensus Statement by Scientists. Retrieved December, 2018, from <https://www.zoo.cam.ac.uk/research/groups/conservation-science/European-Statement>.
- Hanley, N., R. Wright, D. Macmillan, and L. Philip. 2001. Willingness to pay for the conservation and management of wild geese in Scotland. <https://www.cbd.int/financial/pes/united-kingdom-peswill.pdf>.
- Heier, L.S., I.B. Lien, A.E. Strømseng, M. Ljønes, B.O. Rosseland, K.-E. Tollefsen, and B. Salbu. 2009. Speciation of lead, copper, zinc and antimony in water draining a shooting range—time dependant metal accumulation and biomarker responses in brown trout (*Salmo trutta* L.). *Science of the Total Environment* 407: 4047–4055. <https://doi.org/10.1016/j.scitotenv.2009.03.002>.
- Helander, B., J. Axelsson, H. Borg, K. Holm, and A. Bignert. 2009. Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden. *Science of the Total Environment* 407: 5555–5563 <https://doi.org/10.1016/j.scitotenv.2009.07.027>, <https://www.researchgate.net/deref/http%3A%2F%2Fdx.doi.org%2F10.1016%2Fj.scitotenv.2009.07.027>.
- Høgåsen, H.R., R. Ørnsrud, H.K. Knutsen, and A. Bernhoft. 2016. Lead intoxication in dogs: Risk assessment of feeding dogs trimmings of lead-shot game. *BMC Veterinary Research* 12: 152. <https://doi.org/10.1186/s12917-016-0771-z>.
- Ieronymidou, C., R. Pople, I. Burfield, and I. Ramirez. 2015. The European Red List of Birds 2015. *Bird Census News* 28: 3–19.
- Isomursu, M., J. Koivusaari, T. Stjernberg, V. Hirvelä-Koski, and E.R. Venäläinen. 2018. Lead poisoning and other human-related factors cause significant mortality in white-tailed eagles. *Ambio* 47: 858–868. <https://doi.org/10.1007/s13280-018-1052-9>.
- IUCN. 2016. International Union for the Conservation of Nature (IUCN)—WCC 2016 Resolution 82, adopted in 2016. [https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC\\_2016\\_RES\\_082\\_EN.pdf](https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_082_EN.pdf).
- Kajander, S., and A. Parri. (eds.) 2014. Best Available Techniques (BAT) Management of the Environmental Impact of Shooting Ranges. The Finnish Environment. Ministry of the Environment, Helsinki. Pp 300. ISBN 978-952-11-4351-9 (pbk.); ISBN 978-952-11-4352-6 (PDF); ISSN 1238-7312 (print); ISSN 1796-1637 (online).
- Kanstrup, N., and V.G. Thomas. 2019. Availability and prices of non-lead gunshot cartridges in the European retail market. In *Lead in ammunition: Persistent problems and solutions*. *Ambio* vol. 48, Special Issue, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, In press.
- Kanstrup, N., J. Swift, D.A. Stroud, and M. Lewis. 2018. Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47: 846–857. <https://doi.org/10.1007/s13280-018-1042-y>.
- Kays, H. 2018. SCC lead cleanup cost reaches \$500,000. Smoky Mountain News. 21 February 2018. Retrieved November, 2018, from, <https://smokymountainnews.com/news/item/24260-scc-lead-cleanup-cost-reaches-500-000>.
- Kellaway, K. 2009. ‘To a birdwatcher, one glimpse, one moment is happiness enough’ The Observer 22 November 2009. Retrieved December, 2018, from, <https://www.theguardian.com/environment/2009/nov/22/birdwatching-popularity-kate-kellaway>.
- Kelly, A., and S. Kelly. 2005. Are mute swans with elevated blood lead levels more likely to collide with overhead power lines? *Waterbirds* 28: 331–334.
- Knutsen, H.K., A.L. Brantsæter, J. Alexander, and H.M. Meltzer. 2015. Associations between consumption of large game animals and blood lead levels in humans in Europe: The Norwegian experience. In: *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, eds. R.J. Delahay, and C.J. Spray, pp. 44–50. Edward Grey Institute, University of Oxford.
- Krone, O., N. Kenntner, A. Trinogga, M. Nadjafzadeh, F. Scholz, J. Sulawa, K. Totschek, P. Schuck-Wersig, et al. 2009. Lead

- poisoning in White-tailed Sea Eagles: Causes and approaches to solutions in Germany. In *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt. The Peregrine Fund, Boise, Idaho, USA. <https://doi.org/10.4080/ilsa.2009.0207>.
- LAG. 2014. Minutes of the 11th Lead Ammunition Group meeting, 16 April 2014. Point 11.2. [http://www.leadammunitiongroup.org.uk/wp-content/uploads/2015/07/LAG\\_meeting\\_minutes\\_11\\_1600414.pdf](http://www.leadammunitiongroup.org.uk/wp-content/uploads/2015/07/LAG_meeting_minutes_11_1600414.pdf).
- LAG. 2015. Appendix 1 to the Lead Ammunition Group Report. 2 June 2015. <http://www.leadammunitiongroup.org.uk/wp-content/uploads/2015/06/LAG-Report-June-2015-Appendices-without-Appendix-6.pdf>.
- Laidlaw, M.A.S., G. Filippelli, H. Mielke, B. Gulson, and A.S. Ball. 2017. Lead exposure at firing ranges—a review. *Environmental Health* 16: 34. <https://doi.org/10.1186/s12940-017-0246-0>.
- Langner, H.W., R. Domenech, V.A. Slabe, and S.P. Sullivan. 2015. Lead and mercury in fall migrant golden eagles from western North America. *Archives of Environmental Contamination and Toxicology* 69: 54–61. <https://doi.org/10.1007/s00244-015-0139-6>.
- Lanphear, B.P., R. Hornung, J. Khoury, K. Yolton, P. Baghurst, D.C. Bellinger, R.L. Canfield, K.N. Dietrich, et al. 2005. Low-level environmental lead exposure and children's intellectual function: An international pooled analysis. *Environmental Health Perspectives* 113: 894–899. <https://doi.org/10.1289/ehp.7688>.
- Lanphear, B.P., S. Rauch, P. Auinger, R.W. Allen, and R.W. Hornung. 2018. Low-level lead exposure and mortality in US adults: A population-based cohort study. *The Lancet: Public Health* 3: e177–e184. [https://doi.org/10.1016/S2468-2667\(18\)30025-2](https://doi.org/10.1016/S2468-2667(18)30025-2).
- Livsmiddelsverket (National Food Agency) undated. Lead in Game in Sweden. Undated Presentation Retrieved August, 2018, from <https://mobil.bfr.bund.de/cm/343/lead-in-game-in-sweden.pdf>.
- Madden, J.R., A. Hall, and M.A. Whiteside. 2018. Why do many pheasants released in the UK die, and how can we best reduce their natural mortality? *European Journal of Wildlife Research* 64: 40. <https://doi.org/10.1007/s10344-018-1199-5>.
- Mariussen, E., I.V. Johnsen, and A.E. Stromseng. 2015. Selective adsorption of lead, copper and antimony in runoff water from a small arms shooting range with a combination of charcoal and iron hydroxide. *Journal of Environmental Management* 150: 281–287. <https://doi.org/10.1016/j.jenvman.2014.10.019>.
- Mariussen, E., I.V. Johnsen, and A.E. Strømseng. 2017a. Distribution and mobility of lead (Pb), copper (Cu), zinc (Zn), and antimony (Sb) from ammunition residues on shooting ranges for small arms located on mires. *Environmental Science and Pollution Research* 24: 10182–10196. <https://doi.org/10.1007/s11356-017-8647-8>.
- Mariussen, E., L.S. Heier, H.C. Teien, M.N. Pettersen, T.F. Holth, B. Salbu, and B.O. Rosseland. 2017b. Accumulation of lead (Pb) in brown trout (*Salmo trutta*) from a lake downstream a former shooting range. *Ecotoxicology and Environmental Safety* 135: 327–336. <https://doi.org/10.1016/j.ecoenv.2016.10.008>.
- Markandya, A., T. Taylor, A. Longo, M.N. Murty, S. Murty, and K. Dhavala. 2008. Counting the cost of vulture decline—an appraisal of the human health and other benefits of vultures in India. *Ecological Economics* 67: 194–204. <https://doi.org/10.1016/j.ecolecon.2008.04.020>.
- Molenaar, F.M., J.E. Jaffe, I. Carter, E.A. Barnett, R.F. Shore, J.M. Rowcliffe, and A.W. Sainsbury. 2017. Poisoning of reintroduced red kites (*Milvus milvus*) in England. *European Journal of Wildlife Research* 63: 94. <https://doi.org/10.1007/s10344-017-1152-z>.
- Molloy, D. 2011. Wildlife at work. The economic impact of white-tailed eagles on the Isle of Mull., The RSPB, Sandy. [http://www2.rspb.org.uk/Images/wildlifeatwork\\_tcm9-282134.pdf](http://www2.rspb.org.uk/Images/wildlifeatwork_tcm9-282134.pdf).
- Monahan, M., K. Boelaert, K. Jolly, S. Chan, P. Barton, and T.E. Roberts. 2015. Costs and benefits of iodine supplementation for pregnant women in a mildly to moderately iodine-deficient population: A modelling analysis. *The Lancet: Diabetes and Endocrinology* 3: 715–722. [https://doi.org/10.1016/S2213-8587\(15\)00212-0](https://doi.org/10.1016/S2213-8587(15)00212-0).
- Morales-Reyes, Z. 2015. Supplanting ecosystem services provided by scavengers raises greenhouse gas emissions. *Scientific Reports* 5: 7811. <https://www.nature.com/articles/srep07811>.
- Musgrove, A., N. Aebischer, M. Eaton, R. Hearn, S. Newson, D. Noble, M. Parsons, K. Risely, et al. 2013. Population estimates of birds in Great Britain and the United Kingdom. *British Birds* 106: 64–100. <https://www.britishtbirds.co.uk/wp-content/uploads/2010/12/APEP3.pdf>.
- Nadjafzadeh, M., H. Hofer, and O. Krone. 2013. The link between feeding ecology and lead poisoning in white-tailed eagles. *Journal of Wildlife Management* 77: 48–57. <https://doi.org/10.1002/jwmg.440>.
- Office for National Statistics. 2018. Families and Households: 2017 Trends in living arrangements including families (with and without dependent children), people living alone and people in shared accommodation, broken down by size and type of household. <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2017>.
- Okkenhaug, G., A.B. Smebye, T. Pabst, C.E. Amundsen, H. Sævarsson, and G.D. Breedveld. 2017. Shooting range contamination: Mobility and transport of lead (Pb), copper (Cu) and antimony (Sb) in contaminated peatland. *Journal of Soils and Sediments* 18: 1–14. <https://doi.org/10.1007/s11368-017-1739-8>.
- Orabi, P. 2011. Argumentaire et plan d'actions pour la conservation du vautour fauve en France, LPO. [http://www.sepanso64.org/IMG/pdf/LPO\\_Argumentaire\\_et\\_plan\\_d\\_actions\\_pour\\_la\\_conservation\\_du\\_vautour\\_fauve\\_en\\_France\\_2011.pdf](http://www.sepanso64.org/IMG/pdf/LPO_Argumentaire_et_plan_d_actions_pour_la_conservation_du_vautour_fauve_en_France_2011.pdf).
- PACEC—Public and Corporate Economic Consultants. 2006. *The economic and environmental impact of sport shooting in the UK*. Cambridge: PACEC.
- Pain, D.J., R.L. Cromie, J. Newth, M.J. Brown, E. Crutcher, P. Hardman, L. Hurst, R. Mateo, et al. 2010. Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. *PLoS ONE* 5: e10315. <https://doi.org/10.1371/journal.pone.0010315>.
- Pain, D.J., R. Cromie, and R.E. Green. 2015. Poisoning of birds and other wildlife from ammunition-derived lead in the UK. In *The Oxford Lead Symposium. Lead Ammunition: Understanding and minimising the risks to human and environmental health*, eds. R.J. Delahay, and C.J. Spray, pp. 58–84. Edward Grey Institute, The University of Oxford, UK. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_pain\\_cromie\\_green.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_pain_cromie_green.pdf).
- Pain, D.J., R. Mateo, and R.E. Green. 2019. Effects of lead from ammunition on birds and other wildlife: A review and update. In *Lead in ammunition: Persistent problems and solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox. *Special Issue*, In press.
- Pannon Eagle. 2018. 22 years and 24 offspring—one of the oldest known Eastern Imperial Eagles in Hungary died (26/03/2018). Retrieved September, 2018, from, <http://imperial eagle.eu/en/content/22-years-and-24-offspring-one-oldest-known-eastern-imperial-eagles-hungary-died>.
- Payne, J.H., J.P. Holmes, R.A. Hogg, G.M. Van der Burgt, N.J. Jewell, and D. de Welchman. 2013. Lead intoxication incidents associated with shot from clay pigeon shooting. *Veterinary Record* 173: 552. <https://doi.org/10.1136/vr.102120>.
- Pfeiffer, M. B., J.D. Kougher, and T.L. DeVault. 2018. Civil airports from a landscape perspective: A multi-scale approach with

- implications for reducing bird strikes. USDA National Wildlife Research Center—Staff Publications. 2144. [http://digitalcommons.unl.edu/icwdm\\_usdanwrc/2144](http://digitalcommons.unl.edu/icwdm_usdanwrc/2144).
- Pinkstone, J. 2017. For MAIL Online. Return of the golden eagle: Scientists will release 10 birds in southern Scotland over the next five years in the hope they will fly south to England. Published: 17:23, 12 December 2017 | Updated: 17:49, 12 December 2017. Retrieved December, 2018, from, <https://www.dailymail.co.uk/sciencetech/article-5171047/Golden-Eagles-reintroduced-northern-England.html>.
- Piuweb. 2016. Maxi sequestro dei N.a.s in Emilia Romagna: piombo nel ragu e prodotti scaduti da anni. il: 16 Novembre 2016—19:23 Retrieved 14 January, 2019 from, <https://www.piuweb.net/emilia/maxi-sequestro-dei-n-a-s-in-emilia-romagna-piombo-nel-ragu-e-prodotti-scaduti-da-anni/>.
- Rayment, M., S. Sankey, and C. Shedden. 1998. Geese and local economies in Scotland. a report to the national goose forum by RSPB and BASC. Pp 41. [http://ww2.rspb.org.uk/Images/geese\\_tcm9-133022.pdf](http://ww2.rspb.org.uk/Images/geese_tcm9-133022.pdf).
- Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption <https://publications.europa.eu/en/publication-detail/-/publication/28ab554e-8e93-4976-89a9-8b6c9d17dfb4/language-en>.
- Regulation (EU) No 142/2011 of 25 February 2011 implementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and implementing Council Directive 97/78/EC as regards certain samples and items exempt from veterinary checks at the border under that Directive. <https://eu-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:054:0001:0254:EN:PDF>.
- Ricklefs, R.E. 2000. Density dependence, evolutionary optimization, and the diversification of avian life histories. *Condor* 102: 9–22.
- Runia, T.J., and A.J. Solem. 2016. Spent lead shot availability and ingestion by ring-necked pheasants in South Dakota. *Wildlife Society Bulletin* 40: 477–486. <https://doi.org/10.1002/WSB.681>.
- Runia, T.J., and A.J. Solem. 2017. Pheasant response to lead ingestion. *The Prairie Naturalist* 49: 13–18.
- Russell, R.E., and C.J. Franson. 2014. Causes of Mortality in Eagles Submitted to The National Wildlife Health Center 1975–2013. *Wildlife Society Bulletin* 38: 697–704. <https://doi.org/10.1002/WSB.469>.
- Sampson, R.J., and A.S. Winter. 2018. Poisoned development: Assessing childhood lead exposure as a cause of crime in a birth cohort followed through adolescence. *Criminology* 56: 269–301. <https://doi.org/10.1111/1745-9125.12171>.
- Savills. 2017. Shoot Benchmarking Survey. Savills and the Game and Wildlife Conservation Trust. Savills World Research, UK Rural. [savills.com/research](http://savills.com/research).
- Schwartz, J. 1994. Societal benefits of reducing lead exposure. *Environmental Research* 66: 105–124. <https://doi.org/10.1006/enrs.1994.1048>.
- SNFA. 2014. Lead in game meat. Swedish National Food Agency report 18. English summaries of the chapters. Retrieved September, 2018, from, <http://basc.org.uk/wp-content/uploads/2014/10/NFA-report-English-summary-2.pdf>.
- Sorvari, J. 2007. Environmental risks at Finnish shooting ranges—a case study. *Human and Ecological Risk Assessment: An International Journal* 13: 1111–1146. <https://doi.org/10.1080/10807030701506124>.
- Sorvari, J., R. Antikainen, and O. Pyy. 2006. Environmental contamination at Finnish shooting ranges—the scope of the problem and management options. *Science of the Total Environment* 366: 21–31. <https://doi.org/10.1016/j.scitotenv.2005.12.019>.
- Thomas, V.G., and R. Guitart. 2013. Transition to non-toxic gunshot use in olympic shooting: Policy implications for IOC and UNEP in resolving an environmental problem. *Ambio* 42: 746–754.
- Thomas, V.G., C. Gremse, and N. Kanstrup. 2016. Non-lead rifle hunting ammunition: Issues of availability and performance in Europe. *European Journal of Wildlife Research* 62: 633–641. <https://doi.org/10.1007/s10344-016-1044-7>.
- Urrutia-Goyes, R., A. Argyraki, N. Ornelas-Soto. 2017. Assessing Lead, Nickel, and Zinc Pollution in Topsoil from a Historic Shooting Range Rehabilitated into a Public Urban Park. *International Journal of Environmental Research and Public Health* 14: 698. <https://doi.org/10.3390/ijerph14070698>.
- VKM. 2013. Opinion of the Panel on Contaminants of the Norwegian Scientific Committee for Food Safety (VKM). Risk assessment of lead exposure from cervid meat in Norwegian consumers and in hunting dogs. Retrieved July 2015 from, <http://www.vkm.no/dav/cbfe3b0544.pdf>.
- Wilkins, E., L. Wilson, K. Wickramasinghe, P. Bhatnagar, J. Leal, R. Luengo-Fernandez, R. Burns, M. Rayner, et al. 2017. European Cardiovascular Disease Statistics 2017. European Heart Network, Brussels. <http://www.ehnheart.org/images/CVD-statistics-report-August-2017.pdf>.
- WWT. 2018. WWT response to public consultation on the SEAC Draft Opinion May 2018. In: Comments on the SEAC draft opinion and specific information requests on Annex XV restriction report submitted by ECA on 12/04/2017. Lead compounds—shot EC Number 231-100-4. CAS number 7439-92-1.

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## AUTHOR BIOGRAPHIES

**Deborah J. Pain** (✉) is an Honorary Research Fellow in the Department of Zoology, University of Cambridge and an Ambassador for the Wildfowl & Wetlands Trust. Her research interests include diagnosing the causes of declines in threatened bird species and developing and testing practical and policy solutions to reverse them. She has an interest in ecotoxicology, particularly lead poisoning from ammunition, on which she has worked since the early 1980s.

*Address:* Department of Zoology, University of Cambridge, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK. *Address:* Wildfowl & Wetlands Trust, Slimbridge, Gloucestershire GL2 7BT, UK.

e-mail: [pain.debbie@gmail.com](mailto:pain.debbie@gmail.com)

**Ian Dickie** is a Director of Economics For The Environment Consultancy (eftec). He is also a Director of the Aldersgate Group, a fellow of the Royal Society of Arts, a member of the Sustainability Committee of the Institute of Chartered Accountants of England and Wales, and the Advisory Panel of the Natural Capital Coalition. He has led production of natural capital accounts for the UK, Local Authorities and private businesses. He is an author of the Natural Capital Protocol, and the lead technical writer of UNDP's 2016 biodiversity finance initiative (BIOFIN) workbook.

*Address:* eftec - economics for the environment, 4 City Road, London EC1Y 2AA, UK.

e-mail: [ian@eftec.co.uk](mailto:ian@eftec.co.uk)

**Rhys E. Green** is an Honorary Professor of Conservation Science in the Department of Zoology at the University of Cambridge. His research interests include the effects of human activities on population size and demographic rates of wild species. He uses statistical

and simulation models fitted to data on these effects to devise practical interventions that land managers can use to reduce negative effects on wild species so as to improve their conservation status.

*Address:* Department of Zoology, University of Cambridge, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK.  
e-mail: reg29@cam.ac.uk

**Niels Kanstrup** is a biologist, scientist and hunter is an adjunct senior scientist at Aarhus University, Department of Bioscience. He has worked with the Danish Hunters' Association, been the President of the CIC Migratory Bird Commission and is a member of the AEWA Technical Committee. Throughout his career, he has focused on the sustainability of hunting, particularly the issue of lead in hunting ammunition.

*Address:* Department of Bioscience, Aarhus University, Grenåvej 14, 8410 Rønne, Denmark.  
e-mail: nk@bios.au.dk

**Ruth Cromie** is a wildlife health specialist working as the Head of Ecosystem Health at the Wildfowl & Wetlands Trust. She specialises in practical management solutions to promoting health, particularly in wetlands. She has worked on multiple aspects of lead poisoning including surveillance, research (including more latterly social science approaches), advocacy and policy including as a member of various multilateral environmental agreement technical panels and working groups, such as for the UN-Convention on Migratory Species, Ramsar Convention on Wetlands, IUCN and the African Eurasian Waterbird Agreement.

*Address:* Wildfowl & Wetlands Trust, Slimbridge, Gloucestershire GL2 7BT, UK.

e-mail: ruth.cromie@wwt.org.uk



# PAPER 4

Kanstrup N, Swift J, Stroud DA, Lewis M (2018). Hunting with lead ammunition is not sustainable: European perspectives. Ambio 47:846-857 doi:10.1007/s13280-018-1042-y

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

### Order Summary

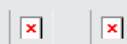
Licensee: Aarhus University  
Order Date: Mar 8, 2020  
Order Number: 4784330083957  
Publication: AMBIO  
Title: Hunting with lead ammunition is not sustainable:  
European perspectives  
Type of Use: Thesis/Dissertation  
Order Ref: Sustain  
Order Total: 0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customer@copyright.com](mailto:customer@copyright.com)  
<https://myaccount.copyright.com>



## AUTHORS' CONTRIBUTIONS

Dear Niels,

Regarding the paper Kanstrup N, Swift J, Stroud DA, Lewis M (2018) Hunting with lead ammunition is not sustainable: European perspectives Ambio 47:846-857 doi:10.1007/s13280-018-1042-y

- Niels Kanstrup conceptualized the work, drafted the manuscript, and served as corresponding author.
- All authors contributed to edition and revision according to their personal competences. All authors approved the final revised manuscript.

I hereby confirm the above statement:

John Swift

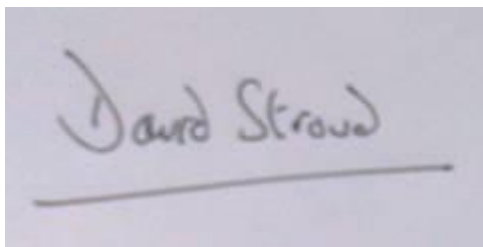
[John Swift Consultancy and UK Lead Ammunition Group]

**Regarding:**

Kanstrup N, Swift J, Stroud DA, Lewis M (2018) Hunting with lead ammunition is not sustainable: European perspectives *Ambio* 47:846-857 doi:10.1007/s13280-018-1042-y

- Niels Kanstrup conceptualized the work, drafted the manuscript, and served as corresponding author.
- All authors contributed to edition and revision according to their personal competences. All authors approved the final revised manuscript.

I hereby confirm this statement:

A photograph of a handwritten signature, "David Stroud", in dark ink on a light-colored surface. The signature is written in a cursive style and is underlined with a single horizontal line.

Confirmed, April 2021

A photograph of a handwritten signature, "Niels Kanstrup", in dark ink on a light-colored surface. The signature is written in a cursive style.

Niels Kanstrup

# *Hunting with lead ammunition is not sustainable: European perspectives*

**Niels Kanstrup, John Swift, David A. Stroud & Melissa Lewis**

**Ambio**

A Journal of the Human Environment

ISSN 0044-7447

Volume 47

Number 8

Ambio (2018) 47:846–857

DOI 10.1007/s13280-018-1042-y

Volume 47 · Number 8 · December 2018 · ISSN 0044-7447

# Ambio



KUNGL.  
VETENSKAPS-  
AKADEMIEN  
THE ROYAL SWEDISH ACADEMY OF SCIENCES

A Journal of the Human Environment



GLACIER PROTECTION LAWS: POTENTIAL CONFLICTS IN MANAGING GLACIAL HAZARDS AND ADAPTING TO CLIMATE CHANGE  
UNSUSTAINABLE LEAD AMMUNITION HUNTING • LEAD POISONING, WHITE-TAILED EAGLE, FINLAND • CULTURAL ECOSYSTEM SERVICES, EDUCATION • PHOSPHORUS CYCLING, INVASIVE POLYCHAETE • LANDSCAPE CHANGE OVER A MILLENNIUM, FRANCE • TRADITIONAL ECOLOGICAL KNOWLEDGE, FOREST CONSERVATION, BOLIVIA • LOCAL KNOWLEDGE IN A BEE HUNTING COMMUNITY, PHILIPPINES

 Springer

 Springer

**Your article is protected by copyright and all rights are held exclusively by Royal Swedish Academy of Sciences. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at [link.springer.com](http://link.springer.com)".**



PERSPECTIVE

# Hunting with lead ammunition is not sustainable: European perspectives

Niels Kanstrup , John Swift, David A. Stroud, Melissa Lewis

Received: 10 December 2017 / Revised: 2 February 2018 / Accepted: 28 February 2018 / Published online: 12 March 2018

**Abstract** Much evidence demonstrates the adverse effects of lead ammunition on wildlife, their habitats and human health, and confirms that the use of such ammunition has no place within sustainable hunting. We identify the provisions that define sustainable hunting according to European law and international treaties, together with their guidance documents. We accept the substantial evidence for lead's actual and potential effects on wildlife, habitats and health as persuasive and assess how these effects relate to stated provisions for sustainability and hunting. We evaluate how continued use of lead ammunition negatively affects international efforts to halt loss of biodiversity, sustain wildlife populations and conserve their habitats. We highlight the indiscriminate and avoidable health and welfare impacts for large numbers of exposed wild animals as ethically unsustainable. In societal terms, continued use of lead ammunition undermines public perceptions of hunting. Given the existence of acceptable, non-toxic alternatives for lead ammunition, we conclude that hunting with lead ammunition cannot be justified under established principles of public/international policy and is not sustainable. Changing from lead ammunition to non-toxic alternatives will bring significant nature conservation and human health gains, and from the hunter's perspective will enhance societal acceptance of hunting. Change will create opportunities for improved constructive dialogue between hunting stakeholders and others engaged with enhancing biodiversity and nature conservation objectives.

**Keywords** Animal welfare · European Union · Human health · Lead ammunition · Poisoning · Sustainable hunting

## INTRODUCTION

International environmental law has traditionally provided for hunting as a wise use of wildlife resources so long as it does not jeopardise the conservation status of hunted or other species and does not result in deterioration of habitats where hunting occurs. These fundamentals for sustainable and acceptable hunting assume it is conducted strictly within international and national laws, according to standards of best practice, in turn shaped by dialogue with other stakeholders, and is beneficial to society in terms of economy and conservation.

Acceptance of hunting as a legitimate sustainable use of wildlife resources has been an important facet of many international environmental instruments during the past half century. Hunting has promoted good practice in many fields, not least for management of harvestable species, controlling pests where needed, and for conservation of habitats and wider landscapes.

Waterbirds ingest shot along with grit and food. Ingested shot is often retained in the gizzard along with grit, and is rapidly mechanically eroded and dissolved by the stomach acids. The toxic salts formed are absorbed into the blood and cause poisoning. For this reason, lead gunshot<sup>1</sup> has been subject to legislative and other forms of regulation in 30–35 countries around the world over the last 50 years,

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s13280-018-1042-y>) contains supplementary material, which is available to authorized users.

<sup>1</sup> The term 'gunshot' refers to small pellets used in shotguns and excludes rifle bullets. The term ammunition includes both gunshot and rifle ammunition (bullets).

especially for the protection of waterbirds and their wetland habitats (Pain 1992; Mateo 2009; Stroud 2015).

More recent research, however, reveals a wider perspective of the problem, including that waterbirds are now known to be poisoned from lead ammunition when feeding outside wetlands. Non-wetland species living in dryland habitats also ingest gunshot. There is also a growing body of strong evidence showing that lead gunshot has wider consequences than formerly appreciated for multiple bird species (as reviewed by Watson et al. 2009; Delahay and Spray 2015). For instance, food chain linkage has been found in North America between the earthworm-eating North American Woodcock *Scolopax minor* and lead gunshot, and it is possible that Woodcock *S. rusticolor* in Europe are similarly exposed to lead in their diet (Scheuhammer et al. 1998, 2003; Hiller and Barclay 2011; Lead Ammunition Group 2015). Avian scavengers, notably eagles, buzzards, kites and vultures are poisoned having consumed meat from animals with elevated tissue lead levels, or containing either lead gunshot or fragments of lead rifle bullets (Scheuhammer and Norris 1995; Pain et al. 1997; Krone et al. 2009; Gangoso et al. 2009; Hunt 2012; Berny et al. 2015; Ecke et al. 2017; Gil-Sánchez et al. 2017).

Recent studies have shown that human consumption of shot game meat is an additional dietary lead exposure and concomitant health risk, especially for children, pregnant women, fetuses and those who eat such meat regularly (EFSA 2010; Mateo et al. 2014; Green and Pain 2015; Knutsen et al. 2015).

As an environmental problem however, eliminating poisoning from lead ammunition is not an inherently complex issue. Lead toxicity has been recognised for thousands of years (Stroud 2015), and there is a large body of scientific literature on ammunition lead's impacts on wildlife as well as on human health (Arnemo et al. 2016). Non-toxic alternatives to lead exist for most hunting applications, and regulatory options through legislation are straightforward (Thomas et al. 2015; Kanstrup et al. 2016). Indeed, some countries with strong hunting traditions, e.g. Denmark, have already phased out lead shot completely, and effectively managed the problem through legislation (Kanstrup 2015). Yet in other countries, resistance remains obdurate, either at government level and/or within hunting communities, suggesting that the issues are social and/or political rather than technical (Cromie et al. 2015).

There is general consensus, reflected in statutes, treaties and guidance documents, that hunting must be sustainable in ecological, economic and social terms. As background for this analysis, we describe principles for acceptance of sustainable hunting in environmental and wildlife conservation policy, and how regional and international law, and associated guidance for its interpretation and

implementation, define it. From this platform, we assess whether the growing evidence for lead ammunition toxicity clashes with the principles so established, and thus whether continued use of lead ammunition, in any context, can be regarded as sustainable.

## PROVISIONS FOR SUSTAINABLE HUNTING

For the purposes of this assessment, “hunting” encompasses any lawful pursuit and killing of animals with shotguns or rifles firing either leaded or lead-free<sup>2</sup> ammunition.

The definition and practical implementation of hunting “sustainability” have evolved in recent decades as this issue has been painstakingly addressed in global, European and national contexts. It began in Europe with discussions and spirit of international dialogue and cooperation for conservation that prevailed after the Second World War. This was founded on recognition of the importance of pursuing research-driven conservation for wild species for their existence value as well as for the benefit of humankind. Many of those involved in drafting the text of the 1971 Ramsar Convention on Wetlands of International Importance and ensuing multilateral environmental agreements (MEAs) came from a generation of hunter-naturalists. They ensured that principled hunting as a wise use was based on the concept of hunters taking a sustainable harvest of a shared natural resource and as such, this concept was firmly embedded within these treaties.

The Ramsar Convention includes no direct reference to lead poisoning of waterbirds. However, its broadly phrased provision regarding the conservation and wise use of wetlands (Article 3) commits Parties to addressing threats to wetland ecological character, including those resulting from wetland species' harvest and release of toxic substances (Resolution VII.19; Recommendation 6.14). Multiple other legally binding international instruments contain provisions which identify principles for sustainable hunting and, either explicitly or by implication, require States to address threats posed by lead ammunition. These are briefly outlined below (see further Table S1), and are revisited in the article's subsequent discussion as relevant. Appropriate non-binding instruments and initiatives are also considered. The topic was previously addressed by Thomas and Guitart (2005), and comparison reveals a steady increase in the number of international policy instruments that promote the transition to lead-free ammunition since then.

<sup>2</sup> According to a general consensus but not necessarily legal applicable in all countries, ‘lead-free’ means that shot or bullets contain less than 1% lead by weight.

## Key provisions and guidance documents

### *The Bern Convention and the European Union's Nature Directives*

After the adoption of Ramsar, further principles for sustainable hunting were included in the Council of Europe's 1979 Convention on the Conservation of European Wildlife and Natural Habitats<sup>3</sup> ("the Bern Convention"), and the two primary nature conservation instruments of the European Community that implemented the Convention within European legal frameworks, the 1979 Birds Directive (79/409/EEC and 2009/147/EC) and the 1992 Habitats Directive (92/43/EEC). Each of these three instruments identifies a standard at which wildlife populations must be maintained or to which they must be adjusted (Article 2).

The Bern Convention prescribes varying levels of protection for species listed in its Appendices (Articles 5–7), and places particular emphasis upon measures to conserve habitats of Appendix II and (insofar as migratory species are concerned) III species (Article 4). Between them, the Appendices cover all bird species, with the exception of 11 abundant species regarded in many Contracting Parties as potential pests requiring control. The Birds Directive goes further by requiring a general system of protection in respect of "*all species of naturally occurring birds in the wild state*" in the EU (Article 1). The Directive requires "special conservation measures" for the habitats of Annex I and migratory species (in particular, the classification and prevention of the deterioration of Special Protection Areas—SPAs). To the extent that it permits hunting, the Directive requires that this practice does not jeopardise conservation efforts in the distribution areas of huntable species, and complies with wise use principles (Articles 4 & 7).

Twenty-two species of European waterbird have been recorded to ingest spent lead shot: eight being listed in the Birds Directive's Annex I (Mateo 2009; UNEP 2014; Pain et al. 2015). Annex I also lists a number of raptor and vulture species known to suffer from lead ammunition ingestion (see also Table S2). It follows that if lead shot is deposited in SPAs designated for these species or negatively impacts conservation efforts elsewhere, there is a clear issue for hunting to address. Indeed, the European Commission has recognised that pollution from lead ammunition "*needs to be considered in the context of wise use*" and that "*any use of it in Special Protection Areas that leads to the deterioration of habitats or significant disturbance to birds is incompatible with the protection requirements of these sites*" (Guide to Sustainable Hunting under the Birds Directive, see below).

The Bern Convention's Standing Committee has recommended that Parties take steps to phase out use of lead shot in wetlands or waterbird hunting and promote a general shift to use of alternatives (Recommendation No. 28<sup>4</sup>).

The Birds Directive requires EU Member States to "*prohibit the use of all means, arrangements or methods used for the large-scale or non-selective capture or killing of birds or capable of causing the local disappearance of a species*" (Article 8). This provision implements a similarly worded requirement of the Bern Convention (which additionally identifies poison as such a means in the non-exhaustive list provided in Appendix IV), as does Article 15 of the Habitats Directive. The precise import of the wording regarding selectivity in the two Directives and the Convention may be debated: whether in each respect it is the indiscriminate intentional method, or the effect of taking, that is material. Taken in the round however, and with emphasis on preventing deterioration of important habitats for potentially vulnerable species, as well as unintended harmful consequences for non-target species, the grain of public policy is clear: hunting sustainability depends on avoidance of methods with indiscriminate (i.e. non-selective) effects.

Notably, both Directives and the Convention identify various justifications for derogating from the prohibition on non-selective methods of killing. However, such derogations cannot be relied upon if another satisfactory solution exists. In the case of lead ammunition, non-toxic and effective alternatives are widely available, and hence derogations cannot be justified.

Finally, several international Species Action Plans developed with support of the European Commission and/or endorsed by the Bern Convention call for specific action on lead shot (Table S2).

### *AEWA and other instruments in the CMS family*

By the time of the adoption of the African-Eurasian Migratory Waterbird Agreement (AEWA)<sup>5</sup> in 1995, awareness of the dangers of lead gunshot was well appreciated in Europe, although such dangers were long understood in North America (Bellrose 1964; Sanderson and Bellrose 1986; Morehouse 1992). As a result, the AEWA Action Plan contained a firm obligation for Parties to endeavour to phase out lead shot for hunting in wetlands before 2000. This has been subject to amendment and at present is formulated: "*Parties shall endeavour to phase out the use of lead shot for hunting in wetlands as soon as possible in accordance with self-imposed and published timetables*" (Action Plan 4.1.4), and with an agreed target

<sup>3</sup> <http://www.coe.int/en/web/bern-convention>.

<sup>4</sup> <https://rm.coe.int/1680746b41>.

<sup>5</sup> <http://www.unep-aewa.org>.

for this phase out to occur by 2017 (AEWA Strategic Plan 2009–2017<sup>6</sup>). This has since been extended until the seventh AEWa Meeting of the Parties (MOP) in December 2018 (Resolution 6.14<sup>7</sup>). Several Parties have entered reservations in respect of this provision. However, Parties' commitments to maintain or restore the favourable conservation status of migratory waterbirds (Article II) and ensure sustainable use (Article III) arguably require that even those states with reservations restrict the use of lead shot if such use is having a significant impact on waterbird populations (Lewis 2016). Several of the Agreement's other provisions are relevant to lead ammunition, including those concerning prohibiting indiscriminate means of taking, and developing and implementing International Single Species Action Plans (Tables S1 and S2).

Certain provisions of, and guidance developed under the 1979 Convention on Migratory Species of Wild Animals (CMS) hold wider relevance for the lead shot issue. Insofar as the use of lead ammunition degrades the habitat or impedes migration of, and/or is a factor endangering, Appendix I species, the Convention would appear to require that Parties endeavour to address this issue (Article III). Guidance adopted by the CMS Conference of the Parties (COP) explicitly encourages phase out of lead ammunition across all habitats (Resolution 11.15;<sup>8</sup> *Guidelines to Prevent the Risk of Poisoning to Migratory Birds*).

Exhortations concerning lead are also found in the non-binding African-Eurasian Migratory Landbirds Action Plan,<sup>9</sup> the Central Asian Flyway (CAF) Action Plan for the Conservation of Migratory Waterbirds and their Habitats,<sup>10</sup> and the Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia ("Raptors MoU"<sup>11</sup>).

### *The EU Sustainable Hunting Initiative*

In 2001, the European Commission recognised the risks to practical conservation of counterproductive disagreement on a limited number of issues between some hunters and some conservationists. In order to find solutions and encourage meeting of minds, the Commission launched the

Sustainable Hunting Initiative.<sup>12</sup> The Initiative's objective was "to achieve and enhance sustainable hunting under the *Birds and Habitats Directives*". It was envisaged as a 'win-win' for biodiversity conservation and responsible hunting, achieved "by dialogue and cooperation between environmental and hunting organisations, and awareness-raising aimed at grassroots hunters".

In 2004, the Sustainable Hunting Initiative was clarified by the European Commission in their *Guide to Sustainable Hunting under the Birds Directive*.<sup>13</sup> This was supported in October 2004 with key delivery objectives agreed<sup>14</sup> between BirdLife International and the Federation of Associations for Hunting and Conservation of the EU (FACE) who agreed to "phase out lead shot for hunting in wetlands throughout the EU as soon as possible, and in any case by 2009 at the latest". This objective mirrored the action agreed between the Commission and Member States in the 25th anniversary Birds Directive Action Plan (2004): "Action 5–8. Aim to phase out the use of lead shot in wetlands as soon as possible and ultimately by 2009 ([Action:] Member States, European Commission)".<sup>15</sup> It reflected AEWa commitments and exhortations from the Bern Convention's Standing Committee.

### *The CBD Addis Ababa Principles and Guidelines and Aichi Targets*

In parallel with these developments, the 2004 COP of the 1992 Convention on Biological Diversity (CBD) adopted the Addis Ababa Principles and Guidelines for the Sustainable Use of Biodiversity,<sup>16</sup> which provided a framework to ensure that "no use of the components of biodiversity will lead to the decline of biodiversity". Principle 5 specifies in particular that "sustainable use management goals and practices should avoid or minimise adverse impacts on ecosystem services, structure and functions as well as other components of ecosystems". Principle 11 specifies the need to minimise adverse environmental impact, including through promotion of more efficient, ethical and humane use of components of biodiversity and reduction of collateral damage to biodiversity.

CBD thus has linked sustainability of hunting to all other uses of biodiversity under a common conceptual framework. Complementary to these Principles, CBD's

<sup>6</sup> [http://www.unep-awea.org/sites/default/files/basic\\_page\\_documents/strategic\\_plan\\_2009-2017\\_1.pdf](http://www.unep-awea.org/sites/default/files/basic_page_documents/strategic_plan_2009-2017_1.pdf).

<sup>7</sup> [http://www.unep-awea.org/sites/default/files/document/awea\\_mop6\\_res14\\_ext\\_rev\\_sp\\_poa\\_en\\_0.pdf](http://www.unep-awea.org/sites/default/files/document/awea_mop6_res14_ext_rev_sp_poa_en_0.pdf).

<sup>8</sup> <http://www.cms.int/en/document/guidelines-prevent-risk-poisoning-migratory-birds-unepcmscop11doc2312annex2>.

<sup>9</sup> <http://www.cms.int/en/document/african-urasian-migratory-landbirds-action-plan-aemlap-2>.

<sup>10</sup> <http://www.cms.int/en/document/central-asian-flyway-action-plan-conservation-migratory-waterbirds-and-their-habitats>.

<sup>11</sup> [http://www.cms.int/sites/default/files/basic\\_page\\_documents/raptors-mou\\_without-annexes\\_e.pdf](http://www.cms.int/sites/default/files/basic_page_documents/raptors-mou_without-annexes_e.pdf).

<sup>12</sup> [http://ec.europa.eu/environment/nature/conservation/wildbirds/hunting/index\\_en.htm](http://ec.europa.eu/environment/nature/conservation/wildbirds/hunting/index_en.htm).

<sup>13</sup> [http://ec.europa.eu/environment/nature/conservation/wildbirds/hunting/docs/hunting\\_guide\\_en.pdf](http://ec.europa.eu/environment/nature/conservation/wildbirds/hunting/docs/hunting_guide_en.pdf).

<sup>14</sup> [http://ec.europa.eu/environment/nature/conservation/wildbirds/hunting/docs/agreement\\_en.pdf](http://ec.europa.eu/environment/nature/conservation/wildbirds/hunting/docs/agreement_en.pdf).

<sup>15</sup> <http://edepot.wur.nl/118449>.

<sup>16</sup> <https://www.cbd.int/sustainable/addis.shtml>.

Aichi Biodiversity Targets (2010) and the United Nations General Assembly's Sustainable Development Goals (2015) were developed. Notably, AEWA's MOP has formally recognised that efforts to phase out lead shot contribute to achieving several of the targets identified in these documents (Resolution 6.15).

### *The Council of Europe's Charter for Hunting*

The Council of Europe's European Charter for Hunting (2007)<sup>17</sup> expanded the European Commission's Sustainable Hunting Initiative's commitment outside the EU and specified that “*sustainable hunting is the use of wild game species and their habitats in a way and at a rate that does not lead to long term decline of biodiversity or hinder its restoration*”. The benefits of such a definition were seen as “*the maintenance of hunting as an accepted social, economic and cultural activity*”, and that hunting “*when conducted sustainably can positively contribute to the conservation of wild populations and their habitats and also benefit society*”.

Further, the Charter developed Addis Ababa Principle 11 (above) and established guidelines to regulators and managers to “(a) *Adopt rules, regulations and incentives that promote methods and equipment that minimise avoidable suffering for animals; (b) Communicate to hunters the need to treat game animals with respect; (c) Recognise and promote best practices.*” (Guideline 3.10.2.1).

## **LEAD AMMUNITION AND SUSTAINABILITY OF HUNTING**

A fundamental principle for sustainable hunting arising from the legal instruments and supporting non-binding guidelines, agreements, and principles outlined above is recognition by all those involved that hunting is acceptable provided: that it does not jeopardise the conservation of biodiversity; is selective as to species that may be taken; and does not inflict avoidable suffering.

The provisions described above focus primarily on the threat to biological sustainability. In reality, sustainability depends on more than preventing lead ammunition's damaging impacts on populations and habitat quality. Lead ammunition raises questions about ethics and humanity (the welfare of individual animals). The indiscriminate nature of lead ammunition poisoning raises questions about collateral damage.

Sustainability depends on hunting being conducted according to law and best practice, and with continuing dialogue with other stakeholders. Hunting's sustainability is enhanced if judged to be a net economic contributor.

Below, we explore what continued use of toxic lead ammunition may mean for judgments about hunting sustainability under these biological as well as societal themes.

## **Lead effects on populations and biodiversity**

Numbers and trends of waterbird populations at different scales are known to be strongly associated with their ingestion of lead shot (Anderson et al. 2000; Samuel and Bowers 2000; Stevenson et al. 2005; Mateo et al. 2014; Pain et al. 2015; Meyer et al. 2016; Green and Pain 2016). The widespread and cumulative deposition of lead shot in soils and wetlands has long been recognised as environmentally damaging (e.g. Bellrose 1964; Pain 1992; Green 2013; Harradine and Leake 2013; Pain and Green 2014). Such cumulative deposition diminishes habitat capacity to support quarry and non-quarry populations alike and is antagonistic to both the provision of hunting, and to the conservation of species and their habitats.

The lethal and sub-lethal consequences of ingesting lead ammunition pellets or bullet fragments are inherently non-selective. This contravenes the requirements that sustainable hunting necessarily needs to be selective. Even though direct harvest of populations may be subject to selective measures, the indiscriminately poisonous effects of lead ammunition dispersed whilst taking such harvest are clearly non-selective. Furthermore, the use of lead shot can be regarded as a “means”, “arrangement” or “method” capable of causing habitat degradation and/or local disappearance of a species, including those listed in the Birds Directive's Annex I. Therefore, allowing hunting with lead shot runs counter to Birds Directive requirements. Provisions of various other international instruments concerning species and habitat conservation are also arguably breached by States' failures to endeavour to phase out lead shot.

The neurotoxic and other physiological effects of very low levels of lead on human health are well known (e.g. Needleman et al. 1979, 2002). Hunt (2012) concluded: “*There are good reasons to expect that sublethal lead is harmful [to wildlife], especially in view of the considerable body of human health literature providing evidence of multiple adverse effects associated with very small amounts of lead, together with the implication that lead physiology is broadly similar among vertebrates.*” Whilst research focus on wildlife lead impacts has mainly been on acute poisoning leading to death, chronic low-level exposure to lead may be at least as significant demographically. Although much less is known about sub-lethal impacts on

<sup>17</sup> [http://www2.nina.no/lcie\\_new/pdf/634991504714143702\\_Hunting\\_Charter\[1\].pdf](http://www2.nina.no/lcie_new/pdf/634991504714143702_Hunting_Charter[1].pdf).

wildlife (compared to humans), recent studies indicate a range of potentially significant effects, including, *inter alia*, sperm motility; immune responses; reduced egg production, hatching rates and duckling survival rates; power-line collision rates; bone mineralization; and movement behaviour (Edens and Garlich 1983; Kelly and Kelly 2005; Gangoso et al. 2009; Hunt 2012; Vallverdú-Coll et al. 2015, 2016; Newth et al. 2016; Ecke et al. 2017). Such adverse physiological outcomes for individuals have potential to negatively affect populations through demographic impacts on productivity and survival, and thus conflict with the Addis Ababa Principle of avoiding or minimising adverse impacts on ecosystem services, structure and functions as well as other components of ecosystems. Furthermore, to the extent that sub-lethal impacts of lead poisoning hinder maintenance or restoration of species' favourable conservation status, such impacts could have implications in terms of Article 2 of the Birds Directive, Habitats Directive, Bern Convention, and AEWa respectively. The CMS COP has additionally expressed concern regarding both lethal and sub-lethal effects of lead (Resolution 10.26).

### Lead and animal welfare

It is a widespread principle, and in some countries a legal requirement, that hunting practices avoid unnecessary animal suffering. As well as being highlighted by Addis Ababa Principle 11, the Council of Europe's Hunting Charter (2007)<sup>18</sup> addresses animal welfare explicitly with wording applying not only to hunting per se but also *methods and equipment* used. The extent of sub-lethal effects and suffering of lead poisoned and dying animals have been little researched. There is, however, considerable expert specialist knowledge of the care that must be taken to avoid poisoning animals being kept for example in collections for public display, captivity for breeding and experimental purposes, or hawks and falcons kept for falconry.

Poisoning will arise where animals can ingest lead shot from contaminated soil or if lead ammunition-contaminated meat or carrion is fed to captive carnivores. Behaviour and symptoms of such accidentally poisoned animals is entirely consistent with extended suffering. In the wild, debilitated or dying individuals are, however, seldom observed because lead poisoned individuals will, if they can, hide themselves away when behavioural impairment reaches a certain point (Pain 1991). Up to then, birds with elevated blood and tissue lead levels derived from ammunition are known to be disproportionately vulnerable to

behavioural changes that render them susceptible to being shot, predated or suffering accidents such as collision with overhead power lines (Kelly and Kelly 2005; Berny et al. 2015; Ecke et al. 2017).

The animal welfare consequences of lead ammunition use have been widely ignored because they are a difficult and emotive topic, but the UK's Lead Ammunition Group, which had the benefit of specialist veterinary expertise in the animal welfare sector, was tasked by its commissioning environment ministry, Defra, to address them. The Group concluded (Lead Ammunition Group 2015) that “*Regardless of lead's population effects, there is no doubt that, depending on the dose, lead poisoning can seriously affect health and welfare (the pathology and clinical signs being consistent with causing severe and prolonged discomfort, distress and pain) and that it can and does kill large numbers of birds. The number of birds suffering welfare problems because of ammunition-derived lead is at least as large as the number killed by lead poisoning annually*”. The Group's 2015 report provided an estimation of numbers of UK animals that might be exposed to welfare effects, and concluded that non-trivial numbers are involved in the order of millions of animals. Hence, allowing large-scale dispersal of lead ammunition conflicts with well-established policy principles of avoiding unnecessary suffering.

The welfare issue should not therefore be ignored in compliance contexts given not only legal provisions to avoid unnecessary suffering where such provisions exist, wider non-binding commitments, but also ultimately in terms of public perception and social acceptability of hunting. From an animal welfare perspective, hunting that causes avoidable widespread suffering by environmental dispersal of lead is unsustainable.

### Lead in relation to national laws

A primary requirement for hunting sustainability is that it should be conducted in compliance with relevant laws and regulations. Enforcement of appropriate national legislation is an essential feature of states' compliance with their international nature conservation commitments. For example, AEWa explicitly requires Parties to “*develop and implement measures to reduce, and as far as possible eliminate, illegal taking*” (Action Plan 4.1.6). In the context of lead ammunition specifically, the Agreement's MOP has urged Parties to “*establish enforcement procedures to assure national compliance with an introduced ban and to establish monitoring procedures to assess its effectiveness*”<sup>19</sup> (Resolution 4.1).

<sup>18</sup> [http://www2.nina.no/lcie\\_new/pdf/634991504714143702\\_Hunting\\_Charter\[1\].pdf](http://www2.nina.no/lcie_new/pdf/634991504714143702_Hunting_Charter[1].pdf).

<sup>19</sup> [http://www.unep-aewa.org/sites/default/files/document/res4\\_1\\_phasing\\_out\\_lead\\_shot\\_final\\_0.pdf](http://www.unep-aewa.org/sites/default/files/document/res4_1_phasing_out_lead_shot_final_0.pdf).

In this context, compliance monitoring procedures are notably lacking or feeble, the exception being England, where post-mortems of randomly collected shot duck conducted a decade after the introduction of legislation showed that 70% had been illegally shot with lead (Cromie et al. 2010), a rate which increased to 77–82% after 15 years (Cromie et al. 2015). A questionnaire survey of English hunters showed widespread awareness of the illegality of such use of lead, with justifications for its use including denial of the problem, dislike of alternative ammunition types, and unlikelihood of prosecution (Cromie et al. 2010). Clearly such instances where hunting is being conducted illegally to a substantial extent cannot be regarded as sustainable.

Levels of compliance in other countries where regulations have been enacted have not been monitored or investigated systematically, and remain subject of speculation. Proportions of waterbirds shown by x-radiography to be carrying lead shot in their tissues picked up on their migrations have shown no signs of declining (Newth et al. 2012, 2016).

### Lead in the context of community economics

Continued use of lead shot for hunting is likely to increase financial burdens on society due to, *inter alia*, continued and irreversible contamination of natural habitats. In the EU, this type of potential environmental damage is addressed by *Directive 2004/35*<sup>20</sup> (April 2004) on *environmental liability with regard to the prevention and remedying of environmental damage*, which is based on the “polluter-pays principle” (Article 1). If hunters and their communities cannot be specifically identified as “polluters”, restoration costs of mitigation efforts and actions to treat pollution falls on society.

The public reputation of hunting is significantly strengthened by the good reputation of game and venison as healthy low-cost sources of meat. In some European communities, notably in Scandinavia, game meat is a major component of total meat consumption. Swedish authorities, for example, have undertaken research and risk reduction through ammunition regulations, guidance to hunters and advice to consumers (Svenska Jägareförbundet 2017). Norwegian efforts to avoid lead in venison for consumption by discarding meat close to wound channels causes the discard of 200 tonnes of contaminated meat annually,<sup>21</sup> representing an economic loss equivalent to 3 million Euros (Arnemo, pers. comm.). UK's Forest Enterprise

requires that all carcasses from deer culled for commercial woodland management is killed with non-lead ammunition. Increased precaution regarding lead content in game meat may result in shot animals not being available for sale on public markets or otherwise distributed. Under such circumstance negative economic consequences may result with implications for the financial viability of game control operations that depend on derived profits.

Much game meat contains lead levels that would be legally unacceptable in farmed meat and poultry on health grounds, rendering it unfit for sale and consumption. EFSA (2010) found that lead content in 14.1% of 754 samples of food groups exceeded 10 mg/kg, with a maximum of 867 mg/kg in muscle of Wild Boar (*Sus scrofa*). Game meat and offal dominated. The Swedish Food Authorities found, in 2014, that one-third of minced Elk (*Alces alces*) meat samples were above the legal limit (0.1 mg/kg) for beef, pork and poultry, while more than 40% of cuts from Roe Deer (*Capreolus capreolus*), Fallow Deer (*Dama dama*) and Wild Boar contained levels above the same threshold.<sup>22</sup> If identical standards (thresholds) for lead contamination in animal food products were applied to game meat, then public health controls would result in game meat originating from hunting with lead ammunition having to be discarded. This would not only undermine the wise use principle but lead to large unquantified costs. It is often suggested by hunters that use of non-lead ammunition causes extra costs. However, the costs of ammunition, no matter what type, are small relative to a hunter's total expenditure, and a much greater and long-term economic benefit accrues to estates and land owners who benefit from selling lead-free game to the public (Thomas 2015).

In summary, continued use of lead shot and other lead ammunition may mean the disposal of much shot game for human consumption is no longer possible, and an important economic and ethical underpinning of game management is lost.

### Lead and hunters' reputation

Sustainability is an established and well-formulated precondition to maintenance of hunting as an accepted social, economic and cultural aspect of public policy (e.g. as embodied in the European Charter for Hunting). Sustainable use is central to the role and functioning of FACE as a representative body for European hunting. In September 2017 EU Environment Commissioner, Karmenu Vella, is reported as stating, “*Sustainable hunting is a positive force*

<sup>20</sup> <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:143:0056:0075:en:PDF>.

<sup>21</sup> <http://www.hegnar.no/Nyheter/Naeringsliv/2016/09/Maa-kaste-200-tonn-viltkjøtt>.

<sup>22</sup> <https://www.livsmedelsverket.se/globalassets/rapporter/2014/bly-i-viltkott-del-2—halter-i-bly-hos-jagarfamiljer.pdf>.

for conservation".<sup>23</sup> Societal acceptance of hunting is less formulated and, while flowing from the principles of sustainability, is dependent on uncertain and potentially changeable public opinion. If sustainability is called into question due to continued lead ammunition use, the hunters' reputation is undermined.

Society is, for very good public policy reasons (e.g. EFSA 2010; World Health Organisation 2010; UNEP 2017), progressively phasing-out exposure to lead from multiple contexts, including in petrol, water, paints, and other products following international health consensus (Markowitz and Rosner 2003; Stroud 2015). Lead will continue to have important and indispensable commercial uses but where alternatives do not yet exist, in every instance, such continued use is very strictly regulated to protect industrial workers and the environment through rigorous recovery and recycling. In this respect, lead ammunition stands out as the striking exception.

Future generations are likely to regard the widespread discharge of lead into the environment with a similarity to past widespread use of DDT and other very harmful substances used commonly just a few decades ago but today prohibited. Continued lead ammunition use is an additional and unnecessary dietary source of lead exposure for all human consumers of food products derived from lead-shot game, as there is no safe lower limit of exposure to lead (EFSA 2010; World Health Organisation 2015). If hunting maintains a dependency on lead it will be associated by wider society as directly connected with the environmental dispersal of a toxic heavy metal pollutant with clear consequences for human health.

Continuing to resist change will damage the reputation of hunting, threaten its legitimacy, and provide argumentation for those who would wish it to cease. If such antipathy takes root, there is risk of significant loss of recreational value for millions of European citizens and of the positive role that wise and sustainable hunting can provide for rural economies, management and conservation (Laws 1997; FACE 2004).

### Lead and meaningful dialogue

The European Commission's Sustainable Hunting Initiative and *Guide to Sustainable Hunting under the Birds Directive* explicitly seek to encourage meaningful dialogue as a requirement of sustainability. AEWA and the Bern Convention also contain provisions for general awareness raising. The governing bodies of both treaties have issued explicit calls for awareness and educational programmes

regarding lead shot (e.g. Bern Convention Recommendation No. 28<sup>24</sup>). The responsiveness of Member State/Contracting Parties' statutory bodies, and of hunting authorities, to the need for dialogue, awareness and educational programmes also shapes perceptions of sustainability.

The problems arising from lead shot have been a topic of regular dialogue between stakeholders at international level since the early 1990s (Pain 1992). Hunting and environmental organisations both recognised the need to be led by the evidence to develop alternatives that would be non-toxic to wildlife as well as effective, safe, available and affordable for hunting. Nonetheless, evidence of wider problems than are accepted to occur in wetlands, and that are well documented and agreed by many wildlife and public health authorities (Health Risks from Lead-Based Ammunition in the Environment 2013; Group of Scientists 2014), are vigorously contested in non-peer-reviewed reports and magazine articles by hunting and ammunition trade lobbyists who cite authorities of their own (Countryside Alliance 2013; Holmgren 2014; Batley et al. 2016). There is a blatant disregard of studies (e.g. Anderson et al. 2000; Stevenson et al. 2005) that show the large savings of wildlife which accompany non-toxic gunshot use.

Reluctance to act on lead reduction by the European Parliament and EU Member States reflects current vested interests of sporting communities (Thomas and Guitart 2010). Questions about efficacy of lead alternatives (Thomas et al. 2015) have been allowed to take root within hunting communities with little sign of effort by responsible hunting bodies to engage in sustained dialogue, correct misunderstandings, raise awareness, or deliver conservation outcomes. Such inclination to defend an indefensible status quo has echoes of similar behaviour by the paint industry to defend toxic leaded paints, and gasoline and car industries who sought to retain leaded fuels—as documented in detail by Markowitz and Rosner (2003), Michaels (2008), Needleman and Gee (2013).

There is little evidence that governments, hunters' communities and other stakeholders have made any significant or sustained investment in delivering promised measures to upgrade relevant communications, awareness raising, and pro-active promotion of best practice concerning this issue. Unfortunately, some attitudes in the hunting community have become entrenched, with the issue seen in antagonistic and competitive terms. Such attitudes make behavioural change difficult, as explored by Cromie et al. (2015).

Though many national hunters' organisations and their international associates positively support needs to phase out lead shot—at least for hunting in wetlands—lack of

<sup>23</sup> <http://mailchi.mp/face/face-press-release-problematic-proposal-restricting-the-importation-of-hunting-trophies-into-the-eu-raises-deep-concerns-1050125?e=cc43aa01d2>.

<sup>24</sup> <https://rm.coe.int/1680746b41>.

proactive campaigning to this end, including lack of actions to improve legislative enforcement, reveals shortcomings in dialogue, and to that extent compromises hunting sustainability.

### Lead and European conservation efforts

The EU is a key player in international efforts to halt loss of biodiversity and sustain wildlife populations and habitats through its legislation, policies and planning, e.g. through the Birds and Habitats Directives and the creation of the Natura 2000 protected area network (Romão et al. 2013). Furthermore, the Union is a Contracting Party to many multilateral environmental agreements. In this role the EU can establish and support (e.g. through its LIFE funding programmes) nature conservation programmes. In this context, the use of lead hunting ammunition is a key issue.

The lead shot issue is becoming increasingly a touchstone for the international wildlife management community. As early as the mid-1990s, AEWA required that Parties endeavour to completely phase-out the use of lead shot for hunting in wetlands by 2000, and this issue has subsequently attracted considerable attention from subsequent AEWA MOPs. Since the coming into force of AEWA, many Parties have taken steps to regulate lead shot in wetlands (Stroud 2015), though actual enforcement and compliance with regulations is poor or unknown in those few countries where this has been actually assessed (above; Cromie et al. 2002, 2010). The fact that the international nature conservation community has not made clear progress on this rather simple environmental policy issue calls into question the ability of this community to handle other, and some even more serious and complex, environmental challenges. So, the lead issue can be seen as a ‘Litmus Test’ on the basic ability of international conservation bodies to deliver actual results in a time when these are more needed than ever.

### ALTERNATIVES

The evidence that lead ammunition is a source of poisoning for wildlife, pollution of ecosystems and additional dietary health hazard for regular human consumers of game is substantial. Though this, per se, questions the sustainability of continued use of such ammunition for hunting, authority and hunter hesitation to take responsive action might be explained by falsely stated lack of alternative ammunition. However, it is a matter of practical reality that effective non-lead and non-toxic alternatives are widely available at market prices comparable with lead ammunition (Thomas 2013; Thomas et al.

2015). Companies in eight European countries already produce non-toxic materials for hunting and shooting, and are not the limiting factor in this issue (Thomas and Guitart 2010). Examples from countries that have already phased out lead ammunition types through regulation show that such initiatives do not negatively affect hunting, whether in terms of participation or harvest levels, or indeed of unretrieved losses. The Danish example of a total ban on lead shot for hunting has demonstrated that this can be achieved without jeopardising hunters’ interests or weakening the hunting community. On the contrary, it is believed, though never scientifically investigated, that the public image value of hunting not being connected to a pollutant such as lead is of importance for the perception and long-term political sustainability of hunting (Kanstrup 2015). This further accentuates the conclusion that future hunting strategies, if based on lead ammunition, cannot be considered as sustainable.

### CONCLUSION

The continued use of lead ammunition is incompatible with European states’ commitments under several international instruments and conflicts with established principles for sustainable hunting. Impacts on wildlife population processes and potential for reduction of population numbers of some hunted and non-hunted wildlife, including rare and threatened species, mean that hunting with lead ammunition is not sustainable in either ecological or wildlife conservation terms. The collateral toxic effects of lead ammunition, avoidable health and welfare impacts for large numbers of exposed wild animals are ethically unsustainable and reinforce this conclusion. In societal terms, continued use of lead ammunition undermines a broadly ambivalent public perception of responsible hunting. Continued use of lead ammunition is an additional and avoidable dietary lead exposure for human consumers of food products made from lead-shot game. This additional exposure not only conflicts with public policy goals of removing all avoidable exposures to lead, but also creates objective and significant population-scale health risks for regular consumers, especially children and pregnant women.

The history of the movements to reduce and eliminate other polluting exposures to lead, including from work places and industrial processes, paints, water supply systems and fuel, records such changes to have been slow, costly and divisive—but ultimately successful. In moving forward from use of toxic lead ammunition to non-toxic alternatives, it would be wise to heed warnings from the past as described in European Environment Agency (2013).

Changing<sup>25</sup> from toxic lead ammunition and encouraging use and further development of existing well-functioning non-lead ammunition types will improve recognition of hunting as a widely accepted, sustainable and wise practice in the 21st century. Doing so will, moreover, benefit conservation efforts; revitalise international strategies for nature conservation; bring significant conservation gains; and open doors to constructive dialogue and beneficial cooperation.

**Acknowledgements** We are very grateful to Vin Fleming and Colin Galbraith for their valuable comments that improved earlier drafts. We thank also multiple colleagues in the fields of conservation and international law, discussions with whom have helped develop our thinking on this subject. We thank also peer reviewers for helpful comments on an earlier text.

## REFERENCES

- Anderson, W.L., S.P. Havera, and B.W. Zercher. 2000. Ingestion of lead and non-toxic shotgun pellets by ducks in the Mississippi flyway. *Journal of Wildlife Management* 64: 848–857.
- Armeno, J.M., O. Andersen, S. Stokke, V.G. Thomas, O. Krone, D.J. Pain, and R. Mateo. 2016. Health and Environmental Risks from Lead-based Ammunition: Science Versus Socio-Politics. *Eco-Health* 13: 618.
- Batley J., S. Crouch, M. Tufnell, and B. White-Spunner. 2016. A non-peer-reviewed report “Agreed findings and recommendations of the Lead Ammunition Group” published on the Countryside Alliance website: <http://www.countryside-alliance.org/ca-flatcap/wp-content/uploads/2016/08/Agreed-Findings-and-Recommendations-by-the-LAG.pdf>.
- Bellrose, F.C. 1964. Spent shot and lead poisoning. In *Waterfowl Tomorrow*, ed. J.P. Linduska, 479–485. Washington: US Department of Interior.
- Berny, P., L. Vilagines, J.-M. Cugnasse, O. Mastain, J.-Y. Chollet, G. Joncour, and M. Razin. 2015. Vigilance Poison: Illegal poisoning and lead intoxication are the main factors affecting avian scavenger survival in the Pyrenees (France). *Ecotoxicology and Environmental Safety* 118: 71–82.
- Countryside Alliance. 2013. *The case for lead*. Brochure. Available at: <http://www.huntfortruth.org/wp-content/uploads/2014/05/Case-For-Lead-2013-Norway.pdf>.
- Cromie, R.L., M.J. Brown, B. Hughes, D.G. Hoccom, and G. Williams. 2002. *Prevalence of shot-in pellets in Mallard purchased from game dealers in England in winter 2001/2002*. Sandy, UK: Royal Society for the Protection of Birds.
- Cromie, R.L., A. Loram, L. Hurst, M. O'Brien, J. Newth, M.J. Brown, and J.P. Harradine. 2010. *Compliance with the Environmental Protection (Restrictions on Use of Lead Shot) (England) Regulations 1999*. DEFRA. Bristol, UK. Available at: [http://randd.defra.gov.uk/Document.aspx?Document=W0730\\_9719\\_FRP.pdf](http://randd.defra.gov.uk/Document.aspx?Document=W0730_9719_FRP.pdf).
- Cromie, R.L., J.L. Newth, J.P. Reeves, M.F. O'Brien, K.M. Beckmann, and M.J. Brown. 2015. The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult, in R.J. Delahay, and C.J. Spray. (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*, pp 104–124. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- Delahay, R.J., and C.J. Spray. 2015. *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- Ecke, F., N.J. Singh, J.M. Arnemo, A. Bignert, B. Helander, Å.M.M. Berglund, H. Borg, C. Brøjer, et al. 2017. Sublethal lead exposure alters movement behaviour in free-ranging Golden Eagles. *Environmental Science and Technology* 51: 5729–5736.
- Edens, F.W., and J.D. Garlich. 1983. Lead-induced egg production decrease in leghorn and Japanese Quail hens. *Poultry Science* 62: 1757–1763.
- EFSA. 2010. Scientific Opinion on Lead in Food. European Food Safety Authority (EFSA), Parma, Italy. *EFSA Journal* 2010; 8(4): 1570. [151 pp.]. Available at: <http://onlinelibrary.wiley.com/doi/10.2903/j.efsa.2010.1570/epdf>.
- European Environment Agency. 2013. *Late lessons from early warnings: science, precaution, innovation*. EEA report No 1/2013. Available at: <https://www.eea.europa.eu/publications/late-lessons-2>.
- FACE. 2004. *Hunting, an added value for Biodiversity*. Brussels.
- Gangoso, L., P.A. Alvarez-Lloret, A.A.B. Rodríguez-Navarro, R. Mateo, F. Hiraldo, and J.A. Donazar. 2009. Long-term effects of lead poisoning on bone mineralization in vultures exposed to ammunition sources. *Environmental Pollution* 157: 569–574.
- Gil-Sánchez, J.M., S. Molleda, J.A. Sánchez-Zapata, J. Bautista, I. Navas, R. Godinho, A.J. García-Fernández, and M. Moleón. 2017. From sport hunting to breeding success: Patterns of lead ammunition ingestion and its effects on an endangered raptor. *Science of The Total Environment* 613–614: 483–491.
- Green, P. 2013. *The risks to human health from livestock feeding in areas of lead gunshot deposition*. Lead Ammunition Group 2015. Appendix 2: 149–179.
- Green, R.E., and D.J. Pain. 2015. Risks of health effects to humans in the UK from ammunition-derived lead, in R.J. Delahay, and C.J. Spray. (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*, pp. 27–42. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- Green, R.E., and D.J. Pain. 2016. Possible effects of ingested lead gunshot on populations of ducks wintering in the UK. *Ibis* 158: 699–710.
- Group of Scientists. 2014. *Wildlife and Human Health Risks from Lead-Based Ammunition in Europe: A Consensus Statement by Scientists*. Available at: <http://www.zoo.cam.ac.uk/leadammunitionstatement/>.
- Harradine, J. and A. Leake. 2013. *Lead Ammunition and Wildlife in England (UK)*. Lead Ammunition Group 2015 Appendix 3, pp. 181–261.
- Health Risks from Lead-Based Ammunition in the Environment. 2013. *A Consensus statement of Scientist*. March 22, 2013. <http://escholarship.org/uc/item/6dq3h64x#page-1>.
- Hiller, B., and J. Barclay. 2011. Concentrations of heavy metals found in American Woodcock harvested in Connecticut. *Archives of Environmental Contamination and Toxicology* 60: 156–164.
- Holmgren, C. 2014. *Frontal Assault on Lead Shot*. Sweden 2014-12-13. Publication source not given.
- Hunt, W.G. 2012. Implications of sublethal lead exposure in avian scavengers. *Journal of Raptor Research* 46: 389–393.

<sup>25</sup> Dr. Jon Armemo, Personal communication. Department of Forestry and Wildlife Management, Hedmark University College, Campus Evenstad, 2480 Koppang, Norway.

- Kanstrup, N. 2015. Practical and social barriers to switching from lead to non-toxic gunshot—A perspective from the EU, in R.J. Delahay, and C.J. Spray. (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*, pp. 98–103. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- Kanstrup, N., V.G. Thomas, O. Krone, and C. Gremse. 2016. The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations. *Ambio* 45: 621–628.
- Kelly, A., and S. Kelly. 2005. Are Mute Swans with elevated blood lead levels more likely to collide with overhead power lines? *Waterbirds* 28: 331–334.
- Knutsen, H., A.-L. Brantsæter, J. Alexander, and H.M. Meltzer. 2015. Associations between consumption of large game animals and blood lead levels in humans in Europe: the Norwegian experience, in R.J. Delahay, and C.J. Spray. (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*, pp. 44–50. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- Krone, O., N. Kennntner, A. Trinogga, M. Nadjafzadem, F. Scholz, J. Sulawa, K. Totschek, P. Schuck-Wersig, et al. 2009. Lead poisoning in white-tailed sea eagles: causes and approaches to solutions in Germany. In *Ingestion of lead from spent ammunition: implications for wildlife and humans*, ed. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 289–301. Boise, Idaho, USA: The Peregrine Fund.
- Laws, A.R. 1997. Waterfowl hunting and coastal zone management in the United Kingdom. *Gibier Faune Sauvage, Game and Wildlife* 14: 237–244.
- Lead Ammunition Group. 2015. *Lead Ammunition, Wildlife and Human Health*. 90 pp. A report prepared for the Department for Environment, Food and Rural Affairs and the Food Standards Agency, United Kingdom. 412 pp. <http://www.leadammunitiongroup.org.uk/wp-content/uploads/2015/06/LAG-Report-June-2015-without-Appendices.pdf>.
- Lewis, M. 2016. AEWa at Twenty: an appraisal of the African-Eurasian Waterbird Agreement and its unique place in international environmental law. *Journal of International Wildlife Law & Policy* 19: 22–61.
- Markowitz, G., and D. Rosner. 2003. *Deceit and denial*, 408. The deadly politics of industrial pollution: University of California, Los Angeles.
- Mateo, R. 2009. Lead poisoning in wild birds in Europe and regulations adopted by different countries. In *Ingestion of lead from spent ammunition: implications for wildlife and humans*, ed. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 71–98. Boise, Idaho, USA: The Peregrine Fund.
- Mateo, R., N. Vallverdú-Coll, A. López-Antia, M.A. Taggart, M. Martínez-Haro, R. Guitart, and M.E. Ortiz-Santaliestra. 2014. Reducing Pb poisoning in birds and Pb exposure in game meat consumers: the dual benefit of effective Pb shot regulation. *Environment International* 63: 163–168.
- Meyer, C.B., J.S. Meyer, A.B. Francisco, J. Holder, and F. Verdonck. 2016. Can ingestion of lead shot and poisons change population trends of three European birds: Grey Partridge, Common Buzzard and Red Kite? *PLoS ONE* 11: e0147189. <https://doi.org/10.1371/journal.pone.0147189>.
- Michaels, D. 2008. *Doubt is their product: how industry's assault on science threatens your health*. 372 pp. Oxford University Press, USA.
- Morehouse, K.A. 1992. *Lead poisoning of migratory birds: the U.S. Fish and Wildlife Service position*, in D.J. Pain. (ed.) *Lead Poisoning in Waterfowl, Proceedings of an IWRB Workshop*, pp. 51–55. International Waterfowl and Wetlands Research Bureau: Brussels, Belgium.
- Needleman, H., & D. Gee. 2013. Lead in petrol 'makes the mind give way'. Chapter 3 in *Late Lessons from early warnings: science, precaution, innovation*. European Environment Agency, Copenhagen.
- Needleman, H.L., C. Gunnoe, A. Leviton, R. Reed, H. Peresie, C. Maher, and P. Barrett. 1979. Deficits in psychologic and classroom performance of children with elevated dentine lead levels. *The New England Journal of Medicine* 300: 689–695.
- Needleman, H.L., C. McFarland, R.B. Ness, S.E. Fienberg, and M.J. Tobin. 2002. Bone lead levels in adjudicated delinquents. A case control study. *Neurotoxicology and Teratology* 24: 711–717.
- Newth, J.L., E.C. Rees, R.L. Cromie, R.A. McDonald, S. Bearhop, D.J. Pain, G.J. Norton, C. Deacon, and G.M. Hilton. 2016. Widespread exposure to lead affects the body condition of free-living whooper swans (*Cygnus cygnus*) wintering in Britain. *Environmental Pollution* 209: 60–67.
- Newth, J.L., R.L. Cromie, M.J. Brown, R.J. Delahay, A.A. Meharg, C. Deacon, G.J. Norton, M.F. O'Brien, and D.J. Pain. 2012. Poisoning from lead gunshot: still a threat to wild waterbirds in Britain. *European Journal of Wildlife Research* 59: 195–204.
- Pain, D.J. 1991. Why are lead-poisoned waterfowl rarely seen? The disappearance of waterfowl carcasses in the Camargue, France. *Wildfowl* 42: 118–122.
- Pain, D.J. (ed.) 1992. *Lead Poisoning in Waterfowl, in Proceedings of an IWRB Workshop*. International Waterfowl and Wetlands Research Bureau: Brussels, Belgium. 105 pp.
- Pain, D.J., C. Bavoux, and G. Burneleau. 1997. Seasonal blood lead concentrations in Marsh Harriers (*Circus aeruginosus*) from Charente-Maritime, France: relationship with the hunting season. *Biological Conservation* 81: 1–7.
- Pain, D.J., and R.E. Green. 2014. *An evaluation of the risks to wildlife in the UK from lead derived ammunition*. Lead Ammunition Group 2015 Appendix 4, pp. 263–382.
- Pain, D.J., R.L. Cromie, and R.E. Green. 2015. Poisoning of birds and other wildlife from ammunition-derived lead in the UK, in R.J. Delahay, and C.J. Spray. (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*, pp. 58–84. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- Romão, C., D. Richard, and L. Jones-Walters. 2013. *Protected areas in Europe—an overview*, 130. Copenhagen: European Environment Agency.
- Samuel, M.D., and E.F. Bowers. 2000. Lead exposure in American black ducks after implementation of non-toxic shot. *Journal of Wildlife Management* 64: 947–953.
- Sanderson, G.C., and F.C. Bellrose. 1986. *A review of the problem of lead poisoning*. Illinois Natural History Survey Special Publication 4. 32 pp. Illinois Natural History Service, Champaign, USA.
- Scheuhammer, A.M., and S.L. Norris. 1995. A review of the environmental impacts of lead shotshell ammunition and lead fishing weights in Canada. *Canadian Wildlife Service Occasional Paper* No. 88. Ottawa, Canada. Available at: <http://www.cws-scf.ec.gc.ca/pub/ops/op88/home.html>.
- Scheuhammer, A.M., D.E. Bond, N.M. Burgess, and J. Rodrigue. 2003. Lead and stable isotope ratios in soil, earthworms and bones of American woodcock from Eastern Canada. *Environmental Toxicology and Chemistry* 22: 2585–2591.
- Scheuhammer, A.M., C.A. Rogers, and D.E. Bond. 1998. Elevated lead exposure in American woodcock (*Scolopax minor*) in Eastern Canada. *Archives of Environmental Contamination and Toxicology* 36: 334–340.
- Stevenson, A.L., A.M. Scheuhammer, and H.M. Chan. 2005. Effects of nontoxic shot regulations on lead accumulation in ducks and

- American woodcock in Canada. *Archives of Environmental Contamination and Toxicology* 48: 405–413.
- Stroud, D.A. 2015. Regulation of some sources of lead poisoning: a brief review, in R.J. Delahay, and C.J. Spray. (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*, pp. 8–26. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- Svenska Jägareförbundet. 2017. *Så undviker du att få bly i viltkötet*. Webpage: <https://jagareforbundet.se/jakten/kotthantering/>.
- Thomas, V.G., and R. Guitart. 2005. Role of international conventions in promoting avian conservation through reduced lead toxicosis: progression towards a non-toxic agenda. *Bird Conservation International* 15: 147–160.
- Thomas, V.G., and R. Guitart. 2010. Limitations of European Union policy and law for regulating use of lead shot and sinkers: comparisons with North American regulation. *Environmental Policy and Governance* 20: 57–72.
- Thomas, V.G. 2013. Lead-free hunting rifle ammunition: Product availability, price, effectiveness, and role in global wildlife conservation. *Ambio* 42: 737–745.
- Thomas, V.G. 2015. Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions, in R.J. Delahay, and C.J. Spray. (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*, pp. 85–197. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- Thomas, V.G., N. Kanstrup, and C. Gremse. 2015. Key questions and responses regarding the transition to use of lead-free ammunition, in R.J. Delahay, and C.J. Spray. (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*, pp. 125–135. Edward Grey Institute, The University of Oxford. Available at: <http://oxfordleadsymposium.info>.
- UNEP. 2014. *Review of the ecological effects of poisoning on migratory birds*. UNEP/CMS/COP11/Inf. 34, 2014.
- UNEP. 2017. *Towards a pollution-free planet*. Report of the Executive Director to the third session of the United Nations Environment Assembly of the United Nations Environment Programme. Nairobi, 4–6 December 2017. UNEP/EA.3/25.
- Vallverdú-Coll, N., A. López-Antia, A. Martínez-Haro, M.E. Ortiz-Santaliestra, and R. Mateo. 2015. Altered immune response in mallard ducklings exposed to lead through maternal transfer in the wild. *Environmental Pollution* 205: 350–356.
- Vallverdú-Coll, N., F. Mougeot, M.E. Ortiz-Santaliestra, J. Rodríguez-Estival, A. López-Antia, and R. Mateo. 2016. Lead exposure reduces carotenoid-based coloration and constitutive immunity in wild mallards. *Environmental Toxicology and Chemistry* 35: 1516–1525.
- Watson, R.T., M. Fuller, M. Pokras, and W.G. Hunt (eds.). 2009. *Ingestion of lead from spent ammunition: implications for wildlife and humans*. Boise, Idaho, USA: The Peregrine Fund.
- World Health Organisation. 2010. *Preventing disease through healthy environments. Exposure to lead: a major public health concern*. WHO Document Production Services, Geneva, Switzerland.

World Health Organisation. 2015. *Lead poisoning and health. Fact sheet*. Updated August 2017. <http://www.who.int/mediacentre/factsheets/fs379/en/>. Accessed: 7 December 2017.

## AUTHOR BIOGRAPHIES

**Niels Kanstrup** (✉) is a Danish biologist, scientist and hunter. He has been working with the Danish Hunters' Association, been President of the CIC Migratory Bird Commission, a member of the AEWA technical Committee, and during his whole career worked with sustainability of hunting and focused particularly on the issue of lead in hunting ammunition. Today he is an independent consultant in nature management and an adjunct scientist with an excessive research program at Aarhus University, Department of Bioscience at Kalø.

*Address:* Institute for Bioscience – Kalø, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark.

e-mail: [nk@bios.au.dk](mailto:nk@bios.au.dk)

**John Swift** is a British biologist and hunter who has served as the CEO of the British Association for Shooting and Conservation (BASC) and been deeply involved in international organisations for the conservation of wildlife. He has for more than five years has been the Chair of the UK Lead Ammunition Group and from this platform achieved particular expertise in biological and socio-political aspects of impact of lead from hunting ammunition on wildlife and human health.

*Address:* John Swift Consultancy – Higher Wych, Malpas, Cheshire SY14 7JS, UK.

**David A. Stroud** is responsible for providing aspects of JNCC's ornithological advice to government, the statutory conservation agencies, and others at both UK and international scales. This has involved managing commissioned research and survey programmes with a range of other governmental and non-governmental organisations. He has been closely involved in many aspects of work related to the implementation of the EU Birds Directive, AEWA and multiple other MEAs.

*Address:* Joint Nature Conservation Committee, Monkstone House, Peterborough PE1 1JY, UK.

**Melissa Lewis** is a South-African specialist in wildlife conservation law. Her research interests lie predominantly within the field of international environmental law in protecting and regulating the use of wildlife. She has held the position of environmental law expert on the Technical Committee of the AEWA and in this capacity been involved in the drafting of amendments, resolutions and guidelines for the adoption by the agreements Meeting of Parties.

*Address:* Department of European and International Public Law, Tilburg University, Warandelaan 2, 5037AB Tilburg, Netherlands.

*Address:* School of Law, University of KwaZulu-Natal, King George V Ave, Durban 4041, ZA, South Africa.

***Ambio***

Electronic Supplementary Material

*This supplementary material has not been peer reviewed.*

Title: **Hunting with lead ammunition is not sustainable: European perspectives**

Authors: Niels Kanstrup<sup>1</sup>, John Swift<sup>2</sup>, David A. Stroud<sup>3</sup> & Melissa Lewis<sup>4</sup>

<sup>1</sup>Aarhus University, Institute for Bioscience – Kalø, Grenåvej 14, DK-8410 Rønde (corresponding author, email: [nk@bios.au.dk](mailto:nk@bios.au.dk), tel. 4520332999).

<sup>2</sup>John Swift Consultancy – Higher Wych, Malpas, Cheshire, SY14 7JS, UK.

<sup>3</sup>Joint Nature Conservation Committee, Monkstone House, Peterborough PE1 1JY, UK.

<sup>4</sup>Tilburg University, Department of European and International Public Law – Warandelaan 2, 5037AB Tilburg, Netherlands;  
University of KwaZulu-Natal, School of Law – King George V Ave, Durban, 4041, ZA, South Africa.

Table S1. International instruments with provisions relevant to the phase out of lead ammunition and to evaluation of sustainability of hunting in the context of continued use of lead-based ammunition.

<b><i>Legally-binding instruments</i></b>		
<b>Instrument</b>	<b>Provisions most relevant to lead ammunition</b>	<b>Guidance documents most relevant to lead ammunition (excl. species action plans)</b>
Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat (1971)	Art. 3(1): <i>“The Contracting Parties shall formulate and implement their planning so as to promote the conservation of the wetlands included in the List, and as far as possible the wise use of wetlands in their territory”</i> .	Rec. 6.14: The COP <i>“CALLS on Contracting Parties to recognize that the adverse impact of toxic substances compromises the ecological character of wetlands and that these threats to ecological character are incompatible with the wise use concept”</i> .  Res. VII.19 (annex): If the harvesting of animal products <i>“is taking place at a Ramsar-listed site, then the Contracting Party has a clear obligation to ensure that the impact of the harvesting will not threaten or alter the ecological character of the site”</i> .  <i>Ramsar Wildlife Disease Manual</i> (Cromie et al. <a href="#">2012</a> ).
Bern Convention on the Conservation of European Wildlife and Natural Habitats (1979)	Art. 2: <i>“The Contracting Parties shall take requisite measures to maintain the population of wild flora and fauna at, or adapt it to, a level which corresponds in particular to ecological, scientific and cultural requirements, while taking account of economic and recreational requirements and the needs of sub-species, varieties or forms at risk locally”</i> .  Art. 3(2): <i>“Each Contracting Party undertakes, [...] in its measures against pollution, to have regard to the conservation of wild flora and fauna”</i> .  Art. 4(1) & (3): <i>“Each Contracting Party shall take appropriate and necessary legislative and administrative measures to ensure the conservation of the habitats of the wild [...] fauna species, especially those specified in [Appendix II]”; “The Contracting Parties undertake to give special attention to the protection of areas that are of importance for the migratory species specified in Appendices II and III [...]”</i> .  Arts 6(1) & 7(1): <i>“Each Contracting Party shall take appropriate and necessary legislative and administrative measures to ensure”</i>	Rec. No. 28: The Standing Committee recommends that Contracting Parties, <i>inter alia</i> , <i>“take steps to phase out the use of lead shot in wetlands or waterfowl hunting as soon as possible”</i> and <i>“promote a general shift to the use of alternatives to lead shot”</i> .  Rec. No. 128: The Standing Committee <i>“RECOMMENDS Contracting Parties to the Convention, and INVITES Observer States and Organisations, to take into consideration the European Charter on Hunting and Biodiversity and apply its principles in the elaboration and implementation of their hunting policies so as to ensure that hunting is carried out in a sustainable way”</i> .

<i>Legally-binding instruments</i>		
<b>Instrument</b>	<b>Provisions most relevant to lead ammunition</b>	<b>Guidance documents most relevant to lead ammunition (excl. species action plans)</b>
	<p>the special protection of Appendix II species and the protection of Appendix III species.</p> <p>Art. 8: “[...] Contracting Parties shall prohibit the use of all indiscriminate means of capture and killing and the use of all means capable of causing local disappearance of, or serious disturbance to, populations of a species, and in particular, the means specified in Appendix IV”.</p>	
EU Birds Directive (1979)	<p>Art. 2: “Member States shall take the requisite measures to maintain the population of the species referred to in Article 1 at a level which corresponds in particular to ecological, scientific and cultural requirements, while taking account of economic and recreational requirements, or to adapt the population of these species to that level”.</p> <p>Art. 4(1): “The species mentioned in Annex I shall be the subject of special conservation measures concerning their habitat in order to ensure their survival and reproduction in their area of distribution [...] Member States shall classify in particular the most suitable territories in number and size as special protection areas for the conservation of these species [...]”. (See also Art. 6(2) of Habitats Directive).</p> <p>Art. 5: “[...] Member States shall take the requisite measures to establish a general system of protection for all species of birds referred to in Article 1 [...]”.</p> <p>Art. 7(1) &amp; (3): “[...] Member States shall ensure that the hunting of [Annex II species] does not jeopardise conservation efforts in their distribution area” and that the practice of hunting “complies with the principles of wise use and ecologically balanced control [...]”.</p> <p>Art. 8: “[...] Member States shall prohibit the use of all means, arrangements or methods used for the</p>	European Commission’s <i>Guide to Sustainable Hunting under the Birds Directive</i> .

<i>Legally-binding instruments</i>		
<b>Instrument</b>	<b>Provisions most relevant to lead ammunition</b>	<b>Guidance documents most relevant to lead ammunition (excl. species action plans)</b>
	<i>large-scale or nonselective capture or killing of birds or capable of causing the local disappearance of a species, in particular the use of those listed in Annex IV, point (a)”.</i>	
Convention on the Conservation of Migratory Species of Wild Animals (1979)	Art III(4): “ <i>Parties that are Range States of a migratory species listed in Appendix I shall endeavour: a) to conserve and, where feasible and appropriate, restore those habitats of the species which are of importance in removing the species from danger of extinction; b) to prevent, remove, compensate for or minimize, as appropriate, the adverse effects of activities or obstacles that seriously impede or prevent the migration of the species; and c) to the extent feasible and appropriate, to prevent, reduce or control factors that are endangering or are likely to further endanger the species [...]</i> ”.	<p>COP calls on Parties to use and promote the Ramsar Disease Manual and guidance produced by the Scientific Task Force on Wildlife and Ecosystem Health (adopted through Res. 10.22).</p> <p>The Strategic Plan for Migratory Species 2015-2023 (adopted through Res. 11.2), Target 6: aims for hunting to have “<i>no significant direct or indirect adverse impacts on migratory species, their habitats or their migration routes</i>”.</p> <p>Guidelines to Prevent the Risk of Poisoning to Migratory Birds (adopted through Res. 11.15).</p> <p>African-Eurasian Migratory Landbirds Action Plan (adopted through Res. 11.17): activities include promoting “<i>the use of, and awareness of, lead ammunition-free hunting, fishing and wildlife management</i>” through the adoption of legislation restricting both the sale and possession of lead ammunition.</p>
Convention on Biological Diversity (1992)	<p>Art. 8(d) &amp; (l): “<i>Each Contracting Party shall, as far as possible and as appropriate [...] [p]romote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings</i>”, and “[w]here a significant adverse effect on biological diversity has been determined [...], regulate or manage the relevant processes and categories of activities”.</p> <p>Art. 10(b): “<i>Each Contracting Party shall, as far as possible and as appropriate [...] [a]dopt measures relating to the use of biological resources to avoid or minimize adverse impacts on biological diversity</i>”.</p>	<p><i>Addis Ababa Principles and Guidelines for the Sustainable Use of Biodiversity</i> (adopted through Dec. VII/12).</p> <p>Aichi Biodiversity Targets (adopted through Decision X/2), Targets 4 &amp; 8: “<i>By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits</i>”; “<i>By 2020, pollution [...] has been brought to levels that are not detrimental to ecosystem function and biodiversity</i>”.</p> <p>Decision XII/21, that <i>inter alia</i> encourages Parties to consider the linkages between biodiversity and human health in the preparation of national biodiversity strategies and action plans; to promote cooperation between sectors and agencies responsible for biodiversity and those responsible for human health; and recognizes “<i>the value of the “One Health” approach to address the cross-</i></p>

<i>Legally-binding instruments</i>		
<b>Instrument</b>	<b>Provisions most relevant to lead ammunition</b>	<b>Guidance documents most relevant to lead ammunition (excl. species action plans)</b>
		<i>cutting issue of biodiversity and human health [...] that integrates the complex relationships between humans [...], wildlife and the environment”.</i>
Agreement on the Conservation of African-Eurasian Migratory Waterbirds (1995)	<p>Art. II (1) &amp; (2): <i>“Parties shall take co-ordinated measures to maintain migratory waterbird species in a favourable conservation status or to restore them to such a status”; and in implementing the measures prescribed by the Agreement, “Parties should take into account the precautionary principle”.</i></p> <p>Art. III (2)(b): Parties shall <i>“ensure that any use of migratory waterbirds is [...] sustainable for the species as well as for the ecological systems that support them”.</i></p> <p>Action Plan para. 2.1.2(b): Parties shall <i>“regulate modes of taking, and in particular prohibit the use of all indiscriminate means of taking and the use of all means capable of causing mass destructions, as well as local disappearance of, or serious disturbance to, populations of a species, including: [...] poison”.</i></p> <p>Action Plan, para. 3.2.3: <i>“Parties shall endeavour to make wise and sustainable use of all wetlands in their territory” and “avoid degradation and loss of habitats [...] through the introduction of appropriate regulations or standards and control measures”.</i></p> <p>Action Plan, para. 4.1.4: <i>“Parties shall endeavour to phase out the use of lead shot for hunting in wetlands as soon as possible in accordance with self-imposed and published timetables”.</i></p>	<p>Res. 2.2: MOP recognizes that <i>“lead poisoning is an unacceptable waste of the waterbird resource”</i>, notes that the implementation of para. 4.1.4 <i>“is still highly insufficient in the majority of Range States”</i>, and calls upon Contracting Parties to, <i>inter alia</i>, <i>“enhance their efforts to phase out the use of lead shot in wetlands as soon as possible, in accordance with the recommendations issued by the Technical Committee in its lead poisoning review – namely, to promote communication between, and awareness within, authorities and the hunting community; to allocate resources for the enforcement of relevant laws; and to stimulate and facilitate the production and availability of non-toxic shot - and to actively inform themselves on the issue and its solutions”.</i></p> <p>Res. 4.1: MOP expresses deep concern that <i>“implementation of paragraph 4.1.4 of the Action Plan is still inadequate in the majority of Range States”</i>, and calls upon Contracting Parties to, <i>inter alia</i>, <i>“phase out the use of lead shot in wetlands as soon as possible, in accordance with the recommendations from the update report on the use of non-toxic shot for hunting in wetlands – namely, to promote communication between, and awareness within, authorities and the hunting community; to put emphasis on the education of hunters, especially new hunters, in order to provide them with sufficient information about non-toxic shot through hunting associations and conservation NGOs; and to stimulate and facilitate the replacement of lead shot by non-toxic shot”</i>, and to publish self-imposed timetables for completing the phase out, and establish enforcement and monitoring procedures.</p> <p>AEWA Strategic Plan 2009-2017 (adopted through Res. 4.7; extended to 2018 through Res. 6.14), Target 2.1: <i>“The use of lead shot for hunting in wetlands is phased out in all [Contracting Parties]”.</i></p> <p>Res. 6.4: MOP <i>“urges those Parties that have not done so yet to [...] publish timetables for</i></p>

<i>Legally-binding instruments</i>		
<b>Instrument</b>	<b>Provisions most relevant to lead ammunition</b>	<b>Guidance documents most relevant to lead ammunition (excl. species action plans)</b>
		<p><i>the phasing out of lead shot use for hunting in wetlands”.</i></p> <p>Res. 6.15: Recognition that phasing out lead gunshot from wetlands will contribute to CBD Aichi Targets 4 and 8, and UN General Assembly Sustainable Development Goal Target 12.4.</p> <p><i>Guidelines on Sustainable Harvest of Migratory Waterbirds</i> (adopted through Res. 6.5).</p>
EU Habitats Directive (1992)	<p>Art. 2(2): <i>“Measures taken pursuant to this Directive shall be designed to maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest”.</i></p> <p>Art. 6(2): <i>“Member States shall take appropriate steps to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this Directive”.</i> (Per Art. 7, this provision also applies in respect of special protection areas designated under the Birds Directive).</p> <p>Art. 15: <i>“In respect of the capture or killing of species of wild fauna listed in Annex V (a) and in cases where, in accordance with Article 16, derogations are applied to the taking, capture or killing of species listed in Annex IV (a), Member States shall prohibit the use of all indiscriminate means capable of causing local disappearance of, or serious disturbance to, populations of such species [...]”.</i></p>	

<i>Non-binding Instruments/Documents</i>	
<b>Instrument/Document</b>	<b>Provisions most relevant to lead ammunition</b>
Central Asian Flyway Action Plan for the Conservation of Migratory Waterbirds and their Habitats (2005)	Para. 4.1.10: <i>“Range States shall reduce as far as possible the lead poisoning in waterbirds by gradual phasing out of lead shot and its replacement by non-toxic shot. They shall endeavour to phase out the use of lead shot for hunting in wetlands by the year 2015”</i> .
Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (2008)	Action Plan, activity 5.4: <i>“Assess and then address the impacts of the use of toxic chemicals, including heavy metals (for example lead in shot pellets), on breeding, passage and wintering populations of birds of prey, and their survival, identify and then implement appropriate measures to assist in achieving and maintaining Favourable Conservation Status”</i> .
Sustainable Development Goals (2015)	Target 12.4: <i>“By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment”</i> .
World Summit on Sustainable Development (2002): Plan of Implementation	<i>“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”</i> .

Table S2. The geographic scope of international species Action Plans varies according to both the distribution of the species concerned and the extent of legal mandate for the relevant endorsing MEA. EU plans relate to relevant Member States; Bern Convention plans apply to appropriate Contracting Parties within Europe and Africa; AEWA Plans apply to appropriate Parties within the African-Eurasia extent of the Agreement area; whilst CMS Plans apply to relevant CMS Parties globally.

Species	Endorsement and date			Summary of evidence and actions with respect to lead ammunition
	EU	AEWA	Other	
Bewick's Swan <i>Cygnus columbianus bewickii</i>		✓ (2012)	Bern ✓ (2013)	Lead poisoning the cause of death in 14.6% of adults subjected to <i>post mortem</i> examination in UK. Action 4.1. "Phase out lead shot completely on all feeding areas of Bewick's Swan around their key sites and enforce existing legislation where lead shot has been already banned. Action 4.2. Phase out lead as angler's weight[s]".
Greenland White-fronted Goose <i>Anser albifrons flavirostris</i>		✓ (2012)	Bern ✓ (2013)	Pollution including poisoning from embedded or ingested lead shot identified as having possible impact on condition.
Taiga Bean Goose <i>Anser fabalis fabalis</i>		✓ (2015)		Lead poisoning is recognised as a potential factor reducing the survival of adult Taiga Bean Geese. Action 1.5.1. "Comply with AEWA provisions on the phasing out of lead ammunition for hunting in wetlands".
Red-breasted Goose <i>Branta ruficollis</i>	✓ (2015)	✓ (2015)		Lead poisoning identified as a possible factor influencing status. Action 36. "Determine lead levels in Red-breasted Geese and, if significant, identify where and how Red-breasted Geese ingest lead".
Ferruginous Duck <i>Aythya nyroca</i>		✓ (2016)		Action 2.6. "Ban use of lead shot for hunting waterfowl and over wetlands, monitor lead shot use by hunters and lead shot ingestion by Ferruginous Ducks".
Red-crested Pochard <i>Netta rufina</i>	✓ (2007)			Lead poisoning recognised as a potential factor but of unknown significance.
Marbled Teal <i>Marmaronetta angustirostris</i>	✓ (2008)		Bern ✓ (2013)	Marble Teals suffer from lead poisoning because of the high density of lead shot in the sediments of wetlands where hunting takes place (e.g. Levante wetlands in Spain) or has stopped only recently. Result 2.2. "Lead poison and other avoidable mortality causes removed". Action 2.2.1. "Phase out the use of lead shot at all key sites throughout the range". Action 2.2.2. "Remove the lead shot from areas of high lead shot concentration".
White-headed Duck <i>Oxyura leucopsis</i>	✓ (2006)	✓ (2006)	CMS ✓ (2006)	Diving ducks suffer from lead poisoning through ingestion of lead shot, which is still used legally in shotgun cartridges in many White-headed Duck Range States. As hunting

Species	Endorsement and date			Summary of evidence and actions with respect to lead ammunition
			Bern ✓ (2006)	is intense at many key sites, the ingestion of lead shot could result in significant mortality. Action 2.5. “ <i>Ban use of lead shot for hunting waterfowl and over wetlands, monitor lead shot use by hunters and lead shot ingestion by White-headed Ducks</i> ”.
Lammergeier <i>Gypaetus barbatus</i>	✓ (1997)			Lead poisoning identified as a possible factor influencing status. Action 3.3.4.3. “ <i>Investigate the exposure and incidence of lead poisoning in untested populations or in susceptible populations</i> ”.
			CMS ✓ (2017)	Lead poisoning is considered a high priority threat in practically every European country where the species occurs and should be taken seriously also at global level. Lead poisoning may be the most significant threat to Bearded Vultures in Europe. Objective 3. “ <i>To ensure that CMS resolution 11.15 on the phasing out of lead ammunition by hunters is fully implemented</i> ”. Action 3.1.1. “ <i>Quantify impacts of lead poisoning on populations of vultures and conduct regular lead and other heavy metal screening in vultures</i> ”. Action 3.1.2. “ <i>Advocate for policy, legislation and action to reduce known risks of lead poisoning to humans and wildlife</i> ”. Action 3.1.3. “ <i>Awareness-raising especially among relevant stakeholders, especially decision makers</i> ”. Action 3.1.4. “ <i>Promote the implementation of CMS Resolution 11.15 by all CMS Parties as well as voluntary lead ammunition bans in Vulture MsAP range states which are not CMS Parties</i> ”. Action 3.1.5. “ <i>Promote best practices and cost effective alternatives to lead ammunition</i> ”.
Griffon Vulture <i>Gyps fulvus</i>			CMS ✓ (2017)	Several instances of lead poisoning have been recorded in the Iberian Peninsula, where it was proved that the source of the lead poisoning was ammunition used in hunting. Objective and actions – as for Lammergeier <i>Gypaetus barbatus</i> above.
Egyptian Vulture <i>Neophron percnopterus</i>	✓ (2008)		Bern ✓ (2013)	Lead poisoning identified as a potentially serious conservation issue. Action 1.3. “ <i>Reduced risk of lead poisoning caused by consumption of contaminated carcasses</i> ”. Action 1.3.1. “ <i>Promote EU ban on use of lead for hunting ammunition (very important for Canary Islands)</i> ”. Action 1.3.2. “ <i>Support AEWA related efforts to phase out lead shot in wetlands by 2009</i> ”.

Species	Endorsement and date			Summary of evidence and actions with respect to lead ammunition
			CMS ✓ (2017)	Lead poisoning known to have long term effects by altering bone composition - the mineralization degree decreases with increasing lead concentration levels. Action 1.1.4. “Study the effect of NSAIDs and lead poisoning on health status and population productivity”. Action 1.3.4. “Strengthen legal control over the use of poisonous substances in line with the CMS Resolution 11.15 and Bern Convention”. Action 5.1.1. “Implement awareness campaign on the legal regime and effects of use of poison baits, improper and inappropriate use of dangerous substances, the use of lead ammunition”.
Spanish Imperial Eagle <i>Aquila adalberti</i>	✓ (2008)		Bern ✓ (2013)	Secondary lead poisoning identified as a potential conservation issue affecting survival of adults.
White-tailed Sea Eagle <i>Haliaeetus albicilla</i> (Danube Basin population)			Bern ✓ (2011)	Secondary lead poisoning identified as an important potential cause of mortality in the Danube basin. “Furthermore, the current policy in some states was not considered to have improved the situation, such as Germany and Austria, who aim to ban lead ammunition for waterfowl hunting in water-rich areas like the Danube but not in the open landscape when hunting other game like the often taken prey Brown Hare ( <i>Lepus europaeus</i> ).” Objective 8. “To totally ban the use of lead ammunition (not only in waterfowl hunting as already implemented in some countries)”.
Greater Spotted Eagle <i>Aquila clanga</i>	✓ (1997)			Lead poisoning identified as a possibly serious conservation issue.
Red Kite <i>Milvus milvus</i>	✓ (2010)		Bern ✓ (2013)	Secondary poisoning from ingestion of fragments of lead gunshot and bullets in their prey has caused mortality in Red Kites in the UK, Germany, and Spain and in captivity when the birds are fed rabbits or other foodstuffs shot with lead ammunition. Action 3.2.1. “Research on impact of veterinary medicines and other contaminants (especially lead)”.
Saker Falcon <i>Falco cherrug</i>			CMS ✓ (2014)	Lead poisoning via contaminated food identified as conservation issue: 16% of 85 captive falcons, including Saker Falcons, treated in the Al Warsan Falcon Hospital, Abu Dhabi, had severe symptoms of lead poisoning between 1999 and 2000.
Purple Gallinule <i>Porphyrio porphyrio</i>	✓ (1999)			Lead poisoning identified as a possible indirect, but important, risk in areas with intense hunting activities of other waterfowl species.

Species	Endorsement and date			Summary of evidence and actions with respect to lead ammunition
Crested Coot <i>Fulica cristata</i>	✓ (1999)			Lead poisoning identified as an issue of conservation concern on the basis of similar ecology to Coot ( <i>Fulica atra</i> ). In the Camargue (France), 20% of Coot, which has a similar feeding technique to Crested Coot <i>Fulica cristata</i> , contained ingested shot.  Action 2.5. “To phase out the use of lead shot at all key sites throughout the range. It is important to reduce the threat of lead poisoning to Crested Coot”.
Lapwing <i>Vanellus vanellus</i>	✓ (2009)			Exposure to lead via ingestion of earthworms identified as a potential issue of unknown significance for survival and productivity.
Redshank <i>Tringa totanus</i>	✓ (2009)			Blood lead levels indicate significant exposure to lead in the Dutch Wadden Sea with unknown significance.
Curlew <i>Numenius arquata</i>		✓ (2015)		Lead shot ingestion identified as a potential issue of unknown importance for the species.  Action 4.4.2. “Investigate the impact of pollution at wintering sites on adult and juvenile survival rates and subsequent breeding success”.
Black-tailed Godwit <i>Limosa limosa</i>	✓ (2007)			Lead shot ingestion identified as a potential issue of unknown importance for the species.
Black-tailed Godwit <i>Limosa limosa</i>	✓ (2008)	✓ (2008)		Lead shot ingestion identified as a potential issue of unknown importance for the species.

## REFERENCES

Cromie, R.L., R. Lee, R. Reeves, and D.A. Stroud. 2012. Ramsar Wetland Disease Manual: Guidelines for Assessment, Monitoring and Management of Animal Disease in Wetlands. *Ramsar Technical Report No. 7. Ramsar Convention Secretariat, Gland, Switzerland.* 248-252. Available at: <http://www.ramsar.org/sites/default/files/documents/library/rtr7-disease.pdf>.



## PAPER 5

Kanstrup, N (2006). Sustainable harvest of waterbirds: a global review. *Waterbirds around the world*. Eds. G.C. Boere, C.A. Galbraith & D.A. Stroud. The Stationery Office, Edinburgh, UK. pp. 98-106.

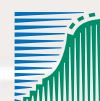
**RIGHTS:** Open access.

# Waterbirds around the world

A global overview of the conservation, management and research of the world's waterbird flyways

*Edited by G.C. Boere, C.A. Galbraith and D.A. Stroud*

*Assisted by L.K. Bridge, I. Colquhoun, D.A. Scott,  
D.B.A. Thompson and L.G. Underhill*



landbouw, natuur en  
voedselkwaliteit



SCOTTISH EXECUTIVE



© Scottish Natural Heritage 2006

First published in 2006 by The Stationery Office Limited  
71 Lothian Road, Edinburgh EH3 9AZ, UK.

Applications for reproduction should be made to Scottish Natural Heritage,  
Great Glen House, Leachkin Road, Inverness IV3 8NW, UK.

British Library Cataloguing in Publication Data  
A catalogue record for this book is available from the British Library

ISBN 0 11 497333 4

Recommended citation:

Boere, G.C., Galbraith, C.A. & Stroud, D.A. (eds). 2006.  
*Waterbirds around the world*. The Stationery Office, Edinburgh, UK. 960 pp.

Names used for geographical entities do not imply recognition, by the organisers of the *Waterbirds around the world* conference or other supporting organisations or governments, of the political status or boundaries of any particular territory. Names of territories used (and any alternatives) are included solely to help users of this publication apply information contained within this volume for waterbird conservation purposes. The views expressed in papers included within this volume do not necessarily represent views of the editors or the organisations and governments that supported the conference and this publication.

*Cover photography:* Whooper Swans *Cygnus cygnus* arriving at Martin Mere, England. Photo: Paul Marshall.  
([www.paulmarshallphotography.com](http://www.paulmarshallphotography.com))

Copyright of all photographs used in this publication resides with the named photographers.

## Sustainable harvest of waterbirds: a global review

Niels Kanstrup

CIC Migratory Bird Commission, Director of Wildlife Management, Danish Hunters' Association, Molsvej 34, DK-8410 Rønne, Denmark. (email: nk@jaegerne.dk)

Kanstrup, N. 2006. Sustainable harvest of waterbirds: a global review. *Waterbirds around the world*. Eds. G.C. Boere, C.A. Galbraith & D.A. Stroud. The Stationery Office, Edinburgh, UK. pp. 98-106.

### ABSTRACT

Waterbirds have a long tradition of being harvested in various ways. In many countries, the harvest takes place as a primary food source, but recreational hunting is also very popular. Various methods are used. Subsistence hunting of waterbirds has a history that dates back to the dawn of modern mankind. In many remote regions, waterbirds are still an important food resource. At the same time, sustainable utilization at all levels is regarded as a cornerstone in the conservation of nature. Sustainability is considered from the perspectives of two main fields: ecology and socio-economic (political) issues. Aspects of ecological sustainability include the harvest and other direct impacts on bird populations, here regarded as the hunting pressure. Socio-economic aspects include the active participation in nature conservation by local communities, motivated by the access to natural resources and the degree of stability in local communities obtained through nature conservation. In many countries there is a long tradition of detailed wildlife harvest management including programmes for bag surveys and monitoring of harvest levels. In most countries, however, the management of waterbird harvests is poor or completely lacking, and very little information is available on the annual harvest and its impact on populations. In addition, international and flyway based co-ordination is lacking in many regions, and systems need to be developed in order to obtain reliable data on harvest rates in relation to population levels and trends. Models for analysing and achieving sustainability and examples of local and integrated management of waterbird harvest are presented.

### INTRODUCTION

Most people equate sustainability with the definition first introduced in the Brundtland Report "Our Common Future": "The ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission for Environment and Development 1987). This fundamental, but not very operational, definition will be the basis for this review. It can be rewritten as "ensuring a high quality of life for everyone, now and for generations to come". This goal will – in this review – be related to the value of the world's waterbirds *per se* and to the value of the human utilization of waterbird resources through sustainable harvest.

Some aspects of the harvest of waterbirds are poorly documented and understood compared to similar aspects for mammals and other wildlife taxa. Due to the high commercial value of meat and trophies, detailed management programmes, including research and monitoring programmes, have been set up for a large number of ungulates and other mammals in all continents. Likewise, it has been shown to be commercially beneficial to establish management programmes for fish

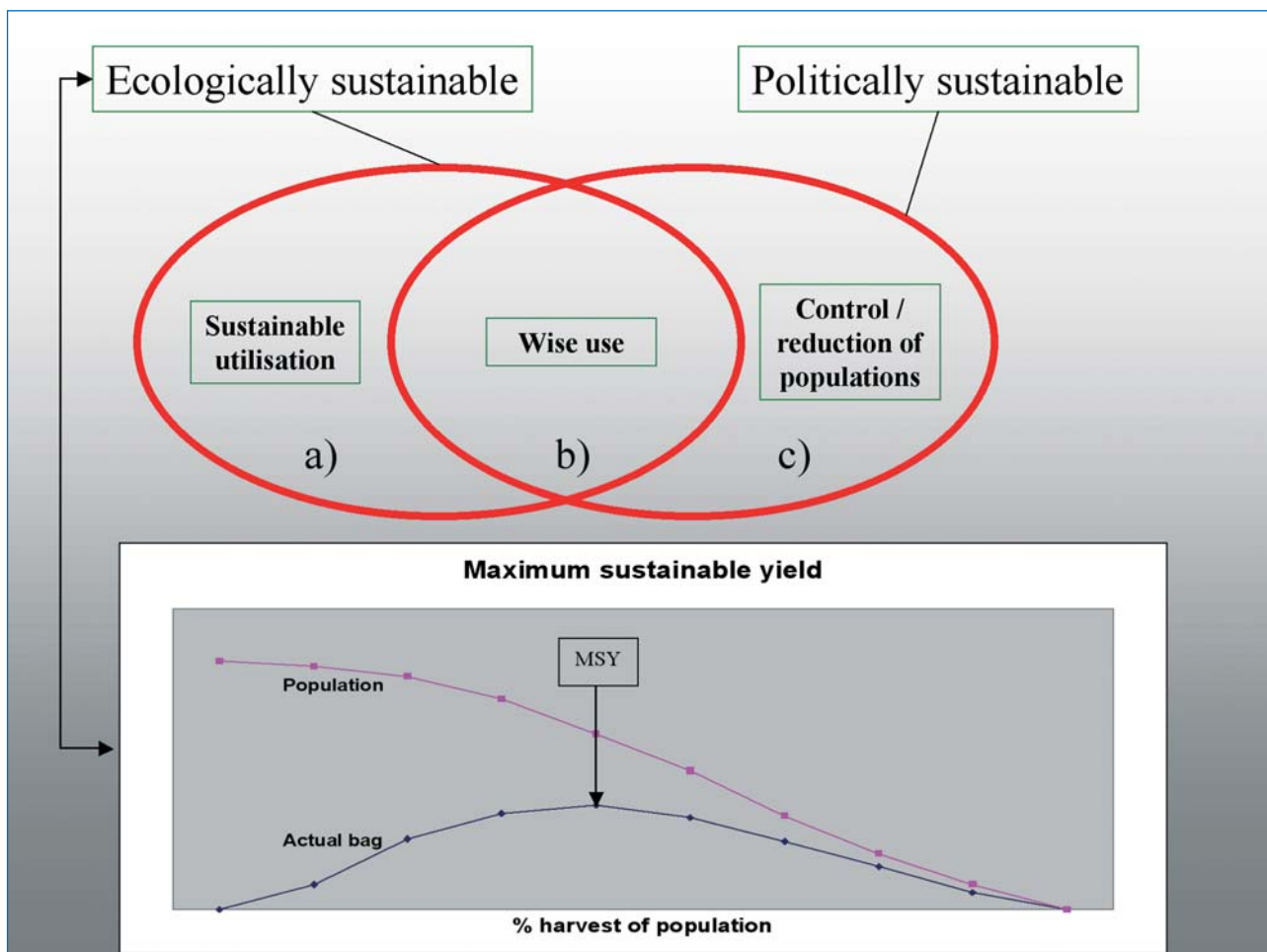
resources, resulting very often in highly sophisticated models for sustainable fishery regimes based on scientific analysis. In contrast, the national and, even more so, international management of wild birds are in a much poorer state, as research and flyway-based harvest programmes still have to be developed in most regions. However, in North America and a number of European countries, there is an elaborate system of monitoring and regulation of waterbird hunting. After many years, a general overview of the impact of bird hunting on populations and sustainability of the harvest is now available for these regions.

Of the 868 species of waterbirds recognized world-wide (Wetlands International 2002), a large proportion are known to be migratory and regularly cross national borders during the course of their migrations. The conservation and sustainable utilization of migratory birds constitute huge challenges in terms of international co-operation, which is very often made difficult by great differences in political regimes, language and culture over relatively short distances. The challenges differ widely from continent to continent. In the Palearctic region in particular, the migratory routes of waterbirds cross a very large number of political borders or limits between political regions where there were until recently (and in some instances, still are) historical and other politically created barriers that impede or prevent the integrated management of bird life. Even though the process of democratization has progressed quite far in many of the world's nations, and even though the last decade has witnessed radically improved means of communication, many countries and regions are lacking the resources and capacity for an elaborate programme of integrated waterbird management that also includes an assessment of harvest.

The terminology of international bird management and harvest assessment is imprecise and far from consistent. In this review, the term "harvest" is used to cover all kinds of active taking of wild bird resources, including any part or product of a bird, whatever the catching method used. Harvest in this sense does not cover the unintentional taking or killing of birds, and thus excludes the by-catch of waterbirds by fishing, and birds killed by oil disasters, traffic, pollution, etc. English terms for activities under this definition of harvest include collecting, gathering, hunting, shooting, wildfowling, trapping and netting.

### ELEMENTS AND TERMS OF SUSTAINABILITY

A widely accepted analysis divides sustainability into three equally important dimensions: ecological, economic and social. This review will focus on the dilemmas between ecological components on the one hand, and social and economic components on the other, and deal less with the significance of the economic resource itself (measured in monetary and meat values) and social dimensions. In the following discussion, social and economic components are treated together under the term "political components".



**Fig. 1.** Terms of sustainability. Fields of activities: a) ecologically, but not politically, sustainable harvest; b) politically acceptable activities that cause reduction or local extinction (regulation) of populations according to clearly set goals; c) ecologically and politically sustainable activities (“wise use”). See text for examples. The maximum sustainable yield (MSY) is defined as the percentage utilization that implies the largest yield and is obtained at intermediate harvest levels. Upper curve (pink): the size of the population; lower curve (blue): the size of the yield in absolute numbers; horizontal axis: the level of utilization of the population in percent.

The simplest component is the ecological one. This comprises the concept of the “harvest principle” which concerns population turnover and population dynamics. Basically, it is about production and mortality and the balance between these two. If production is greater than mortality, the population is growing; if production is smaller than mortality, the population is decreasing. In this context, it is important to consider the concepts of compensatory and additive mortality. The harvest principle is based on the fact that the causes of mortality may to some extent compensate for one another. If one mortality factor is reduced, another one increases, and the overall mortality remains constant. The same goes for mortality as a result of hunting. This effect appears to act within certain limits; it is most pronounced for r-strategists and least for K-strategists. If hunting mortality exceeds a certain limit, compensation mechanisms will no longer be sufficient to ensure that the other mortality factors are correspondingly reduced. Mortality has become additive, and hunting will, over time, cause a reduction in the population (see Fig. 1).

A fundamental concept in this context is maximum sustainable yield (MSY). This is defined on the basis of a given impact of utilization on the population in respect of density dependent productivity. Fig. 1 shows a classic relationship between utiliza-

tion, or harvest, of a population and the response of the population. The maximum sustainable yield is defined as the percentage utilization that implies the largest yield. It may be viewed as an element in the perception of ecological sustainability.

Ecological sustainability is a quantitative concept and requires only that a given harvest causes neither the extinction of the population nor a long-term decline. The term “long-term decline” is an open concept that until recently has not been formally defined in international bird management. At its third Meeting of Parties however, the African-Eurasian Migratory Waterbird Agreement (AEWA 2004) decided that: “A population in ‘significant long-term decline’ is one where the best available data, information or assessments indicate that it has declined by at least 25% in numbers or range over a period of 25 years or 7.5 generations.” When, where and how the harvest takes place is of secondary importance in relation to ecological sustainability. A quantitative optimization of the annual yield may require that the harvest occurs in the period after reproduction and, at least in the case of waterbirds, in a system where the hunting areas and hunting methods are planned in such a way that disturbance is minimized and birds are not prevented from utilizing a given area. To ensure wider ecological sustainability of a given harvest, it is essential that the system is selective in

relation to species or species groups, so that the harvest does not unintentionally influence the populations of other species in an unsustainable way through incidental catch or extensive disturbance.

Far more complex is the concept of political sustainability. This will be determined by what is “allowable” within a political region, typically a country, and will vary from region to region. Traditions, culture, ethics and a series of other societal elements will characteristically play a role in political sustainability.

It seems fundamental that a harvest must be ecologically sustainable in order to be politically sustainable, i.e. political sustainability is a subset of ecological sustainability. There is, however, an exception when management is aimed directly at reducing or eliminating a given species in a given area. The means to achieve such an objective maybe seen as ecologically unsustainable utilization – or what one may more appropriately call regulation or population control. Even though – or indeed because – the activity is ecologically unsustainable, it is politically sustainable. Hence, there is an extension of the politically sustainable field that falls outside the ecologically sustainable field (see Fig. 1).

In other words, in this model there are three fields within sustainability as a broad concept:

- a) A field that expresses sustainable harvest ecologically, but not politically. Hence, there exists a series of species and species groups which, from a strictly ecological viewpoint, could be hunted, yet in most countries this does not occur because culture, tradition and other socially created conditions do not allow it;
- b) A field that describes activities regarded as politically acceptable, in as much as they cause reduction or local extinction (regulation) of populations through management guided by clearly set goals. An example is the control measures taken against populations of waterbirds that damage agricultural crops. Even though there may not be a reduction in the overall population (meta-population), the objective of control is to reduce, or at best eradicate, a local population in a specific area; and
- c) A field that describes the overlap between what is ecologically and politically sustainable. This field may be categorized within “wise use”, a well-known concept that figures in a number of the international conventions on nature conservation.

On the whole, ecological sustainability may be viewed as a well-founded concept that refers to a mathematical assessment of MSY based on monitoring of populations as well as harvest, while political sustainability varies a great deal between countries and cultures, just as individual persons, on the basis of purely subjective judgement, may have widely differing perceptions of what may be accepted as sustainable utilization of natural resources.

## HARVEST – WHAT AND WHY?

As mentioned above, the term “harvest” is not unambiguous. In this review, the concept covers the “active taking of wild birds and products thereof”. This makes a distinction between the gathering of products (collecting), trapping (where the prey is utilized for consumption or in some instances kept or traded alive), and

hunting. Methods differ widely from country to country and from one continent to another. The harvesting of waterbirds has been a very important activity for mankind since the Stone Age, and has been practised particularly by trapping in nets and snares and the collection of products from birds, notably their eggs. Only in recent times has the use of firearms become widespread. Collection of products is still very widespread in many parts of the world. One example is the collection of down of the Common Eider *Somateria mollissima* in Iceland. Here, 400 collectors annually gather 17 gm of down from each of 180 000 nests, amounting to a total harvest of three tonnes (S.B. Hauksson pers. comm.). Another example is the collection of eggs of the Northern Lapwing *Vanellus vanellus* in The Netherlands. This remains a very popular activity. No detailed information is available on the extent of the harvest, but in 2003 the European Court of Justice recognized the activity as legal under the terms of the EC Birds Directive, Article 9, which states that such activities must only account for “small quantities” (European Community 1979).

The capture of waterbirds is still common the world over. Methods differ widely from poisoning to passive trapping with snares, nets or fish traps, and active trapping systems that involve the release of nets by the hunter or the bird itself. The driving of birds, e.g. moulting geese, into nets is also a common activity. Nets are employed on land, in areas of shallow water. e.g. where birds are moulting, and in deeper water where birds are caught during their dives. As one example of waterbird catching on a large scale, more than one million waterbirds may be caught in a single year at Lake Chilwa in Malawi (Malawi Government 2000).

Hunting with weapons began with the use of throwing and thrusting tools such as stones, lances and spears. Over 20 000 years ago, hunting was revolutionized by the development of the bow and arrow. Only much later – less than one thousand years ago – have real firearms come into play. Today, these weapons are crucial for hunting, particularly in Europe and North America, and in many countries, no other method of harvesting is permitted. The rifle is used in some types of hunting, but the shotgun is by far the most important weapon in the hunting of waterbirds.

One example is the hunting of ducks and geese in North America (Table 1). This hunting takes place in autumn during the migration of the birds from their breeding areas to their wintering areas, and also in the wintering areas. Another example is the spring hunting of geese in Siberia. It has been estimated that about 300 000 geese of several species, but particularly the Greylag Goose *Anser anser*, are killed during a single season (E.E. Syroechkovski, Jr. pers. comm.).

Why harvest? Throughout the millennia, the primary motivation for harvest has been to ensure a supply of food and other useful natural products. This is still a very important motivation,

**Table 1.** Harvest of Anseriformes in the USA in 1998. After Rothe (1999).

Flyway	Ducks	Geese
Atlantic	2 371 000	498 000
Mississippi	9 384 000	1 424 000
Central	3 743 000	1 187 000
Pacific	3 643 000	396 000
Total	19 141 000	3 505 000

not only in developing countries, but also in Arctic regions where access to food resources other than those produced by nature is limited. An element of this “consumptive” motivation is that the harvest may be converted into other values, including monetary value. In much of the developed world, however, the primary motivation for harvest is relaxation, leisure and a passion for the hunt. This may be referred to as “recreational” motivation.

A third motivation for harvest is “management”. Here, harvesting activities are carried out as part of the regulation or management of nature. Such activities include the control of wildlife to reduce damage to croplands, fisheries and the like. Usually, a harvest is driven by two of these motivations – or possibly by all three of them.

A typical example of hunting driven by both the need for food and the desire for recreation is the duck hunting in Western Europe, for example in Denmark. Here, the principal motivation is overtly the pleasure and excitement of hunting, but the reward in the shape of fresh, tasty meat is to many an equally strong factor. In Denmark, as in many other countries, one may encounter the whole three-fold motivation, for example in connection with goose hunting, where the hunt, in addition to providing recreation and the prospect of nice meat, may also be driven by a local need for management of the goose populations.

## HOW MUCH IS HARVESTED? – IMPACT AND MONITORING

An obvious question that most people might ask in relation to the harvest of waterbirds is “how much is actually harvested?” In order to assess the ecological sustainability of the harvest, it seems essential to be able to answer this question. Yet there are no surveys or censuses that give anything like a reliable estimate of the global extent of harvest of waterbirds. In North America and a number of Western European countries, quite detailed assessments of the harvest exist. In North America, it is even possible in the case of some species to compare measures of harvest with estimates of population size and thereby obtain an impression of the mortality imposed by hunting on the populations. The Mallard *Anas platyrhynchos* is considered to be the most heavily hunted species in North America. Judging from estimates of population size and harvest, the annual hunting mortality for Mallard is estimated to be below ten percent of the total population in autumn. Other species of waterfowl are pursued less intensively, and it is considered that the hunting mortality for these is in the order of a few percent.

Programmes for the monitoring of hunting harvests exist in a number of countries. In some cases, the reporting of harvests is voluntarily, while in others, it is mandatory. Denmark is one of the countries with the best reporting systems. The official Danish harvest statistics are derived from a mandatory reporting system for all Danish hunters, and have existed since 1942. They indicate that in Denmark about one million waterbirds are brought down annually. Of these, about one-third are thought to be Mallard that have been reared and released for hunting. However, the reporting is not carried out at the species level, but primarily refers to groups of species. For instance, six species of dabbling ducks, Northern Pintail *Anas acuta*, Eurasian Wigeon *A. penelope*, Common Teal *A. crecca*, Gadwall *A. strepera*, Garganey *A. querquedula* and Northern Shoveler *A. clypeata*, are grouped under the heading “other dabbling ducks”. Hence,

no direct comparison of harvest and population size can be made at the species level. Therefore the Danish harvest statistics do not constitute a tool that can be used on its own for detailed management of species, either nationally or at the flyway level. First and foremost, the statistics provide basic information that can be used in a broader research context, e.g. interview surveys among hunters. For the last 20 years, the Danish harvest (bag) statistics have been supplemented by the collection of wings of bagged waterbirds and other migratory species. This is a voluntary system and provides valuable insight into the composition of the harvest with respect to species, age and sex. Moreover, it gives a picture of the geographical distribution of the harvest throughout the hunting season, as hunters report on the hunting ground. The number of collected wings has varied over the years, averaging about 11 000 per year (Clausager 2004).

Similar programmes for the collection of bag statistics are found in other countries, while at international level, there are various strategies, with that of Wetlands International’s Waterbird Harvest Specialist Group (WHSG) being the most relevant with regard to the integrated monitoring of waterbird harvests.

Statistics on hunting bags are based on reports by the hunters. In this regard, the following analysis is important. Two concepts of yield are employed: the real yield (B) which is unknown, and the reported yield ( $B_r$ ). The real yield (B) may be viewed as a product of the population size (N) of a given species or species group multiplied by the hunting mortality ( $m_h$ ):

$$B = N \times m_h$$

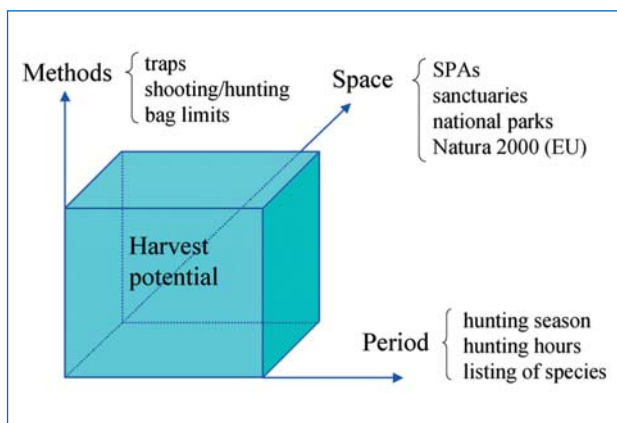
If it is assumed that the hunting mortality is constant, trends in the yield will reflect trends in the population size. If the hunting mortality is known, which is only rarely the case in waterbirds, the yield may be recalculated into an actual population size.

The reported yield ( $B_r$ ) is a product of the real yield and a factor ( $f_h$ ) that expresses the willingness and ability of the hunters to report. Hence,

$$B_r = B \times f_h$$

This factor varies according to a series of circumstances, which include legislation for and promotion of the reporting system, the efficiency of the system, and the scepticism of the hunters towards the use of the data.

Given the above relationship, it must be recognized that the possibility for using reported bags as a reflection of the real bag and population size relies on a series of assumptions, and that sound management requires analysis of the various factors in play. Data, not least data at the flyway level, are considered to be vitiated by such uncertainty that for a broad range of species it is not possible to develop a reliable system that can serve as a stand-alone monitoring tool in international bird management. Assessments of yield are viewed first and foremost as a valuable supplement to internationally co-ordinated population counts, for instance, when special yield surveys are launched in relation to “hot species”, e.g. huntable species that according to international standards have an unfavourable conservation status. It is, however, important to note that in many countries game yield statistics constitute a very valuable scientific basis for bird management. The systems that have been developed and the efforts which, for example, Wetlands International’s Waterbird Harvest Specialist Group is carrying out at flyway level should therefore be promoted and supported.



**Fig. 2.** Harvest management tools are the parameters that define the legal potential for harvest, here illustrated as a cube defined by three categories of management tools – period, methods and space – that specify 1) time periods, 2) harvest methodology, and 3) geographical areas, respectively.

### HARVEST MANAGEMENT TOOLS

The world over, there is a large number of different management tools regarding the harvest of waterbirds. In a few regions and countries, there are complete bans on harvest, but in by far the most countries, there is management that allows for harvest within certain limitations. The framework within which harvest can occur may be internationally established. At a global level, for example, the Ramsar Convention on Wetlands (Ramsar, 1971) sets certain guidelines for harvesting by referring generally to the principle of wise use, although it makes no specific demands regarding harvest.

In order to make the management tools operative, it may be useful to divide them into the following categories: (1) tools that specify time periods; (2) tools that specify harvest methodology; and (3) tools that specify geographical areas (Fig. 2).

The classic tool for management of harvest is the establishment of hunting seasons and hunting timetables. In many European countries, the first regulations based on hunting periods were established long ago in the nineteenth century. As mentioned above, the framework for hunting periods is determined in some regions by an international forum, e.g. within the European Union (EU). Hunting seasons are determined at national or sub-national level, and the fundamental principle is that there is no hunting either during spring migration or during the birds' breeding season, but rather immediately after reproduction when populations are at their largest and the biological potential for harvest is at its maximum. In many areas, however, hunting is also carried out before and during the breeding season. Such practice is not necessarily sustainable. In many countries, regulations are made concerning the time of day at which hunting is allowed. Thus, hunting at night is frequently regulated. In some countries, the hunting of geese, for example, is allowed only in the morning hours.

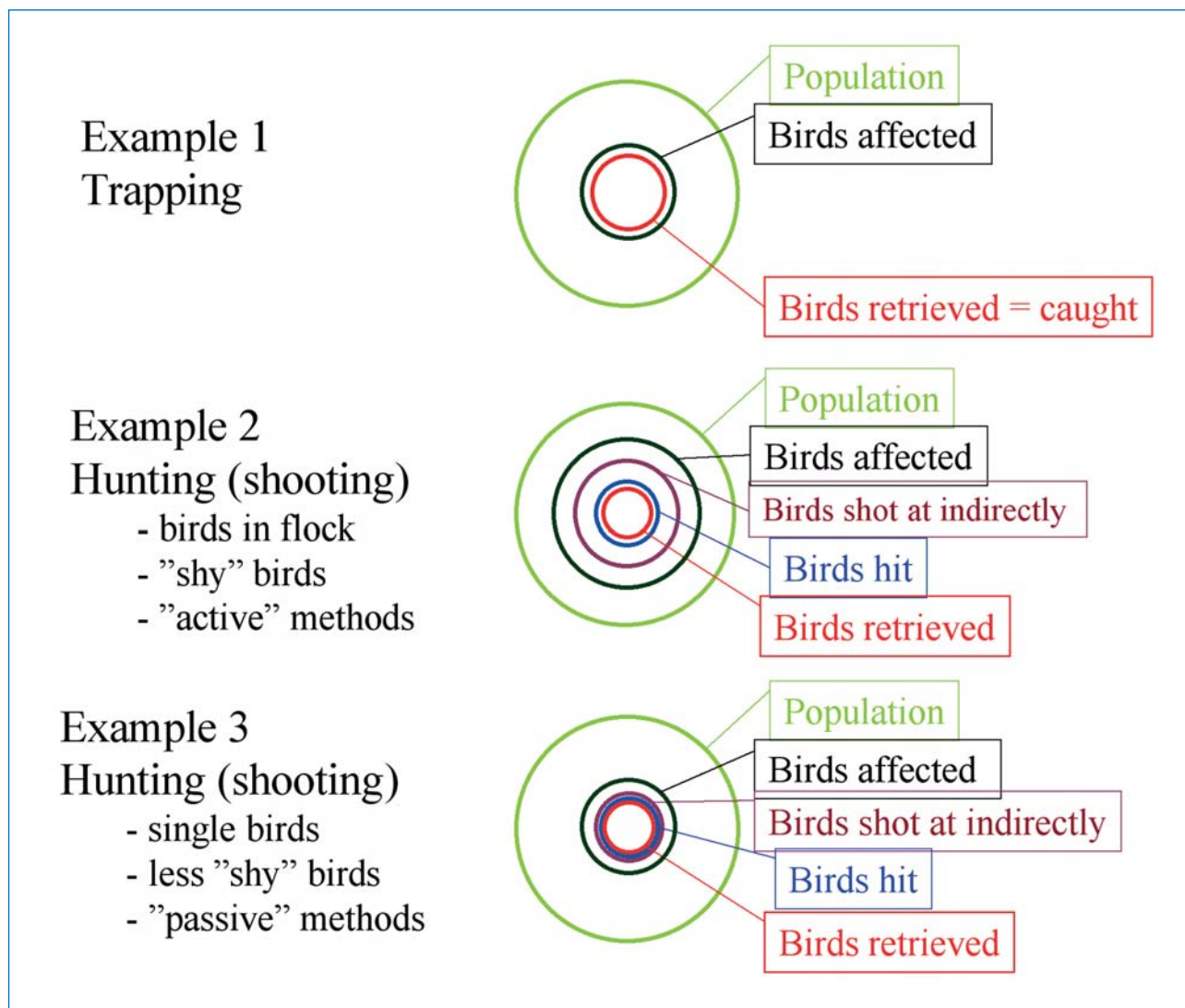
Another management tool which is frequently applied is based on regulation of the harvest in specific geographical management areas. There are a large number of definitions and concepts for such areas world-wide. The World Conservation Union – IUCN has established a series of categories, but the variation is great – from “strict nature reserves” to national parks, wildlife management areas and sanctuaries. Many of

these management areas relate to an international classification, while others relate to national legislation. A well-known global network of areas some of which are especially designated for waterbirds are Ramsar sites, designated under the Convention on Wetlands. The Natura 2000 network is a network of sites established under the Birds and Habitats Directives of the EU. Even though the Ramsar Convention and the EU Directives do not specify particular rules for harvest in their respective designated sites, but merely call for general sustainability and a limitation of extensive disturbance, specific limitations on harvest have been established in both Ramsar sites and Natura 2000 sites in a number of countries. These limitations may constitute a complete ban on harvest, but more commonplace is the establishment of core areas with a very restrictive management regime, e.g. with prohibition of harvest, surrounded by a zone in which harvest may be regulated both in time and in the harvest methods that may be employed.

The third category of management tools is based on the methods of hunting and capture. As mentioned earlier, the methods of harvest of waterbirds vary widely throughout the world. Harvest methods are products of culture, tradition and technological development through the millennia. No quantification of the distribution of use of the various methods has ever been made. However, in the vast majority of western countries, the harvesting of waterbirds is carried out almost exclusively with firearms. Several international texts establish particular rules for harvest methods. The AEWPA prescribes in its Action Plan (2.1.2 b) that the modes of taking are to be regulated. The EC Birds Directive (European Community 1979) prohibits the methods listed in its Annex IV, *inter alia*, snares, hooks, nets, traps, poisoned or anaesthetic bait, and semi-automatic or automatic weapons with a magazine capable of holding more than two rounds of ammunition. The Directive permits Member States to depart from these rules under certain conditions (Article 9). In many developing countries, firearms are used only to a limited extent in the harvesting of waterbirds. Here, nets, traps and snares are far more widespread.

A frequently used method of regulation is the establishment of bag limits. This is found in many regions of the Americas where the annual harvest is regulated by a special scoring system that sets limits on the number of waterbirds that a hunter may bag in a day. Bag limits are less widespread in Europe, where other means of regulation are more traditional. For certain species, the AEWPA Action Plan (2.1.2 c) requires that its Parties to “establish limits on taking, where appropriate, and provide adequate controls to ensure that these limits are observed”. Bag limits provide an option for regulating the total size of the harvest. However, the drawback to daily bag limits is that this system contributes to increasing the number of hunting days, and hence potentially increasing the temporal extent of hunting disturbance to waterbirds.

This model, in which management tools are divided into three dimensions (time periods, spatial tools and methods), provides a basis for analysing harvest management and comparing systems from different regions and countries. If the legal potential for harvest (the volume of the blue cube in Fig. 2) is perceived as a level for a sustainable harvest of a given population of waterbirds, it is up to the appropriate authorities in co-operation with stakeholders to organize each one of the dimensions of the cube in such a way that they comply best with



**Fig. 3.** Three examples of the impact of hunting / harvest. Example 1: passive capture, where the indirect effect of the harvest is limited relative to the yield. Example 2: active methods, where the effects are particularly strong, since the birds appear in flocks. Example 3: a situation is imagined where the hunting method is less aggressive and where the birds appear singly. The circles in Example 2 illustrate the gradient from all birds in the population (outer circle) to the birds that are bagged (innermost circle). In between lie the birds that are affected by the disturbance caused by the harvesting activity (circle 2), birds that are shot at indirectly or directly (circle 3), and birds that are hit (circle 4).

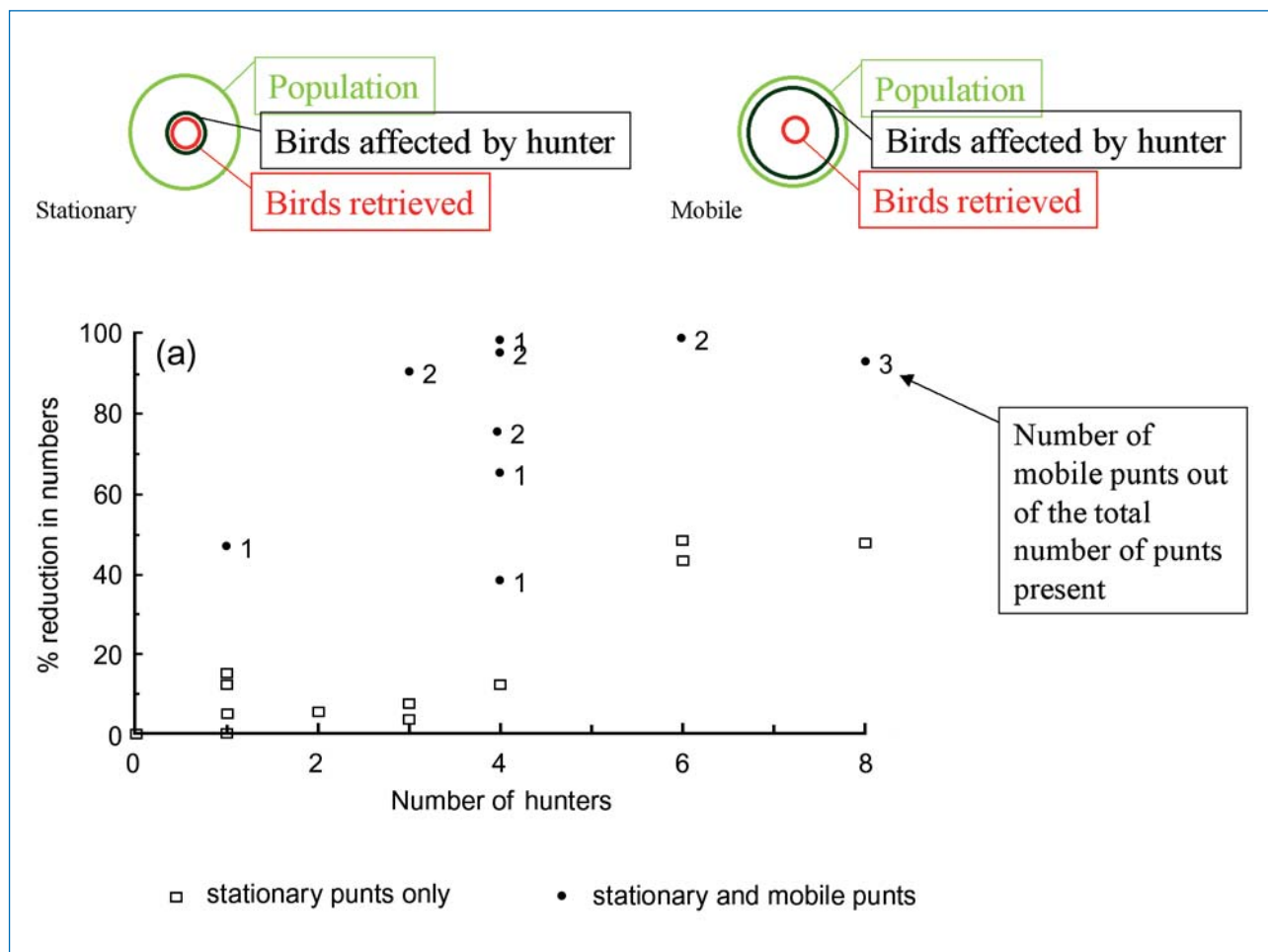
local traditions. This may produce an input to flyway-based management of migratory birds, with the Range States within the flyway first and foremost discussing and reaching agreement on levels of harvest, while the actual management takes place nationally or sub-nationally, and thereby in full compliance with the users and considering both ecological and social sustainability.

#### IMPACT ON POPULATIONS

An assessment of the ecological sustainability of a harvest should contain both an assessment of the actual yield and an assessment of the disturbance that a given harvest method inflicts on the population. Yield and disturbance both depend on the choice of harvesting methods. The use of firearms usually gives high selectivity in the yield itself, but has the potential to cause disturbance that has an impact on more species than just the target. The use of methods of passive capture, such as nets, traps and snares, gives low species selectivity, but also has a limited disturbance effect.

Fig. 3 shows a model that describes a gradient from the total number of individuals in a population to the number that are bagged. In between lie the number of birds that are affected by the disturbance caused by the harvesting activity, the birds that are shot at indirectly or directly, and the birds that are hit. It is customary for people involved in the administration of waterbird management to focus on the innermost and outermost quantities, i.e. the yield relative to the population, without giving serious consideration to the quantities lying in between. In effective management, however, it is important to assess sustainability with more refinement, so that it is emphasized in the choice of management that the populations are affected as little as possible relative to the purpose of the harvest. In this context, it is important to keep making a point of both the ecological and the political sustainability of the harvest.

One concrete example from Danish studies is shown in Fig. 4. This shows how the numbers of Eurasian Wigeon resting at Nibe Bredning are affected by the intensity of shooting from two types of shooting punts, i.e. small, flat-bottomed boats used



**Fig. 4.** The numbers of Eurasian Wigeon *Anas penelope* resting at Nibe Bredning, Denmark, in relation to 1) the numbers of punts, and 2) the type of hunting practice (stationary/mobile). After Madsen (1998).

for concealment during hunting (Madsen 1998). This analysis could open up a discussion of the selection of hunting methods. As trapping seems to cause less indirect impact on populations than other hunting methods, it might seem obvious to select this method instead of methods with a larger indirect impact. However, in most countries trapping is not seen as being selective (ecological aspects), and is therefore in direct conflict with national and international standards for the harvesting of waterbirds. Furthermore, in many countries, trapping of waterbirds does not meet ethical standards and does not comply with the general motivation for hunting. On the basis of the Danish studies, it could also be questioned why the use of mobile punts is allowed in Denmark. The answer is that mobile hunting can be managed in a sustainable way, even in areas with dense populations, as long as birds are provided with secure refuges (spatial tools). Furthermore, “stalking” birds with mobile punts is seen as a huge challenge, and complies very well with the “joy of hunting” motivation.

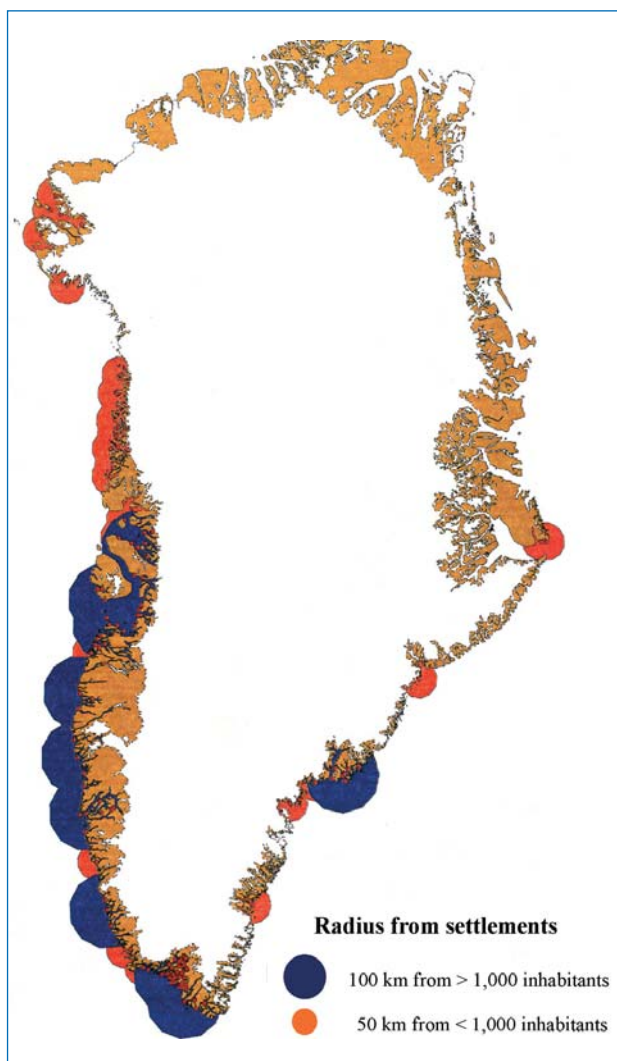
One more example to illustrate the model in Fig. 3 relates to circle 4, which describes the number of birds that are hit by shots. From a series of research programmes, it is known that only a subset of these are bagged. The difference between the two sets is calculated as the “non-retrieved harvest” which again may be subdivided into two groups: birds that die, and birds that survive. Birds that die without being retrieved should, from a management viewpoint, be added to the yield in as much as they

are lost to the population. In the USA, the “non-retrieved harvest” must be reported together with the rest of the yield. Birds that survive after being hit are defined as “wounded”. This group has been the focus of attention in a number of countries, and the debate has been particularly directed towards the political (ethical) sustainability of the harvest. Experience in Denmark, for example, has shown that it has been possible to reduce the numbers of wounded Pink-footed Goose *Anser brachyrhynchus* by 75% simply by means of a campaign directed at hunters, and without legal interference.

#### CO-MANAGEMENT

In order to ensure political sustainability – in particular, the socio-economic aspects – programmes have been developed in many parts of the world to involve the local population in the management of natural resources, including the harvesting of waterbirds. An overall term for these efforts is “co-management”. Co-management may be described in terms of co-operation between international, national and local stakeholders, and between stakeholders at the same level, e.g. various local user interests. Co-management is necessary, partly because many communities around the world are dependent on the utilization of natural resources including wild birds, and partly because no ecosystem is now “beyond the reach” of humans.

An example that illustrates the need for co-management is hunting in Greenland – a vast area with huge natural resources



**Fig. 5.** The regions of Greenland's vast coastal areas that can be reached by motorboat, shown by circles with a radius of 100 km from communities of more than 1 000 inhabitants (blue), and 50 km from settlements of less than 1 000 inhabitants (orange). Communities around the world are dependent on the utilisation of natural resources including wild birds, and no ecosystem is "out of reach" of humans. Source: Due & Ingerslev (2000).

and a very small human population. However, there are indications that waterbird management in Greenland is not sustainable in every respect (Hansen 2001). Greenland has developed from being a vast natural environment which, by virtue of its size, could not be overexploited, into an area that because of modern means of transportation and capture has become vulnerable to human exploitation. Fig. 5 indicates those coastal areas of Greenland within a 100 km radius of communities of more than 1 000 inhabitants and those within a 50 km radius of settlements of less than 1 000 inhabitants. The figure demonstrates that very substantial parts of the west coast of Greenland may be reached in a short time from both small and large villages by modern means of transportation such as fast motor boats.

Another example is found at Lake Chilwa in the southern region of Malawi. This wetland, which has been designated as a Ramsar site (Ramsar Convention 1996), comprises mainly open water, *Typha* swamps, marshes and floodplain grasslands. Every year, Lake Chilwa supports about 153 resident species of waterbirds and 30 species of Palearctic migrants. The Lake Chilwa

catchment has a population density of 162 persons/sq. km, one of the highest in Malawi. Most of these people are subsistence farmers and/or fishermen. The waterbird populations are heavily utilized. There are at least 461 bird trappers using traditional traps and snares. Catching of birds takes place every year with a peak period in the rainy season. Birds are harvested for local consumption and for trade.

Management plans were developed at Lake Chilwa in 2001. The objectives were to enable the local communities to manage the natural resources in a sustainable manner for their own benefit. Bird hunting committees and a bird hunters' association were formed. A project was initiated in 2004 to build capacity in the local community, to encourage the participation of local NGOs in advising communities on sustainable bird management, and to encourage international NGOs to participate in research and monitoring.

## CONCLUSION

Waterbird harvest is widespread and is an important activity in local communities around the world. It is diverse and includes a huge variety of management systems. Although there are some examples of harvest practices being non-sustainable, there seems to be no reason to believe that harvesting/hunting is a general contradiction to the conservation of bird life. On the contrary, the right to use natural resources can motivate local people – especially hunters – to get involved in conservation. Training is a vital element. To build capacity at all levels, more knowledge is needed in terms of (a) the direct impact of harvest (bag, products) and indirect impact (disturbance); (b) population status and trends at flyway, migration route and population level; (c) mankind and nature, *vis-a-vis* development and conservation systems. To secure the conservation of flyways across borders and across continents world-wide, co-operation is needed at all levels – including that of the hunters.

## ACKNOWLEDGEMENTS

Colleagues and friends who supported the preparation of this paper are warmly acknowledged; in particular, Karsten Thomsen, who assisted with the technical aspects and final editing.

## REFERENCES

- AEWA** 2004. Agreement on the Conservation of African-Eurasian Migratory Waterbirds. Available at: [http://www.cms.int/species/aeewa/aew\\_text.htm](http://www.cms.int/species/aeewa/aew_text.htm).
- Clausager, I.** 2004. Wing survey from the 2003/04 hunting season in Denmark. Technical Report 504, Danish National Environmental Research Institute.
- Due, R. & Ingerslev, T.** (eds). 2000. Naturbeskyttelse i Grønland [Nature protection in Greenland]. Pinngortitaleriffik, Greenland Nature Institute. Technical Report No. 29. Available at: [http://www.natur.gl/filer/Foelsomme\\_omraeder.pdf](http://www.natur.gl/filer/Foelsomme_omraeder.pdf).
- European Community** 1979. Council Directive of 2 April 1979 on the conservation of wild birds (79/409/EEC as amended). Available at: [http://europa.eu.int/eur-lex/en/consleg/pdf/1979/en\\_1979\\_L0409\\_do\\_001.pdf](http://europa.eu.int/eur-lex/en/consleg/pdf/1979/en_1979_L0409_do_001.pdf).
- Hansen, K.** 2001. Farvel til Grønlands Natur [Farewell to Greenland's nature]. Gads Forlag.
- Madsen, J.** 1998. Experimental refuges for migratory waterfowl in Danish wetlands. I. Baseline assessment of the

disturbance effects of recreational activities. *Journal of Applied Ecology* 35(3): 386-397.

**Malawi Government** 2000. Lake Chilwa Wetland State of the Environment. Environmental Affairs Department, Ministry of Natural Resources and Environmental Affairs. Report, June 2000.

**Ramsar Convention** 1996. Ramsar Convention Directory of Wetlands of International Importance, Lake Chilwa, Malawi. Wetlands International Site No. 1MW001. Available at: <http://www.wetlands.org/reports/index.cfm>.

**Rothe, T.C.** 1999. Compilation of data from the USA. U.S. Fish and Wildlife Service, Division of Migratory Bird Management.

**Wetlands International** 2002. Waterbird Population Estimates. Third Edition. Wetlands International Global Series No. 12, Wageningen, The Netherlands.

**World Commission for Environment and Development** 1987. *Our Common Future*. Oxford University Press, New York.



The Mallard *Anas platyrhynchos* is one of the most widely hunted waterbirds in the world.  
Photo: Niels Søndergaard.

## PAPER 6

Kanstrup N, Hansen HP, Balsby TJS, Møllerup KA (2021). Non-lead rifle ammunition: Danish hunters' attitudes. Environmental Sciences Europe 33, 41.  
<https://doi.org/10.1186/s12302-021-00485-z>

**RIGHTS:** Open access.

### AUTHORS' CONTRIBUTIONS

Described in the paper and approved by all authors.

Confirmed, April 2021

A handwritten signature in black ink, appearing to read 'Niels Kanstrup', with a stylized, cursive script.

Niels Kanstrup

RESEARCH

Open Access



# Non-lead rifle ammunition: Danish hunters' attitudes

Niels Kanstrup<sup>\*</sup> , Thorsten Johannes Skovbjerg Balsby, Kavi Askholm Møllerup and Hans Peter Hansen

## Abstract

**Background:** Lead particles from hunting rifle ammunition become embedded in the tissue of shot animals and pose a health risk to predators and scavengers that eat discarded offal or parts of non-retrieved carcasses of shot game animals, as well as to humans who consume game. Copper and copper–zinc alloys are the most widely used alternatives to lead ammunition. In Denmark, there has been a growing awareness of the toxic environmental effects of lead ammunition and the Danish government, supported by the Danish Hunters' Association, announced in November 2020 a forthcoming ban on the use of lead-based bullets for hunting purposes intended to take effect in 2023. The question that remains to be addressed is how the Danish hunting community perceives lead ammunition as a problem and non-lead alternatives as a solution, and whether the willingness to change demonstrated by the hunters' representatives reflects the attitude of the individual hunters. We studied this in a survey targeting 6000 randomly selected Danish rifle hunters, mapping their knowledge and concerns regarding lead rifle ammunition as well as their use of lead and non-lead ammunition.

**Results:** We found that approximately one-fifth of the use of rifle ammunition for hunting in Denmark in 2019 was non-lead. Hunters' knowledge of and concern for the adverse impacts of lead ammunition and the opportunities to switch to non-lead alternatives were generally limited. However, some showed an open-minded attitude and we found that such knowledge and concern increased the likelihood of hunters deciding to use non-lead ammunition. Hunters mainly got their information from hunting organizations and colleagues and expressed a distinct lack of information and guidance on the topic from ministerial authorities responsible for hunting administration.

**Conclusions:** Some hunters have already changed to use non-lead rifle ammunition completely or in part, and others show an open attitude to discussing the issue and receiving more information particularly from hunting authorities. Some hunters demonstrated a critical or negative attitude towards a change. Communication of the adverse impacts of lead ammunition in terms of the risk of lead poisoning to wildlife and humans and the opportunities of switching to the existing efficient and safe alternatives is essential regardless of the formal approach and will be crucial for the effectiveness of the regulation announced by the Danish government.

**Keywords:** Copper ammunition, Hunter resistance, Lead ammunition, Regulation, Transition, Voluntary

## Background

The adverse impacts of the use of lead ammunition in hunting and the possibility of replacing it with non-lead ammunition are well described [1]. For many years, the primary concern was on lead gunshot, but in recent

years, the environmental, human and animal health consequences from the dispersal of lead from rifle ammunition have come into focus. Lead particles become embedded in the tissue of shot animals [2, 3] and risk poisoning predators and scavengers that eat discarded offal or parts of non-retrieved carcasses of shot game animals, as well as human consumers who eat game [4, 5]. Several studies document high amounts of lead from ammunition among, e.g., white-tailed eagles (*Haliaeetus*

<sup>\*</sup>Correspondence: nk@bios.au.dk  
Department of Bioscience, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark

*albicilla*) and golden eagles (*Aquila chrysaetos*) and consequently higher mortality [6–8] and sub-lethal impacts including behavioral changes [9].

Several types of non-lead and non-toxic rifle bullets are produced and marketed, among which copper and copper–zinc alloys are the most widely used. At present, the retail market offers a wide variety of non-lead rifle ammunition designed for a wide range of applications [10–12]. For practical hunting use, the common non-lead types meet the same standards of efficacy and safety as leaded ammunition [13–15].

Worldwide, only a few countries have introduced regulation of leaded rifle ammunition. In 2019, California introduced a ban on all lead hunting ammunition, just as some federal states in Germany (e.g., Schleswig Holstein, Baden-Württemberg and Saarland) have regulated the use of lead rifle ammunition. In other European countries, regulation is only sporadic and targets specific areas, such as national parks and wildlife management areas [16]. There is a significant resistance to change promoted mainly by the international ammunition industry and hunting community although the denial of problems and unwillingness to discuss solutions has not been universal [17].

Although there is no actual ban on lead-based rifle ammunition in Denmark, there is a growing interest in the problem of such ammunition poisoning wildlife and posing risks to humans who consume game meat, and some hunters have switched from lead to non-lead ammunition. Within the Danish hunting community and hunting media, the risk of lead in rifle ammunition and the possibility of using non-lead alternatives have occasionally been debated (e.g., Kanstrup [18]; Knudsen [19], Sand [20]). However, at the governmental level, there has until now been no explicit position or communication on the consequences of leaded rifle ammunition and the possibility of replacing lead ammunition with non-lead alternatives. Although the Danish regulation of leaded gunshot for hunting may have created a certain awareness of the adverse impact of lead in ammunition among hunters, it is likely, that Danish hunters' concern for the environmental impact of leaded rifle ammunition and their awareness of the possibility of changing to non-lead alternatives, in general, are weak and that only a minority of hunters, therefore, have switched to non-lead ammunition. In 2019, Aarhus University initiated this national survey to test this hypothesis and to explore the influence of socio-demographic variables on the hunters' knowledge, concern and use of ammunition, the relationships between knowledge and concern, and the influence of these variables on the choice of ammunition, and not least, to clarify what sources hunters get their information from or expect to get it from. The survey included

Danish rifle hunters' attitudes to the environmental and health consequences of using lead ammunition, their use of alternatives, and factors likely to affect their choice of rifle ammunition.

## Method

The study was conducted as an electronic questionnaire during the period October 2019 to February 2020. The questionnaire (Additional file 1) was accessible from all major browsers, smartphones and tablets and was sent to 6000 rifle hunters randomly selected from the Danish National Hunting Register consisting of approximately 165,000 hunters. The selection followed a standard approach undertaken by the Danish Environmental Protection Agency (EPA), based on a randomizing generator referring to the unique registration number of all hunters. Socio-economic variables such as the hunters' age, gender, place of residence, school/professional education, and income for which there exists reference data [21] were included in the questionnaire to evaluate representativeness of the sample or to survey to which degree some of these background parameters influence the primary study variables, i.e., the hunters' knowledge and concerns regarding potential adverse impacts of leaded ammunition, their knowledge and potential reservations concerning essential properties of non-lead rifle ammunition (e.g. safety, ballistics and price), and their use of ammunition. The parameter "knowledge" was chosen to assess the level of objective information that hunters had about the two types of ammunition, whereas "concern" was included to evaluate to which degree such knowledge was subjected to reflections of positive and/or negative aspects of both types, hence to reflect an attitude. Furthermore, the questionnaire included the hunters' use of ammunition to test whether this related to their knowledge and concern. Respondents were given the opportunity to add additional textual information to some open-ended questions and to add general comments at the end. The latter was included to capture any aspect not included in the questionnaire, for example attitudes toward the questionnaire per se, and the experiences of respondents of whom many have extensive experience.

The study was executed in collaboration with the Danish Ministry of Environment and subject to procedures of ethics, protection of participants, anonymity, and safe storage of personal data at the same level as similar research and advisory activities under a present joint collaboration agreement between the Ministry and Aarhus University.

Prior to the submission of the questionnaire, two pilots were tested on two groups of 8 and 34 hunters, respectively. The first group was recruited among personal contacts of the project team. The second was suggested

by members of the first group. The first pilot was circulated as a pdf by e-mail and the second as an electronic questionnaire. Respondents in both pilots were asked to comment on clarity and function of questions as well as on the overall impression of scope, content, structure, relevance, and balance of the study and the practical use of the electronic setup. Based on the results of the pilots, the questionnaire was modified accordingly.

The questionnaire was first distributed on October 11, 2019 to 3000 randomly selected rifle hunters. Individualized URL's were circulated by the Danish Environmental Protection Agency (EPA) via e-Boks which is a trusted Nordic provider of secure platforms and digital post-boxes for all citizens. Due to an error in the URL, the questionnaire was re-distributed to the same sample on October 14, 2019. A closer analysis revealed that out of the 3000 randomly selected rifle hunters, 2778 met the criteria to be included in the study in terms of valid hunting license and the required permission to hunt with a rifle. As of December 2019, 1257 (45%) had answered the questionnaire sent to the first group. No reminder letter was sent to this group.

Assuming the error in the URL might have had a negative effect on the number of responses we decided to circulate the questionnaire to an additional second sample of hunters. Again 3000 rifle hunters were randomly selected and a new circulation with a URL was sent out on December 12, 2019. Out of the 3000, 2801 qualified to be included in the study by holding a valid hunting license and permission to hunt with a rifle. On February 1, 2020, 946 (33.8%) from the second sample had completed and submitted the questionnaire. On February 3, 2020, a reminder was sent out to all those who had not responded. On February 17, 2020, the registration of responses was closed with a total number of responses of 1422 (51%). The total number of electronic responses from the two samples qualified for inclusion was 2679. In addition to the responses to the electronic questionnaire, 22 recipients stated by e-mail that they for various reasons did not find themselves eligible (e.g., because of age) to answer the survey. Including these emailed responses which were not included in the data analysis, the total response rate of the two circulations was 2701 (48%) out of a total of 5579 qualified recipients. Response rates for surveys targeting the hunting community in Denmark have been variable, ranging between 27 and 79% [21–23].

The two samples in the present study did not differ significantly regarding the variables included in the study (see rationale and statistical testing approach in the data processing section). We, therefore, merged the two samples ( $n=2679$ ) into one pool as the basis for the further analysis.

Several variables were included in the study to analyze the sample representativeness. As the survey did not have access to basic information about Danish rifle hunters, respondents' age, sex, and place of residence were compared to all hunting license holders registered in 2019<sup>1</sup> and—where possible—with Seismonaut [23]. The educational backgrounds of respondents were compared with all Danes (see Table 1 for actual distribution). Compared to all hunting license holders, there was an underrepresentation of hunters <34 years among the respondents in this study (as in Seismonaut [23]), as well as an overrepresentation of hunters in the 35–64 years age range in this study (Table 1). The mean age of the respondents in the sample was 54.6 years, almost the same as the 55.2 years that appeared in Seismonaut [23], compared to 52.2 years among all hunting licenses.

Ninety-seven percent of all respondents were male, which is an overrepresentation, compared to all hunting licensees (92%). This was most pronounced in the oldest category of respondents as only 1% of respondents >64 years of age were female. In total women appeared to be underrepresented. In Seismonaut [23], 94% of respondents were male. A comparison of postal codes of respondents versus all hunters showed a rather similar distribution of places of residence between the two groups, although there seemed to be a slight underrepresentation of respondents from the Copenhagen region. This was not tested statistically.

The vast majority of respondents reported their level of formal education (school/professional). There was no comparable dataset available pertaining to the educational characteristics/background/experience of Danish hunters. However, a comparison with the Danish population in general<sup>2</sup> revealed that our sample was overrepresented in the category 'vocational education' and underrepresented in the category 'primary school' as the most recently completed education. This corresponds to previous studies of Danish hunters [21]. The same applies to gross income, where the respondents in this survey revealed an underrepresentation of income below DKK 300,000 per year and a corresponding overrepresentation in the high-income classes as also demonstrated by Hansen [21].

We compared annual game bags reported by respondents with the equivalent mandatory reports of all Danish hunters<sup>3</sup> and found a clear tendency for the respondents to bag more animals than the average Danish hunter,

<sup>1</sup> Basic data achieved from EPA.

<sup>2</sup> Basic data achieved from Statistics Denmark (<https://www.dst.dk/da/>).

<sup>3</sup> Basic data achieved from the official Danish Wildlife Bag Statistics (<https://fauna.au.dk/jagt-og-vildtforvaltning/vildtudbytte/>).

**Table 1** Three groups of socio-economic variables to compare respondents with other groups of hunters or Danes: Top: Age [a Kolmogorov–Smirnov test showed that the average age of respondents were slightly higher than that of all hunters ( $D=0.082$ ,  $p<0.001$ )]

Age intervals (years)	Respondents	Seismonaut [23]	All hunters
16–34	9	11	16
35–64	66	61	61
65–99	25	28	24
Place of residence	Respondents		All hunters
Copenhagen area	7		11
North Sealand	5		5
Bornholm	1		1
East Sealand	16		16
Funen and islands	10		9
South Jutland	16		16
North West/Mid Jutland	15		13
East Jutland	17		17
North Jutland	12		11
	Respondents		Danes
Basic school	8		25
High school (gymnasium)	3		10
Vocational	42		30
Short academic education	8		5
Medium academic education	16		15
Bachelor	6		2
Long academic education	13		10
Phd/scientist	1		1
Do not know	4		2

Middle: Formal education (not tested). Bottom: Place of residence (not tested). All numbers refer to percentages.

demonstrating an overrepresentation of particularly active hunters among the respondents. This was supported by the fact that 60% of respondents reported that they were members of a hunting organization versus 50% of hunters in general [23].

Overall, we assessed the data to be representative of Danish hunters, although with a few exceptions. First, there seemed to be an overrepresentation of particularly active hunters, i.e., hunters that have a larger annual bag and who are more likely will be organized than the average hunter. This is unsurprising, since those hunters who do not currently hunt or who are less active are presumably less likely to respond, meaning that the sample will exhibit a bias. Second, the average age of respondents seemed to be slightly higher than average hunters which may be because hunters begin their hunting career with shotgun hunting and tend to develop to hunting with a rifle at a slightly later stage. Finally, there was an underrepresentation of women compared to the frequency of women among hunters in general. However, according to the low number of participating women, this factor has

only limited relevance to the study. It was, therefore, disregarded in the discussion/analysis.

Additional comments given by some respondents were subject to a thematic analysis where we established eight themes and quantified comments according to statement keywords.

## Data processing

### Merging of the two samples

The two samples in the present study did not differ significantly regarding the key variables included in the study (Kolmogorov–Smirnov test for continuous variables, respondents' age:  $KS=0.70$ ,  $p=0.0711$ ; game bag:  $KS=0.655$ ,  $p=0.785$ ; level of knowledge:  $KS=0.329$ ,  $p=0.999$ ; level of concern:  $KS=0.607$ ,  $p=0.855$ ), (Chi-square tests for discrete variables; sex:  $X_1^2=0.011$ ,  $p=0.915$ ; education:  $X_8^2=9.922$ ,  $p=0.271$ ; use of lead-free ammunition  $X_1^2=0.011$ ,  $p=0.773$ ). We, therefore, merged the two samples ( $n=2679$ ) into one pool as the basis for the further analysis.

### Knowledge

To test whether the sources of information from which the hunters expected to get their information on leaded and non-lead ammunition, were also the sources from which they actually got their information, we used a  $\chi^2$  test. Since each hunter could indicate multiple expected and real sources of information, the expected values estimated as row sum \* column sum were corrected with the factor: SUM observed/SUM expected to ensure that number of expected and observed observations were equal. Only data from hunters who had reported knowledge > 0 of lead and non-lead ammunition were included here.

### Concern and knowledge

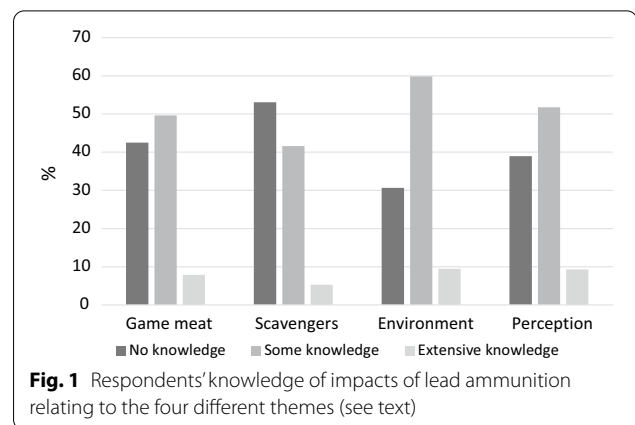
To test the association between knowledge about and concern for adverse impacts of the use of lead ammunition, we used a  $\chi^2$  test. Concern had four levels (3 graded levels: “Not concerned”, “Slightly concerned”, “Much concerned” and one “Don’t know”) and knowledge had three graded levels (“No knowledge”, “Some knowledge”, “Extensive knowledge”).

### Choice of non-lead ammunition in relation to knowledge and concern

To test whether the hunters’ knowledge about and concern for impacts of lead ammunition affected the likelihood of using unleaded ammunition, we used a generalized linear model. This model followed a multinomial distribution as the extent of use of non-lead ammunition had three categories of reply: “No use”, “Occasionally” and “Exclusively”. In addition to awareness and concern, the model included age and sex. The model, therefore, looked like this: Use = age + sex + awareness + concern. The generalized linear model tested the probability of more frequent use of non-lead among those with higher levels of knowledge about/concern for the adverse impacts of lead ammunition. Education might also affect the probability of using non-lead ammunition. However, age differed significantly between education categories (General linear model  $F_{8,2670} = 23.4$ ,  $p < 0.001$ ). We, therefore, tested education in a separate model: Use = education + sex + awareness + concern.

### Reasons given for using non-lead ammunition

The hunters gave different reasons for the use of non-lead ammunition. For each hunter we counted the number of reasons for using non-lead ammunition. We tested the relation between the sum and specific reasons for using non-lead ammunition to identify the reasons which primarily contributed to the decision to use non-lead ammunition. The model used was:



Use = Consumer + Scavengers + Environment + Perception + Hunting in Germany + Precision + Efficiency + Age + sex. Beside the seven possible reasons for choosing non-lead ammunition, the model also included age and sex to account for the variation that these variables may contribute with. We tested this model using a generalized linear model with a Poisson distribution.

All generalized linear models were calculated in PROC GENMOD, general linear models in PROC GLM, Kolmogorov–Smirnov tests were calculated in PROC NPAR1WAY, and Chi-square test were calculated in PROC FREQ in SAS ver 9.4.

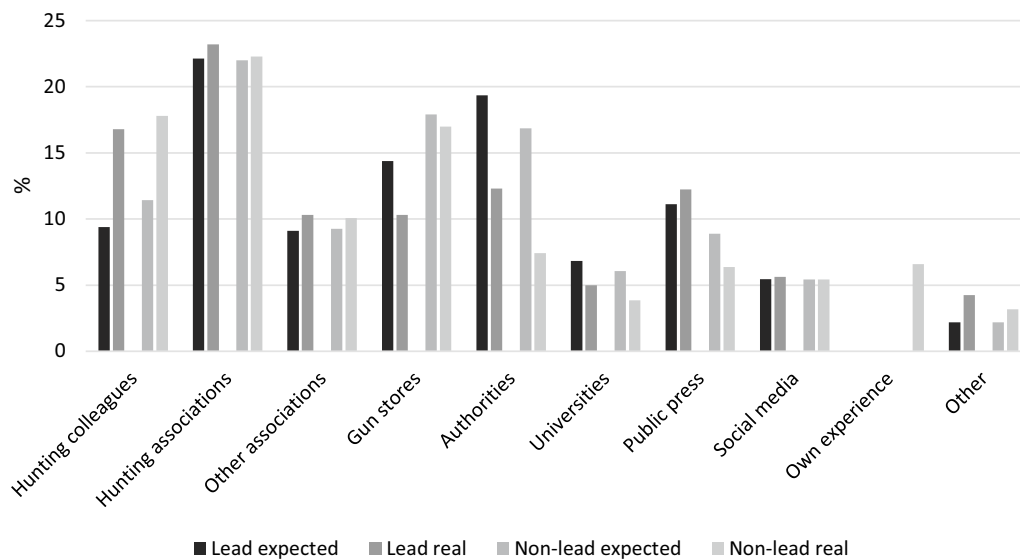
### Results

Out of 5579 qualified recipients of the survey, 2701 (48%) responded. Of these, 22 responded by email and did not provide data via the electronic questionnaire. Hence, 2679 responses contributed to the dataset.

### Knowledge

Respondents reported their knowledge of the possible adverse impacts of lead in rifle ammunition in relation to four topics: “Human consumers of game meat”, “Predators/scavengers”, “The environment”, and “Public perception of hunting”. On average only 8.0% marked that they had “Extensive knowledge” on all four topics, while almost half stated to have “Some knowledge” on the four listed topics. The topic about which hunters reported most knowledge was adverse impacts of lead ammunition on the environment (Fig. 1). The topic about which hunters reported the least knowledge related to the poisoning of the predators and scavengers.

Regarding sources of knowledge on the impacts of lead ammunition, the respondents indicated hunting colleagues (16.8%) and associations (23.2%) as the main source, while universities (5.0%) and social media (5.6%) scored lower (Fig. 2). Hunting authorities (19.3%) and to



**Fig. 2** Sources from which respondents expected to get their information on the impact of lead in rifle ammunition and non-lead rifle ammunition compared to the sources from which they actually obtained this information. “Own experience” was not optional concerning lead ammunition and had no expected option in the non-lead question

**Table 2** Statistical output concerning the number of observations,  $\chi^2$  values, and differences between the hunters’ real use and their expected use of sources of information on the impact of lead and on knowledge on non-lead ammunition

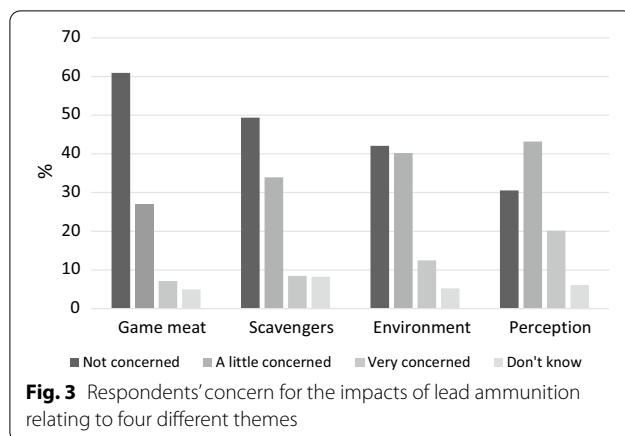
Source of information	Observations	Lead $\chi^2$	Difference real/ expected	Observations	Non-lead $\chi^2$	Difference real/ expected
Hunting colleagues	981	380.6	449.7	792	239.8	332.1
Hunting organizations	1356	2.2	53.1	991	4.6	65.1
Other organizations	603	6.6	60	448	1	20.7
Hunting stores	603	68.8	– 241	756	0.3	14.2
Authorities	719	150.5	– 412.7	330	170.7	– 337.5
Universities	292	35.2	– 120.4	172	45.2	– 113.7
Newspapers	715	8.7	74.8	284	5.5	– 42.6
Social media	329	0.4	11.4	242	1.7	19.2
Other	249	126.3	125.1	141	19.1	43.3

some extent universities (6.8%) were expected to play a more significant role in knowledge transfer than they actually did with reported sources of knowledge differing significantly from expected sources ( $\chi^2_9 = 779.2$ ,  $p < 0.001$ , Fig. 2).

Respondents ( $N = 2679$ ) reported their knowledge of non-lead rifle ammunition (categories: “No knowledge”, “A little knowledge”, “Some knowledge”, and “Extensive knowledge”) and provided information on expected and real sources for such information (Fig. 2). Expected and real sources of knowledge differed significantly ( $\chi^2_9 = 487.8$ ,  $p < 0.001$ ). Once again, hunting associations

(22%) and hunting colleagues (18%) were the most important sources but compared to the figures for knowledge about lead ammunition, gun stores played a more significant role.

In total, the difference between values for the sources from which hunters expected to get their information and the sources that they actually get it from were statistically significant. Statistical output concerning the number of observations,  $\chi^2$  values, and differences between the hunters’ real use and their expected importance of nine sources of information about lead and non-lead ammunition are shown in Table 2.



The differences between observed and expected sources of information on both lead and non-lead ammunition showed that more information than expected was obtained from hunting colleagues, whereas less information than expected was obtained from the authorities and to some extent also universities. The same goes for hunting stores, but only in relation to lead ammunition. For the other sources, there were only slight discrepancies between the expected and the actual level of information.

### Concern for impacts of lead ammunition

Respondents indicated their level of concern for the potentially adverse impacts of lead in rifle ammunition relating to the same four themes as for knowledge (see above) (Fig. 3).

In total, 82% of the responses were in the categories “Not concerned” and “A little concerned”. Most respondents were concerned for the “Public perception of hunting” (20.2% “Very concerned”). The risk to “Human consumers of game meat” caused less concern (60.9% “Not concerned” and 7.1% “Very concerned”). A rather constant but small number of respondents indicated that they did not know if they were concerned (average 6.1% for all four themes).

### Concern, knowledge and the use of non-lead ammunition

We analyzed values for knowledge and concern relating to the four themes: “Human consumers of game meat”, “Predators/scavengers”, “The environment”, and “Public perception of hunting”. All showed a significant association (Table 3), meaning that knowledge and concern were dependent. In this case, it meant that respondents who expressed the highest degree of knowledge also expressed the highest degree of concern. The statistical output suggested that hunters were most concerned about the public perception of hunting and least concerned about the

**Table 3** Statistical output ( $\chi^2$  test) for the analysis relationship between hunters' knowledge of and their concern for potential adverse impacts of lead rifle ammunition relating to the four themes: “Human consumers of game meat”, “Predators/scavengers”, “The environment”, and “Public perception of hunting”

Impact themes	df	$\chi^2$	p
Game meat	6	264.9	< 0.001
Scavengers	6	368.6	< 0.001
Environment	6	484.9	< 0.001
Perception	6	774.3	< 0.001

**Table 4** Statistical output of the tests (generalized linear model) of possible variables that might impact the use of non-lead ammunition

Variable	df	$\chi^2$	p	Slope
Level of knowledge	1	26.7	< .0001	0.116
Level of concern	1	54.2	< .0001	0.134
Age	1	9.7	0.0018	− 0.0095
Sex	1	0.1	0.748	

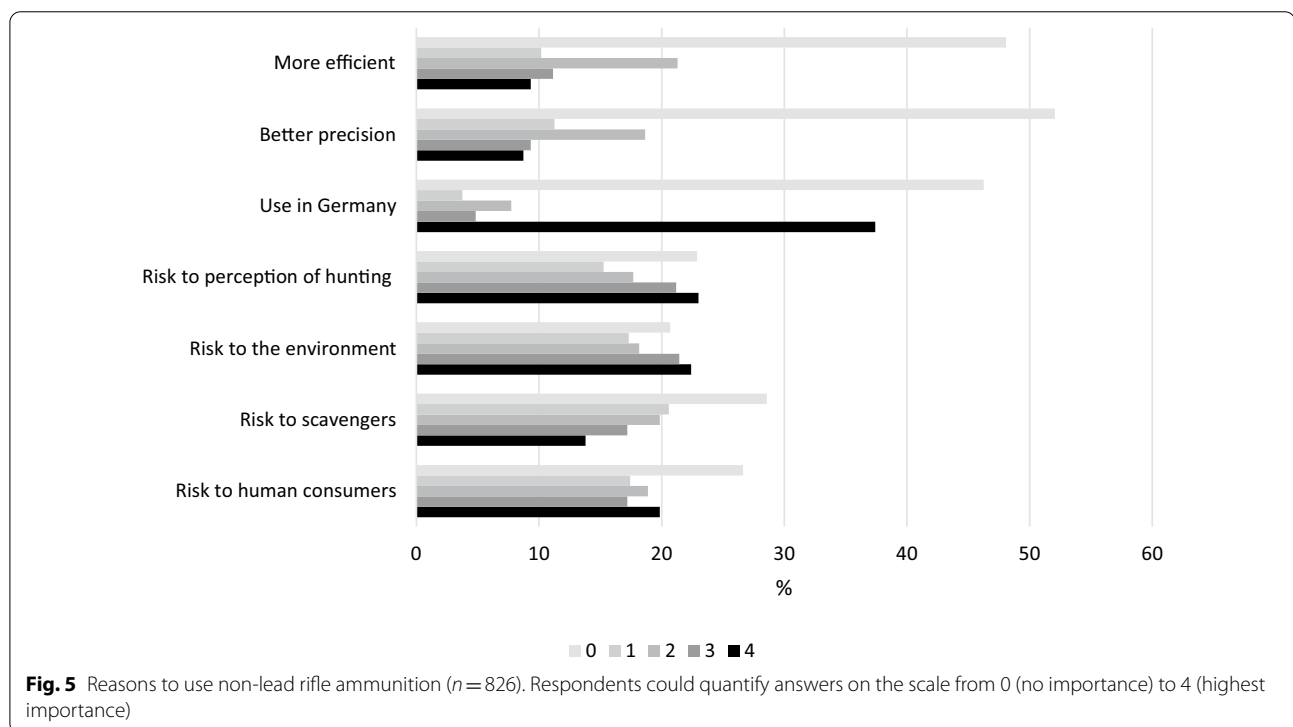
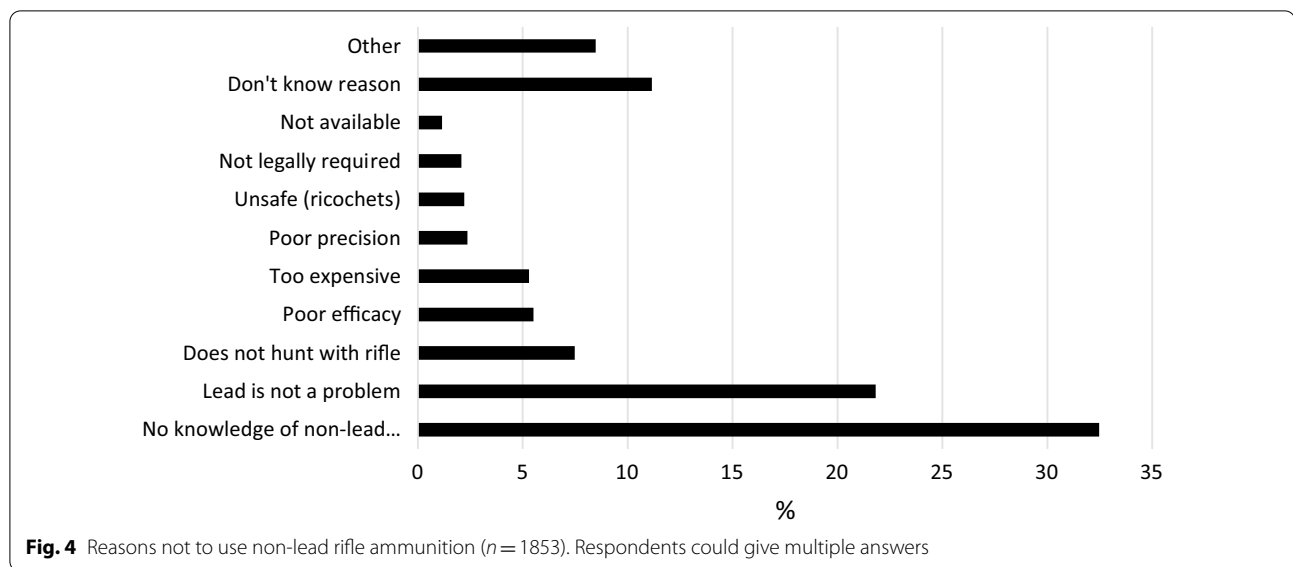
risk to human consumers of game meat contaminated by lead ammunition.

The degree of knowledge and concern significantly influenced the use of non-lead ammunition. Those reporting higher levels of knowledge and concern were more likely to use non-lead ammunition (Table 4). This means that knowledge as well as concern increased the tendency of hunters to use non-lead ammunition. The significant negative estimate of age demonstrated that young hunters are more likely to use non-lead ammunition than older ones. Sex had no significant impact. The tests indicated that education did not influence the likelihood of using non-lead ammunition.

### Use of ammunition

1,853 (69%) respondents reported that they did not use non-lead rifle ammunition, while 450 (17%) used it occasionally, and 376 (14%) exclusively. The distributions of reasons for not using or using non-lead ammunition are illustrated in Figs. 4 and 5, respectively.

The motivation for using non-lead ammunition, to a certain degree, reflected the concerns that respondents had for the possible negative impact of lead ammunition (“Concern, knowledge and the use of non-lead ammunition”). To clarify which aspects contributed most to the extent of the use of non-lead ammunition, we tested the sum for the number of reasons for using non-lead ammunition in relation to the individual aspects that



contributed to the sums. This was also tested with a generalized linear mixed model. In this model, the sum was assumed to follow a Poisson distribution. All aspects showed a significant positive relation to the extent of use (Table 5).

According to the parameter estimates (slope), “Damage to the environment” and “The perception of hunting” made the largest contribution. The impact of hunters

being introduced to non-lead rifle ammunition in Germany showed a lower contribution to their choice of ammunition, based on the slope estimate. However, this factor was the most significant, which indicates its impact is quite clear compared to the other parameters. The impact of hunting in Germany upon the use of non-lead ammunition was supported by the fact that 73.2% of 213 respondents who hunted in Germany in 2018,

**Table 5** Statistical output of tests to compare the importance of different variables and the hunters' choice of using non-lead ammunition

Variable	df	$\chi^2$	<i>p</i>	Slope
Risk to human consumers	1	53.91	<.0001	0.0907
Scavengers	1	16.08	<.0001	0.0562
Environment	1	65.30	<.0001	0.1136
Perception	1	82.94	<.0001	0.1024
Hunting in Germany	1	168.15	<.0001	0.0745
Improved precision	1	20.93	<.0001	0.0549
More efficient	1	45.23	<.0001	0.0824

reported that they used non-lead ammunition whereas this was only 27.2% for other respondents.

Respondents reported their use of rifle rounds per year for hunting and training, indicating a mean use of around 6.6 (73% lead; 27% non-lead) rounds per year for hunting and 69.5 (79% lead; 21% non-lead) for training.

#### Additional comments

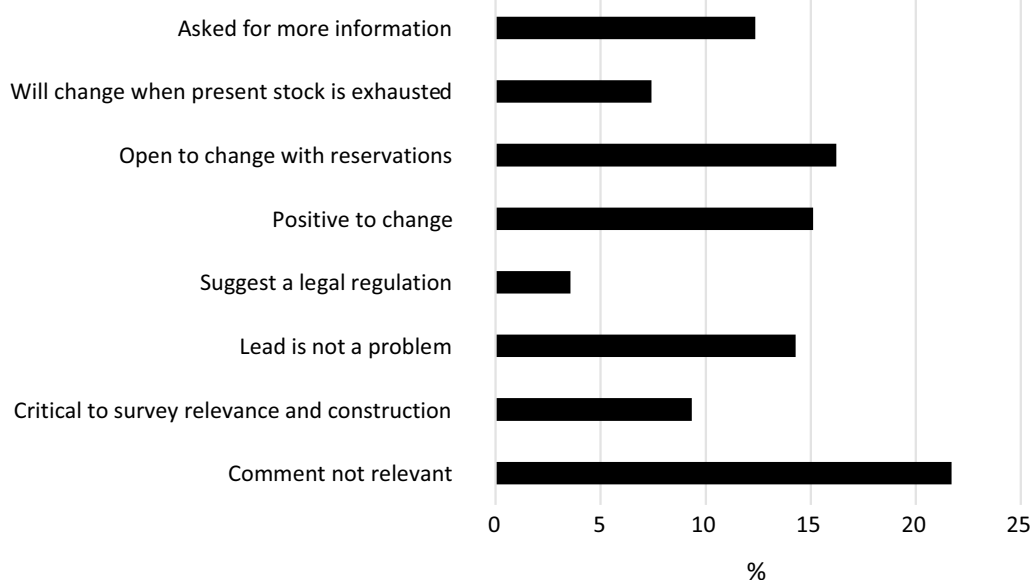
The questionnaire gave respondents the opportunity to add their own general or specific comments and reflections. The comments were classified in different themes (Fig. 6). In total, 377 respondents gave additional comments. Some had comments on the relevance or construction of the study or otherwise expressed a negative attitude to the survey (9%). Some argued that lead ammunition is not a problem (14%) while, others supported

a ban on lead rifle ammunition (4%). A rather large group (total 31%) expressed a positive and open attitude to change, however, many had reservations, such as the importance of non-lead ammunition living up to standards of efficacy and safety. Some respondents (7%) stated that they would switch to non-lead when their existing stock of lead ammunition was exhausted. Finally, there was a group (12%) requesting more information including access to the project report. A rather large group gave comments that were of no direct relevance for the survey, for example that they did not at present have a rifle or have the opportunity to hunt (22%).

#### Discussion

##### One-fifth of the 2019 use was non-lead

Almost one-third (31%) of the respondents stated that they used non-lead rifle ammunition occasionally or exclusively. Game bag statistics further reveal that respondents were more active in their hunting pursuits than the average hunter in Denmark, and thus, have more practical experience of hunting, including rifle hunting. Higher levels of knowledge of the adverse impacts of lead ammunition correlates to an increased likelihood of using unleaded ammunition. Hence, the proportion of respondents who stated that they use non-lead ammunition is not representative of all hunters but must be considered a maximum figure. The same is likely to be the case for the figures provided by the respondents regarding ammunition use, which for hunting was distributed as 73% on lead and 27% on lead-free ammunition and for

**Fig. 6** Categories of additional information given by 377 respondents. See text for more details

training as 79% and 21%, respectively. Furthermore, the figures were above the levels found by questioning Danish gun stores indicating that 10–15% of sales over the years 2017–2019 were non-lead, however, the amount is clearly increasing (Kanstrup, unpublished data). Based on the present study and information from the gun stores it is likely that 15–25% of the rifle ammunition currently used for hunting and related training in 2019 in Denmark is unleaded.

### Knowledge, concern, and use are interconnected

Our study demonstrates that the more hunters know about lead ammunition and non-lead alternatives, and the more concerned they are about the impacts of lead ammunition, the higher the tendency is for them to use non-lead ammunition. This highlights the importance of communication and learning as tools for change as demonstrated in other studies [24].

Knowledge and concern predominantly related to “The perception of hunting” and “The environment”. This is interesting, because these two themes are poorly covered by literature, whereas the risks to “Human consumers of game meat” and “Predators/scavengers” are well documented at least in the scientific literature [4, 5]. However, comparatively fewer hunters drew on scientific sources for their information on the subject, hence, their knowledge and concern will to a higher degree rely on information from hunting colleagues and hunting associations. Information exchanged between hunters may be intuitive rather than based on research and empirical data. Although Danish hunters’ associations and media have been open to discussing the impact of lead in rifle ammunition, the scientific information has not yet reached the wider hunting community. The information has not specifically addressed risks to human health and scavengers but rather the negative implications of hunting being associated with the dispersal of a toxic substance that society in general is in the process of phasing out. This may explain why hunters mostly regard lead in rifle ammunition as a concern for the public perception of hunting.

Before November 2020, i.e., when this study was carried out, Danish authorities had no explicit position on the consequences of lead rifle ammunition. The website of the Veterinary and Food Administration currently provides the following information: “*Game animals shot with lead ammunition can contain high concentrations of lead—especially in the meat around the bullet hole. Children under seven years of age and pregnant women should therefore avoid eating meat from the area around the bullet hole*” [25]. Implicitly, this formulation issues no warning to people other than children and pregnant women against eating meat from any part of the shot animal,

including meat from the area around the bullet hole. This contradicts widely accepted guidelines recommending that particularly children up to the age of seven, pregnant women and women of childbearing age should abstain from eating game meat that has been hunted with lead ammunition due to their specific sensitivity towards the toxic effects of lead [26]. It further contradicts the Swedish guidelines to which the Danish administration makes an explicit website reference. Swedish authorities recommend hunters “*to cut and discard the wound channel after the bullet, meat that looks affected or bloodstained, and at least ten cm of visible unaffected meat around the wound canal. This meat should not be used as food for humans or animals*” [27].

Our study showed that authorities play an important potential role as a source of awareness building for Danish hunters. The scarce and misleading information that has been and still is available from the food authorities may well be one reason for the limited level of knowledge and concern expressed by respondents in this study, particularly in terms of the risk that lead ammunition poses to human health. This suggests that increased focus on the risks associated with human consumption of game meat shot with lead ammunition could be instrumental in a future communication strategy and raise more concern among hunters if communicated more effectively and less misleadingly. Hunters are, themselves, consumers of game meat as are their families including children and young women. Hunters are the primary producers of game meat for the public food market and it is in the interest of hunters to provide game meat products that are safe for consumers thereby also enhancing the long-term positive reputation of recreational hunting in the public [17]. X-ray photos demonstrating “a snowstorm” of lead fragments in carcasses of killed deer [2] often elicit a strong and spontaneous reaction among hunters and others that are not aware of this phenomenon (authors’ personal observation) and could be an illustrative communication tool. Another argument for change could be the more general subject of political sustainability and the public perception of hunting which was the most concern-raising element among respondents. This may primarily be an intuition, however, it is scientifically well established that hunting with lead ammunition is not sustainable [28]. The Danish regulation of leaded gunshot pellets for hunting has established the narrative of the adverse impact of lead in ammunition among hunters [29]. This could be included in a general strategy for future communication on leaded ammunition and the possible transition to non-leaded rifle ammunition.

The study identified a group of respondents who reported a high amount of knowledge but at the same time little concern about the impact of lead rifle

ammunition. Additional comments from these hunters demonstrated that some of them found the risk negligible not least compared to other lead sources (including lead in military ammunition, and fireworks). Some stated that non-lead rifle ammunition is just as toxic as lead ammunition, hence, a transition would only exchange one potential problem with another. Some criticized the project team for “wasting” their (and that of the “respondents”) time on a survey like this and found the whole discourse on lead in rifle ammunition to be an attempt to discredit hunters and, in the long term, develop an anti-hunting ploy as also demonstrated in the other studies [30, 31]. This combination of dismissing the potential problem with lead ammunition and at the same time dismissing non-lead types was also observed in the discourse among hunters during the Danish phase-out of lead shotgun pellets in the 1980s [29] and in similar processes in the other countries [32]. This indicates the existence of (i) a group of hunters who are unlikely to switch from lead to non-lead rifle ammunition voluntarily, and (ii) a group of hunters who are unlikely to comply even with legal regulations on the subject, as it was seen also in the process of phasing out lead shotgun pellets [33]. A transition process and the mechanisms to provide such a process must, therefore, be seen in a broader perspective and should include factors beyond those investigated in this study. Some may be rather fundamental and connected to the personal ideology of hunters. There are indications that some societies over the recent decades have witnessed a turn towards a neoliberal paradigm making regulatory conservation approaches problematic while simultaneously making voluntary programs the default policy option [30]. It is conceivable that some hunters are exponents of such a development and that the political conditions for programs for phasing out lead in ammunition today are fundamentally different from what was the case in the initial processes of regulating lead shot for waterbird hunting in the 1980s and 1990s both in North America and an array of European countries.

A rather large group of respondents demonstrated an open attitude towards a transition from lead to non-lead rifle ammunition. 27% of all respondents offered their e-mail addresses to receive further information on the subject and to participate in future follow-up studies. Some demonstrated willingness to discuss the whole issue of lead in rifle ammunition, while simultaneously expressing various reservations, including concern for lethality, safety, availability and price of non-lead ammunition types. Furthermore, respondents expressed that the actual amount of information they receive from authorities, etc., was lower than expected which demonstrates a potential for more communication. Hence,

there seems to be a large potential to improve the communication of information about the transition from lead to non-lead rifle ammunition including detailed information covering the specific concerns of hunters all of which have been thoroughly covered by research of direct relevance to Danish hunters [34]. This applies to the efficacy of non-lead bullets investigated in Northern Europe including Germany [35], Scandinavia [14] and Denmark [13] availability [36, 37] including availability on the Danish retail market where a wide range of lead-free rifle ammunition is already available to suit most Danish hunting applications [19]. In terms of the overall budget of hunters, the cost of ammunition plays a minor role. However, the price of ammunition appears to be an essential concern for hunters in their considerations of changing to use non-lead types. In this study, extra costs were given as a reason for not using non-lead rifle at a level of c 5% of answers given by respondents (Fig. 4), which was similar to the percentage of respondents with concerns for the poor efficacy of non-lead ammunition. It is well established that non-lead rifle ammunition is available at prices comparable to equivalent leaded ammunition [12, 36]. Regarding safety, research generally suggests that it is not the material (lead or non-lead) that is decisive for the ricochet tendency but rather the bullet shape and construction [38].

#### Future perspectives

Non-lead rifle ammunition was first introduced to the Danish market in around 2013 and this study suggests that approximately one-fifth of the consumption in 2019 was non-lead. This change has until now occurred without any legal encouragement, apart from the formal regulation of lead rifle bullets in Germany which evidently has a knock-on effect in Denmark, because Danish hunters who hunt in German regions with regulations on lead rifle ammunition get acquainted with non-lead ammunition and tend to also use it in Denmark. However, by November 2020, the Danish government announced a legal regulation of leaded rifle ammunition to come into force in 2023. Therefore, speculation about to what extent a transition could occur without a legal regulation in Denmark, i.e., based only on a voluntary transition supported by an extended outreach strategy, appears with the recent governmental initiative to be a purely theoretical endeavor. Nevertheless, the traditional components of a non-regulative approach, not least solid communication, is still needed to facilitate and improve the rate of success of an effective regulative phase-out of leaded rifle bullets.

Our study shows that young hunters are more likely to switch from leaded to lead-free ammunition than older ones. Furthermore, some hunters plan to switch

to non-lead ammunition when their existing stock of lead ammunition is exhausted. Both findings suggest that the shift will accelerate even without a legal regulation. The elimination of lead ammunition in some private hunting districts in 2020 will further contribute both in the form of ammunition used in these districts and the impact that such an initiative will have on hunters' choice of ammunition for hunting in other areas. The broad request from many respondent hunters to receive more information about our study as well as the hunters' willingness to learn from each other demonstrate a potential for improving communication from all relevant bodies. Improved information and knowledge will motivate concern and, thus, stimulate the transition whether it is voluntary or regulative. However, information and knowledge alone are unlikely to lead to changes of attitude and behavior, as described in the "information deficit model". Successful governance relies on more than just one-way information and should ensure communication in the broadest possible capacity embracing that information, its content of technical knowledge and the consequences of that knowledge are understood by, reflected on, debated and, where relevant, commented on by key target audiences.

Segerson [39] found the concept of voluntary approaches in environmental protection programs to encompass three types: (i) unilateral initiatives, under which polluters voluntarily take actions to reduce pollution without any government involvement; (ii) negotiated agreements, under which a regulatory agency negotiates with polluters over the terms of an agreement involving obligations on both sides, and (iii) public voluntary programs, under which the government unilaterally determines both the rewards and obligations of participation and eligible polluters are encouraged to participate. Regardless of the impact of regulation in Germany, the approach taken until now in Denmark seems to belong to unilateral initiatives driven only by the hunters themselves with no or only little contribution from Danish authorities. According to this it is, however, overall likely that the establishment of a negotiated agreement between the Danish government and the hunting community could lead to a further and significant transition from the use of lead to non-lead rifle ammunition based solely on a voluntary approach. However, several factors would limit the success of such a program in terms of a full transition including a free-rider behavior of a rather large group of hunters that disregards the adverse impacts of lead ammunition and, at the same time, regards the whole discourse and possible regulation to be an anti-hunting ploy. Furthermore, the group of hunters who will transition to non-lead ammunition once their present stocks of lead ammunition are exhausted could

hinder a quick transition. Finally, voluntary programs to phase-out lead ammunition as seen in Europe and North America during the past 2 decades have been largely unsuccessful and ineffective [24, 30, 32, 34].

The consistent approach taken by Danish authorities to phase-out lead shot in the 1990s has been successful and has posed no risk to the future of hunting [29, 40]. Although Denmark is one of Europe's smallest countries, it holds a high proportion of hunters with multifaceted hunting traditions resembling those of larger European countries, e.g., Germany, UK, and France. The Danish success of phasing out lead shot pellets, including almost 40 years of accumulated knowledge, experience, and communication are, therefore, a valid and representative contribution to the international discourse in the years to come.

Lead is toxic and our understanding of the adverse impacts of this form of lead exposure on wildlife and humans will change little with further eco-toxicological research. The issue is now socio-political [41]. This increases the demand for knowledge about the mechanisms that govern human behavior, i.e., an increased effort within the socio-scientific disciplines. There is a growing need for an effort that transcends the classical research sectors. Such an interdisciplinary approach will provide a deeper understanding of the factors predicting and affecting perception and compliance with the established regulations and acceptability of any future changes to practice.

## Conclusions

This study demonstrates that many Danish hunters are not yet aware of the adverse impacts of lead in rifle hunting ammunition and neither do they know about the possibilities to changing to alternative, non-toxic types. At the same time, some hunters have already changed completely or in part as approximately one-fifth of the rifle hunting ammunition used in Denmark in 2019 was non-lead. Others show an open attitude to discussing the issue and receiving more information particularly from hunting authorities. Nevertheless, a group of hunters demonstrated a critical or negative attitude towards a change.

Knowledge is a key to concern for lead's impact and the possibility of using alternatives and both knowledge and concern increase the likelihood of hunters changing to use non-lead rifle ammunition. Introduction to the use of non-lead rifle ammunition via hunting in Germany further stimulates Danish hunters to use non-lead ammunition also for hunting in Denmark. Hunters requested more information from hunting authorities, and a transition is likely to succeed if campaigned efficiently by authorities and hunters' organizations.

The study identifies essential elements of communication in a transition program, including information on the problem in terms of, for example the risks that lead rifle ammunition poses to human consumers as well as the solution in terms of efficacy and safety of non-lead ammunition types that are widely available. Communication of this information is essential in the regulative approach as announced by the Danish government in November 2020 whereby lead in rifle ammunition will be banned by 2023. A clear strategy to maintain and improve the communication with the hunters is essential for the success of such initiative.

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12302-021-00485-z>.

**Additional file 1.** Questions included in the questionnaire study: Non-lead rifle ammunition: Danish hunters' attitudes.

## Acknowledgements

We want to thank the many Danish rifle hunters who took the time to provide all the data we requested. We also thank 15. Juni Fonden, Arboretet, Kirkegårdsvej 3A, DK-2970 Hørsholm for funding this project. The grant was given for the 1-year study period 2019–2020 (grant number 19-J-1). Not least, we thank the Danish Agency for the Protection of the Environment for broadcasting several E-boks-letters to the extracted hunters. Finally, we are grateful to Gwen Fox for her valuable linguistic assistance and other highly relevant comments on the work.

## Authors' contributions

NK conceptualized and directed the study, analyzed and interpreted the data, drafted, revised and finalized the manuscript. TJSB undertook statistical analysis and data interpretation. KAM designed data collecting software and administered the technology. HPH supported conceptualization, undertook data interpretation and critical revision of manuscript. All the authors read and approved the final manuscript.

## Funding

15. Juni Fonden, Arboretet, Kirkegårdsvej 3A, DK-2970 Hørsholm funded this project through a grant given for the 1-year study period 2019–2020 (grant number 19-J-1).

## Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

Received: 9 January 2021 Accepted: 16 March 2021

Published online: 31 March 2021

## References

- Kanstrup N, Thomas VG, Fox AD (2019) (Eds.) Lead in hunting ammunition: Persistent problems and solutions. *Ambio* 48. <https://link.springer.com/journal/13280/volumes-and-issues/48-9>
- Trinogga AL, Courtiol A, Krone O (2019) Fragmentation of lead-free and lead-based hunting rifle bullets under real life hunting conditions in Germany. *Ambio*. <https://doi.org/10.1007/s13280-019-01168-z>
- Kollander B, Widemo F, Ågren E, Larsen EH, Loeschner K (2017) Detection of lead nanoparticles in game meat by single particle ICP-MS following use of lead-containing bullets. *Anal Bioanal Chem* 409:1877–1885. <https://doi.org/10.1007/s00216-016-0132-6>
- Pain DJ, Mateo R, Green RE (2019) Effects of lead from ammunition on birds and other wildlife: a review and update. *Ambio*. <https://doi.org/10.1007/s13280-019-01159-0>
- Green RE, Pain DJ (2019) Risks to human health from ammunition-derived lead in Europe. *Ambio*. <https://doi.org/10.1007/s13280-019-01194-x>
- Krone O (2018) Lead poisoning in birds of prey. In: *Birds of prey: biology and conservation in the XXI century*, p 251–272. Doi: [https://doi.org/10.1007/978-3-319-73745-4\\_11](https://doi.org/10.1007/978-3-319-73745-4_11).
- Kenntner N, Tataruch F, Krone O (2001) Heavy metals in soft tissue of white-tailed eagles found dead or moribund in Germany and Austria from 1993 to 2000. *Environ Toxicol Chem* 20:1831–1837. [https://doi.org/10.1897/1551-5028\(2001\)020%3c1831:hmidt%3e2.0.co;2](https://doi.org/10.1897/1551-5028(2001)020%3c1831:hmidt%3e2.0.co;2)
- Helander B, Axelsson J, Borg H, Holm K, Bignert A (2009) Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden. *Sci Total Environ* 407:5555–5563. <https://doi.org/10.1016/j.scitotenv.2009.07.027>
- Ecke F, Singh NJ, Arnemo JM, Bignert A, Helander B, Berglund ÅMM, Borg H, Bröjer C, Holm K, Lanzone M, Miller T, Nordström Å, Räikkönen J, Rodushkin I, Ågren E, Hörnfeldt B (2017) Sublethal lead exposure alters movement behavior in free-ranging golden eagles. *Environ Sci Technol* 51:5729–5736. <https://doi.org/10.1021/acs.est.6b06024>
- Kanstrup N, Haugaard L (2020) Krav til projektilvægt, anslagsenergi m.v. for rifellammunition, der anvendes til jagt og regulering. Technical Notice Nr. 36. DCE. Aarhus University. [https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet\\_2020/N2020\\_36.pdf](https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet_2020/N2020_36.pdf). (In Danish with an English summary).
- Kanstrup N, Thomas VG, Krone O, Gremse C (2016) The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations. *Ambio* 45:621–628. <https://doi.org/10.1007/s13280-016-0780-y>
- Thomas VG (2013) Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. *Ambio* 42:737–745. <https://doi.org/10.1007/s13280-012-0361-7>
- Kanstrup N, Balsby TJS, Thomas TG (2016) Efficacy of non-lead rifle ammunition for hunting in Denmark. *Eur J Wildl Res* 62:333–340. <https://doi.org/10.1007/s10344-016-1006-0>
- Stokke S, Arnemo JM, Brainerd S (2019) Unleaded hunting: Are copper bullets and lead-based bullets equally effective for killing big game? *Ambio* 48:1044–1055. <https://doi.org/10.1007/s13280-019-01171-4>
- Gremse F, Krone O, Thamm M, Kiessling F, Tolba RH, Rieger S, Gremse C (2014) Performance of lead-free versus lead-based hunting ammunition in ballistic soap. *PLoS ONE* 9:e102015–e102015. <https://doi.org/10.1371/journal.pone.0102015>
- Mateo R, Kanstrup N (2019) Regulations on lead ammunition adopted in Europe and evidence of compliance. *Ambio* 48:989–998. <https://doi.org/10.1007/s13280-019-01170-5>
- Kanstrup N, Thomas VG (2020) Transitioning to lead-free ammunition use in hunting: socio-economic and regulatory considerations for the European Union and other jurisdictions. *Environ Sci Eur* 32:91. <https://doi.org/10.1186/s12302-020-00368-9>
- Kanstrup N (2016) Blyfri rifellammunition virker. *Jæger* 4/2016 [https://www.jaegerforbundet.dk/media/13975/blyfri-ammunition-virker\\_april16.pdf](https://www.jaegerforbundet.dk/media/13975/blyfri-ammunition-virker_april16.pdf). (In Danish).
- Knudsen, NV (2020) Blyfri Riffellammunition: Den store test. *Jæger* 4/2020, 118–127 (2020) <https://www.jaegerforbundet.dk/om-dj/dj-medier/nyhedsarkiv/2020/blyfri-riffellammunition-den-store-test/>. (In Danish).
- Sand M (2015) Blyfri rifellammunition virker. *Netnatur*. June 2015. (In Danish). <https://www.netnatur.dk/blyfri-riffellammunition-virker/>.

21. Hansen HP (2001) Jagt i Danmark år 2000: Analyserapport. Rapportserien nr. 100. Department of Environment, Technology and Social Studies, Roskilde University, Denmark (In Danish).
22. Christensen TK, Haugaard L, Møllerup KA, Mikkelsen PH (2020). Kronvildt—vurdering af dæmrings- og skumringsjagten betydning for afskydningen. Aarhus Universitet, DCE—Nationalt Center for Miljø og Energi. 26 p. [https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet\\_2020/N2020\\_10.pdf](https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notatet_2020/N2020_10.pdf). (In Danish).
23. Seismonaut (2019) Evaluering af formidling og efteruddannelse inden for jagt og vildtforvaltning. 36 p. <https://mst.dk/media/189149/evaluering-af-formidling-og-efteruddannelse-inden-for-jagt-og-vildtforvaltning-rapport.pdf>. (In Danish).
24. Widemo F (2021) Shooting habits and habitats – effects of education and legislation on the phasing out of lead shot. *Environ Sci Policy* 118:56–62. <https://doi.org/10.1016/j.envsci.2021.01.010>
25. Fødevarestyrelsen (2020) Vær opmærksom på bly i dyrevildt. [https://www.foedevarestyrelsen.dk/Selvbetjening/Guides/Kend\\_kemien/Sider/Saad-an-begraenser-du-dit-indtag-af-bly.aspx](https://www.foedevarestyrelsen.dk/Selvbetjening/Guides/Kend_kemien/Sider/Saad-an-begraenser-du-dit-indtag-af-bly.aspx). (In Danish).
26. Gerofke A, Ullbig E, Martin A, Müller-Graf C, Selhorst T, Gremse C, Spolders M, Schafft H, Heinemeyer G, Greiner M, Lahrssen-Wiederholt M, Hensel A (2018) Lead content in wild game shot with lead or non-lead ammunition—Does “state of the art consumer health protection” require non-lead ammunition? *PLoS ONE* 13:e0200792. <https://doi.org/10.1371/journal.pone.0200792>
27. Livsmedelsverket (2020) Jakt <https://www.livsmedelsverket.se/produktion-handel-kontroll/produktion-av-livsmedel/primarproduktion/jakt#Bly%20%20vilt%20C3%B6tt> (In Swedish).
28. Kanstrup N, Swift J, Stroud DA, Lewis M (2018) Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47:846–857. <https://doi.org/10.1007/s13280-018-1042-y>
29. Kanstrup N (2018) Lessons learned from 33 years of lead shot regulation in Denmark. *Ambio* 48(999):1008. <https://doi.org/10.1007/s13280-018-1125-9>
30. Schulz J, Wilhelm SS, Hall D, Webb E (2020) Until It's a regulation It's not my fight: complexities of a voluntary nonlead hunting ammunition program. *J Environ Manage* 277:111438. <https://doi.org/10.1016/j.jenvman.2020.111438>
31. Newth JL, Lawrence A, Cromie RL, Swift JA, Rees EC, Wood KA, Strong EA, Reeves J, McDonald RA (2019) Perspectives of ammunition users on the use of lead ammunition and its potential impacts on wildlife and humans. *People Nat* 1:347–361. <https://doi.org/10.1002/pan3.30>
32. Cromie R, Newth J, Reeves JP, O'Brien M, Beckmann K, Brown MJ (2015) The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult. In: Delahay RJ, Spray CJ eds. Proceedings of the Oxford Lead Symposium. Lead Ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, The University of Oxford, UK. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings\\_papers/OLS\\_proceedings\\_kanstrup.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings_papers/OLS_proceedings_kanstrup.pdf)
33. Kanstrup N, Balsby TJS (2019) Danish pheasant and mallard hunters comply with the lead shot ban. *Ambio* 48:1009–1014. <https://doi.org/10.1007/s13280-019-01152-7>
34. Thomas VG, Gremse C, Kanstrup N (2015) Key questions and responses regarding the transition to use of lead-free ammunition. In: Delahay RJ, Spray CJ eds. Proceedings of the Oxford Lead Symposium. Lead Ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, The University of Oxford, UK. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings\\_papers/OLS\\_proceedings\\_thomas\\_kanstrup\\_gremse.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings_papers/OLS_proceedings_thomas_kanstrup_gremse.pdf)
35. Gremse C, Rieger S (2012) Ergänzende Untersuchungen zur Tötungswirkung bleifreier Geschosse, Bundesanstalt für Landwirtschaft und Ernährung (BLE) [https://www.hnee.de/\\_obj/85DD11C1-35B5-4435-B044-4F6B7B6975F0/inline/FWWJ\\_Endbericht\\_09H5023\\_25.02.14.pdf](https://www.hnee.de/_obj/85DD11C1-35B5-4435-B044-4F6B7B6975F0/inline/FWWJ_Endbericht_09H5023_25.02.14.pdf). (In German with an English summary).
36. Thomas VG, Gremse C, Kanstrup N (2016) Non-lead rifle hunting ammunition: issues of availability and performance in Europe. *Eur J Wildl Res* 62:633–641. <https://doi.org/10.1007/s10344-016-1044-7>
37. Kanstrup N, Thomas VG (2019) Availability and prices of non-lead gunshot cartridges in the European retail market. *Ambio* 48:1039–1043. <https://doi.org/10.1007/s13280-019-01151-8>
38. DEVA (2011) Schlussbericht zum Forschungsvorhaben “Abprallverhalten von Jagdmunition”, [https://www.seeadlerforschung.de/downloads/DEVA\\_Projektbericht\\_Ablenkverhalten.pdf](https://www.seeadlerforschung.de/downloads/DEVA_Projektbericht_Ablenkverhalten.pdf) (In German with an English summary).
39. Segerson K (2013) Voluntary approaches to environmental protection and resource management. *Annual Rev Res Econ* 5:161–180. <https://doi.org/10.1146/annurev-resource-091912-151945>
40. Kanstrup N (2015) Practical and social barriers to switching from lead to non-toxic gunshot—a perspective from the EU. In: Delahay RJ, Spray CJ eds. Proceedings of the Oxford Lead Symposium. Lead Ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, The University of Oxford, UK. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings\\_papers/OLS\\_proceedings\\_kanstrup.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings_papers/OLS_proceedings_kanstrup.pdf)
41. Arnemo JM, Andersen O, Stokke S, Thomas VG, Krone O, Pain DJ, Mateo R (2016) Health and environmental risks from lead-based ammunition: science versus socio-politics. *EcoHealth* 13:618–622. <https://doi.org/10.1007/s10393-016-1177-x>

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

**Submit your manuscript to a SpringerOpen<sup>®</sup> journal and benefit from:**

- Convenient online submission
- Rigorous peer review
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at ► [springeropen.com](https://www.springeropen.com)



# PAPER 7

Kanstrup N, Thomas VG (2019). Availability and prices of non-lead gunshot cartridges in the European retail market. Ambio 48:1039-1043 doi:10.1007/s13280-019-01151-8

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

### Order Summary

Licensee:	Aarhus University
Order Date:	Mar 8, 2020
Order Number:	4784270126552
Publication:	AMBIO
Title:	Availability and prices of non-lead gunshot cartridges in the European retail market
Type of Use:	Thesis/Dissertation
Order Ref:	Availability
Order Total:	0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

## AUTHORS' CONTRIBUTIONS

Kanstrup N, Thomas VG (2019) Availability and prices of non-lead gunshot cartridges in the European retail market Ambio 48:1039-1043 doi:10.1007/s13280-019-01151-8

- Kanstrup N conceptualized the project and publication, analyzed data, drafted, edited and revised the manuscript and acted as corresponding author.
- Thomas VG undertook edition and critical commentary.

I hereby confirm this statement of the authors' contributions to the above mentioned paper.

Vernon G. Thomas, Professor Emeritus, Department of Integrative Biology, University of Guelph, Guelph, Ontario N1G 2W1

Confirmed, April 2021



Niels Kanstrup

# Availability and prices of non-lead gunshot cartridges in the European retail market

Niels Kanstrup , Vernon G. Thomas

Received: 26 September 2018 / Revised: 9 January 2019 / Accepted: 17 January 2019

**Abstract** To analyse those factors that inhibit or facilitate the shift from lead to non-lead ammunition, it is important to evaluate the extent to which hunters can purchase suitable non-lead products. Based on an Internet search, we identified 22 European and 6 North American manufacturers of non-lead shot cartridges distributed in 10 different countries. During the web search, we found non-lead shot cartridges available in retail stores with online sales of these products in 22 of 29 European countries. The most common non-lead shot type was steel shot, although bismuth, tungsten and copper were available in some countries. We conclude that non-lead shot cartridges are available to purchasers in most European countries, but in a limited variety. Availability of non-lead ammunition is not limited by production but by the demand at the national, regional, and local levels. Multiple manufacturers provide such ammunition, and their products may become available in any member state, regionally and locally, once the demand is established. The collective experience of Denmark, Canada, and the USA indicate that the demand for non-lead products will be stimulated by any intergovernmental initiatives to regulate lead ammunition for hunting and target shooting, especially when such initiatives are accomplished through well-enforced national regulation.

**Keywords** Ammunition · Availability · Demand · Gunshot · Non-lead · Steel

## INTRODUCTION

A successful phase-out of lead shotgun ammunition for all types of hunting requires that lead-free alternative types of cartridges be available to hunters. Several types of non-lead

gunshot have been developed, manufactured and made available at the retail level (Kanstrup et al. 2018; Thomas 2019). However, the extent of the availability of the different products varies, depending on the demand at national and local levels. Demand is regulation driven. Partial and poorly enforced regulations have weak impact, whereas full regulation stimulates availability. Poor availability may result in non-compliance with regulations. Also hunters inclined to use non-lead shot types may keep using lead ammunition because they cannot readily purchase non-lead products.

To analyse those factors that inhibit or facilitate the shift from lead to non-lead products, it is important to evaluate the extent to which hunters can purchase suitable non-lead shot cartridges.

In this study, we assessed “product availability” as defined by Thomas (2013) by identifying ammunition manufacturers that produce non-lead shotgun ammunition and “market availability” (Thomas 2013) by compiling a list of non-lead cartridges brands available in retail gun and ammunition stores in 29 European countries. This was combined with a comparison of prices of non-lead and traditional lead shot cartridges.

## METHOD

The method used for the evaluation was based on Internet searches, primarily using Google. We presumed that most available ammunition is marketed via the Internet. We realize that this is complicated as many local retailers will advertise the ammunition obtainable face-to-face from their outlets. Also, orders delivered remotely over the Internet to purchasers are complicated by firearms licensing, shipping, and delivery regulations that differ among countries. However, marketing of products may be Internet

based despite the actual purchase of ammunition being local and based on the single gun shop. An Internet survey is, therefore, indicative of the product availability. We spent a minimum of 30 min per country on searching and investigated at least five online ammunition shops per country. However, the results must be regarded as a minimal assessment, given the inherent limits of this methodology.

One part was an Internet search of product catalogues found online at web pages of members of AFEMS<sup>1</sup> (Association of European Manufacturers of Sporting Ammunition) and other companies. Another part of the study was a search using the words “hunting cartridges”, “steel shot”, “bismuth shot”, “tungsten shot”, “gun store”, “online”, and “web shop” translated into national languages of the countries in question. Words were used solely or in combination. We made this type of search in 29 European countries. This resulted in hits of retail-level webshops which showed a similar appearance in most countries. The number of brands (i.e. manufacturer’s name) of non-lead cartridges and variety of shot types were used to assess the market availability in the different countries.

Various search engines including Google offer facilities for direct translation of webpages’ texts (into English). Thus, it was possible to decipher website content including information on non-lead ammunition brands for retail sale in most European countries, despite the variety of languages encountered. Results were recorded in terms of cartridge brand and type (hunting, clay target, low velocity, high velocity etc.), shot type, load weight (if available) and price. Price was assessed from gauge 12/70 cartridges with a 30–32 g load and calculated on the basis of 25 cartridges, i.e. the normal quantity of cartridges in one “box”. A sample of prices for lead shot cartridges was included for comparison.

## RESULTS

We identified 22 European manufactures of non-lead shot cartridges distributed among the following 8 countries: Italy (6), UK (4), France (4), Spain (4), Sweden (1), Germany (1), Poland (1), and Czech Rep. (1). All companies had a steel shot line, some with a wide selection of gauges and loads. Bismuth shot cartridges were produced by two, copper by two, and zinc by one company (Table 1). In addition, six North American manufacturers produced non-lead cartridges. One (Kent Cartridge) had specialized in this type of non-lead cartridge and was directly affiliated with a British company (Gamebore). The 28 manufacturers, including the six North American companies, had

agencies in most European countries; hence, their products, including lead-free ammunition, were available, or could easily become available in any region or country, subject to demand.

The web search for retail ammunition stores with online sales in the 29 European countries showed that all had online services for retail sale of hunting accessories, including shotgun ammunition. We found non-lead products available in 22 countries (Table 1). The number of available cartridge brands per country varied considerably: from 16 in Denmark, 8 in Finland, 7 in the UK, 4 in Germany, and only one in 11 of the investigated countries.

We failed to identify any online retail sale of non-lead shotgun cartridges in seven countries, which had website shops listing a wide selection of lead shot shotgun cartridges: these included Croatia, Slovakia, Slovenia and Spain, all of which have bans on wetland or waterbird hunting with lead shot. This may seem anomalous, but suggests that hunters rely on non-web outlets for their purchases if wishing to comply with national regulations. In Ireland, Poland, and Romania (all countries with no regulation of lead ammunition), we did not find non-lead cartridges available online. However, in Greece where there is also no regulation, one online shop offered two types of steel shot. The most common non-lead shot type was steel shot, although bismuth, tungsten, and copper shot were available in some countries (Table 1).

There were large differences among the prices of the shot types. Table 2 shows average prices of the five types that were identified.

Tungsten shot was by far the most expensive type of non-lead shot. Steel shot cartridges are available at much lower prices, approximately the same as equivalent, high-quality lead shot cartridges, which correspond with the findings of Thomas (2015). A given product may occur at different prices in different countries, an example being ELEY VIP Bismuth (12/67) 32 g, which costs 60 Euros per 25 pcs. in Norway and 38 Euros per 25 pcs. in the UK.

One overall result is that lead-free shotgun cartridges are available in most countries from retail shops with online service, apart from countries with no regulations. However, more qualitatively, the survey showed that the product range of lead-free ammunition in countries with partial regulations of lead shot (wetlands/waterbirds) was very restricted compared to lead shot brands. Furthermore, non-lead types were not prominently displayed on most websites, often on the last page of several pages displaying lead products, and often grouped as “special loads”. It is likely that some of the investigated gun stores may offer non-lead shot if particularly requested, but due to low interest from their customers did not display it on their web shops.

<sup>1</sup> <http://www.afems.org/>.

**Table 1** Manufacture of non-lead shotgun cartridges and availability hereof in the 29 European countries that were subject to Internet search

Country	Regulation of lead shot for hunting <sup>a</sup>	Number of non-lead cartridge manufacturers identified	Number of non-lead cartridge brands identified	Non-lead shot types available
Austria	x		1	S
Belgium	x		1	S, B
Bulgaria	x		1	S
Czech Rep.	x	1	1	S
Croatia	x		0	–
Denmark	xx		16	S, B, T
Estonia	x		1	S
Finland	x		8	S, B, C
France	x	4	3	S
Germany	x	1	4	S, B
Greece	–		2	S
Hungary	x		1	S
Iceland	–		1	S
Ireland	–		0	–
Italy	x	6	1	S
Latvia	x		2	S
Lithuania	x		2	S
Luxemburg	x		2	S
Malta	x		1	S
Norway	x		2	S, B
Poland	–	1	0	–
Portugal	x		1	S, B, T
Romania	–		0	–
Slovakia	x		0	–
Slovenia	x		0	–
Spain	x	4	0	–
Sweden	x	1	1	S, B
The Netherlands	xx		4	S
UK	x	4	7	S, B, T

<sup>a</sup>No regulation, x = ban of lead shot in wetlands/waterbird hunting, xx = total ban of lead shot

S steel shot, B bismuth shot, T tungsten shot, C copper shot, – none

## DISCUSSION

The study has not evaluated to what degree traditional advertisement and retail sale of hunting ammunition from online stores differs among European countries, and therefore results from different countries may not be comparable. However, the fact that online sale of hunting accessories was offered to some degree in all 29 investigated countries indicates that the methodology is valid for

**Table 2** Average prices of shot types in retail sale identified in the Internet search in 29 European countries

Type	N <sup>a</sup>	Price Euro/25 pcs	
		Average	Range <sup>b</sup>
Steel	36	11.90	7.50–25.25
Bismuth	8	57.81	42.25–60.00
Tungsten	2	85.00	79.25–90.00
Copper	3	37.28	21.50–41.25
Lead	25	10.45	6.50–18.25

<sup>a</sup>Number of web shops, <sup>b</sup>rounded up to nearest quarter Euro

assessing the availability of non-lead products. The web searches were conducted more intensively for those countries with no lead shot regulation, i.e. Greece, Ireland, Poland, and Romania. Except for Greece, it was not possible to identify non-lead gunshot available for sale, despite all these countries listing lead shot cartridges from different manufacturers. Thus, Poland has its own manufacturer of non-lead cartridges (FAM Pionki), which exports non-lead products to other markets. Among the countries with partial bans, only the UK and Germany were shown to have many different brands, and the general picture is that countries with partial bans have a rather limited availability of non-lead products. This is in contrast to the number of companies making non-lead shot in some of those countries: e.g. Italy 6, France 4, and Spain 4. Although we identified four companies in Spain making non-lead cartridges, and despite Spain having a ban on lead shot use in its wetlands, no website indicated the availability of non-lead cartridges for sale. Due to the long-lasting and well-established ban on lead shot for both hunting and target shooting, Denmark showed the most diverse selection of non-lead ammunition with the highest variety of brands, gauges, loads, and shot sizes, based mainly on steel products.

The identification of 28 manufacturers of non-lead shot lines in Europe and North America demonstrates that the availability of non-lead ammunition is not limited by technologies or production potential. The results also show that some European makers of non-lead cartridges are actively engaged in export of their products, especially to the USA, Canada, and Denmark, where a well-established demand exists. The similar prices for lead shot and steel shot products demonstrate that production costs are not limiting availability. This emphasizes the point that availability is driven mainly by demand at national, regional, and local levels, as also concluded in other studies. For instance, the UK LAG (Lead Ammunition Group) (2015) concluded “*the variety and performance of non-lead ammunition will, if demand exists, improve to meet demand*”. Also, Thomas (2015) found that manufacturers

in Europe make and distribute cartridges according to hunters' demands, which, in turn, are driven by regulations.

The production price of a shotgun cartridge consists basically of three elements: costs of component materials, costs of construction of components, and costs of assembling the components into a cartridge (loading). This applies to lead as well as non-lead products. In terms of the shell, primer, wad, and powder, there are no significant differences between production costs. Nor is the loading process different, though some components of the machinery may be modified and adjusted to change from one type to another. Hence, the main driver for production price differences is the price of shot material combined with shot manufacture. We found the following current approximate prices for metals on world markets by Internet search: Lead: 2 Euro/kg; Iron: 0.07 Euro/kg; Bismuth: 20 Euro/kg; and Tungsten (powder): 40+ Euro/kg. Prices are dependent on market forces, purity, etc. and therefore only indicative of the raw material costs for shot types. However, the figure that bismuth is 10-fold more expensive than lead, but at the same time, that lead is 30-fold more expensive than iron, explains why bismuth shot cartridges are much more expensive than lead and steel shot cartridges. It also demonstrates that prices of bismuth (and tungsten) shot will not fall to levels comparable to lead and steel. Secondly, the prices indicate a potential for steel shot to be significantly cheaper than lead shot if the costs of making steel shot can be reduced. However, this has not yet been demonstrated in the retail sale prices of loaded cartridges in Europe and North America. We investigated further retail prices of bulk lead and steel shot being offered in stores to hand loaders of cartridges and found no appreciable difference (lead shot approx. 3 Euro/kilo<sup>2</sup>; steel shot approx. 4 Euro/kilo<sup>3</sup>). The reason why the much lower price of raw iron compared to raw lead is not reflected in more pronounced differences in shot prices is related to processing technologies,<sup>4</sup> energy consumption, production volumes, market demand, and transport. Production of lead shot is a traditional technology in many European cartridge manufactory companies, whereas the production of steel shot is based almost exclusively on Chinese manufacture. Hence, the economic and technological conditions vary

greatly. A detailed survey of this situation lies beyond the scope of this study. However, we believe that an increased demand for steel shot, driven for instance by European Union regulations as prepared by REACH<sup>5</sup> (Registration, Evaluation, Authorisation, and Restriction of Chemicals), and thus an increased production volume would gradually influence the production price, and could lower prices further in the long term. Another factor affecting the cartridge price is the cartridge gauge and the relative market demand for gauges different from the normal 12 gauge. This explains why smaller gauges, for instance 20 gauge cartridges in both lead and non-lead varieties, cost more than equivalent 12 gauge cartridges, despite the lesser content of gunpowder, shot and other components. A manufacturer will require a single production run of about one million cartridges to justify the costs of switching the manufacturing equipment settings, product testing for quality assurances, and packaging set-up (Cove, R. personal communication<sup>6</sup>). Understandably, demand has a major effect on price as well as availability of lesser-used cartridge types, both lead and non-lead.

Wholesale and retail prices of cartridges will basically depend on production prices, but will also, and to a very high degree, be influenced of volume of production, transport costs and other basic factors. In particular, the profit margins of producers, taxes, and export duties influence the prices paid by the hunter. One example of this is the UK-made product ELEY VIP Bismuth cal. 12/67 (shot size 3.2 mm, 32 g) which is listed on the webpage of a British supplier at less than two thirds of the price in Norway. This shows that the price of a given cartridge may differ significantly depending on impact of market demand and other costs in addition to production cost.

## CONCLUSION

Since concerns about dispersal of hunting lead shot in wetlands and the fatal lead poisoning of birds were raised in Europe in the 1960s, and earlier in the USA, several non-lead and approved non-toxic shot types have been developed and produced commercially. Steel shot cartridges are produced by most European manufacturers (in this study sample, all 22 companies). Steel is the by far the cheapest, most widely used, and most available alternative. However, some European manufacturers have lines of other non-lead products, including bismuth and tungsten shot cartridges. In addition, North American manufacturers distribute via

<sup>2</sup> <http://www.cabelas.com/>.

<sup>3</sup> <http://www.huntinglife.net/>.

<sup>4</sup> Lead shot is made traditionally by dropping molten lead through sieves into cold water from a great height in shot towers, or by the "bleimeister method" where molten lead is dripped from small orifices into a hot liquid, followed by rolling along an incline to remove out-of-round pellets. Steel shot is made by hammering small pieces of low-carbon iron wire into spheres of desired diameter followed by softening (annealing) the shot in furnaces. These processes are energy intensive and more time consuming than traditional lead shot making.

<sup>5</sup> <https://echa.europa.eu/da/-/echa-identifies-risks-to-terrestrial-environment-from-lead-ammunition>.

<sup>6</sup> Personal communication: R. Cove, CEO, Kent Cartridge, Markham, Canada.

their agencies a variety of non-lead ammunition types in Europe, thus expanding product availability.

The web shop surveys in this study demonstrated that non-lead shot cartridges are available to purchasers in most European countries, but in a limited variety. Stocks of non-lead ammunition held in local retail shops may be very limited in variety and quantity, specification and brand. Hence, a small-scale local purchaser may not be able to purchase what might be best suited for his/her needs.

It is well established that the availability of non-lead ammunition is first and foremost limited by the demand at the national, regional, and local level. Multiple manufacturers currently provide such ammunition and their products are available, or can easily become available in any member state, regionally and locally, once the demand is there. This is demonstrated clearly by the Danish example, and the US situation since 1991. The demand for non-lead products will be stimulated by any intergovernmental initiatives to regulate lead ammunition for hunting and target shooting, especially when such initiatives are accomplished through well-enforced national regulation.

**Acknowledgements** We thank colleagues and reviewers for helpful comments on an earlier text. Funding was provided by the personal financial resources of the authors.

## REFERENCES

- Kanstrup, N., J. Swift, D.A. Stroud, and M. Lewis. 2018. Hunting with Lead Ammunition is not Sustainable: European Perspectives. *Ambio*. <https://doi.org/10.1007/s13280-018-1042-y>.
- Lead Ammunition Group. 2015. Lead Ammunition, Wildlife and Human Health. A report prepared for the Department for Environment, Food and Rural Affairs and the Food Standards Agency in the United Kingdom.
- Thomas, V.G. 2013. Lead-Free Hunting Rifle Ammunition: Product Availability, Price, Effectiveness, and Role in Global Wildlife Conservation. *Ambio* 42: 737–745. <https://doi.org/10.1007/s13280-012-0361-7>.
- Thomas V.G. 2015. Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimizing the risks to human and environmental health*, ed. R.J. Delahay, and C.J. Spray, 85–98. Oxford: The Edward Grey Institute. [http://www.oxfordleadsymposium.info/wp-content/uploads/OLS\\_proceedings/papers/OLS\\_proceedings\\_thomas.pdf](http://www.oxfordleadsymposium.info/wp-content/uploads/OLS_proceedings/papers/OLS_proceedings_thomas.pdf).
- Thomas, V.G. 2019. Chemical compositional standards for non-lead hunting ammunition and fishing weights. In *Lead in hunting ammunition: Persistent problems and solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. <https://doi.org/10.1007/s13280-018-1124-x>.

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## AUTHOR BIOGRAPHIES

**Niels Kanstrup** (✉) is a biologist, scientist and hunter. His research program is focused on sustainability of hunting with emphasis on dispersal of ammunition components in the natural environment, particularly the impact of ammunition lead.

*Address:* Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, 8410 Rønde, Denmark.  
e-mail: nk@bios.au.dk

**Vernon G. Thomas** is a Professor Emeritus specializing in the transfer of scientific knowledge to conservation policy and law, especially in the issue of lead exposure and toxicity in wildlife and humans.

*Address:* Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, ON N1G 2W1, Canada.  
e-mail: vthomas@uoguelph.ca

# PAPER 8

Kanstrup N, Thomas VG, Krone O, Gremse C (2016). The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations Ambio 45:621-628 doi:10.1007/s13280-016-0780-y

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

### Order Summary

Licensee:	Aarhus University
Order Date:	Mar 8, 2020
Order Number:	4784321332283
Publication:	AMBIO
Title:	The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations
Type of Use:	Thesis/Dissertation
Order Ref:	Transistion rifle
Order Total:	0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customercare@copyright.com](mailto:customercare@copyright.com)  
<https://myaccount.copyright.com>



## AUTHORS' CONTRIBUTIONS

Kanstrup N, Thomas VG, Krone O, Gremse C (2016) The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations *Ambio* 45:621-628 doi:10.1007/s13280-016-0780-y

- Kanstrup N conceptualized the paper, included and analyzed data, drafted essential sections and undertook edition and critical commentary.
- Thomas VG drafted the manuscript, undertook edition and critical commentary and acted as corresponding author.
- Krone O undertook edition and critical commentary.
- Gremse C undertook edition and critical commentary.

I hereby confirm this statement of the authors' contributions to the above mentioned paper.

Vernon G. Thomas

Professor Emeritus, Department of Integrative Biology, University of Guelph,  
Guelph, Ontario N1G 2W1


Niels Kanstrup, biologist, adj. ass. prof.  
Aarhus University, Department of Bioscience - Kalø  
Grenåvej 14  
DK-8410 Rønde

## AUTHORS' CONTRIBUTIONS

Kanstrup N, Thomas VG, Krone O, Gremse C (2016) The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations *Ambio* 45:621-628 doi:10.1007/s13280-016-0780-y

- Kanstrup N conceptualized the paper, included and analyzed data, drafted essential sections and undertook edition and critical commentary.
- Thomas VG drafted the manuscript, undertook edition and critical commentary and acted as corresponding author.
- Krone O undertook edition and critical commentary.
- Gremse C undertook edition and critical commentary.

I hereby confirm this statement of the authors' contributions to the above mentioned paper.



Dr. Oliver Krone  
Dept. Wildlife Diseases  
Leibniz Institute for Zoo and Wildlife Research  
Alfred-Kowalke-Str. 17  
10315 Berlin  
Germany

Confirmed, March 2021



Niels Kanstrup

# The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations

Niels Kanstrup, Vernon G. Thomas,  
Oliver Krone, Carl Gremse

Received: 13 January 2016 / Revised: 18 March 2016 / Accepted: 21 March 2016

**Abstract** The issue of Denmark regulating use of lead-free rifle ammunition because of potential risks of lead exposure in wildlife and humans was examined from a scientific and objective policy perspective. The consequences of adopting or rejecting such regulation were identified. Denmark is obliged to examine this topic because of its national policy on lead reduction, its being a Party to the UN Bonn Convention on Migratory Species, and its role in protecting White-tailed Sea Eagles (*Haliaeetus albicilla*), a species prone to lead poisoning from lead ingestion. Lead-free bullets suited for deer hunting are available at comparable cost to lead bullets, and have been demonstrated to be as effective. National adoption of lead-free bullets would complete the Danish transition to lead-free ammunition use. It would reduce the risk of lead exposure to scavenging wildlife, and humans who might eat lead-contaminated wild game meat. Opposition from hunting organizations would be expected.

**Keywords** Denmark · Hunting · Lead-free bullets · Health · Regulation · Conservation

## INTRODUCTION

It is established that exposure to lead from ingested spent ammunition poses toxic risks to wildlife (Watson et al. 2009; Haig et al. 2014) and humans, who are at risk when eating game meat killed with lead ammunition (Knott et al. 2010; Pain et al. 2010; Knutsen et al. 2015). There is no safe threshold for blood lead in humans (CDC 2012) and, presumably, for different species of wildlife. Denmark banned the use and possession of lead shot in 1996 and sport fishing weights in 2002, making it a global leader in

hunting/angling lead reduction (Kanstrup 2015a), but use of lead rifle bullets is still allowed.

The UNEP Convention on Migratory Species (CMS) and the African Eurasian Waterbird Agreement (AEWA) have requested, repeatedly, Parties (including Denmark) to engage in lead reduction to prevent lead exposure of migrating birds along the European-African flyways (Thomas and Guitart 2005). The Conference of the Parties to the CMS (COP11, November 2014) resolved that all Parties replace lead ammunition with non-toxic substitutes within 3 years. This applies to lead gun shot and lead-based bullets used for hunting in all habitats. The CMS lacks regulatory powers, but each Party with demonstrated lead exposure in wildlife must determine how to achieve this goal at the political and regulatory levels (UNEP 2014).

Poisoning of European White-tailed Sea Eagles (*Haliaeetus albicilla*) and other scavengers occurs from the ingestion of lead bullet fragments in discarded gut piles and fatally shot-and-lost animals (Krone et al. 2009; Helander et al. 2009; Nadjafzadeh et al. 2013). White-tailed Sea Eagles are protected in Europe under the EU Birds Directive, Annex 1. Lead-free rifle ammunition<sup>1</sup> is made by major US, Scandinavian, and European companies (Thomas 2013, 2015a, b). This type of ammunition will be required, by law, throughout California in 2019 (Thomas 2015b). Germany also requires the use of lead-free rifle ammunition when hunting in state forests and on private land in 5 of 16 federal states, and is evaluating the use of this ammunition (Gremse and Rieger 2015). Lead-free rifle bullets could be used for hunting all species that are hunted with rifle in Denmark, including Red Deer (*Cervus elaphus*), Fallow Deer (*Dama dama*), and Roe Deer (*Capreolus capreolus*) (Knott et al. 2009; Kanstrup 2015a).

<sup>1</sup> Bullets that contain <1 % lead by mass.

The calibers used commonly are available to Danish hunters, and their prices are competitive with their lead-based equivalents (Thomas 2013, 2015a, b; Kanstrup 2015b).

A transition to lead-free rifle ammunition has to be justified both scientifically and politically. The scientific rationale has been identified. A symposium, convened for the International Council for Game and Wildlife Conservation (CIC) to evaluate the continued use of lead hunting ammunition and their lead-free substitutes, resolved the following:

Article 6:

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:

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).

A 2015 symposium devoted to this topic in Denmark concluded that

... the presently-available and tested non-lead bullets meet all the efficacy requirements for rifle ammunition used in traditional hunting in Denmark. (Kanstrup and Knudsen 2015).

This paper details the national and international obligations Denmark has to end use of lead rifle ammunition, the economic consequences of such action, the possible impacts on Danish hunting, and the policy issues to be resolved. Objectively, the implications of Denmark not extending the current lead shot ban to rifle ammunition are examined.

## DENMARK'S INTERNATIONAL AND NATIONAL OBLIGATIONS

Denmark is required to address the CMS Resolution (UNEP 2014) because lead rifle ammunition has been identified. Denmark's regulated ban on lead gunshot and fishing weights constitutes a strong legal and political precedent to extend the ban to lead rifle bullets, as the CMS Resolution requires. Denmark, as a Party to the Birds Directive, is further obliged to protect the recently established populations of White-tailed Sea and Golden Eagles

(*Aquila chrysaetos*) (Ehmsen et al. 2011), which are likely to be negatively affected by lead ingestion from spent ammunition, as shown for the population development of White-tailed Sea Eagles in Germany (Sulawa et al. 2010). Dispersing young and adult eagles seek new territories in Denmark from neighboring countries (Saurola et al. 2013; Bairlein et al. 2014). Additionally, Denmark is part of a major flyway for European migratory birds, including large birds of prey (Zalles and Bildstein 2000). Nearly all migratory and resident birds of prey are facultative scavengers, or hunt live wounded prey. Mateo (2009) described 17 European raptorial species which were lead-poisoned from ingested fragments of spent ammunition. Ravens (*Corvus corax*) also ingest lead particles from shot carcasses, and show high lead blood levels during the hunting season (Craighead and Bedrosian 2008). Ravens occur also throughout Denmark and scavenge the remains of hunted animals.

Larsen et al. (2014) surveyed the presence of lead compounds in the Danish environment in relation to human health. While human exposure to lead from shooting (presumably indoor shooting ranges) was mentioned, there was no analysis of lead in hunted game and its consequences for human and wildlife health, except for a stated single high value of 232 000 µgPb/Kg in boar meat (Larsen et al. 2014). The publication concludes:

Lead is classified as toxic to reproduction due to severe effects on fertility and on the brain development in the unborn and developing child. Lead is furthermore classified as toxic after repeated exposure and toxic for the aquatic environment.

## LEAD EXPOSURE IN DANISH WILDLIFE AND HUMANS EATING GAME MEAT

Tissue lead analyses have not been conducted on dead White-tailed Sea Eagles, or any other scavengers, found in Denmark. Other than the single value of lead in imported boar meat (Larsen et al. 2014), lead levels in Danish game meat are measured only sporadically. Thus, it is not possible to determine, directly, the risk posed by lead ingestion to scavenging species and humans.

Rifle hunting/stalking is growing in popularity in Denmark. Roe deer is the most common deer species and is hunted with rifle or shotgun. Red deer and fallow deer can be hunted only with rifles. Table 1 shows the numbers of hunted species in 2013. About 14 % of the harvest (approximately 33 000 animals) were killed with rifles and, potentially, lead-core bullets.

It is common practice to gralloch (i.e., remove internal organs) killed deer (especially roe deer) where the hunting

**Table 1** Annual kill (2013) of game species or groups of species, including the number of animals taken by shot gun and/or rifle. Some roe deer and smaller animals are taken with bow. \* “Other” includes trapping. Numbers of red fox killed by shot and bullets inferred from Kanstrup (2015a, b). Source Naturstyrelsen (2014)

	Shot	Bullet	Other*
Roe deer	40 000	87 400	
Other ungulates		18 200	
Hare	55 300		
Rabbit	10 400		
Red fox*	20 000	17 500	
Other mammals	9000		8000
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	9800		
Total	2 122 700	213 800	33 000

takes place. Although this practice is normally regarded by government as disposal of animal by-products, the European and Danish regulations make an explicit exemption for entire bodies or parts of wild game not collected after killing, in accordance with good hunting practice.<sup>2</sup> It is assumed that few hunters either remove the gralloch from the hunting area or bury it. However, at some (mainly state-owned) districts, disposal of grallochs of red and fallow deer is organized at central slaughter facilities close to the hunting area by official companies specialized in such disposal. No statistics exist for this practice, but it represents a minor part of the red and fallow deer harvest, and therefore only a small proportion of the total bag of all deer species. Hence, the number of gut piles left in nature is close to the number of killed deer. To this should be added the number of unretrieved, fatally wounded animals that remain available to scavengers. It is estimated that over 1200 wounded deer were never retrieved in 2014/2015 (Flinterup, pers comm.<sup>3</sup>).

<sup>2</sup> Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October, 2009.

<sup>3</sup> Flinterup, M. Consultant in the Danish Hunters' Association, Molsvej 34, DK.8410 Rønne. October, 2015.

Although no data on the prevalence of lead exposure in Danish White-tailed Sea Eagles exist, given the occurrence of lead exposure from spent lead ammunition in this species in both Sweden and Germany, the estimated number of Danish gut piles available each year (over 34 000), and the close proximity of Denmark to these two countries, the potential for exposure exists, both for eagles and other scavengers.

Guidelines for New Nordic Diet recommends that Danes reduce their consumption of domestic meat by 35 %, and take 4 % of their meat as venison, since venison is presumed to be healthier, more palatable, and more environmentally sustainable. Presently, Danes consume 0.8 % of their meat as venison. Most hunters keep the main portion for themselves (Saxe 2015). Although Denmark does not monitor regularly lead levels in marketed game meat, there is no reason to believe that they differ from game meat in other countries. Data from Norway, Poland, Sweden, the UK, and Canada reveal that meat from hunter-killed deer species and Wild Boar (*Sus scrofa*) may contain metallic lead levels far exceeding the European Commission 0.1 mg Pb/kg criterion for domestically reared meats, especially in minced meat (Knott et al. 2010; Fachehoun et al. 2015; Knutsen et al. 2015). The Danish roe and red deer are the same species as in other European countries. The manner of hunting them is the same, using the same types of lead-core rifle ammunition. Shot animals are handled in the field and prepared for human consumption in the same manner across these countries. While the European Commission has set the maximum level of lead in domesticated meats at 0.1 mg Pb/Kg under Commission Regulation 1881/2006 (EC 2006), no comparable level has been set for wild game meat. The European Food Safety Authority did not set up a guidance level because there was no clear threshold below which the Panel was confident that adverse effects would not occur (EFSA CONTAM 2010). National food safety agencies in the UK, Germany, Norway, Spain, and Sweden provide advice on the consumption of wild game meat that might contain lead (Knutsen et al. 2015), but not Denmark.

## DEVELOPMENT, AVAILABILITY OF LEAD-FREE BULLETS, AND ECONOMIC ISSUES

Non-lead bullets are made primarily of copper or copper alloys. American and European companies have made proprietary types of bullets in all the calibers, bullet shapes, and weights typical for hunting anywhere in the world (Thomas 2013, 2015a). California is the only US jurisdiction that currently requires use of non-lead bullets for hunting in one region of the state. However, in 2019, hunting in the entire state will require non-lead ammunition (Thomas 2015a). Several German states have required use

of non-lead rifle ammunition when hunting in state forests, and are examining the implementation of this transition (Gremse and Rieger 2015). The term “availability” includes whether the product is made, whether it is sold in Denmark, especially at a local level, and whether it is sold at a comparable price with lead-based ammunition. Underlying these considerations is the issue of regulation that would create the assured market for non-lead ammunition among all Danish hunters, as it has done for non-lead shotgun ammunition.

Denmark currently imports all hunting rifle ammunition and cartridge reloading components. Six major European companies and at least six US companies make non-lead rifle ammunition in all of the commonly used calibers for hunting deer in Denmark (Thomas 2013, 2015a). These same US and European companies already have a market presence in Denmark. Ammunition cannot be sent by Danish postal service, precluding online purchase. Hunters normally purchase their products from local gun stores.

There was no major retail price difference between lead-based and equivalent non-lead rifle ammunition in the US, based on listed online prices for a major retailing company (Thomas 2013). A well-established market for lead-free bullets exists in this country, especially in regions of California, where use of lead-free rifle ammunition is mandatory (Thomas 2015a, b). Where differences existed, they were not of such a magnitude as to thwart participation in hunting. Kanstrup (2015b) concluded that non-lead rifle ammunition is largely available in Danish hunting stores at prices comparable to equivalent lead products. Thus, there is no economic barrier to Danish hunters making the transition to lead-free bullet use, especially in view of the relatively low numbers fired each year, and the other costs of participating in hunting in Denmark.

Kanstrup et al. (2016) compared the efficacy of lead-core and lead-free, copper, bullets to hunt Danish red and roe deer under real field situations over two seasons. The lead-free bullets performed as effectively as traditional lead-core bullets when used by sport hunters in producing rapid death of both deer species. These conclusions are supported by the results of field research on the lethality of lead-free bullets for hunting German Wild Boar, Red Deer, and Roe Deer (Trinogga et al. 2013).

## TOXICITY AND SAFETY OF LEAD-FREE SUBSTITUTES

Anecdotal reports of potential toxicity of ingested lead-free bullet fragments to humans and wild scavengers have been made, ostensibly to thwart adoption of lead-free bullets (Thomas et al. 2015). Scientific studies indicate that the copper from lead-free bullets mobilized under simulated

storage and human digestion conditions did not pose health risks to humans (Irschik et al. 2013; Paulsen et al. 2015). Paulsen et al. (2015) did advise that levels of aluminum, nickel, and lead be kept as low as possible during bullets’ manufacture. Franson et al. (2012) experimentally dosed falcons (*Falco sparverius*) with pure copper pellets and observed no deleterious effects on the birds’ health. No national or international regulation exists for the composition of non-lead rifle ammunition (Thomas 2016). Only California regulations stipulate that non-lead bullets must contain less than 1 % lead by mass. According to this criterion, all of the non-lead bullets tested by Paulsen et al. (2015) pass this test, except for RWS Bionic Yellow with 1.9 % lead content.

Safety concerns about ricochet of lead-free bullets have been raised (mainly in Germany), as when bullets deflect from oblique hard surfaces. All rifle bullets, regardless of composition, profile, and size, are prone to ricochet. This applies especially to high-velocity, copper-jacketed, pointed-profile bullets (e.g., Spitzers) and, to a lesser extent, to lower-velocity, round-nosed and exposed lead-core bullets. In the USA, the issue of ricochet has not arisen as an objection to the use of lead-free bullets. There, preventing ricochet is seen as the responsibility of individual hunters to practice disciplined shooting, especially in rocky or forested terrains (Thomas et al. 2015).

## POTENTIAL IMPACTS ON DANISH HUNTING

The phase-out of lead gun shot for hunting in Denmark during 1985–1996 did not impact the popularity of traditional hunting (Kanstrup 2015a). Similarly, a phase-out of lead rifle bullets is not expected to have a significant influence on future participation in hunting. The deer species hunted in Denmark are all hunted with rifle calibers (Kanstrup et al. 2016) that, potentially, would require non-lead ammunition available at prices equivalent to prices for lead ammunition, and with a similar efficacy. Fox (*Vulpes vulpes*) and other small game are hunted with smaller calibers (e.g., .17 HMR), for which non-lead alternatives are still not available. Rooks are regulated under the EU Bird Directive Article 9, and are usually hunted with caliber .22 LR, for which there are still no highly effective, non-lead alternatives. There are no physical obstructions to the development of non-lead ammunition for these calibers, and a wider market demand would stimulate their development; however, a wider time frame must be given to their substitution.

## POTENTIAL REGULATORY AND ENFORCEMENT FRAMEWORK

Gunshot and fishing sinkers are banned under Danish law related to chemical products, which also includes

products with a potential lead content, e.g., paint, solders, and roof coverings. Fishing sinkers are regulated under the ban on import and sale of lead products. Sale, possession, and use of gunshot were banned in 1996 under the Hunting Act regulations.<sup>4</sup> The legal prohibition on the importation, sale, possession, and use of lead ammunition provides the current basis of hunters' compliance with the mandatory use of lead-free shotgun ammunition. The same legal framework could provide the same basis for banning lead hunting bullets. Enforcement of hunting regulations is the responsibility of the police, although other authorities perform regular inspections, including confiscation and technical investigation of "suspicious" ammunition. Although the lead shot ban is not completely respected (Kanstrup 2012) (e.g., hunters who illegally import lead shot cartridges), there is a consensus that the regulation is generally enforced and fulfilled. In theory, the Danish government could enforce regulation of lead bullets under the same legislation.

#### PHASE-IN TIMETABLES AND EXTENSION/AWARENESS

Thomas (2015a) identified eight European and European-US companies that make lead-free rifle bullets in 27 different calibers, all available to Danish hunters. The results of the field testing of copper bullets for hunting roe and red deer indicate that bullets of caliber >6 mm could be authorized for immediate use throughout Denmark (Kanstrup et al. 2016). Copper bullets of caliber <6 mm may not stabilize as well when fired from the same rifle barrel. This is a function of the twist rate of the barrel's rifling (Caudell et al. 2012). A transition to the regulated use of these smaller caliber bullets should take longer to allow hunters to change gun barrels to a more appropriate twist rate, and/or to await the development of denser lead-free bullets. Any transition to lead-free bullet use must be based on product development, which, in turn, is based on assurances that the products will have a strong market demand. The role of government is to provide the assured market demand by passing the appropriate legislation (Thomas 2015b). It is also incumbent on government to increase public awareness of the need for the transition, the nature of lead-free bullets, and how to use them. This could involve cooperative extension initiatives with Danish hunting organizations.

<sup>4</sup> Demand nr. 444 of 07/052014 on arms and ammunition allowed for hunting.

#### CONSEQUENCES OF DENMARK REJECTING THE TRANSITION

Denmark would have to defend not adopting the 2014 Resolution of the CMS, which would be difficult given the existing national ban on lead gunshot and sinker use. Such a decision would be made with full awareness of the numbers of animals shot by hunters, the potential for exposure of wildlife from discarded gut piles, and the potential exposure of hunters and other consumers from lead-contaminated meat. The Danish government would have to condone, publicly, the risk of future lead exposure to both humans and wildlife. This should be seen in the context of rising deer populations and a general recommendation to Danes to eat more game meat (6-fold increase according to New Nordic Diet) (Saxe 2015). Denmark would then have lost its leading international role in removing this form of lead exposure from the environment. This could be interpreted as an endorsement of the continued use of lead in hunting rifle ammunition. While that decision might be favored by many hunters, the public image of hunters as conservationists would be diminished. It is possible that individuals and conservation organizations favoring a total ban on lead ammunition might petition the government directly and via the media to regulate completely all forms of lead ammunition. In such a political move, the relative number of active hunters in Denmark (Kanstrup 2015a) versus the number of petitioners becomes an important issue.

Although the main driver of Danish hunting is recreation, the food product of hunting is often used as a major argument to defend hunting rights. Offsetting public concerns about the welfare and ethics of intensively reared farmed animals is the belief that animals living in the wild, and hunted humanely, represent a more sustainable source of food. This trend is increasingly used by hunters and their organizations to reinforce their political platform to sustain hunting. In this context, any indication of a health hazard connected to the consumption of game meat would be detrimental. Danish consumers are very aware of the health risks related to lead, and could reject consumption of game meat if there were a wider public awareness of the present connection between hunting with lead ammunition and a potential risk.

#### CONSEQUENCES OF DENMARK FAVORING THE TRANSITION

Denmark would be seen to have discharged in full its responsibility and obligation to the CMS 2014 Resolution (UNEP 2014). However, Danish hunters and their

representative organizations would likely oppose any government proposal. Their argument would be reinforced by the current policy of the Association of European Manufacturers of Sporting Ammunition (AFEMS) on the sustainable use of lead in hunting ammunition, i.e., that ingested metallic lead does not pose threats to human or wildlife health (AFEMS/WFSA 2015). The Danish government would have to consider the political consequences of acting contrary to the interests of this constituency, especially in the face of only indirect, or inferred, Danish evidence of health risks posed by lead bullet use. However, the government could use the example of Germany's requiring the use of lead-free bullets (Gremse and Rieger 2015) as their rationale. Moreover, the creation of a regional lead-free ammunition zone in Europe could act as a policy precedent for other neighboring countries to pass similar regulations.

A decision to ban the use of lead bullets would stimulate further production, marketing, and sales of lead-free products to satisfy an increased demand from hunters. Such a ban would also stimulate development of ballistically improved lead-free bullets in calibers < 6 mm, including rim-fired cartridges in .22 caliber. For caliber 6 mm and larger, it is generally accepted that the modern, well-maintained, rifles can be used to fire accurately non-lead as well as lead bullets. However, for those small caliber rifles that may not fire copper bullets as accurately, the rifle should be either substituted, or the barrel be changed to one having the appropriate rifling (Caudell et al. 2012). The purchase price of a new rifle depends on many factors, but a Danish standard model retails between 1000 and 1500 Euros. Changing the barrel would cost approximately 500 Euros.

A key factor determining support for a ban would be the timing and extent of the phase-in period, which should reflect the availability of substitute ammunition and the creation and application of education-awareness programs, ideally in close collaboration with hunter organizations. Consistent with this approach, the government would have to consider how to achieve regulation and enforcement of a ban on lead bullet use, and how this would relate to training (as opposed to hunting) and rifle shooting competitions.

Denmark could issue immediately a public health advisory about health risks from eating game meat shot with lead ammunition, especially for pregnant women and children. In the longer term, Denmark, as a member of the European Union, could present the need for change in regulations on allowable levels of lead in marketed game meat by proposing amendment of Commission Regulation 1881/2006 (EC 2006) to include provision for all hunter-killed wild game and processed meats.

## DISCUSSION

Continued use of lead bullets by Danish hunters must be examined in an international context. Only one jurisdiction, California, has regulated an end to their use, but only from 2019. The CIC, while aware of the problems of lead exposure from lead ammunition, has yet to act on the advice received in 2010, despite the availability of non-lead substitutes. While individual arms companies have developed the lead-free products, organizations representing shooting refuse to encourage their use (AFEMS/WFSA 2015). Most government public health agencies and wildlife divisions appear not to be concerned about health risks, despite the evidence (Cromie et al. 2015). Thus, it is understandable that Denmark has not yet initiated the transition to lead-free rifle ammunition.

Although the Danish government has not collected extensive data on lead levels in wild game meat and humans who frequently consume shot game (Larsen et al. 2014), there is evidence from neighboring countries hunting the same game animals in the same manner that risks to human health exist (Knott et al. 2010; Knutsen et al. 2015). The same consideration applies to scavenging wildlife that ingests lead bullet fragments (Helander et al. 2009; Krone et al. 2009; Nadjafzadeh et al. 2013; Pain et al. 2015). Thus, there is already evidence to support a governmental regulation of lead bullets, although skeptics could argue that an extensive data collection should already exist to support such regulation. The Danish government's experience with the banning of lead gunshot could act as a powerful precedent in this case.

Substitutes for lead-core rifle bullets in all commonly used calibers used by Danish hunters already exist (Thomas 2015a) and there is no extra economic cost to their use (Kanstrup 2015b). Their efficacy in killing common deer species is similar to that of equivalent lead-core bullets when used by Danish hunters. Thus, there appears little barrier to their adoption for hunting, except for, possibly, the need to change rifle barrels, and the political implications of change.

Exposure of Danish consumers to lead from game meat arises from animals killed in Denmark and those imported into the country. Danish game meat killed with lead bullets is also exported within the EU. Regulating an end to this potential health risk requires not only political action within Denmark, but action to define allowable lead levels in game marketed among EU and non-EU nations. In this regard, Denmark's role in amending EC Regulation 1881/2006 would show great international leadership.

**Acknowledgments** We thank 15 Juni Fonden (Denmark) for funding aspects of the research on the transitioning to lead-free ammunition, and Susanne Auls (IZW) for her excellent and continuous help during analyses of lead-intoxicated White-tailed Sea Eagles.

## REFERENCES

- AFEMS/WFSA. 2015. Symposium “the sustainable use of lead ammunition in hunting and sports shooting: Facts and emotions” Association of European Manufacturers of Sporting Ammunition Press Release. [http://www.leadssymposium.eu/en/the\\_symposium/press\\_release.aspx](http://www.leadssymposium.eu/en/the_symposium/press_release.aspx). Accessed 4 Jan 2016.
- Bairlein, F., J. Dierschke, V. Dierschke, V. Salewski, O. Geiter, K. Hüppop, U. Köppen, and W. Fiedler. 2014. *Atlas des Vogelzugs. Ringfunde deutscher Brut- und Gastvögel*. Wiebelsheim: Aula Verlag GmbH.
- Caudell, J.N., S.R. Stopak, and P.C. Wolf. 2012. Lead-free, high-powered rifle bullets and their applicability to wildlife management. *Human-Wildlife Interactions* 6: 105–111.
- CDC (Centres for Disease Control and Prevention). 2012. *Low level lead exposure harms children: A renewed call for primary prevention*. Report of the Advisory Committee on Childhood Lead Poisoning Prevention of the Centres for Disease Control and Prevention. Atlanta, GA: Centres for Disease Control and Prevention.
- Craighead, D., and B. Bedrosian. 2008. Blood lead levels of common ravens with access to big-game offal. *Journal of Wildlife Management* 72: 240–245.
- Cromie, R., J. Newth, J. Reeves, M. O'Brien, K. Beckman, and M. Brown. 2015. The sociological and political aspects of reducing lead poisoning from ammunition in the UK: Why the transition to non-toxic ammunition is so difficult. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay, and C.J. Spray, 104–124. Oxford: The Edward Grey Institute.
- EC. 2006. European Commission Regulation EC 1881/2006 *Setting maximum levels for certain contaminants in foodstuffs*. Official Journal of the European Union EC 1881/2006 (20.12.2006), L364/365–L364/324. <http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1442063437890&uri=CELEX:32006R1881>. Accessed Dec 2015.
- EFSA Panel on Contaminants in the Food Chain (CONTAM). 2010. Scientific opinion on lead in food. *EFSA Journal* 8:1570. doi:10.2903/j.efsa.2010.1570. [www.efsa.europa.eu](http://www.efsa.europa.eu).
- Ehmsen, E., L. Pedersen, H. Meltøfte, T. Clausen, and T. Nyegaard. 2011. The occurrence and reestablishment of White-tailed Eagle and Golden Eagle as breeding birds in Denmark. *Dansk Ornithologisk Forenings Tidsskrift* 105: 139–150.
- Fachehoun, R.C., B. Lévesque, P. Dumas, A. St-Louis, M. Dubé, and P. Ayotte. 2015. Lead exposure through consumption of big game meat in Quebec, Canada: Risk assessment and perception. *Food Additives and Contaminants: Part A* 32: 1501–1511. doi:10.1080/19440049.2015.1071921.
- Franson, J.C., L.L. Lahner, C.U. Meteyer, and B.A. Rattner. 2012. Copper pellets simulating oral exposure to copper ammunition: Absence of toxicity in American kestrels (*Falco sparverius*). *Archives of Environmental Contamination* 62: 145–153. doi:10.1007/s00244-011-9671-1.
- Gremse, C., and S. Rieger. 2015. Lead from hunting ammunition in wild game meat: Research initiatives and current legislation in Germany and the EU. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay, and C.J. Spray, 51–57. Oxford: The Edward Grey Institute.
- Haig, S.M., J. D'Elia, C. Smith-Eagles, J.M. Fair, J. Gervais, G. Herring, J.W. Rivers, and J.H. Schultz. 2014. The persistent problem of lead poisoning in birds from ammunition and fishing tackle. *Condor* 116: 408–428. doi:10.1650/CONDOR.14-36.1.
- Helander, B., J. Axelsson, H. Borg, K. Holm, and A. Bignert. 2009. Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden. *Science of the Total Environment* 407: 5555–5563. doi:10.1016/j.scitotenv.2009.07.027.
- Irschik, I., F. Bauer, M. Sager, and P. Paulsen. 2013. Copper residues in meat from wild artiodactyls hunted with two types of rifle bullets manufactured from copper. *European Journal of Wildlife Research* 59: 129–136. doi:10.1017/s10344-012-0656-9.
- Kanstrup, N. (ed.). 2010. *Sustainable hunting ammunition. Workshop Report, CIC Workshop, Aarhus, Denmark, November 5–7, 2009*. Budakeszi: The International Council for Game and Wildlife Conservation.
- Kanstrup, N. 2012. *Lead in game birds in Denmark: Levels and sources*. Article 2012-02-1. Rønde: Danish Academy of Hunting.
- Kanstrup, N. 2015a. Practical and social barriers to switching from lead to non-toxic gunshot—A perspective from the EU. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay, and C.J. Spray, 98–103. Oxford: The Edward Grey Institute.
- Kanstrup, N. 2015b. *Non-lead rifle ammunition—Availability in Danish gun stores*. 2015. Report 1508-2. Danish Academy of Hunting, Skrejrupsvej 31, DK-8410, Rønde.
- Kanstrup, N., and N.V. Knudsen. (eds.). 2015. *Efficacy and other aspects of transition from lead to non-lead rifle ammunition, Vingstedcentret, Denmark, April 22, 2015*. Rønde: Dansk Jagtakademi.
- Kanstrup, N., T.J.S. Balsby, and V.G. Thomas. 2016. Efficacy of non-lead rifle ammunition for hunting in Denmark. *European Journal of Wildlife Research*. (in press).
- Knott, J., J. Gilbert, R.E. Green, and D.G. Hoccom. 2009. Comparison of the lethality of lead and copper bullets in deer control operations to reduce incidental lead poisoning: Field trials in England and Scotland. *Conservation Evidence* 6: 71–78.
- Knott, J., J. Gilbert, D.G. Hoccom, and R.E. Green. 2010. Implications for wildlife and humans of dietary exposure to lead from fragments of lead rifle bullets in deer shot in the UK. *Science of the Total Environment* 409: 95–99. doi:10.1016/j.scitotenv.2010.08.053.
- Knutsen, H.K., A.L. Brantsæter, J. Alexander, and H.M. Meltzer. 2015. Associations between consumption of large game animals and blood lead levels in humans in Europe: the Norwegian experience. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay, and C.J. Spray, 44–50. Oxford: The Edward Grey Institute.
- Krone, O., N. Kenntner, A. Trinogga, N. Nadjafzadeh, F. Scholz, J. Sulawa, K. Totschek, P. Schuck-Wersig, and R. Zieschank. 2009. Lead poisoning in white-tailed sea eagles: Causes and approaches to solutions in Germany. In *Ingestion of lead from spent ammunition: Implications for wildlife and humans*, ed. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 289–301. Boise, ID: The Peregrine Fund. doi:10.4080/ilsa.2009.0207.
- Larsen, P.B., F.L. Fotel, T. Slothuus, O. Hjelmar, H.B. Boyd, L.-L. Højlund, and J. Tørsløv. 2014. *Survey of lead and lead compounds. Environmental Project No. 1539, 2014*. Copenhagen: Danish Environmental Protection Agency.
- Mateo, R. 2009. Lead poisoning in wild birds in Europe and the regulations adopted by different countries. In *Ingestion of Lead from spent ammunition: Implications for wildlife and humans*, ed. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 71–98. Boise, ID, USA: The Peregrine Fund. doi:10.4080/ilsa.2009.0107.
- Nadjafzadeh, M., H. Hofer, and O. Krone. 2013. The link between feeding ecology and lead poisoning in White-Tailed Eagles.

- Journal of Wildlife Management* 77: 48–57. doi:[10.1002/jwmg.440](https://doi.org/10.1002/jwmg.440).
- Naturstyrelsen. 2014. *Vildtinformation 2014*. Ministry of the Environment, National Nature Agency. [http://naturstyrelsen.dk/media/133538/vildtinformation\\_2014.pdf](http://naturstyrelsen.dk/media/133538/vildtinformation_2014.pdf).
- Pain, D.J., R.L. Cromie, J. Newth, M.J. Brown, E. Crutcher, P. Hardman, L. Hurst, R. Mateo, A.A. Meharg, A.C. Moran, A. Raab, M.A. Taggart, and R.E. Green. 2010. Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. *PLoS One* 5: e10315. doi:[10.1371/journal.pone.001031](https://doi.org/10.1371/journal.pone.001031).
- Pain, D.J., R. Cromie, and R.E. Green. 2015. Poisoning of birds and other wildlife from ammunition-derived lead in the UK. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay, and C.J. Spray, 58–84. Oxford: The Edward Grey Institute.
- Paulsen, P., F. Bauer, M. Sager, and I. Schumann-Irschik. 2015. Model studies for the release of metals from embedded rifle bullet fragments during simulated meat storage and food ingestion. *European Journal of Wildlife Research* 61: 629–633. doi:[10.1007/s10344-015-0926-4](https://doi.org/10.1007/s10344-015-0926-4).
- Saurola, P., J. Valkama, and W. Velmala. 2013. *Suomen regastusatlas 1—The Finnish bird ringing atlas*, vol. 1. Finland: Luomus.
- Saxe, H. 2015. *Is Danish venison production environmentally sustainable?* 2015 Report. Technical University of Denmark, DTU Management Engineering Division for Quantitative Sustainability Assessment (QSA).
- Sulawa, J., A. Robert, U. Köppen, P. Hauff, and O. Krone. 2010. Recovery dynamics and viability of the white-tailed eagle (*Haliaeetus albicilla*) in Germany. *Biodiversity and Conservation* 19: 97–112.
- Thomas, V.G. 2013. Lead-free hunting rifle ammunition: Product availability, price, effectiveness, and role in global wildlife conservation. *Ambio* 42: 737–745. doi:[10.1007/s13280-012-0361-7](https://doi.org/10.1007/s13280-012-0361-7).
- Thomas, V.G. 2015a. Lead-free rifle bullets: Product availability, and issues concerning use in USA. In *Efficacy and other aspects of transition from lead to non-lead rifle ammunition*, ed. N. Kanstrup, and N.V. Knudsen. Ronde: Dansk Jagtakademi.
- Thomas, V.G. 2015b. Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay, and C.J. Spray, 85–97. Oxford: The Edward Grey Institute.
- Thomas, V.G. 2016. Elemental tungsten, tungsten-nickel alloys and shotgun ammunition: Resolving issues of their relative toxicity. *European Journal of Wildlife Research* 62: 1–9. doi:[10.1007/s10344-015-0979-4](https://doi.org/10.1007/s10344-015-0979-4).
- Thomas, V.G., and R. Guitart. 2005. Role of international conventions in promoting avian conservation through reduced lead toxicosis: Progression towards a non-toxic agenda. *Bird Conservation International* 15: 147–160. doi:[10.1017/S0959270905000110](https://doi.org/10.1017/S0959270905000110).
- Thomas, V.G., N. Kanstrup, and C. Gremse. 2015. Key questions and responses regarding the transition to use of lead-free ammunition. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay, and C.J. Spray, 125–135. Oxford: The Edward Grey Institute.
- Trinogga, A., G. Fritsch, H. Hofer, and O. Krone. 2013. Are lead-free hunting rifle bullets as effective at killing wildlife as conventional lead bullets? A comparison based on wound size and morphology. *Science of the Total Environment* 443: 226–232. doi:[10.1016/j.scitotenv.2012.10.084](https://doi.org/10.1016/j.scitotenv.2012.10.084).
- UNEP. 2014. *Review and guidelines to prevent the risk of poisoning of migratory birds*. UNEP/CMS/COP11/Doc.23.1.2. Bonn: United Nations Environment Programme.
- Watson, R.T., M. Fuller, M. Pokras, and W.G. Hunt (eds.). 2009. *Ingestion of Lead from spent ammunition: Implications for wildlife and humans*. Boise, ID: The Peregrine Fund.
- Zalles, J.I., and K.L. Bildstein. 2000. *Raptor watch. A global directory of raptor migration sites*. Cambridge and Kempton: Birdlife International and Hawk Mountain Sanctuary.

## AUTHOR BIOGRAPHIES

**Niels Kanstrup** is a biologist, hunter, and Director of the Danish Academy of Hunting. He is a specialist in wildlife management with a long national and international experience in the substitution of lead ammunition with non-lead ammunition.  
Address: Danish Academy of Hunting, Skrejrupsvej 31, 8410 Rønne, Denmark.  
e-mail: [nk@danskjagtakademi.dk](mailto:nk@danskjagtakademi.dk)

**Vernon G. Thomas** (✉) is a Professor Emeritus specializing in the transfer of scientific knowledge to conservation policy and law, as in lead exposure from ammunition and its toxicity to wildlife and humans.  
Address: Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, ON N1G 2W1, Canada.  
e-mail: [vthomas@uoguelph.ca](mailto:vthomas@uoguelph.ca)

**Oliver Krone** is a veterinarian and senior scientist focusing on conservation medicine, especially that of birds of prey, other top predators, and their resilience in the Anthropocene. He conducts a national project on lead accumulation in sea eagles and involves stakeholders to resolve the problem.  
Address: Department of Wildlife Diseases, Leibniz Institute for Zoo and Wildlife Research, Alfred-Kowalke-Strasse 17, 10315 Berlin, Germany.  
e-mail: [krone@izw-berlin.de](mailto:krone@izw-berlin.de)

**Carl Gremse** is a forestry scientist and focuses on terminal ballistics.  
Address: Wildlife Department, Eberswalde-University, Schicklerstrasse 5, 16225 Eberswalde, Germany.  
e-mail: [carl.gremse@hnee.de](mailto:carl.gremse@hnee.de)

COMMENT

## Response to “Consumption of wild-harvested meat from New Zealand feral animals provides a unique opportunity to study the health effects of lead exposure in hunters” by Buenz et al.

Niels Kanstrup, Vernon G. Thomas,  
Oliver Krone, Carl Gremse

Published online: 25 June 2016

Comment to: Buenz, E., G. Parry, and M.M. Peacey. 2016. Consumption of wild-harvested meat from New Zealand feral animals provides a unique opportunity to study the health effects of lead exposure in hunters. *Ambio*. doi:[10.1007/s13280-016-0798-1](https://doi.org/10.1007/s13280-016-0798-1).

While acknowledging endorsement of our paper from Buenz et al. (2016), we believe that further study of relations between elevated human blood lead levels and lead in game meat is not required to validate the transition to non-lead bullets. The essence of our article (Kanstrup et al. 2016) was that Denmark could extend its existing bans on possession and use of lead gunshot and fishing weights to lead-core rifle ammunition, and thus complete the transition. Denmark faces several binding legal obligations to do so. We presented evidence for defined risks from bullet-derived lead: human health concerns from eating game meat, and the health of scavenging wildlife. Because Denmark has not monitored these areas, our evidence was indirect.

Sport hunting is international, as are the types of lead-core ammunition used, and behaviours of such bullets in animals. Thus, international research can support progressive changes in government policy on environmental lead reduction, especially given the same sources and routes of exposure.

Levels of lead in blood and game meat were correlated for US and Norwegian hunters (Iqbal et al. 2009; Meltzer et al. 2013; Knutsen et al. 2015), and confirmed by isotope analyses (Tsuji et al. 2008). High levels of bullet-derived lead exist in wild game meat (Dobrowolska and Melosik 2008; Morales et al. 2011; Fachehoun et al. 2015) that often exceed the European Commission threshold of 0.2 mg Pb/Kg.

Our paper emphasized the risks of lead exposure to wild scavengers from ingested lead fragments in shot animals, an aspect not addressed by Buenz et al. (2016). The scientific evidence for this relationship is compelling, especially for avian scavengers of the Baltic-European region (Helander et al. 2009; Krone et al. 2009; Nadjafzadeh et al. 2013).

Given the consistent conclusions from the above-cited research, further monitoring is not likely to alter our understanding of the risks to human and avian health. However, the study proposed by Buenz et al. (2016) could facilitate awareness at the local level and stimulate a regulated transition to non-lead hunting ammunition in New Zealand.

### REFERENCES

- Buenz, E., G. Parry, and M.M. Peacey. 2016. Consumption of wild-harvested meat from New Zealand feral animals provides a unique opportunity to study the health effects of lead exposure in hunters. *Ambio*. doi:[10.1007/s13280-016-0798-1](https://doi.org/10.1007/s13280-016-0798-1).
- Dobrowolska, A., and M. Melosik. 2008. Bullet-derived lead in tissues of the wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*). *European Journal of Wildlife Research* 54: 231–235. doi:[10.1007/s10344-007-0134-y](https://doi.org/10.1007/s10344-007-0134-y).
- Fachehoun, R.C., B. Lévesque, P. Dumas, A. St-Louis, M. Dubé, and P. Ayotte. 2015. Lead exposure through consumption of big game meat in Quebec, Canada: Risk assessment and perception. *Food Additives and Contaminants: Part A* 32: 1501–1511. doi:[10.1080/19440049.2015.1071921](https://doi.org/10.1080/19440049.2015.1071921).
- Helander, B., J. Axelsson, H. Borg, K. Holm, and A. Bignert. 2009. Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden. *Science of the Total Environment* 407: 5555–5563. doi:[10.1016/j.scitotenv.2009.07.027](https://doi.org/10.1016/j.scitotenv.2009.07.027).

- Iqbal, S., W. Blumenthal, C. Kennedy, F.Y. Yip, S. Pickard, W.D. Flanders, K. Loring, K. Kruger, et al. 2009. Hunting with lead: association between blood lead levels and wild game consumption. *Environmental Research* 109: 952–959. doi:[10.1016/j.envres.2009.08.007](https://doi.org/10.1016/j.envres.2009.08.007).
- Kanstrup, N., V.G. Thomas, O. Krone, and C. Gremse. 2016. The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations. *Ambio*. doi:[10.1007/s13280-016-0780-y](https://doi.org/10.1007/s13280-016-0780-y).
- Knutsen, H.K., A.L. Brantsæter, J. Alexander, and H.M. Meltzer. 2015. Associations between consumption of large game animals and blood lead levels in humans in Europe: the Norwegian experience. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay and C.J. Spray, 44–50. Oxford, UK: The Edward Grey Institute.
- Krone, O., N. Kennntner, A. Trinogga, N. Nadjafzadeh, F. Scholz, J. Sulawa, K. Totschek, P. Schuck-Wersig, et al. 2009. Lead poisoning in white-tailed sea eagles: Causes and approaches to solutions in Germany. In *Ingestion of lead from spent ammunition: Implications for wildlife and humans*, ed. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 289–301, Boise, ID: The Peregrine Fund. doi:[10.4080/ilsa.2009.0207](https://doi.org/10.4080/ilsa.2009.0207).
- Meltzer, H.M., H. Dahl, A.L. Brantsæter, B.E. Birgisdottir, H.K. Knutsen, A. Bernhoft, B. Oftedal, U.S. Lande, et al. 2013. Consumption of lead-shot cervid meat and blood lead concentrations in a group of adult Norwegians. *Environmental Research* 127: 29–39. doi:[10.1016/j.envres.2013.08.007](https://doi.org/10.1016/j.envres.2013.08.007).
- Morales, J.S.S., R.M. Rojas, F. Pérez-Rodríguez, A.A. Casas, and M.A.A. López. 2011. Risk assessment of the lead intake by consumption of red deer and wild boar meat in Southern Spain. *Food Additives & Contaminants* 28: 1021–1033. doi:[10.1080/19440049.2011.583282](https://doi.org/10.1080/19440049.2011.583282).
- Nadjafzadeh, M., H. Hofer, and O. Krone. 2013. The link between feeding ecology and lead poisoning in White-Tailed Eagles. *Journal of Wildlife Management* 77: 48–57. doi:[10.1002/jwmg.440](https://doi.org/10.1002/jwmg.440).
- Tsuji, L.J.S., B.C. Wainman, I.D. Martin, C. Sutherland, J.-P. Weber, P. Dumas, and E. Nieboer. 2008. Lead shot contribution to blood lead of First Nations people: the use of lead isotopes to identify the source of exposure. *Science of the Total Environment* 405: 180–185. doi:[10.1016/j.scitotenv.2008.06.048](https://doi.org/10.1016/j.scitotenv.2008.06.048).
- Niels Kanstrup**  
Address: Danish Academy of Hunting, Skrejrupsvej 31, 8410 Rønne, Denmark.  
e-mail: [nk@danskjagtakademi.dk](mailto:nk@danskjagtakademi.dk)
- Vernon G. Thomas** (✉)  
Address: Department of Integrative Biology, University of Guelph, Guelph, ON N1G 2W1, Canada.  
e-mail: [vthomas@uoguelph.ca](mailto:vthomas@uoguelph.ca)
- Oliver Krone**  
Address: Department of Wildlife Diseases, Leibniz Institute for Zoo and Wildlife Research, P.O. 601103, 10252 Berlin, Germany.  
e-mail: [krone@izw-berlin.de](mailto:krone@izw-berlin.de)
- Carl Gremse**  
Address: Wildlife Department, Eberswalde-University, Schicklerstrasse 5, 16225 Eberswalde, Germany.  
e-mail: [carl.gremse@hnee.de](mailto:carl.gremse@hnee.de)

## PAPER 9

Thomas VG, Gremse C, Kanstrup N (2015). Key questions and responses regarding the transition to use of lead-free ammunition. In: Delahay RJ, Spray CJ (eds) Oxford Lead Symposium: Lead Ammunition: understanding and minimising the risks to human and environmental health, 2015. Edward Grey Institute.

### RIGHTS:

Open access.

### AUTHORS' CONTRIBUTIONS

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above, of which I am first author, was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Prof. Emeritus Vernon Thomas  
Department of Integrative Biology, College of Biological Science, University of Guelph,  
Guelph, Ontario N1G 2W1, Canada

Email: [vthomas@uoguelph.ca](mailto:vthomas@uoguelph.ca)

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

Vernon G. Thomas<sup>1†</sup>, Niels Kanstrup<sup>2</sup> & Carl Gremse<sup>3, 4</sup>

<sup>1</sup> Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, Ontario N1G 2W1, Canada

<sup>2</sup> Danish Academy of Hunting, DK-8410, Ronde, Denmark

<sup>3</sup> Faculty of Wildlife Biology, Management and Hunting Practice, University of Applied Sciences Eberswalde, Alfred – Moeller – Str. 1, 16225 Eberswalde, Germany

<sup>4</sup> Leibniz – Institute for Zoo and Wildlife Research, P.O. Box 601103, D-10252 Berlin, Germany

<sup>†</sup> Corresponding author email address: vthomas@uoguelph.ca

*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 its 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<sup>1</sup>.

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

<sup>1</sup><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 #7 1/2 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<sup>1</sup> 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.

## 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

<sup>1</sup> T. A. Roster, 1190 Lynnewood Boulevard, Klamath Falls, Oregon 97601, USA.

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 ricochet 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.

## REFERENCES

- ANDERSON WL, HAVERA SP, ZERCHER BW (2000).** Ingestion of lead and non-toxic shotgun pellets by ducks in the Mississippi flyway. *The Journal of Wildlife Management* 64(3), 848-857.
- CROMIE R, LORAM A, HURST L, O'BRIEN M, NEWTH J, BROWN M, HARRADINE J (2010).** Compliance with the environmental protection (Restrictions on Use of Lead Shot)(England) Regulations 1999. Defra, Bristol. Available at: <http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=16075>. Accessed: August 2015.
- CROMIE RL, BROWN MJ, HUGHES B, HOCCOM DG, WILLIAMS G (2002).** Prevalence of shot-in pellets in mallard purchased from game dealers in England in winter 2001/2002. *Compliance with the Lead Shot Regulations (England) during winter 2001/02*. RSPB. Sandy, UK.
- CROMIE RL, NEWTH JL, REEVES JP, O'BRIEN MF, BECKMANN KM, BROWN MJ (2015).** The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. pp 104-124. Available at: <http://oxfordleadsymposium.info>. Accessed: October 2015.
- FSA (2012).** Advice to frequent eaters of game shot with lead. Available at: <http://www.food.gov.uk/science/advice-to-frequent-eaters-of-game-shot-with-lead>. Accessed: August 2015.
- GARWOOD GT (1994).** *Gough Thomas's gun book: shotgun lore for the sportsman*. The Gunnerman Press: Auburn Hills, Michigan, USA.
- GREMSE C, RIEGER S (2015).** Lead from hunting ammunition in wild game meat: research initiatives and current legislation in Germany and the EU. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. pp 51-57. Available at: <http://oxfordleadsymposium.info>. Accessed: October 2015.
- GROUP OF SCIENTISTS (2013).** Health risks from lead-based ammunition in the environment: a consensus statement of scientists. March 22, 2013 Available at: <http://www.escholarship.org/uc/item/6dq3h64x>. Accessed: August 2015.
- GROUP OF SCIENTISTS (2014).** Wildlife and human health risks from lead-based ammunition in Europe: a consensus statement by scientists. Available at: <http://www.zoo.cam.ac.uk/leadammunitionstatement/>. Accessed: August 2015.
- HAAS GH (1977).** Unretrieved shooting loss of mourning doves in north-central South Carolina. *Wildlife Society Bulletin* 5(3), 123-125.
- IRBY HD, LOCKE LN, BAGLEY GE (1967).** Relative toxicity of lead and selected substitute shot types to game farm mallards. *The Journal of Wildlife Management*, 253-257.
- KANSTRUP N (2015).** Practical and social barriers to switching from lead to non-toxic gunshot – a perspective from the EU. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. pp 44-50. Available at: <http://oxfordleadsymposium.info>. Accessed: October 2015.

- KELLY TR, BLOOM PH, TORRES SG, HERNANDEZ YZ, POPPENG RH, BOYCE WM, JOHNSON CK (2011).** Impact of the California lead ammunition ban on reducing lead exposure in golden eagles and turkey vultures. *PLoS ONE* 6(4), e17656. DOI:10.1371/journal.pone.0017656.
- KNOTT J, GILBERT J, GREEN RE, HOCOCOM DG (2009).** Comparison of the lethality of lead and copper bullets in deer control operations to reduce incidental lead poisoning; field trials in England and Scotland. *Conservation Evidence* 6, 71-78.
- KNUTSEN HK, BRANTSÆTER A-L, ALEXANDER J, MELTZER HM (2015).** Associations between consumption of large game animals and blood lead levels in humans in Europe: The Norwegian experience. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. pp 44-50. Available at: <http://oxfordleadsymposium.info>. Accessed: October 2015.
- LEVENGOD JM, SANDERSON GC, ANDERSON WL, FOLEY GL, SKOWRON LM, BROWN PW, SEETS JW (1999).** Acute toxicity of ingested zinc shot to game-farm mallards. *Illinois Natural History Survey Bulletin* 36(1).
- MATEO R, VALLVERDÚ-COLL N, LÓPEZ-ANTIA A, TAGGART MA, MARTÍNEZ-HARO M, GUITART R, ORTIZ-SANTALIESTRA ME (2014).** Reducing Pb poisoning in birds and Pb exposure in game meat consumers: the dual benefit of effective Pb shot regulation. *Environment International* 63, 163-168. DOI:10.1016/j.envint.2013.11.006.
- MONDAIN-MONVAL JY, DEFOS DU RAU P, GUILLEMAIN M, OLIVIER A (2015).** Switch to non-toxic shot in the Camargue, France: effect on waterbird contamination and hunter effectiveness. *European Journal of Wildlife Research* 61(2), 271-283. DOI:10.1007/s10344-014-0897-x.
- MOREHOUSE KA (1992).** Crippling loss and shot-type: the United States experience. In: Pain DJ (ed). *Lead Poisoning in Waterfowl. IWRB Special Publication No. 16*. International Waterfowl and Wetlands Research Bureau. pp 32-37.
- NIEMAN D, HOCHBAUM GS, CASWELL FD, TURNER BC (1987).** Monitoring hunter performance in prairie Canada. *Transactions of the North American Wildlife and Natural Resources Conference* 52, 233-245.
- NOER H, MADSEN J, HARTMANN P (2007).** Reducing wounding of game by shotgun hunting: effects of a Danish action plan on pink-footed geese. *Journal of Applied Ecology* 44(3), 653-662. DOI:10.1111/j.1365-2664.2007.01293.x.
- O'CONNELL MM, REES EC, EINARSSON O, SPRAY CJ, THORSTENSEN S, O'HALLORAN J (2008).** Blood lead levels in wintering and moulting Icelandic whooper swans over two decades. *Journal of Zoology* 276(1), 21-27.
- PAIN DJ (1991).** Why are lead-poisoned waterfowl rarely seen? The disappearance of waterfowl carcasses in the Camargue, France. *Wildfowl* 42, 118-122.
- PAIN DJ, CROMIE RL, GREEN RE (2015).** Poisoning of birds and other wildlife from ammunition-derived lead in the UK. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. pp 58-84. Available at: <http://oxfordleadsymposium.info>. Accessed: October 2015.
- PERRINS CM, COUSQUER G, WAINE J (2003).** A survey of blood lead levels in mute swans *Cygnus olor*. *Avian Pathology* 32(2), 205-212. DOI:10.1080/0307946021000071597.
- PIERCE BL, ROSTER TA, FRISBIE MC, MASON CD, ROBERSON JA (2014).** A comparison of lead and steel shot loads for harvesting mourning doves. *Wildlife Society Bulletin*. DOI: 10.1002/wsb.504.
- RCEP (1983).** Royal Commission on Environmental Pollution. Ninth report. Lead in the environment. (T.R.E. Southwood). CMND 8852 Monograph. HMSO. London.
- SAMUEL MD, BOWERS EF (2000).** Lead exposure in American black ducks after implementation of non-toxic shot. *Journal of Wildlife Management* 64(4), 947-953. DOI:10.2307/3803203.
- SCHEUHAMMER AM (1996).** Influence of reduced dietary calcium on the accumulation and effects of lead, cadmium, and aluminum in birds. *Environmental Pollution* 94(3), 337-343. DOI:10.1016/S0269-7496(96)00084-X.
- SEARS J, HUNT A (1991).** Lead poisoning in mute swans, *Cygnus olor*, in England. *Wildfowl* (Suppl. 1), 383-388.
- SNOEIJTS T, DAUWET T, PINXTEN R, DARRAS VM, ARCKENS L, EENS M (2005).** The combined effect of lead exposure and high or low dietary calcium on health and immunocompetence in the zebra finch (*Taeniopygia guttata*). *Environmental Pollution* 134(1), 123-132. DOI:10.1016/j.envpol.2004.07.009.
- STEVENSON AL, SCHEUHAMMER AM, CHAN HM (2005).** Effects of nontoxic shot regulations on lead accumulation in ducks and American woodcock in Canada. *Archives of Environmental Contamination and Toxicology* 48(3), 405-413. DOI:10.1007/s00244-004-0044-x.
- STROUD DA (2015).** Regulation of some sources of lead poisoning: a brief review. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. pp 8-26. Available at: <http://oxfordleadsymposium.info>. Accessed: October 2015.
- THOMAS VG, ROBERTS MJ, HARRISON PT (2009).** Assessment of the environmental toxicity and carcinogenicity of tungsten-based shot. *Ecotoxicology and Environmental Safety* 72(4), 1031-1037. DOI:10.1016/j.ecoenv.2009.01.001.
- THOMAS VG (2013).** Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. *AMBIO* 42(6), 737-745. DOI: 10.1007/s13280-012-0361-7.
- THOMAS VG, GUITART R (2013).** Transition to non-toxic gunshot use in Olympic shooting: policy implications for IOC and UNEP in resolving an environmental problem. *AMBIO* 42(6), 746-754. DOI: 10.1007/s13280-013-0393-7.
- THOMAS VG (2015).** Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In: Delahay RJ, Spray CJ (eds). *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. pp 85-97. Available at: <http://oxfordleadsymposium.info>. Accessed: October 2015.
- UNEP-CONVENTION ON MIGRATORY SPECIES (2014a).** Review and Guidelines to Prevent the Risk of Poisoning of Migratory Birds. *UNEP/CMS/COP11/Doc.23.1.2*. Bonn, Germany. Available at: [http://www.cms.int/sites/default/files/document/COP11\\_Doc\\_23\\_1\\_2\\_Bird\\_Poisoning\\_Review\\_%26\\_Guidelines\\_E\\_0.pdf](http://www.cms.int/sites/default/files/document/COP11_Doc_23_1_2_Bird_Poisoning_Review_%26_Guidelines_E_0.pdf). Accessed: August 2015.
- UNEP-CONVENTION ON MIGRATORY SPECIES (2014b).** Resolution 11.15. Preventing poisoning of migratory birds. Adopted by the Conference of the Parties at its 11th meeting, 4-9 November 2014, Quito, Ecuador Available at: [http://www.cms.int/sites/default/files/document/Res\\_11\\_15\\_Preventing\\_Bird\\_Poisoning\\_of\\_Birds\\_E\\_0.pdf](http://www.cms.int/sites/default/files/document/Res_11_15_Preventing_Bird_Poisoning_of_Birds_E_0.pdf). Accessed: August 2015.
- USFWS (1997).** Migratory bird hunting: revised test protocol for nontoxic approval procedures for shot and shot coatings. 50CFR Part 20. Department of the Interior, U.S. Fish and Wildlife Service, Washington, D.C. Federal register 62(230): 63608-63615.
- WATSON RT, FULLER M, POKRAS M, HUNT W (eds) (2009).** *Proceedings of the conference ingestion of lead from spent ammunition: implications for wildlife and humans*. The Peregrine Fund, Boise, ID, USA.



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

# PAPER 10

Kanstrup N (2018). Lessons learned from 33 years of lead shot regulation in Denmark. Ambio 48:999,1008 doi:10.1007/s13280-018-1125-9

## RIGHTS:

### Thank you for your order!

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

### Order Summary

Licensee:	Aarhus University
Order Date:	Feb 16, 2020
Order Number:	4770960323233
Publication:	AMBIO
Title:	Lessons learned from 33 years of lead shot regulation in Denmark
Type of Use:	Thesis/Dissertation
Order Ref:	2018 Kanstrup Lessons learned
Order Total:	0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customercare@copyright.com](mailto:customercare@copyright.com)  
<https://myaccount.copyright.com>



# *Lessons learned from 33 years of lead shot regulation in Denmark*

**Niels Kanstrup**

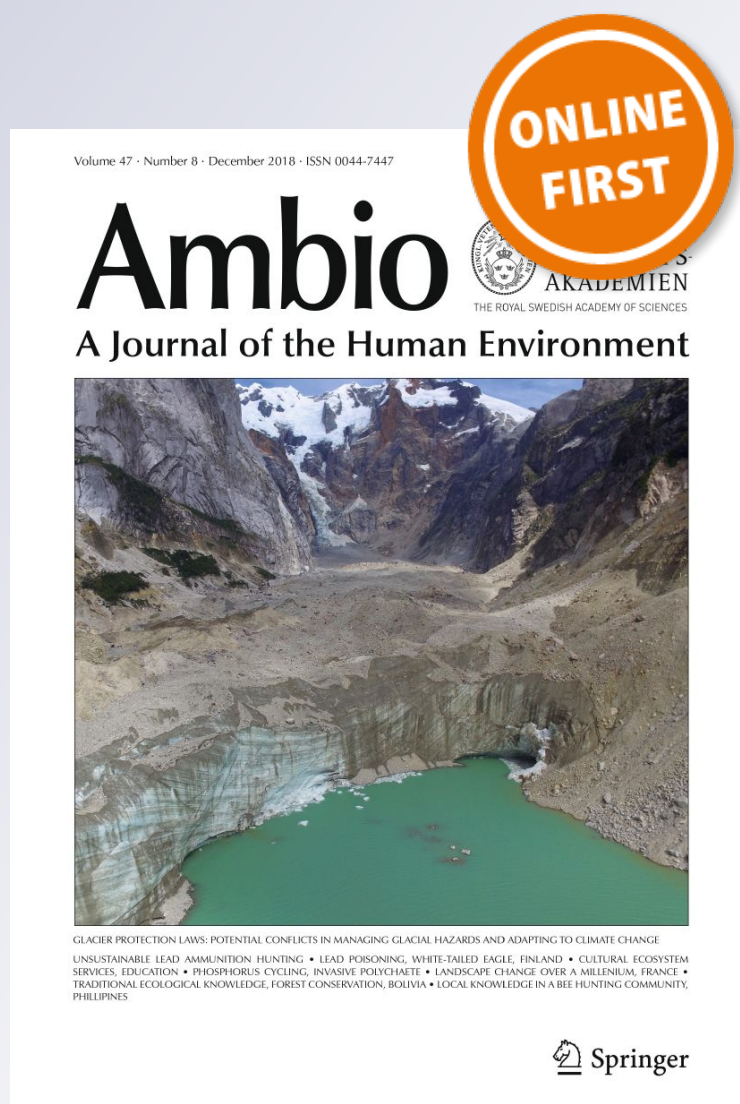
**Ambio**

A Journal of the Human Environment

ISSN 0044-7447

Ambio

DOI 10.1007/s13280-018-1125-9



**Your article is protected by copyright and all rights are held exclusively by Royal Swedish Academy of Sciences. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at [link.springer.com](http://link.springer.com)".**



## LEAD USE IN HUNTING

# Lessons learned from 33 years of lead shot regulation in Denmark

Niels Kanstrup

Received: 20 August 2018 / Revised: 16 October 2018 / Accepted: 31 October 2018

**Abstract** Denmark was the first European country to completely ban lead shot for hunting and target shooting. This paper reviews the process behind this phase-out to document its history, successes, and pitfalls, and to make the Danish experiences accessible for the benefit of other countries, authorities, and stakeholders who face nature management challenges implementing similar change. A review of the content of magazines published by the three hunters' organizations during the 1978–1992 transition period was carried out, to assess the general discourse and identify the primary concerns and attitudes during the phase-out of lead shot for hunting in Denmark. Hunters were initially negative towards the change. Resistance was driven by concern about the quality, safety issues, and expensive cost of non-toxic alternatives, compounded by lack of organizational leadership and tensions between stakeholders. As a result of the widening appreciation of the environmental effects of dispersed lead shot and the introduction of new generations of alternative shot types, hunter attitudes became positive and constructive. Change need not pose an obstruction to continued hunting opportunity. On the contrary, it is believed that the value from the enhancement of the public image of hunters resulting from the reduction in the environmental dispersal of a recognized contaminant is of paramount importance for the long-term political sustainability of hunting.

**Keywords** Ammunition · Efficacy · Hunting · Lead · Safety · Sustainability

## INTRODUCTION

Lead from hunting ammunition puts at risk the health of wildlife and of humans who regularly consume hunted

game. Waterbirds ingest shot along with grit and their food. Ingested shot are often retained in the gizzard, which causes poisoning. For this reason, lead gunshot have been subject to legislative and other forms of regulation under international and national law over the last 50 years, especially for the protection of waterbirds and their wetland habitats. To date, 33 countries worldwide (Stroud 2015) have introduced total or partial bans on the use of lead shot for hunting, generating substantial experience from different jurisdictions. Denmark was the first European country to ban lead shot for hunting and target shooting completely, based on initial regulation in the early 1980s, with a total phase-out in 1996.

In Denmark, initial evidence that lead shot from shotgun ammunition was poisoning birds came in the late 1960s and mid-1970s, when studies showed Mallard (*Anas platyrhynchos*) and (one) Pheasant (*Phasianus colchicus*) dying from lead poisoning by gunshot ingestion (Munch 1968), and severe poisoning of Mute Swans (*Cygnus olor*) ingesting lead shot from nearby target shooting ranges (Clausen and Wolstrup 1979). These cases drew the attention of environmental authorities, who drafted proposals to regulate its use for target shooting, which contributed lead shot to wetlands. In Denmark at that time, most small target shooting ranges were owned or administered by local shooting clubs, who protested against the proposed regulation. The two arguments from the shooting community against regulation revolved around lack of proof of the risk of lead shot in wetlands and lack of alternatives to lead ammunition. Despite these arguments, the first regulation was implemented in 1981, banning clay target shooting where lead shot could fall into wetlands.<sup>1</sup>

<sup>1</sup> <https://www.retsinformation.dk/forms/R0710.aspx?id=47959>.

At the same time, growing evidence and concern from conservationists that lead shot from hunting was poisoning waterbirds came from the high prevalence of ingested shot in waterbirds and high densities of lead shot in wetland sediments (Wium-Andersen 1973; Wium-Andersen and Franzmann 1974; Meltofte and Petersen 1979; Eskildsen 1980), supported by evidence from abroad, not least from USA where the problem had been identified in the 1950s (Bellrose 1959). Consequently, during 1983–1985, proposals to regulate lead shot for hunting included a 3-year “experimental ban” of lead shot at eight Danish wetlands subject to intensive waterbird hunting, and legislation based on hunting particular waterbird species.

During the subsequent implementation of lead shot regulation, Denmark social-democratic government (until December 1981) was followed by a conservative/liberal minority government (September 1982–December 1990). However, Parliament throughout was characterized by a so-called “green majority”, an alliance of left-wing opposition parties that implemented several environmental protection initiatives outside of government. This was to play a significant role in the process of phasing out lead shot for hunting. The Environmental Protection Agency (Ministry of Environment) was responsible for implementing regulation, even though wildlife management and hunting legislation was (until 1989) under the administration of the Ministry of Agriculture. Non-governmental stakeholders were primarily the three hunters’ organizations, Dansk Jagtforening, Landsjagtforeningen af 1923, and the smaller Dansk Strandjagtforening. In addition, conservationist organizations like Dansk Ornitologisk Forening (the Danish Ornithological Society/Birdlife Denmark) and some of their more vocal members and other active individuals played a central and active role in promoting regulation.

By mid-1985, consensus between hunters’ representatives and the authorities effected a time-limited experimental ban on lead shot for hunting at eight wetlands. However, in December 1985 Parliament decided to ban the use of lead shot in all Danish Ramsar sites (then 26) and on ponds used for captive-reared Mallard hunting. This was orchestrated by conservationist groups and pushed forward by the “green majority” in Parliament. The ban was effective from 1986 until 1993, when it was replaced by a regulation banning all hunting use of lead shot and the trade of lead shot cartridges (although only enforceable in forests and trading from 1996). Since then, the regulation has been amended slightly so the present regulation<sup>2</sup> bans the use, trade, and possession of cartridges with lead shot for all hunting and clay target shooting.

The total ban was not motivated by evidence of a significant risk of lead poisoning to non-wetland species, but by the need to enforce the regulation efficiently. Regulations related to specific habitats such as Ramsar sites were highly inefficient as enforcement required intensive policing of individual hunters’ use of non-lead shot types (Dansk Jagt 1987). However, the total phase-out of lead shot coincided with a broader national strategy to phase out all lead compounds in the environment wherever possible.

In summary, from initial concerns that shotgun ammunition lead shot was poisoning wildlife in Denmark 40 years ago, legislation restricting its use has now prevailed for more than 30 years, including the last 23 years of a total ban on the use, trade, and possession of lead shot. This paper reviews the Danish process by documenting its history, success, and pitfalls, to make the Danish experiences accessible to other countries, authorities, and stakeholders who face nature management challenges implementing similar change. The paper specifically addresses the following questions. What were stakeholders’ concerns and how were they managed? What characterized the discourse at user level and did the discourse change? Has regulation limited the opportunities for recreational hunting, the capacity of hunters to sustain their harvest, and the control of pest species? Has regulation achieved conservation benefits (in terms of reduced levels of lead poisoning), which was the original purpose of the process?

## METHODS

The magazines published by and associated with the three hunters’ organizations during the 1978–1992 transition period were reviewed to assess the general discourse, the political reactions within the hunter community, and to identify their primary concerns and attitudes during the phase-out of lead shot for hunting in Denmark. During this 15-year period, 352 individual editions of the hunters’ magazines were published, of which 345 were provided from library archives and their content reviewed. For each of the articles, which mention directly or indirectly the subjects of lead poisoning from gunshot, possible regulation of lead shot, and the introduction of alternative shot types, the following subject variables were extracted:

### *Time of publication*

- Year.
- Month.

### *Type*

- Editorial article.
- Information.

<sup>2</sup> <https://www.retsinformation.dk/Forms/R0710.aspx?id=182003>.

- Report from annual meetings in the associated organizations.
- Tests of non-lead products.
- Readers' letters.

#### Subject

- Politics.
- Legislation.
- Lead poisoning.
- Challenges relating to lead alternatives:
  - Efficacy.
  - Safety.
  - Firearms/technique.
  - Costs/price.

#### Attitude to change

- Negative.
- Neutral.
- Positive.

Because of the large numbers of articles, it was not feasible to carry out a detailed discourse analysis. Categorization of articles was based on a judgement of the choice of words, themes, and narratives in the single articles. Narratives were used to assess of attitude to change. Many authors raised concrete concerns and sought more information. This would result in a categorization as "neutral". Only articles concluding clear opposition to change was categorized as "negative", and conversely, articles concluding support for change were assigned to the "positive" category. The analysis was used to identify concerns and to evaluate any change from resistance to acceptance and the reasons given.

From the categorization and quantification of article subjects, the importance of the many different concerns that were raised during the transition period was assessed. Categorization, quantification, and assessments were carried out by one person (the author).

The probability that the attitude did not change with year (null hypothesis) by assigning the attitude for each article as negative, neutral, or positive was modelled. The generalized linear model assumed a multinomial distribution with publication year as the independent variable and attitude as the dependent variable. The statistical test was conducted using proc genmod in SAS 9.4 (SAS Institute, Cary, NC).

## RESULTS

During 1978–1992, 210 articles in the three magazines covered the issue of regulation of lead shot which grew to peak in 1986, falling subsequently (Fig. 1).

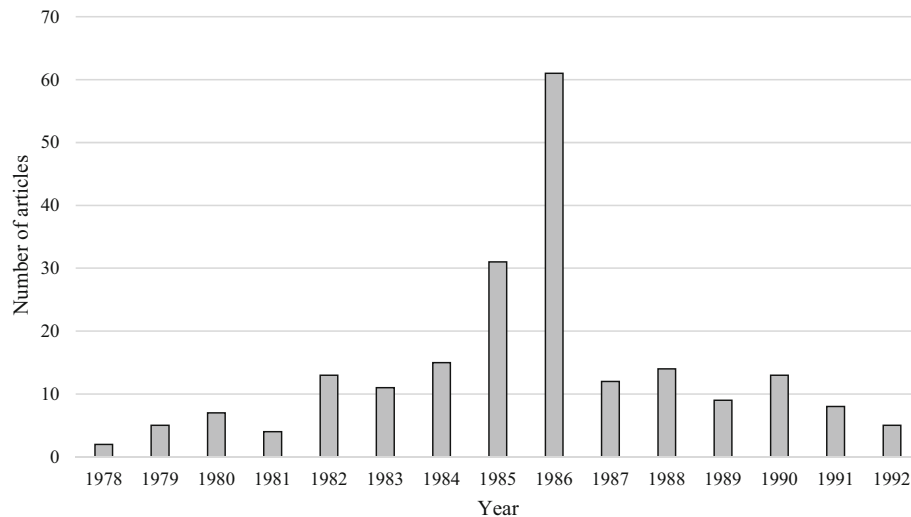
The main concern expressed in 69 articles was the lack of suitable alternatives to lead shot. At that time, only American-made steel shot (until 1986) was available in Denmark. Many hunters were concerned about efficacy (27 articles), human safety (17 articles), damage to guns (16 articles), price of cartridges (9 articles), and damage to forests (5 articles). Thirty-three articles posed legislative/regulatory questions, of which six related to law enforcement, compliance, and control of regulations. The risk of lead poisoning to waterbirds was covered in 41 articles, in four cases by scientists or governmental representatives reporting documented evidence. However, in 27 articles the lead poisoning risk was ignored by hunters' representatives, magazine editors, editorial articles (9), and readers' letters. Fifty-five articles described the political process, e.g. the procedure in Parliament, the negotiation processes, or adopted strategies. Of these, 12 articles included personal attacks on scientists, officials, or individual persons in other organizations including other hunters' organizations (9 articles). Ten articles were concerned about the consequences of lead shot regulation for future clay target shooting. Table 1 shows the distribution of the different types of articles.

Most articles fell within the category "Information", i.e. updates on new developments, legislation, and products. However, the frequency of editorial articles, readers' letters and reports from annual meeting/general assemblies (total 105) demonstrates the concern of stakeholders about lead shot regulation and the desire to retain the status quo relative to the rather few tests of alternatives to lead shot products (15).

However, there were shifts in attitude, i.e. whether authors expressed negative, neutral, or positive attitudes to the subject of transition from lead shot to alternative shot types (Fig. 2). The grouping resulted in 75 negative attitudes, 104 neutral attitudes, and 30 positive attitudes. The attitude changed significantly over the observation period (generalized linear model  $\chi^2 = 47.7$ ,  $p < 0.001$ , slope =  $-0.344$ ). The significant negative slope indicates that the number of negative attitudes declined and the number of positive attitudes increased during the transition period.

This shift in attitudes was expressed, for instance, when the President of the organization Landsjagtföreningen af 1923 concluded in a May 1989 article in the magazine Dansk Jagt, published by the competing organization Dansk Jagtförening, that the steel shot then available was fully acceptable for all hunting and clay target shooting, stating:

Without hesitation, I urge everyone to use steel shot as far as possible - not just where lead shot is banned, but everywhere you go hunting and shooting clay



**Fig. 1** During 1978–1992, 210 articles covered the issue of regulating the use of lead shot for hunting and clay target shooting in Denmark. The first regulation of lead shot for clay pigeon shooting which came into force in 1981 did not generate much reaction. The regulation of lead shot for hunting was negotiated in the years 1984–1985, was passed in late 1985, came into force on 1 August 1986, and caused a heavy written response. The total ban on lead shot for all hunting and clay target shooting (prepared during 1991–1992) received little attention in any of the magazines during this period

**Table 1** Types of articles of which “Information” was the most common

Type	Number
Editorial articles	47
Information	90
Tests of lead shot alternatives	15
Readers’ letter	39
Report from annual meetings	19
Total	210

targets. The hunters’ credibility as environmentalists depends on how we keep our own house in order.

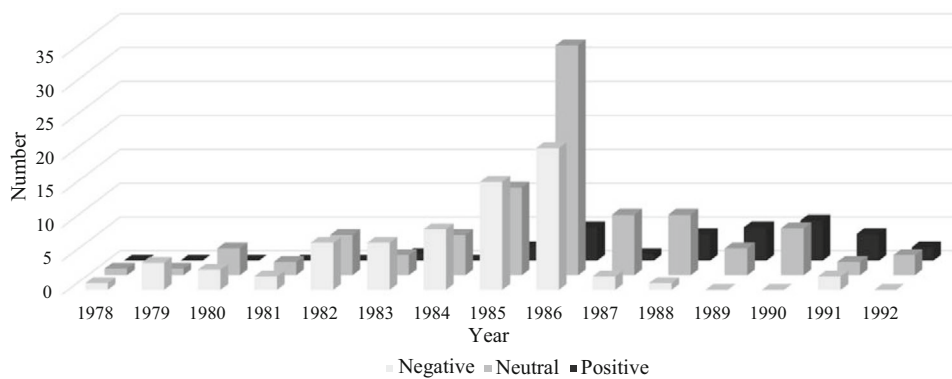
The article was published with the support of the organization Dansk Jagtforening, and it demonstrated a change in leadership attitude, recognizing the need for hunters to publicly address and engage with the lead shot issue. Furthermore, it became a turning point in terms of both the attitude to the phase-out of lead shot and cooperation among three hunters’ organizations that merged 3 years later. Another sign of changing attitudes was a report from the 1988 general assembly of Landsjagforeningen af 1923 published in the magazine *Jagt og Fiskeri* under the headline: “A stable period without any big problems”, which failed to mention the 1986 lead shot regulation at all. Finally, the total ban on lead shot for all hunting and clay target shooting in 1993 (prepared during 1991–1992) received almost no attention in any of the magazines during this period.

## DISCUSSION

To fully understand the lessons learned from the Danish phase-out of lead shot from the 1980s until the present, it is important to know the level of respect and compliance from Danish hunters to the regulations. Five hunters’ magazine articles reviewed in this study reported that compliance was far from complete in the first years following regulation, based on regular police checks and other observations. Even after the 1996 complete ban on use, trade, and possession of lead shot in Denmark, examples of non-compliance were forthcoming. Police checks from October 2010 until January 2011 revealed that hunters still used lead shot (Politiken 2011). Kanstrup (2012) demonstrated that 15.6% of Pheasant gizzards ( $N = 77$ ) and 9.6% of Mallard gizzards ( $N = 94$ ) from Danish shoots in 2010 had embedded lead shot. As of 2018, however, compliance with lead shot regulations in Denmark is almost complete (Kanstrup, unpublished data).

### From resistance to acceptance

From the beginning, Danish hunters’ and their organizations were negative and skeptical of the proposed regulation of lead shot both for clay target shooting and, in particular, hunting. Resistance to change was driven by concerns about performance and safety associated with the use of non-lead shot and an under-appreciation of the true extent of poisoning of waterbirds and ecosystems from lead gun shot. These misperceptions were stimulated by lack of responsible organizational leadership at the time. Issues of trust and tension between field sports and conservation



**Fig. 2** Distribution of 210 articles on year and categorization of attitudes to change from lead shot to non-lead shot during the transition period 1978–1992. The attitude changed significantly over the observation period (generalized linear model  $\chi^2 = 47.7$ ,  $p < 0.001$ , slope =  $-0.344$ )

communities and inter-organizational politics became major factors to frustrate change, as has also subsequently been described in the UK (Cromie et al. 2015).

However, during the transition period, attitudes changed significantly. This owed much to a combination of improved availability of suitable alternative shot types and, in particular, a change in the opinions of hunters, resulting from a more proactive leadership and the positive results forthcoming from the hunters' own testing of new non-lead products. These studies demonstrated that shooting efficacy is more related to hunters' experience and the distance over which they shoot, than to cartridge performance (Kanstrup 1987). Indeed, cartridge performance was shown to be largely independent of the shot material itself. The early (1981) introduction of steel shot for clay target shooting prompted many Danish hunters to rapidly acquire experience of firing many non-lead rounds. The general impression was that there was little difference in terms of hitting probability, safety, and price. The price of non-lead cartridges was a major concern in the transition period, mentioned in 9 of the magazines reviewed in this study. Today, sport shooting cartridges with steel shot are cheaper than lead shot equivalents and are preferred by some top competition shooters (Bjergegaard, 2018, Danish shooting instructor, personal communication, <http://www.skydeinstruktion.dk>). Steel shot cartridges for hunting purposes are available at the same price as lead shot cartridges, whereas other non-lead types, like bismuth and tungsten shot, cost significantly more.

The change of attitude among Danish hunters was manifested clearly in 2015, when the Norwegian Parliament decided to lift the total ban on lead shot for hunting (which had been enacted there in 2005) and allowed use of lead shot for hunting non-waterbird species. The Danish Hunters' Association expressed the following reaction to the Norwegian decision<sup>3</sup>:

The Board of the Danish Hunters' Association has, on top of the Norwegian decision, discussed whether we should work on something similar in Denmark. We all agreed that we should not. There are a number of underlying considerations: Now we have become accustomed to using steel as well as the other alternatives, and steel strikes just as good if not better than lead. ...and no matter how you look at it: lead is bad to cast out in nature - even in small quantities. It is hard to see that Norway should have found "the philosopher's Stone" and we wonder a little bit about the decision. We cannot see any good arguments and therefore we are not going to work for anything like it.

The Danish situation is mirrored in The Netherlands, where, since 1993, there has been a complete ban on lead shot for all hunting. This regulation was implemented in response to growing awareness of lead shot contamination of waterbirds on a flyway level and the particularly high prevalence of ingested shot in Dutch waterbird populations (e.g. Lumeij et al. 1989). The Royal Dutch Hunters Association summarized the lessons learned as follows (2017, personal communication, <https://www.jagersvereniging.nl/>):

From the beginning, hunters were very skeptical, mostly due to lack of suitable alternative shot types. The first generations of non-lead shot types were of low quality, and many hunters had bad experiences. Later generations of alternative types showed to be more efficient. Today, steel shot is the most widespread type, but many hunters use bismuth shot. There are examples of hunters bringing steel shot to the UK when going there for Pheasant shooting. Old generations of hunters have adapted to the use of lead-free shot. New generations have never used lead shot. The shot ammunition is not an issue. Nobody complains about the situation, and there is no movement at all in order to question the regulation,

<sup>3</sup> February 2015: Statement from Board Member Jens Bjørn Andersen, Danish Hunters' Association. <http://www.huntersmagazine.com/article/blyhagl-bliver-ikke-tilladt-i-danmark>.

alternatively, to lift the ban. The harvest of certain waterbird species, e.g. geese, is larger than ever.

### Efficacy of non-lead ammunition

One of the major concerns in the transition period was the risk of non-lead shot being less efficient than lead shot (mentioned in 27 articles). Cromie et al. (2015) also found that concern about the efficacy and costs of non-toxic ammunition was the most prevalent themes, accounting for 20 of 131 (15.3%) opinions cited in a survey of the British hunting media during 2010–2015. Generally, lead has been believed to be the best metal for ammunition, due to its ubiquity, density, and softness. However, the preference for lead gunshot is more likely the result of tradition shaping demand and subsequent economies of scale relating to commercial production, than any true ballistic advantage to the use of the material. The transition from lead to other shot types should therefore not only discuss the efficacy of lead-free shot, but also address to which degree this transition can improve the efficacy of shotgun hunting in general and lead to better performance and reduced crippling rates that are consistent with the modern demands of sustainable hunting.

Comparative studies of the efficacy of lead versus non-lead shot are extensive. Among the early Danish studies, Hartmann (1982) concluded that "... modern technique causes a concurrent development that even out the differences between lead and steel in such a degree that steel shot within normal shooting distances (max. 35 m) are suitable for waterbird hunting". Kanstrup (1987) found no difference in efficacy between lead and steel shot for Eider Duck (*Somateria mollissima*) hunting. Strandgaard (1993) concluded that steel shot was just as effective as lead shot when used to kill roe deer (*Capreolus capreolus*). According to Noer et al. (1996), 36% of a sample of Pink-footed Goose (*Anser brachyrhynchus*) were found to carry embedded pellets (crippling rate) corresponding to one bird wounded for every bird shot and killed. Most examined birds had been wounded before the Danish phase-out of lead shot, so embedded shot was mostly lead. The results created a political furore and immediate calls for actions to reduce wounding. An action plan drafted by the Wildlife Management Council in 1997<sup>4</sup> included a programme to monitor the impact of the actions, and monitoring results were reported regularly. The latest evaluation of the impact of the campaign showed a reduction in the crippling ratio (crippling rate/harvest rate) for Pink-footed Goose from 9.75 in 1992 to 1.99 in 2016, a reduction of 80% (Clausen

et al. 2017). This research coincided with the phasing out of lead shot and "phase-in" of steel shot in Denmark, but also with the increase in the Pink-footed Goose population size and associated annual kill, better organization and planning of hunting, combined with education of hunters.

European and American studies support these findings. Mondain-Monval et al. (2015) showed similar performance of lead and steel for hunting waterfowl. The study showed that hunter behaviour and judgement, the abundance of birds, and strong wind conditions played significant major roles in determining the hunters' ability to kill birds. Pierce et al. (2014) compared lead and steel shot for hunting Mourning Dove (*Zenaidura macroura*), showing hunters using lead shot (cal. 12, with 32 g of US #7<sup>1/2</sup> shot) and steel shot (cal. 12, 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".

In summary, shot material plays a secondary role in shot performance. The right choice of shot sizes, shooting distances, and cartridge quality, i.e. sufficient energy and conformity of components, play a more important role. Furthermore, shooting efficacy and the success of the shot are related to the shooter rather than the ammunition, though shooters may need to adapt to using different ammunition. Steel and other alternatives can be used as effectively as lead shot (Thomas et al. 2015).

### Safety and damage to guns

Safety, mentioned in 16 articles in this study, was a central part of the Danish debate during the transition from lead to non-lead gunshot in the 1990s. Many were concerned that steel shot, which was initially the only available alternative, would create an increase in accidents caused primarily by ricocheting shot. For this reason, a suite of measures was introduced. Codes of safe hunting were adopted, including the recommended safe shooting angle be increased from 25° to 40°, and hunters were advised to wear safety glasses when hunting in groups. A safety campaign was also launched (under the motto "better red than dead") urging hunters to wear red caps or hat ribbons to enhance their visibility to fellow hunters, a campaign inspired by the switch from lead to lead-free shot. Two decades later, there is no evidence that the transition from lead to non-lead shot has changed the risk of injury. The

<sup>4</sup> <http://naturstyrelsen.dk/publikationer/2008/dec/handlingsplan-til-forebyggelse-af-anskydning-af-vildt/>.

Danish Hunting Insurance<sup>5</sup> company registers reports on shooting accidents, including accidents caused by ricocheting gunshot which show that, following the phase-out of lead shot, there was no increase in the frequency of such accidents.

Since 1981, the use of lead shot for training and competitive clay target shooting has gradually been phased out in Denmark and steel shot has become the only realistic alternative. Steel shot was predicted to generate increased risk of accidents caused by shot ricocheting from clay targets, installations, ground (running target), and other objects. However, 38 years after the first regulations were enacted there has been no detectable change in the frequency of such accidents, neither generally, nor accidents caused by ricocheting shot (Danish Wing Shooting Organisation, 2016, personal communication, <http://www.danskflugtskydningsforbund.dk/>). So, this initial concern has proved groundless. Shooters are recommended to wear safety glasses (in some disciplines this is mandatory). This precaution is to prevent eye injuries mainly from clay target fragments but will also protect against both falling and ricocheting shot. This applies equally to steel and other shot types.

The suitability of guns and the risk of damage caused by steel was a major concern during the transition period, as mentioned in 16 articles. Part of the governmental and private campaign to support the phase-out of lead shot was to recommend (and facilitate) hunters to get their guns re-proofed and checked. In most cases the guns passed the proofing. In other cases, hunters replaced their gun(s). In many cases, tightly choked guns were opened to pattern better with the available ammunition. Today, most experts regard these modifications as un-necessary as the development of lead-free ammunition went much faster than expected, not least supported by European (including Danish) ammunition manufacturers who started production of specifically types for Danish conditions. During the late 1980s and early 1990s when the decision to enact a total ban of lead shot was taken (and came into force in 1996), the debate on guns was silenced as the predicted damage to guns (explosions, etc.) caused by non-lead ammunition never realized. Also, new shot types based on bismuth and tungsten sharing similar ballistic properties as lead shot (including use with old shotguns) fulfilled the needs of the hunters.

### Hunting in forests

When the ban on lead shot for hunting in forests was introduced in 1996, the Danish Forest Association and Danish Tree Industries introduced a non-statutory

requirement for the use of specially approved “forest shot”, mostly bismuth–tin shot for hunting in forests. This requirement was due to the risk that steel gunshot shot into trees might damage cutting tools in the timber industry. Although addressed in only five articles in hunting magazines during the transition period, the concern was covered by non-hunting media (e.g. Bach and Thomsen 1992). Based on questionnaires and interviews with key stakeholders at all levels, from production to processing of wood, Kanstrup and Stenkjær (2015) showed that a large proportion forest districts complied with this requirement from the beginning, although an increasing number have waived it in recent years. These authors found no examples of actual economic loss as a result of damage caused by unapproved (steel) hunting shot. This is either because such shot has not been used at any significant level or because the risk of non-approved shot causing damage to tree cutting tools is infinitesimally small. Shot is often detected in the inspection of wood or prior to processing with delicate cutting tools. Kanstrup and Stenkjær (2015) assessed the annual added cost for using forest shot instead of steel shot at approximately Euro 2 million, which corresponds to at least five times the total value of the annual production of veneer timber in Denmark.

Today, the regulation of gunshot for forest hunting has changed so that concern for timber production is met through targeted district-based requirements in areas with particularly valuable timber production (effectively only beech and oak produced for veneer production). Effective organization of hunting can ensure that reforestation and single high-value trees are not affected by hunting ammunition.

### Conservation benefits from using non-lead shot

The primary goal of regulating lead shot for hunting in wetlands in Denmark and other countries was to prevent contamination of waterbirds and their environment. So, has such regulation reduced lead exposure and poisoning of waterbirds in Denmark and elsewhere?

There are very few Danish studies of the actual conservation benefits of the regulation. Kanstrup (2012) showed a 1.2% prevalence of ingested lead shot in Mallard gizzards ( $N = 656$ ) obtained in 2010, significantly lower than in historical Danish and European studies (Clausen and Wolstrup 1979; Meltofte and Petersen 1979; Lumeij et al. 1989). Lead shot was found in 13.6% of Mallard gizzards with ingested shot ( $N = 59$ ) compared to 54.2% steel and 32.2% bismuth, demonstrating ingestion of lead shot in 2010 has been replaced by ingestion of alternative, non-toxic shot types. In a sample ( $N = 690$ ) of Mallard gizzards obtained in 2017, ingested lead shot prevalence ranged from 0 to 11.8% with an average of 1.7% in 14

<sup>5</sup> <http://www.danskjagtforsikring.dk/>.

different batches of shot Mallard from 10 different shooting districts (Kanstrup, unpublished data). This compared with 0–16.0% (average 8.9%) for steel and 0–4.0% (0.7%) for bismuth.

This evidence of the potential benefits of the switch to non-lead gunshot is mirrored in foreign studies. In the USA and Canada, the mandatory transition to non-toxic shot for waterbird hunting in 1991 and 1999, respectively, resulted in significant reductions in duck mortality from lead poisoning within a few years (Anderson et al. 2000; Samuel and Bowers 2000; Stevenson et al. 2005). Spain required the use of non-toxic shot for hunting in its Ramsar sites from 2001, since the time when a measurable reduction in lead-induced mortality has occurred (Mateo et al. 2014). Between 1995 and 2005, a lead shot ban was self-imposed at 403 ha wetlands at the Tour du Valat Foundation estate in the Camargue, France (Mondain-Monval et al. 2015). Analysis of the gizzards of ducks showed that at the end of the 11-year period, the lead shot ban prevented 456 kg of lead from entering 403 ha of temporary marshes and avoided the contamination of 8% of the ducks foraging at Tour du Valat. These studies show that the scale of the problem can be reduced quickly by switching to non-toxic ammunition. However, once lead shot is dispersed into the upper levels of wetland sediments it remains a potential future source of poisoning to wildlife and ecosystems because of its chemical and physical persistence.

### Future perspectives

The Danish process of phasing out lead shot for hunting and target shooting has enhanced the sustainability of field and shooting sports in terms of conservation of wildlife and ecosystems. By this regulation and by banning also the trade of lead based sport fishing weights in 2002, Denmark has become a global leader in hunting/angling lead reduction. However, other issues revolve around the environmental footprint of these recreational activities. Lead in rifle ammunition is still unregulated in Denmark, despite the well-established fact that exposure to lead fragments from rifle hunting bullets poses toxic risks to wildlife and humans, who are at risk when eating game meat killed with lead ammunition (Kanstrup et al. 2016). Plastic shotgun ammunition cases and wads which feature among the top 10 litter items found on reference beaches in Denmark are an unwelcome source of plastic pollution of marine and other ecosystems (Kanstrup and Balsby 2018). Non-toxic rifle ammunition is widely available, and the rapid development of non-plastic shot gun cartridge components could be stimulated by a more pronounced market demand.

Lessons learned from the Danish phase-out of lead shot in the 1980s and 1990s could be instructional not only for other countries facing the same challenge but also for

Denmark itself in order to further reduce the adverse environmental footprints from recreational hunting and thereby enhance its long-term sustainability.

### CONCLUSIONS

Although the progress towards eliminating lead shot from use in hunting has been slow, the results in Denmark have been important and long-lasting. Positive experiences from the use of non-lead ammunition are increasingly available from more countries that have enforced regulations for three decades, including North America countries, The Netherlands, Spain, and France. Most Danish hunters were initially negative and skeptical towards the change. This was due to biased information about the actual environmental consequences of firing lead shot into wetlands, postulated (but unfounded) damage to guns caused by non-lead shot, poor killing impact, safety issues, and high prices of non-lead products. Resistance to change was driven by these concerns, combined with tensions between hunting and conservation communities and lack of organizational leadership. The legal progress was ensured by a firm parliamentary regulatory process stimulated particularly by a forceful approach from a “green” opposition and strong conservationists, both organized and individuals, who influenced the government of the time.

Within a few years of the first regulations coming into force, hunters and their organizations changed their attitude towards the regulation, becoming positive and constructive. This was driven by a wider understanding of the risks of dispersed of lead shot in ecosystems. The introduction of new generations of shot types manufactured of non-lead alternatives from a growing number of manufacturers increased hunters' confidence that the transition from lead to non-lead shot could occur without jeopardizing shooting performance and safety, and without reducing personal harvest rates or increasing cartridge consumption. The early introduction of steel shot for clay target shooting exposed many hunters to good training experiences. Contrary to some hunters' fears, change was not an obstruction to continued hunting opportunity (Kanstrup 2015). On the contrary, it is believed that the valuable public image of hunters visibly seen to be reducing the dispersal of a recognized contaminant poison (i.e. lead) into the environment has been of paramount importance for the long-term political sustainability of hunting (Kanstrup et al. 2018).

It is well documented that the effective transition to non-toxic ammunition quickly reduces the level of poisoning in wild birds. However, it is easy to ignore lead ammunition's toxic legacy and the long-term persistence of lead shot in ecosystems. These historical residues constitute a persistent and significant toxic threat to wildlife and the reputation of

hunting. The single take-home lesson from the Danish and other experiences is that it takes the initiative of active conservationist groups and a responsible public authority with statutory powers to change mindsets in the wider public interest, no matter how unpopular, and to encourage all affected stakeholders to support the process in resolving this major environmental problem.

Lessons learned from the Danish process could be instructive to other countries facing the same challenge at different stages of the process, but also to Denmark in further reducing the adverse environmental footprints of recreational hunting and thereby enhancing its long-term sustainability.

**Acknowledgements** I am grateful to colleagues, in particular, Hans Peter Hansen and Tony Fox, who made valuable comments that improved earlier drafts. Vernon Thomas also supported the process considerably. I thank also peer reviewers who gave substantial and very helpful comments and suggested many relevant improvements.

## REFERENCES

- Anderson, W.L., S.P. Havera, and B.W. Zercher. 2000. Ingestion of lead and nontoxic shotgun pellets by ducks in the Mississippi Flyway. *Journal of Wildlife Management* 64: 848–857.
- Bach, J., and I.M. Thomsen. 1992. Konsekvenser ved stålhagl i skoven. *Skoven* 24: 97–98.
- Bellrose, F.C. 1959. Lead poisoning as a mortality factor in waterfowl populations. *Bulletin: Illinois Natural History Survey* 7 27: 233–238.
- Clausen, B., and C. Wolstrup. 1979. Lead poisoning in game from Denmark. *Danish Review of Game Biology* 11: 1–22.
- Clausen, K.K., T.E. Holm, L. Haugaard, and J. Madsen. 2017. Crippling ratio: A novel approach to assess hunting-induced wounding of wild animals. *Ecological Indicators* 80: 242–246.
- Cromie, R., J. Newth, J. Reeves, M. O'Brien, K. Beckmann, and M. Brown. 2015. The sociological and political aspects of reducing lead poisoning from ammunition in the UK: Why the transition to non-toxic ammunition is so difficult. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay and C.J. Spray. Oxford: Edward Grey Institute, The University of Oxford.
- Dansk Jagt. 1987. Blyhagl-razzia—jægere står til bøde. Notice in *Dansk Jagt*. December 1987, p. 6.
- Eskildsen, J. 1980. *Tætheden af blyhagl i lavvandede vestjyske fjordområder*. Naturhistorisk Museum.
- Hartmann, P. 1982. *Stålhaglpatroner. Vurdering af stålhaglpatroners egnethed til jagt i Danmark*. København: Miljøstyrelsen.
- Kanstrup, N. 1987. Jernhaglpatroners anvendelighed. *Jagt- & Fiskeri*, 10/1987.
- Kanstrup, N. 2012. *Lead in game birds in Denmark: Levels and sources*. Danish Academy of Hunting. Article 2012-1.
- Kanstrup, N. 2015. Practical and social barriers to switching from lead to non-toxic gunshot—A perspective from the EU. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay and C.J. Spray. Oxford: Edward Grey Institute, The University of Oxford.
- Kanstrup, N., and T.J.S. Balsby. 2018. Plastic litter from shotgun ammunition on Danish coastlines—Amounts and provenance. *Environmental Pollution* 237: 601–610.
- Kanstrup, N. and K. Stenkjær. 2015. Skovhagl—er der fortsat grundlag for en særlig forvaltning? Institute of Geoscience and Nature Management, Copenhagen University. Report. Maj 2015. ISBN 978-87-7903711-3 (with an English summary). [https://forskning.ku.dk/find-en-forsker/?pure=files%2F138856612%2Fskovhagl\\_IGU.pdf](https://forskning.ku.dk/find-en-forsker/?pure=files%2F138856612%2Fskovhagl_IGU.pdf).
- Kanstrup, N., V.G. Thomas, O. Krone, and C. Gremse. 2016. The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations. *Ambio* 45: 621–628. <https://doi.org/10.1007/s13280-016-0780-y>.
- Kanstrup, N., J. Swift, D.A. Stroud, and M. Lewis. 2018. Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47: 846–857. <https://doi.org/10.1007/s13280-018-1042-y>.
- Lumeij, J.T., H. Hendriks, A. Timmers, and A. 1989. The prevalence of lead shot ingestion in wild mallards (*Anas platyrhynchos*) in the Netherlands. *Veterinary Quarterly* 11: 51–55. <https://doi.org/10.1080/01652176.1989.9694196>.
- Mateo, R., N. Vallverdú-Coll, A. López-Antia, M.A. Taggart, M. Martínez-Haro, R. Guitart, and M.E. Ortiz-Santaliestra. 2014. Reducing Pb poisoning in birds and Pb exposure in game meat consumers: The dual benefit of effective Pb shot regulation. *Environment International* 63: 163–168.
- Meltofte, H., and B.D. Petersen. 1979. Forekomst af blyhagl i vestjyske vådområder samt i kråsen hos danske ænder. *DOFT* 73: 265–272.
- Mondain-Monval, J.Y., P. Defos du Rau, M. Guillemain, and A. Olivier. 2015. Switch to non-toxic shot in the Camargue, France: Effect on waterbird contamination and hunter effectiveness. *European Journal of Wildlife Research* 61: 271–283. <https://doi.org/10.1007/s10344-014-0897-x>.
- Munch, B. 1968. Blyforgiftning hos fuglevildt efter optagelse af hagl. *Dansk Vildtforskning* 1967–68. Meddelelse nr. 65 fra Vildtbiologisk Station.
- Noer, H., J. Madsen, H. Strandgaard, and P. Hartmann. 1996. Anskydning af vildt. - *TEMA-rapport fra DMU*, nr. 8.
- Pierce, B.L., T.A. Roster, M.C. Frisbie, C.D. Mason, and J.A. Roberson. 2014. A comparison of lead and steel shot loads for harvesting mourning doves. *Wildlife Society Bulletin* 39: 103–115. <https://doi.org/10.1002/wsb.504>.
- Politiken. 2011. Jægere bruger stadig blyhagl trods forbud. Newspaper article 11 March 2011.
- Samuel, M.D., and E.F. Bowers. 2000. Lead exposure in American black ducks after implementation of non-toxic shot. *Journal of Wildlife Management* 64: 947–953.
- Stevenson, A.L., A.M. Scheuhammer, and H.M. Chan. 2005. Effects of nontoxic shot regulations on lead accumulation in ducks and American woodcock in Canada. *Archives of Environmental Contamination Toxicology* 48: 405–413.
- Strandgaard, H. 1993. Untersuchungen zur tödenden Wirkung von Eisen- und Bleischroten. *Zeitschrift für Jagdwissenschaft* (1993) 39: 34. <https://doi.org/10.1007/bf02310215>.
- Stroud, D. 2015. Regulation of some sources of lead poisoning: A brief review. In *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay and C.J. Spray, 152 pp. UK: Edward Grey Institute, The University of Oxford.
- Thomas, V.G., N. Kanstrup, and C. Gremse. 2015. Key questions and responses regarding the transition to use of lead-free ammunition. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay and C.J. Spray, 125–135. Oxford: The Edward Grey Institute.
- Wium-Andersen, S. 1973. Bly ... et regneeksempel. *Feltornitologen* 1: 27.

Wium-Andersen, S., and N.E. Franzmann. 1974. Dør andefugle af at spise blyhagl? *Feltornitologen* 1974: 14.

## AUTHOR BIOGRAPHY

**Niels Kanstrup** (✉) is a Danish biologist, scientist, and hunter. He has been working with the Danish Hunters' Association, been President of the CIC Migratory Bird Commission, a member of the AEWa technical Committee, and during his whole career worked

with sustainability of hunting and focused particularly on the issue of lead in hunting ammunition. Today he is an independent consultant in nature management and an adjunct scientist with an excessive research program at Aarhus University, Department of Bioscience at Kalø.

*Address:* Institute for Bioscience – Kalø, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark.

e-mail: nk@bios.au.dk



# PAPER 11

Thomas VG, Kanstrup N, Fox AD (2019). The transition to non-lead sporting ammunition and fishing weights: Review of progress and barriers to implementation. Ambio 48:925-934 doi:10.1007/s13280-018-1132-x

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

## Order Summary

Licensee:	Aarhus University
Order Date:	Mar 8, 2020
Order Number:	4784340636060
Publication:	AMBIO
Title:	The transition to non-lead sporting ammunition and fishing weights: Review of progress and barriers to implementation
Type of Use:	Thesis/Dissertation
Order Ref:	Intro'
Order Total:	0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customercare@copyright.com](mailto:customercare@copyright.com)  
<https://myaccount.copyright.com>



## AUTHORS' CONTRIBUTIONS

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above, of which I am first author, was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Prof. Emeritus Vernon Thomas

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

Email: [vthomas@uoguelph.ca](mailto:vthomas@uoguelph.ca)

Dear Niels

I hereby confirm the following contribution to the article of which I am an author:

Thomas VG, Kanstrup N, Fox AD (2019) The transition to non-lead sporting ammunition and fishing weights: Review of progress and barriers to implementation *Ambio* 48:925-934 doi:10.1007/s13280-018-1132-x

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above, of which I am an author, was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely



*Professor Anthony D. Fox  
Department of Bioscience  
Aarhus University  
Køge  
Grenåvej 14  
DK-8410 Rønde  
Denmark*

Confirmed, April 2021



Niels Kanstrup

# The transition to non-lead sporting ammunition and fishing weights: Review of progress and barriers to implementation

Vernon G. Thomas, Niels Kanstrup, Anthony D. Fox

Received: 18 September 2018 / Revised: 12 November 2018 / Accepted: 13 November 2018

**Abstract** This review presents evidence of lead exposure and toxicity to wildlife and humans from spent shotgun and rifle ammunition and fishing weights, and the barriers and bridges to completing the transition to non-lead products. Despite the international availability of effective non-lead substitutes, and that more jurisdictions are adopting suitable policies and regulations, a broader transition to non-lead alternatives is prevented because resolution remains divided among disparate human user constituencies. Progress has occurred only where evidence is most compelling or where a responsible public authority with statutory powers has managed to change mindsets in the wider public interest. Arguments opposing lead bans are shown to lack validity. Differing national regulations impede progress, requiring analysis to achieve better regulation. Evidence that lead bans have reduced wildlife exposure should be used more to promote sustainable hunting and fishing. Evidence of the lead contribution from hunted game to human exposure should shape policy and regulation to end lead ammunition use. The Special Issue presents evidence that a transition to non-lead products is both warranted and feasible.

**Keywords** Bullets · Effectiveness · Exposure · Regulations · Shot · Socio-politics

*... that this mischievous Effect of Lead is at least above Sixty years old, and you will observe with Concern how long a useful Truth may be known and exist before it is receiv'd and practic'd on. (Franklin 1786)*

## INTRODUCTION

Although lead is biologically unessential, it has been important in human cultural evolution, despite awareness of its toxicity to humans for many centuries (Hernberg 2000). The biochemical actions of lead in the bloodstream (Kirberger et al. 2013; Maret 2017) are similar among diverse animal species because of their homologous physiological origins. Hence, the similar manifestations of exposure and toxicity in different animal and human species regardless of whether the lead originated from lead shot, bullets, sinkers, or other anthropogenic sources. Awareness of the toxic effects of assimilated lead in humans has led to passing of national laws and regulations in many nations, mainly in relation to paints and gasoline, and is still continuing (UNEP 2010, 2016). A consensus statement by some of the leading scientific experts on the deleterious effects of lead ingestion called for action to reduce the use of lead ammunition (Bellinger et al. 2013), in the same manner as lead reduction in paints, gasolines, and other human applications.

The above quotation of Franklin attests to the problems of eliminating lead from all human uses, especially the lengthy, highly contested attempts to thwart bans on the use of lead, in gasoline and paint (Rosner and Markowitz 2007), and, more recently, in ammunition and fishing weights (Stroud 2015). Evidence of the toxicity of ingested lead to birds is over a century old (Bowles 1908). However, it was not until the 1970s that attempts to prevent this wildlife disease began (U.S. Fish and Wildlife Service 1986). A temporal progression in the understanding of the

extent and impacts of lead exposure among wildlife exists. Initially, it was seen primarily among migratory waterfowl and their predators, then to upland game and their predators. The role of lead from spent rifle bullets in the poisoning of carrion feeders appeared later (Helander et al. 2009; Legagneux et al. 2014; Garbett et al. 2018; Isomursu et al. 2018), as did the effects of ingested lead from hunter-shot game meat upon human health (Bjerregaard et al. 2004; Fachehoun et al. 2015; Green and Pain 2015). The same time frame has accompanied bans on the use of lead shot, beginning in 1986 with Denmark and 1991 in the USA, with bans for hunting waterfowl over wetland habitats, and continues to the present. To date, 33 nations have passed national or regional legislation requiring use of non-lead<sup>1</sup> shotgun ammunition, but mainly for hunting in wetlands or hunting particular waterfowl species (Stroud 2015). Only in continental USA, California, and some German jurisdictions has enforced regulation been implemented to protect susceptible raptor species from ingestion of lead from hunted game: Bald Eagles (*Haliaeetus leucocephalus*) throughout the USA, California Condors (*Gymnogyps californianus*) in California (Thomas 2009), and White-tailed Sea Eagles (*Haliaeetus albicilla*) in Germany (Krone et al. 2009).

Canada banned the use of lead fishing sinkers to prevent fatal poisoning of Common Loons (*Gavia immer*) in 1997, but only in national parks and national wildlife areas which comprise a minority of the species national habitat. Only five US states (Maine, Massachusetts, New York, New Hampshire, and Vermont) have enacted legislation to prevent lead poisoning from ingested lead sinkers during their breeding period, leaving this species, and other piscivorous species, susceptible to lead sinker exposure in other parts of their winter range (Thomas 2019). The UK passed in 1987 a regulation to prevent use of commonly ingested fishing sinkers by Mute Swans (*Cygnus olor*) (Sears and Hunt 1991). Denmark and The Netherlands stand out as the only nations to have banned completely the use of lead shot for hunting. Paradoxically, Denmark, while also banning trade in lead fishing weights, still allows use of lead-core rifle ammunition for hunting (Kanstrup et al. 2016a).

The development of non-lead shotgun and rifle ammunition and fishing sinkers has facilitated the transition to non-lead products. However, despite the existence of effective non-toxic substitutes for hunting and fishing, a range of obstacles has been created to impede this transition. While there is a single lead exposure issue arising from the use of lead gunshot, rifle bullets, and fishing sinkers, and their predictable effects on wildlife and the

environment, the different socio-political issues surrounding their use often prevent that which scientific evidence would recommend (Cromie et al. 2015; Arnemo et al. 2016).

Several major reviews of lead exposure and toxicity to wildlife have been made by the U.S. Fish and Wildlife Service (1986, for the USA), Pain (1992), Watson et al. (2009), Delahay and Spray (2015, for Britain and Europe). The present review, with emphasis on the more recent literature, examines the principal factors that have made the transition to non-lead products such a slow process, and indicates how regulatory progress on this issue could be accelerated. Denial of the issue (Arnemo et al. 2016) and recalcitrance to progress thrive on ignorance of scientific understanding (Cromie et al. 2015). Thus, the development of government policy and petitions for the use of non-lead products has to be based on the latest and best available scientific evidence. This includes evidence of the latest geographic occurrences of lead exposure and toxicity to convince authorities that the issue does occur within their jurisdiction, and further evidence of the adverse overt and sub-clinical effects on an ever-growing number of species, including humans. Reports on the conservation benefits of using non-lead ammunition are growing rapidly, as is the economic evidence concerning their availability and costs.

## FACTORS IMPEDING THE TRANSITION TO NON-LEAD PRODUCTS

### Diversity of sporting communities using lead products

The enormous scientific evidence of lead exposure and toxicity to wildlife and humans from different types and uses of ammunition (Arnemo et al. 2016) and sinkers (Franson et al. 2003) would suggest that a broad transition to non-lead products would occur. Such is not the case. Requirements for non-lead ammunition and sinkers have been made only where and when the evidence is most compelling or where a responsible public authority with statutory powers has managed to change mindsets in the wider public interest. This is due, partly, to the diversity of the sporting constituencies and their national and international representative agencies. Thus hunters of waterfowl, upland game, and big game have different perceptions of problematic lead exposure and how to resolve it. Even more distinct are the perceptions of the non-hunting target shooters and sport anglers. The only commonality among these constituencies is a reluctance to forgo use of lead products (Thomas and Guitart 2016)—the antithesis of their sports' sustainability (Kanstrup et al. 2018).

<sup>1</sup> "Non-lead" means containing less than 1% lead by mass, as is used synonymously with "lead-free" and "non-toxic."

The international ammunition industry, while well able to supply non-lead ammunition to all its consumers, endorses the pro-lead lobby by mis-representing scientific information to contend that lead in ammunition is not toxic (AFEMS/WFSA 2015; Arnemo et al. 2016). The International Shooting Sports Federation that represents target shooting at the Olympic level denies that its sports warrant use of non-lead munitions (Thomas and Guitart 2013). While current emphasis to use non-lead ammunition is placed on hunting, the release of lead from target shooting is regulated in few jurisdictions, despite its much higher release of lead to environments (Thomas and Guitart 2013). Collectively, these disparate sport groups and their representative agencies are a potent barrier to ending lead exposure, despite the universally common symptoms of lead exposure and toxicity seen in the environment, wildlife, and humans. Complementing the interests of these sporting groups are the arms and ammunition industries whose economic interests also favor the continued use of lead products (AFEMS/WFSA 2015).

### Questionable validity of the population-level criterion

Opposition to a ban on lead shot for game hunting has been based on the criterion of whether the observed level of lead-induced mortality depresses the population status of a species in question, meaning a negative effect on recruitment and survivorship (GWCT 2016). It is contended that if the afflicted population can withstand that level of mortality, in addition to hunting mortality, there is no case to ban lead shot use. This argument rests on the traditional practice used for defining a harvestable level of surplus animals from some population (Leopold 1930), plus the assumption that some of those animals affected by lead exposure would have succumbed to natural mortality, i.e., compensatory mortality. This argument supposes that one can define accurately the population in question, a problem facing all ecologists (Krebs 1994). It begs the question of scale of population size and distribution: whether continental, national, international, regional, or local, and especially for migratory species. Members of migratory species may disperse and breed in diverse locations, but aggregate in geographically confined wintering locations, so defying population identification. Moreover, there is no scientifically agreed-upon consensus that intervention to prevent further poisoning of a wildlife species should begin only when evidence of risk is confirmed at some defined population, rather than the individual level. This is, therefore, an arbitrary criterion, devised to serve the interests of the pro-lead lobby. With passage of time and further lead deposition, all exposure becomes, inevitably, a wider

population issue, however defined. Dispersed gunshot is available to be ingested by both game and non-game species. Twenty-two species of European waterbirds have been recorded to have ingested spent lead gunshot, eight of which are listed in the Birds Directive's Annex 1 (CEC 1979). Lead poisoning is also about the health of individual animals.

Loss et al. (2012) reviewed the topic of human-caused mortality and impact on populations, and commented that:

Since direct mortality sources kill large numbers of birds and uncertainty is inherent in even the most sophisticated analytical approaches, we conclude by proposing that those making policy decisions based on mortality estimates and population assessments should consider adopting a precautionary approach.

Unintended losses of wildlife attend hunting due to the inefficiency of the hunting process. They arise from animals wounded and lost, and animals killed, but not retrieved. In the case of waterfowl hunting in North America, this loss (known as crippling losses) is large, often exceeding 20% of the actual retrieved kill (Norton and Thomas 1994). However, national waterfowl harvests have been adjusted to accommodate such losses that are regarded, by some, as the acceptable costs of inefficient waterfowl hunting. These losses generally exceed the reported rates of lead-induced mortality among North American waterfowl species, an argument used, again, to negate the need to ban use of lead shot for hunting in other jurisdictions. Thus, the criteria for regulating the use of potentially toxic lead ammunition differ when applied to wild species and humans. For humans, it is the individual and not the population that matters. It is simply that the health of individual humans is held in higher ethical and legal regard than the welfare of most wild species, and that lead-induced mortality among wildlife can be readily externalized to wild populations, regardless of scale. Lead exposure from spent ammunition is a humanly induced problem, but is also humanly preventable.

Regardless of the questionable validity of using population-level effects as the criterion warranting the transition to non-lead hunting ammunition, recent scientific evidence indicates that there are already significant impacts of lead-induced poisoning and subsequent mortality of birds at the national–international scale, including rare and globally threatened species. This is demonstrated in the endangerment of White-backed Vultures (*Gyps africanus*) in Botswana (Garbett et al. 2018), California Condors, and other scavenging birds in the continental USA (Golden et al. 2016). Different species of eagles have been shown to be seriously impacted by lead ammunition ingestion across the holarctic (Nadjafzadeh et al. 2013; Ecke et al. 2017; Ishii et al. 2017; Gil-Sánchez et al. 2018; Isomursu et al.

2018). Population-level declines in waterfowl wintering in the UK have been identified (Green and Pain 2016). Lead fishing weights have been identified in the toxicity and substantial population decline of Common Loons in the north-eastern part of their US range (Grade et al. 2018).

For several bird species, the issue of a putative population-level effect has now become a definite species-level effect. Kanstrup et al. (2018) identified international action plans for 23 species of birds where poisoning from lead ammunition was concluded to have negative impact on conservation. One example is Bewick's Swan (*Cygnus columbianus*), an European migrant and wintering species listed in Annex I of the Birds Directive, thus requiring the designation of Special Protection Areas and proactive planning to ensure a favorable conservation status. Despite its being a protected species in every country within its international range, between 1995 and 2010 numbers of Bewick's Swans in the flyway from arctic Russia to northern Europe declined from 29 000 to 18 000. Consequently, an array of conservation efforts has been established. This includes an International Single Species Action Plan under AEWA (Nagy et al. 2012), which is also supported by the Bern Convention's Standing Committee (Rec. No. 165) and which calls for measures to reduce mortality from lead poisoning. Bewick's Swan and other swan species are exposed to contamination by spent lead shot (Newth et al. 2013, 2016). In the North-west Europe flyway, lead ingestion was the cause of death in 14.6% of adults examined *post mortem* in the UK (Brown et al. 1992; Rees 2006). International efforts to improve the conservation status of this species are hindered by increased mortality, morbidity, and other impacts of sub-lethal contamination from lead shot.

The Spanish Imperial Eagle (*Aquila adalberti*) exists only in the Iberian Peninsula and is one of Europe's most threatened birds of prey. Rodríguez-Ramos Fernández et al. (2011) found that three birds of a sample of 84 (3.6%) had bone lead concentration  $> 20 \mu\text{g/g}$ . Lead concentrations in feathers were positively associated with the density of large game animals in the area where birds were found dead or injured. Death of adults of this *K*-selected species, even in small numbers, could impede the recovery of its small population (Pain et al. 2009). Rodríguez-Ramos Fernández et al. (2011) concluded that the use of lead-free ammunition in upland hunting would reduce potential lead exposure to the Spanish Imperial Eagle and contribute to its recovery. A similar situation exists for the Andean Condor (*Vultur gryphus*), in which high levels of bone and blood lead indicate that the species is threatened at the continental level across South America (Wiemeyer et al. 2017).

Ferreya et al. (2015) indicated that serious sub-clinical effects of lead that may pre-dispose animals (waterfowl) to mortality are equally important to consider as observed

mortality in favoring adoption of non-lead ammunition. Such an example is the deleterious effect of ingested lead on the immune response of birds (Vallverdú-Coll et al. 2015). The extent of sub-lethal effects and suffering of lead poisoned and dying animals has been little researched. There is, however, considerable expert knowledge that lead poisoning can seriously affect health and welfare, the pathological and clinical signs being consistent with causing severe and prolonged suffering. These considerations negate, further, the use of a population-level effect as a criterion for ending lead products' use. Collectively, these studies implicate lead derived from gunshot, rifle bullets, and sinkers. As Reed and Blaustein (1997) commented:

Therefore determining biological significance a priori of a population decline is arbitrary – a political decision.

### Availability, costs, and effectiveness of non-lead products

These three terms are often central to objections to banning use of lead products (Thomas 2015). Retail availability of any product is directly related to its public demand. Thus, a Catch-22 situation exists in which the ammunition makers are reluctant to invest in product development, production, marketing, and distribution unless there are assurances of public demand. The unpopular replacement of traditional lead products by novel lead substitutes requires regulation to ensure public demand, and thus, availability (Thomas 2015). The growing number of jurisdictions requiring use of non-toxic shot has resulted in most major ammunition makers offering lines of steel shot and other non-lead cartridges, so increasing availability (Thomas and Guitart 2010).

Prices of certain non-lead products reflect world prices of their principal ingredients (especially tungsten, tin, and bismuth). Prices also reflect consumer demand directly. Furthermore, prices may decline when economies of scale increase, and when increased demand spurs competition among manufacturers. Prices of non-lead products have not presented a barrier to participation in shooting and fishing sports (Kanstrup 2015). Steel shot cartridges may be as comparably priced as their high-quality lead shot cartridges of similar gauge and loads (Thomas 2015). The same general finding applies to non-lead and lead-core rifle ammunition (Thomas 2013). Moreover, the range of non-lead rifle cartridge calibers and bullet types made by North American and European companies satisfies the vast majority of hunters' requirements (Thomas et al. 2016).

Since 1991, American and European hunters of waterfowl and upland game have shown that shotgun cartridges

containing steel or other non-lead materials are highly effective when used competently and responsibly (Kanstrup 2015; Pierce et al. 2015). More recently, published field studies indicate that non-lead rifle ammunition is equally as effective as lead-core equivalents in killing game (Trinogga et al. 2013; Kanstrup et al. 2016b; McCann et al. 2016; Martin et al. 2017; McTee et al. 2017). These studies report on the killing of animals ranging in size from Columbian Ground Squirrels (*Urocitellus columbianus*), Roe Deer (*Capreolus capreolus*), Red Deer (*Cervus elaphus*), and Wild Boar (*Sus scrofa*) to American Elk (*Cervus canadensis*) taken by hunters under prevailing field conditions. What is limiting is the regulation requiring its wide-scale use. Widespread use of lead bullets to kill Australian wildlife poses significant threats to both wildlife and human health (Hampton et al. 2018). However, no regulatory initiatives are underway, despite the extensive evidence of potential exposure and availability of non-lead substitutes (Hampton et al. 2018).

Substitutes for lead sinkers are made from pure tin, stainless steel, tungsten-plastics, and bismuth-tin alloys, all of which are non-toxic to wildlife (Twiss and Thomas 1998). They are available for use in wet-fly fishing and as conventional sinkers, and their use in the UK has certainly contributed to reduced lead exposure and mortality in Mute Swans (Sears and Hunt 1991). It is not possible to assess their role in reducing lead exposure and mortality among piscivorous species in North America. This is because non-lead sinkers are required in only parts of the species' annual migratory range, and continued use of lead sinkers outside those areas still poses risk to these species, especially Common Loons (Grade et al. 2018).

### Regulatory limitations and inconsistencies

While repeated attempts to regulate bans on the use of lead ammunition have been made at the international level by the African Eurasian Waterbird Agreement (AEWA) and the Convention on Migratory Species (CMS) of the United Nations Environment Programme (Kanstrup et al. 2018), none, to date, has succeeded. This is because it behooves any national or multinational Party (such as the European Union) to such an agreement or treaty to enact enabling legislation, but this has proven limiting. For migratory species, the primary consideration is protection of the flyways and the critical wintering grounds from lead exposure, so necessitating cooperation among all nations involved, especially those where the greatest risks of exposure exist. Clearly, this is where common and consistent regulation among countries that share migratory routes is required.

The issue of regulatory jurisdiction is central to understanding the capacity of laws to protect wildlife from lead

exposure. Thomas and Guitart (2010) analyzed the legislation of the EU and the USA with regard to implementing bans on lead shot use, and indicated why the US federal law was able to effectively ban lead shot use for waterfowl hunting. However, while both the USA and Canada (under the Canada–USA Migratory Birds Treaty) have nationwide requirements for non-lead shot when hunting federally regulated waterfowl, such requirements still do not exist when hunting species controlled by individual state and provincial jurisdiction. Where such a jurisdiction does develop regulation to control lead ammunition use (e.g., California in 2019), there is no obligation for other or adjacent states to develop complementary regulation. As an example, California passed the Ridley-Tree Condor Preservation Act in 2007 requiring hunters to use non-lead ammunition when hunting in the California range of that species. However, Utah and Arizona also comprise part of that species' range, but no complementary legislation still exists (Thomas 2009).

While regulatory progress has been made by some countries and jurisdictions within them, regulatory limitations and inconsistencies prevent a complete transition to non-lead products. Although California is the leading US state in regulating lead ammunition (both shotgun and rifle) use, under Assembly Bill 711, it does not apply to target shooting or sport fishing when due to take effect in 2019. Denmark, while banning trade in lead sinkers for fishing, and lead shot for hunting and target shooting, still allows use of lead rifle bullets. Because bullets are used to hunt large species of mammals, and those animals' carcasses become human foods, this issue is of direct relevance to human health and its regulation. The five US states that regulate the use of non-lead fishing sinkers to protect piscivorous birds have different provisions for use, sale, and possession (Thomas 2019), so limiting their effectiveness. British regulations relate to non-lead shot use over wetlands and for hunting wildfowl, ostensibly to prevent lead exposure in wildfowl, but do not apply to adjacent uplands where many wildfowl feed. Separate UK legislation has been used to deal with lead sinkers in Mute Swan habitats and shot in wetlands, again reflecting the perceived disparate nature of the exposure. This disparate perception of the source of the problem, and the restricted regulation that sometimes follows, ultimately refers back to the sporting constituencies using the lead products. As an example, lead shot use in target shooting is regulated at the national level in few jurisdictions, despite the tonnage of lead it adds to environments each year (Thomas and Guitart 2013). These are only some of the inconsistencies to be found in the diverse legislation pertaining to lead ammunition and sinker use.

Passage of regulations assumes that provisions exist to enforce them. While such provision may well exist in

North America, they are often absent in many European countries where hunting occurs mainly on private lands (Thomas and Guitart 2010). This has resulted in low compliance in the UK (Cromie et al. 2015). However, in Spanish wetland hunting, Mateo et al. (2014) reported marked compliance with non-lead shot regulations from 2007 to 2012 that resulted in reduced rates of lead shot ingestion in several species of common waterfowl. The Danish and Dutch regulation of sale, possession, and use of lead shot ammunition obviates this compliance problem. An in-depth examination of the regulations used by different governments would be a fruitful method to develop, and perhaps revise, legislation that serves better the needs of wildlife and the environment.

### Impacts on human health

Animals killed with lead ammunition may contain fragments of lead that are ingested by humans who eat game. This represents the latest awareness of the impact of spent lead ammunition, whether the lead originates from shot or bullets, and especially among societies that consume large quantities of wild game, including avid hunters and aboriginal people (Bjerregaard et al. 2004; Hunt et al. 2009; Lindboe et al. 2012; Fachehoun et al. 2015; Green and Pain 2015; Juric et al. 2018). The greater the consumption of shot game, the greater is the level of lead exposure and its potential effects (Gerofke et al. 2018), especially upon pregnant women and their fetuses, and young children (WHO 2015).

The scientific interest in this aspect of lead exposure is increasing rapidly because of the human public health connection (Delahay and Spray 2015; Arnemo et al. 2016; Gerofke et al. 2018). In Europe, and other parts of the world where lead-killed game is sold legally, concern arises over the higher lead levels in retail game meats (Morales et al. 2011; Vogt and Tysnes (2015) relative to permitted levels in domestically reared meats [European Commission threshold is 0.1 mg Pb/kg domesticated meat (Commission Regulation 2001)]. Lead ingested from the carcass of game animals used for human food, and in the discarded gut piles and non-retrieved game ingested by scavengers, afflict both alike. Thus, recent calls for the use of non-lead ammunition are now based on effects on both wildlife and humans (for example Hampton et al. 2018). It is interesting to note that use of non-lead ammunition to kill game eaten by humans would have an immediate effect in eliminating lead exposure in both humans and scavengers.

Public health agencies in a number of countries are aware of the contribution of ingested lead to humans, and advisories about eating lead-contaminated game exist. However, such advisories have yet to evolve into

government policy and regulation of lead ammunition. It is vital to build the body of evidence about this source of food contamination, not least because venison is increasing in popularity among consumers. Lead-killed game meat is exported internationally, especially in Europe, so the local issue of ammunition use in hunting quickly becomes an international issue of food quality and health risks. This provides a newer approach to resolving the problem of lead shotgun and rifle ammunition use for game shooting.

### Emphasizing the proven benefits of using non-lead products in policy development

In some regions where use of non-lead ammunition and fishing sinkers has been required, a growing body of evidence indicates that lead exposure and toxicity to wildlife is diminishing. This applies to continental waterfowl in the USA and Canada (Anderson et al. 2000; Samuel and Bowers 2000; Stevenson et al. 2005), waterfowl in Denmark and Spain (Mateo et al. 2014; Kanstrup 2019), avian scavengers in part of California (Kelly et al. 2011), and Mute Swans in the UK (Sears and Hunt 1991). In the USA, the Bald Eagle numbers have shown a progressive recovery, due both to the prohibition of harmful pesticides and the nationwide ban on lead ammunition since 1991 (Bedrosian et al. 2012; Eakle et al. 2015). Given the importance of such publications in supporting the case for using non-lead products, it is necessary to continue monitoring and reporting on trends in the prevalence of lead exposure in wildlife to demonstrate the efficacy of this practice. It is also important to emphasize and use this evidence of deliberate conservation of wild life that serves the interests of the hunting constituencies and is consistent with “sustainable hunting,” as defined by Kanstrup et al. (2018).

### CONCLUSIONS

Two policy/regulatory approaches emerge to reduce lead exposure from hunting. One bans lead ammunition and lead sinker use in all of the habitats comprising international migratory bird flyways to protect the health of waterbirds. The other bans lead ammunition used to kill animals used for human food, which, if adopted, would quickly reduce dietary lead exposure in humans and scavengers. Both approaches are needed to address the single lead exposure issue. While there is redundancy in the two approaches, they are complementary, and apply across several of the hunting constituencies. As more jurisdictions (especially California in 2019) require use of non-lead ammunition, there is need for monitoring of the success of this management option, as it relates to the further development, availability, and use of non-lead

products, their contribution to lower lead exposure and mortality, and their role in more sustainable hunting. The conservation successes that are already apparent from non-lead product use should be used more as the basis of policy and regulatory initiatives, as, for instance, in the current European REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) initiative.<sup>2</sup> Lowering lead exposure across all habitats of migratory bird flyways requires equal levels of regulatory participation among nations, and especially the harmonization of enforceable regulations. The benefit to human health from using non-lead ammunition to procure wild game food could be a novel and propitious avenue to banning lead shot and bullet use. If successful, this approach would assist the international sales of “lead-free” game meat, while simultaneously reducing the incidence of lead ingestion in humans and among different species of scavengers. The existing array of non-lead ammunition and sinker products that could replace lead is not limiting. It is the socio-politically contrived resistance to their use that has to be overcome.

**Acknowledgements** The authors are grateful to the reviewers for their constructive comments on this paper. Funding was provided from the personal private resources of the authors.

## REFERENCES

- AFEMS/WFSA. 2015. Symposium “The sustainable use of lead ammunition in hunting and sports shooting: Facts and emotions” press release. [http://leadsymposium.eu/en/the\\_symposium\\_release.aspx](http://leadsymposium.eu/en/the_symposium_release.aspx).
- Anderson, W.L., S.P. Havera, and B.W. Zercher. 2000. Ingestion of lead and non-toxic gunshot pellets by ducks in the Mississippi flyway. *Journal of Wildlife Management* 64: 848–857. <https://doi.org/10.2307/3802755>.
- Arnemo, J.M., O. Anderson, S. Stokke, V.G. Thomas, O. Krone, D.J. Pain, and R. Mateo. 2016. Health and environmental risks from lead-based ammunition: Science versus socio-politics. *Eco-Health* 13: 618–622. <https://doi.org/10.1007/s10393-016-1177-x>.
- Bedrosian, B., D. Craighead, and R. Crandall. 2012. Lead exposure in bald eagles from big game hunting, the continental implications and successful mitigation. *PLoS ONE* 7: e51978. <https://doi.org/10.1371/journal.pone.0051978>.
- Bellinger, D.C., J. Burger, T.J. Cade, D.A. Cory-Slechta, M. Finkelstein, H. Hu, M. Kosnett, P.J. Landrigan, et al. 2013. Health risks from lead-based ammunition in the environment. *Environmental Health Perspectives* 121: A178–A179. <https://doi.org/10.1289/ehp.1306945>.
- Bjerregaard, P., P. Johansen, G. Mulvad, H. Pedersen, and J.C. Hansen. 2004. Lead sources in human diet in Greenland. *Environmental Health Perspectives* 112: 1496–1498. <https://doi.org/10.1289/ehp.7083>.
- Bowles, J.H. 1908. Lead poisoning in ducks. *Auk* 25: 312–313.
- Brown, M., E. Linton, and E.C. Rees. 1992. Causes of mortality among wild swans in Britain. *Wildfowl* 43: 70–79.
- Commission of the European Communities (CEC). 1979. Council Directive 79/409/EEC of 2 April on the conservation of wild birds. *Official Journal of the European Union* L103: 1–18.
- Commission Regulation (EC). 2001. Setting maximum levels for certain contaminants in foodstuffs. *Official Journal of the European Communities* No. 466/2001.
- Cromie, R., J. Newth, J. Reeves, M. O’Brien, K. Beckmann, and M. Brown. 2015. The sociological and political aspects of reducing lead poisoning from ammunition in the UK: Why the transition to non-toxic ammunition is so difficult. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, ed. R.J. Delahay and C.J. Spray, 104–124. Oxford: Edward Grey Institute, The University of Oxford.
- Delahay, R.J. and C.J. Spray (eds.). 2015. *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*. Oxford: Edward Grey Institute, The University of Oxford.
- Eakle, W.L., L. Bond, M.R. Fuller, R.A. Fischer, and K. Steenhof. 2015. Wintering bald eagle count trends in the conterminous United States, 1986–2010. *Journal of Raptor Research* 49: 259–268.
- Ecke, F., N.J. Singh, J.M. Arnemo, A. Bignert, B. Helander, A.M.M. Berglund, H. Borg, C. Bröjer, et al. 2017. Sublethal lead exposure alters movement behavior in free-ranging golden eagles. *Environmental Science and Technology* 51: 5729–5736. <https://doi.org/10.1021/acs.est.6b06024>.
- Fachehoun, R.C., B. Lévesque, P. Dumas, A. St-Louis, M. Dubé, and P. Ayotte. 2015. Lead exposure through consumption of big game meat in Quebec, Canada: Risk assessment and perception. *Food Additives and Contaminants: Part: A* 32: 1501–1511. <https://doi.org/10.1080/19440049.2015.1071921>.
- Ferreira, H., P.M. Beldomenico, K. Marchese, M. Romano, A. Caselli, A.I. Correa, and M. Uhart. 2015. Lead exposure affects health indices in free-ranging ducks in Argentina. *Ecotoxicology* 24: 735–745. <https://doi.org/10.1007/s10646-015-1419-7>.
- Franklin, B. 1786. The famous Benjamin Franklin letter on lead poisoning. <http://environmentaleducation.com/wp-content/uploads/userfiles/Ben%20Franklin%20Letter%20on%20EEA%281%29.pdf>.
- Franson, J.C., S.P. Hansen, T.E. Creekmore, C.J. Brand, D.C. Evers, A.E. Duerr, and S. DeStefano. 2003. Lead fishing weights and other fishing tackle in selected waterbirds. *Waterbirds* 26: 345–352. [https://doi.org/10.1675/1524-4695\(2003\)026%5b0345:LFWAOF%5d2.0.CO;2](https://doi.org/10.1675/1524-4695(2003)026%5b0345:LFWAOF%5d2.0.CO;2).
- Garbett, R., G. Maude, P. Hancock, D. Kenny, R. Reading, and A. Amar. 2018. Association between hunting and elevated blood lead levels in the critically endangered African White-backed Vulture *Gyps africanus*. *Science of the Total Environment* 631–632: 1654–1665. <https://doi.org/10.1016/j.scitotenv.2018.02.220>.
- Gerofke, A., E. Ubig, A. Martin, C. Müller-Graf, T. Selhorst, C. Gremse, M. Spolders, H. Schafft, et al. 2018. Lead content in wild game shot with lead or non-lead ammunition—does “state of the art consumer health protection” require non-lead ammunition?. *PLoS ONE* 13 (7): e0200792. <https://doi.org/10.1371/journal.pone.0200792>.
- Gil-Sánchez, J.M., S. Molleda, J.A. Sánchez-Zapata, J. Bautista, I. Navas, R. Godinho, A.J. García-Fernández, and M. Moleón. 2018. From sport hunting to breeding success: Patterns of lead ammunition ingestion and its effects on an endangered raptor. *Science of the Total Environment* 613–614: 483–491. <https://doi.org/10.1016/j.scitotenv.2017.09.069>.
- Golden, N.H., S.E. Warner, and M.J. Coffey. 2016. Review and assessment of spent lead ammunition and its exposure and effects to scavenging birds in the United States. In *Review of*

<sup>2</sup> <https://echa.europa.eu/documents/10162/d7fb96cf-7956-7406-3568-399ca20151e0>.

- Environmental Contamination and Toxicology*, Vol. 37, ed. P. de Voogt, 123–191. Switzerland: Springer. [https://doi.org/10.1007/978-3-319-23573-8\\_6](https://doi.org/10.1007/978-3-319-23573-8_6).
- Grade, T.J., M.A. Pokras, E.A. Laflamme, and H.S. Vogel. 2018. Population-level effects of lead fishing tackle on common loons. *Journal of Wildlife Management* 82: 155–164. <https://doi.org/10.1002/jwmg.21348>.
- Green, R.E., and D.J. Pain. 2015. Risks of health effects to humans in the UK from ammunition-derived lead. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, eds. R.J. Delahay and C.J. Spray, 27–43. Oxford: Edward Grey Institute, The University of Oxford.
- Green, R.E., and D.J. Pain. 2016. Possible effects of ingested lead gunshot on populations of ducks wintering in the UK. *Ibis* 158: 699–710. <https://doi.org/10.1111/ibi.12400>.
- GWCT (Game and Wildlife Conservation Trust). 2016. Position statement: Lead ammunition. [http://www.gwct.org.uk/policy/position-statements/lead-ammunition/?utm\\_source=Game](http://www.gwct.org.uk/policy/position-statements/lead-ammunition/?utm_source=Game).
- Hampton, J.O., M. Laidlaw, E. Buenz, and J.M. Arnemo. 2018. Heads in the sand: Public health and ecological risks of lead-based bullets for wildlife shooting in Australia. *Wildlife Research* 45: 287–306. <https://doi.org/10.1071/WR17180>.
- Helander, B., J. Axelsson, H. Borg, K. Holm, and A. Bignert. 2009. Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden. *Science of the Total Environment* 407: 5555–5563. <https://doi.org/10.1016/j.scitotenv.2009.07.027>.
- Hernberg, S. 2000. Lead poisoning in a historical perspective. *American Journal of Industrial Medicine* 38: 244–254.
- Hunt, W.G., R.T. Watson, J.L. Oaks, C.N. Parish, K.K. Burnham, R.L. Tucker, J.R. Belthoff, and G. Hart. 2009. Lead bullet fragments in venison from rifle-killed deer: Potential for human dietary exposure. *PLoS ONE* 4: e5330. <https://doi.org/10.1371/journal.pone.0005330>.
- Ishii, C., S.M.M. Nakayama, Y. Ikenaka, H. Nakata, K. Saito, Y. Watanabe, H. Mizukawa, S. Tanabe, et al. 2017. Lead exposure in raptors from Japan and source identification using Pb stable isotope ratios. *Chemosphere* 186: 367–373. <https://doi.org/10.1016/j.chemosphere.2017.07.143>.
- Isomursu, M., J. Koivusaari, T. Stjernberg, V. Hirvelä-Koski, and E.-R. Venäläinen. 2018. Lead poisoning and other human-related factors cause significant mortality in white-tailed eagles. *Ambio* 47: 858–868. <https://doi.org/10.1007/s13280-018-1052-9>.
- Juric, A.K., M. Batal, W. David, D. Sharp, H. Schwartz, A. Ing, K. Fediuk, A. Black, et al. 2018. Risk assessment of dietary lead exposure among First Nations people living on-reserve in Ontario, Canada using a total diet study and a probabilistic approach. *Journal of Hazardous Materials* 344: 55–63. <https://doi.org/10.1016/j.jhazmat.2017.09.035>.
- Kanstrup, N. 2015. Practical and social barriers to switching from lead to non-toxic gunshot—a perspective from the EU. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, eds. R.J. Delahay and C.J. Spray, 98–103. Oxford: Edward Grey Institute, The University of Oxford.
- Kanstrup, N. 2019. Lessons learned from 33 years of lead shot regulation in Denmark. In *Lead in hunting ammunition: Persistent problems and solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. <https://doi.org/10.1007/s13280-018-1125-9>.
- Kanstrup, N., V.G. Thomas, O. Krone, and C. Gremse. 2016a. The transition to non-lead rifle ammunition in Denmark: National obligations and policy considerations. *Ambio* 45: 621–628. <https://doi.org/10.1007/s13280-016-0780-y>.
- Kanstrup, N., T.J.S. Balsby, and V.G. Thomas. 2016b. Efficacy of non-lead rifle ammunition for hunting in Denmark. *European Journal of Wildlife Research* 62: 333–340. <https://doi.org/10.1007/s10344-016-1006-0>.
- Kanstrup, N., J. Swift, D.A. Stroud, and M. Lewis. 2018. Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47: 846–857. <https://doi.org/10.1007/s13280-018-1042-y>.
- Kelly, T.R., P.H. Bloom, S.G. Torres, Y.Z. Hernandez, R.H. Poppenga, W.M. Boyce, and C.K. Johnson. 2011. Impact of the California lead ammunition ban on reducing lead exposure in golden eagles and turkey vultures. *PLoS ONE* 6: e17656. <https://doi.org/10.1371/journal.pone.0017656>.
- Kirberger, M., H.C. Wong, J. Jiang, and J.J. Yang. 2013. Metal toxicity and opportunistic binding of Pb<sup>2+</sup> in proteins. *Journal of Inorganic Biochemistry* 125: 40–49. <https://doi.org/10.1016/j.jinorgbio.2013.04.002>.
- Krebs, C.J. 1994. *Ecology: The experimental analysis of distribution and abundance*, 4th ed. New York, NY: Harper Collins.
- Krone, O., N. Kenntner, A. Trinogga, M. Nadjafzadeh, F. Scholz, J. Sulawa, K. Totschek, P. Schuck-Wersig, et al. 2009. Lead poisoning in White-tailed Sea Eagles: Causes and approaches to solutions in Germany. In *Ingestion of lead from spent ammunition: Implications for wildlife and humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 289–301. Boise, ID: The Peregrine Fund. <https://doi.org/10.4080/ilsa.2009.0207>.
- Legagneux, P., P. Suffice, J.-S. Messier, F. Lelievre, J.A. Tremblay, C. Maisonneuve, R. Saint-Louis, and J. Bêty. 2014. High risk of lead contamination for scavengers in an area with high moose hunting success. *PLoS ONE* 9: e111546. <https://doi.org/10.1371/journal.pone.0111546>.
- Leopold, A. 1930. *Game management*. Madison, Wisconsin: University of Wisconsin Press.
- Lindboe, M., E.N. Henrichsen, H.R. Høgåsen, and A. Bernhoft. 2012. Lead concentration in meat from lead-killed moose and predicted human exposure using Monte Carlo simulation. *Food Additives and Contaminants: Part A* 29: 1052–1057. <https://doi.org/10.1080/19440049.2012.680201>.
- Loss, S.R., T. Will, and P.P. Marra. 2012. Direct human-caused mortality of birds: Improving quantification of magnitude and assessment of population impact. *Frontiers in Ecology and Environment* 10: 357–364. <https://doi.org/10.1890/110251>.
- Maret, W. 2017. The bioinorganic chemistry of lead in the context of its toxicity. In *Lead: Its effects on environment and health*, ed. A. Siegel, H. Siegel, and R. Siegel, 1–20. Berlin: Walter de Gruyter and Co. KG.
- Martin, A., C. Gremse, T. Selhorst, N. Bandick, C. Müller-Graf, M. Geiner, and M. Lahrssen-Wiederholt. 2017. Hunting of roe deer and wild boar in Germany: Is non-lead ammunition suitable for hunting? *PLoS ONE* 12: e0185029. <https://doi.org/10.1371/journal.pone.0185029>.
- Mateo, R., N. Vallverdú-Coll, A. López-Antia, M.A. Taggart, M. Matínez-Haro, R. Guitart, and M.E. Ortiz-Santaliestra. 2014. Reducing Pb poisoning in birds and Pb exposure in game meat consumers: The dual benefit of effective Pb shot regulation. *Environment International* 63: 163–168. <https://doi.org/10.1016/j.envint.2013.11.006>.
- McCann, B.E., W. Whitworth, and R.A. Newman. 2016. Efficacy of non-lead ammunition for culling elk at Theodore Roosevelt National Park. *Human-Wildlife Interactions* 10: 268–282.
- McTee, M., M. Young, A. Umansky, and P. Ramsey. 2017. Better bullets to shoot small mammals without poisoning scavengers. *Wildlife Society Bulletin* 41: 736–742. <https://doi.org/10.1002/wsb.822>.
- Morales, J.S.S., R.M. Rojas, F. Pérez-Rodríguez, A.A. Casas, and M.A.A. López. 2011. Risk assessment of the lead intake by consumption of red deer and wild boar meat in Southern Spain.

- Food Additives & Contaminants* 28: 1021–1033. <https://doi.org/10.1080/19440049.2011.583282>.
- Nadjafzadeh, M., H. Hofer, and O. Krone. 2013. The link between feeding ecology and lead poisoning in white-tailed eagles. *Journal of Wildlife Management* 77: 48–57. <https://doi.org/10.1002/jwmg.440>.
- Nagy, S., N. Petkov, E. Rees, A. Solokha, G. Hilton, J. Beekman, and B. Nolet. 2012. International Single Species Action Plan for the conservation of the Northwest European population of Bewick's Swan *Cygnus columbianus bewickii*. AEWa Technical Series No. 44, 63 pp. Bonn, Germany: AEWa. [http://www.unep-aewa.org/meetings/en/mop/mop5\\_docs/pdf/mop5\\_26\\_draft\\_ssap\\_bewicks-swan\\_jkrev.pdf](http://www.unep-aewa.org/meetings/en/mop/mop5_docs/pdf/mop5_26_draft_ssap_bewicks-swan_jkrev.pdf).
- Newth, J.L., R.L. Cromie, M.J. Brown, R.J. Delahay, A.A. Meharg, C. Deacon, G.J. Norton, M.F. O'Brien, et al. 2013. Poisoning from lead gunshot: Still a threat to wild waterbirds in Britain. *European Journal of Wildlife Research* 59: 195–204. <https://doi.org/10.1007/s10344-012-0666-7>.
- Newth, J.L., E.C. Rees, R.L. Cromie, R.A. McDonald, S. Bearhop, D.J. Pain, G.L. Norton, C. Deacon, et al. 2016. Widespread exposure to lead affects body condition of free-living whooper swans *Cygnus cygnus* wintering in Britain. *Environmental Pollution* 209: 60–67. <https://doi.org/10.1016/j.envpol.2015.11.007>.
- Norton, M.R., and V.G. Thomas. 1994. Economic analyses of crippling losses of North American waterfowl and their policy implications for management. *Environmental Conservation* 21: 347–353. <https://doi.org/10.1017/S037689290003366X>.
- Pain, D.J. (ed.). 1992. *Lead poisoning in waterfowl. Proceedings of an IWRB workshop*. Slimbridge: IWRB Special Publication No. 16. The International Waterfowl and Wetlands Research Bureau.
- Pain, D.J., I.J. Fisher, and V.G. Thomas. 2009. A global update of lead poisoning in terrestrial birds from ammunition sources. In *Ingestion of lead from spent ammunition: Implications for wildlife and humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 99–118. Boise, ID: The Peregrine Fund. <https://doi.org/10.4080/ilsa.2009.010.8>.
- Pierce, B.L., T.A. Roster, M.C. Frisbie, and C.D. Mason. 2015. A comparison of lead and steel shot loads for harvesting mourning doves. *Wildlife Society Bulletin* 39: 103–115. <https://doi.org/10.1002/wsb.504>.
- Reed, J.M., and A.R. Blaustein. 1997. Biologically significant population declines and statistical power. *Conservation Biology* 11: 281–282. <https://doi.org/10.1046/j.1523-1739.1997.96339.x>.
- Rees, E.C. 2006. *Bewick's Swan*. London: T. and A.D. Poyser.
- Rodriguez-Ramos Fernandez, J., U. Höfle, R. Mateo, O. Nicolas de Francisco, R. Abbott, P. Acevedo, and J.M. Blanco. 2011. Assessment of lead exposure in Spanish imperial eagle (*Aquila adalberti*) from spent ammunition in central Spain. *Ecotoxicology* 20: 670–681. <https://doi.org/10.1007/s10646-011-0607-3>.
- Rosner, D., and G. Markowitz. 2007. The politics of lead toxicology and the devastating consequences for children. *American Journal of Industrial Medicine* 50: 740–756. <https://doi.org/10.1002/ajim.20435>.
- Samuel, M.D., and E.F. Bowers. 2000. Lead exposure in American black ducks after implementation of non-toxic shot. *Journal of Wildlife Management* 64: 947–953. <https://doi.org/10.2307/3803203>.
- Sears, J., and A. Hunt. 1991. Lead poisoning in Mute Swans, *Cygnus olor*, in England. *Wildfowl Supplement No. 1*: 383–388.
- Stevenson, A.L., A.M. Scheuhammer, and H.M. Chan. 2005. Effects of nontoxic shot regulations on lead accumulation in ducks and American woodcock in Canada. *Archives of Environmental Contamination and Toxicology* 48: 405–413. <https://doi.org/10.1007/s00244-004-0044-x>.
- Stroud, D.A. 2015. Regulation of some sources of lead poisoning: A brief review. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, eds. R.J. Delahay and C.J. Spray, 8–26. Oxford: Edward Grey Institute, The University of Oxford.
- Thomas, V.G. 2009. The policy and legislative dimensions of nontoxic shot and bullet use in North America. In *Ingestion of lead from spent ammunition: Implications for wildlife and humans*, eds. R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, 351–362. Boise, ID: The Peregrine Fund. <https://doi.org/10.4080/ilsa.2009.0311>.
- Thomas, V.G. 2013. Lead-free hunting rifle ammunition: Product availability, price, effectiveness, and role in global wildlife conservation. *Ambio* 42: 737–745. <https://doi.org/10.1007/s13280-012-0361-7>.
- Thomas, V.G. 2015. Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*, eds. R.J. Delahay and C.J. Spray, 85–97. Oxford: Edward Grey Institute, The University of Oxford.
- Thomas, V.G. 2019. Rationale for the regulated transition to non-lead products in Canada: A policy discussion paper. *Science of the Total Environment* 649: 839–845. <https://doi.org/10.1016/j.scitotenv.2018.08.363>.
- Thomas, V.G., and R. Guitart. 2010. Limitations of European Union policy and law for regulating use of lead shot and sinkers: Comparisons with North American regulation. *Environmental Policy and Governance* 20: 57–72. <https://doi.org/10.1002/et.527>.
- Thomas, V.G., and R. Guitart. 2013. Transition to non-toxic gunshot use in Olympic shooting: Policy implications for IOC and UNEP in resolving an environmental problem. *Ambio* 42: 746–754. <https://doi.org/10.1007/s13280-013-0393-7>.
- Thomas, V.G., and R. Guitart. 2016. Exposure to lead through ammunition—need to revise strategies. *Environmental Policy and Law* 46: 127–131. <https://doi.org/10.3233/EPL-46202>.
- Thomas, V.G., C. Gremse, and N. Kanstrup. 2016. Non-lead rifle hunting ammunition: Issues of availability and performance in Europe. *European Journal of Wildlife Research* 62: 633–641. <https://doi.org/10.1007/s10344-016-1044-7>.
- Trinogga, A., G. Fritsch, H. Hofer, and O. Krone. 2013. Are lead-free hunting rifle bullets as effective at killing wildlife as conventional lead bullets? A comparison based on wound size and morphology. *Science of the Total Environment* 443: 226–232. <https://doi.org/10.1016/j.scitotenv.2012.10.084>.
- Twiss, M.P., and V.G. Thomas. 1998. Preventing fishing-sinker-induced lead poisoning of common loons through Canadian policy and regulatory reform. *Journal of Environmental Management* 53: 49–59. <https://doi.org/10.1006/jema.1998.0190>.
- UNEP (United Nations Environment Programme). 2010. *Final review of scientific information on lead*. Paris: DTIE, United Nations Environment Programme.
- UNEP (United Nations Environment Programme). 2016. *Global report on the status of legal limits on lead in paint*. Nairobi: United Nations Environment Programme.
- U.S. Fish and Wildlife Service. 1986. *Use of lead shot for hunting migratory birds in the United States*. Washington, DC: Office of Migratory Bird Management.
- Vallverdú-Coll, N., A. López-Anita, M. Martínez-Haro, M.E. Ortiz-Santaliestra, and R. Mateo. 2015. Altered immune response in mallard ducklings exposed to lead through maternal transfer in

- the wild. *Environmental Pollution* 205: 350–356. <https://doi.org/10.1016/j.envpol.2015.06.014>.
- Vogt, G., and E.A. Tysnes. 2015. *Lead in minced beef from Norwegian hunted game, Elg (Alces alces)*. Moss: Eurofins Food and Feed Testing Norway AS.
- Watson, R.T., M. Fuller, M. Pokras, and W.G. Hunt (eds.). 2009. *Ingestion of lead from spent ammunition: Implications for wildlife and humans*. Boise, ID: The Peregrine Fund.
- WHO (World Health Organization). 2015. Lead poisoning and health. <http://www.who.int/mediacentre/factsheets/fs379/en/>.
- Wiemeyer, G.M., M.A. Pérez, L.T. Bianchini, L. Sampietro, G.F. Bravo, N.L. Jácome, V. Astore, and S.A. Lambertucci. 2017. Repeated conservation threats across the Americas: High levels of blood and bone lead in the Andean Condor widen the problem to a continental scale. *Environmental Pollution* 220: 672–679. <https://doi.org/10.1016/j.envpol.2016.10.025>.

## AUTHOR BIOGRAPHIES

**Vernon G. Thomas** (✉) is a Professor Emeritus specializing in the transfer of scientific knowledge to conservation policy and law, especially in the issue of lead exposure and toxicity in wildlife and

humans.

*Address:* Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, ON N1G 2W1, Canada.  
e-mail: vthomas@uoguelph.ca

**Niels Kanstrup** is a biologist, scientist, and hunter. His research program is focused on sustainability of hunting with emphasis on dispersal of ammunition components in the natural environment, particularly the impact of ammunition lead.

*Address:* Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, 8410 Rønne, Denmark.  
e-mail: nk@bios.au.dk

**Anthony D. Fox** is a Professor of Waterbird Ecology at Aarhus University. His research focuses on applied waterbird issues throughout the northern hemisphere.

*Address:* Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, 8410 Rønne, Denmark.  
e-mail: tfo@bios.au.dk

# PAPER 12

Kanstrup N (2012). Lead in game birds in Denmark: Levels and sources. Danish Academy of Hunting. Article 2012-02-1

## RIGHTS:

Open access.

# Lead in game birds in Denmark: levels and sources

Niels Kanstrup, MSc.

Danish Academy of Hunting • Skrejrupsvej 31 • DK-8410 Rønne • Tel +45 2033 2999  
e-mail: nk@danskjagtakademi.dk • www.danskjagtakademi.dk • CVR 20027045

**Title: Kanstrup, N. 2012. *Lead in game birds in Denmark: levels and sources.***

**Abstract:** In June 2008, the National Food Agency contacted Bjarne Frost Vildt<sup>1</sup> against the background that the Danish surveillance of heavy metals in food (EU Directive 96/23 of 29 April 1996) had, for several years, shown elevated lead levels in game meat. These elevated levels exceeded the official threshold limits for food, with a significant prevalence in game bird species, in particular pheasant and, sporadically, venison.

As a result, Bjarne Frost Vildt submitted an action plan, including a campaign to raise awareness of the Danish regulations on lead shot, and the establishment of a research project to identify the source of lead in game meat. In July 2008, the Danish Academy of Hunting was tasked to design and carry out the investigation, in cooperation with the Veterinary Institute (*Technical University of Denmark*) and Food Region North (*Ministry of Food, Agriculture and Fisheries*). The study was carried out from August 2008 to April 2009, and followed up in April 2010 and October 2011.

The study was based on sampling of a control group of 30 pheasants (*Phasianus colchicus*) on six private estates which had shown elevated lead levels in 2007. For this group, the local employees were instructed to be careful to ensure that the samples were obtained either with steel (non-lead) shot or without the use of firearms. However, at one estate the sample (N=5) was taken with bismuth shot. The lead levels of the control group were measured using the same methodology as the standard measurement (ICP-MS Agilent 7500i) and compared statistically with lead levels from the previous standard measurements. This showed markedly lower levels of lead (statistically significant), when compared to the 2007 standard, in birds that originated from the same districts. Based on x-ray and dissection, the number of “shot-in” pellets in the 2008 standard and the 2008 control groups was estimated and compared to the measured lead levels in the total group. A positive and statistically significant correlation was identified between the number of shot pellets found in pheasant and residue levels in the meat. The standard measurement carried out by Food Region North on pheasant sampled during the hunting seasons 2008/2009, 2009/2010 and 2010/2011, showed a decline in the prevalence of pheasants exceeding the official threshold limits, in comparison with previous years.

To supplement the data, lead levels were measured in meat of pheasants with two lead shot (3.2 mm) embedded. Further, lead was measured in pheasant meat penetrated by six lead shot (3.2 mm). To quantify the erosion impact of the preparation procedure (grinding), two lead and two bismuth shot were placed in pheasant meat before preparation and weight loss was calculated. The lead content of two bismuth shot from two different cartridges was also measured. Similar measurements were made on new generations of bismuth shot in January 2010.

Additionally, 1,434 gizzards from mainly pheasant (N=614) and mallard (*Anas platyrhynchos*) (N=656) were sampled, x-rayed, and dissected. Shot were categorized in shot types and origin (“shot-in” or “ingested”).

It was concluded that the source of elevated lead levels is not contained in the food or the general environment of the birds, although ingestion of lead shot is a possible minor source. Different and independent factors indicate that the lead in the meat samples first and foremost originates from shot and fragments of shot situated in the breast muscles of the bird, and thus contaminating the sample for lead measurement. The contamination is accelerated by the method used for preparation of the sample (grinding). It was concluded that the elevated lead levels originate from the continued and illegal use of lead shot for hunting, and also from bismuth shot in which lead was found to be a contaminator. The decline in prevalence of pheasant meat exceeding the threshold limit during the hunting seasons 2008/2009 and 2009/2010 may be driven by three

---

<sup>1</sup> The biggest Danish butchery for game meat

different reasons: reduced illegal use of lead shot due to the campaign initiated in 2008; reduced concentration of lead in bismuth shot (2009/2010) due to the conclusions of this study; and/or reluctance to deliver pheasants to official slaughterhouses by districts being aware of illegal use of lead shot by hunters, and being aware of the study and the general attention being given.

## 1. Background

### 1.1 The study

Since the year 2000, lead content of game meat has been monitored in Denmark according to EU Directive 96/23. 29 April 1996. The monitoring is undertaken by the Ministry of Food (Northern Region). The game species involved are primarily pheasant (*Phasianus colchicus*), mallard (*Anas platyrhynchos*) and wood pigeon (*Colomba palumbus*), and lead levels exceeding 0.1 mgPb/kg (corresponding to the action threshold for poultry<sup>2</sup>) have been found repeatedly in all species.

Table 1 shows the results of the analysis of pheasant for the years 2000–2009 (unit: mg Pb/kg), showing that for some samples there is a very large excess over the action limit of 0.1 mg Pb/kg.

Year	N	Min	Max	Mean	Deviation	Median
2000	28	0	<b>0.556</b>	0,056	0.111	0.011
2001	26	0	<b>119</b>	<b>4.66</b>	23.3	0.0043
2002	26	0.00073	<b>7.6</b>	<b>0.508</b>	1.56	0.006
2003	25	0.00046	<b>0.165</b>	0.023	0.0464	0.0028
2004	46	0	<b>0.432</b>	0.0448	0.0951	0.0051
2005	70	0.0006	<b>10.9</b>	<b>0.449</b>	1.44	0.023
2006	20	0.0005	<b>7.97</b>	<b>0.601</b>	1.82	0.0109
2007	89	0.0003	<b>81.3</b>	<b>1.27</b>	8.93	0.0157
2008	56	0.0001	<b>42.2</b>	<b>0.95</b>	5.65	0.027
2009	30	0.0014	<b>3.9</b>	<b>0.16</b>	0.71	0.0057

Table 1. Content of lead in pheasants 2000–2009. Source: Food Northern Region Reports, years 2000–2007. > 0.1 mg Pb/kg is shown in **bold**.

On this basis, the Food Authority approached *Bjarne Frost Vildt*, who submitted an action plan involving practical actions to be taken in the hunting season 2008/2009, including the establishment of a research project to identify the source of lead in game meat. In July 2008, the Danish Academy of Hunting was tasked to design and carry out the investigation in cooperation with the Veterinary Institute (*The Danish Technical University*) and Food Region North (*Ministry of Foods*). The study was carried out during August 2008 to April 2009, and followed up in March 2010.

### 1.2 Lead sources

Lead in birds could theoretically be admitted through the bird's digestive system. The source may be contaminated food or ingestion of lead containing shot scattered by hunting in the past or the same hunting season. The density of shot in the environment is quite large. In some hunting districts, 50,000 rounds or more may be fired annually, resulting in dispersion of 1.5 tonnes, or up to 10 million shot, being deposited in the environment and often in the birds' feeding grounds. British studies have shown that 3% of pheasants (N=437) from 32 properties have shot deposited in their gizzards (Butler *et al* 2005).

The source of the lead can also be shot which has been injected into the bird either from the lethal shot or from previous wounding. Pain *et al* (2010) show that lead gunshot undergoes sufficient fragmentation on

<sup>2</sup> For the years 2000 to 2006, the national threshold values for poultry meat was 0.3 mg Pb/kg. In 2007, this was replaced by an "action limit" of 0.1 mg Pb/kg. In 2008 this was changed to 0.5 mg Pb/kg. When used in this study, the term "action limit" means 0.1 mg Pb/kg.

impact with gamebirds for lead fragments to cause contamination of their meat. Johansen *et al* similarly showed that lead concentration is very high in meat of eiders killed with lead shot, and about 44 times higher than in drowned eiders. For some species, e.g. common eider (*Somateria mollissima*) and pink-footed goose (*Anser brachyrhynchus*), studies have shown that between one quarter and one third have shot in the body, resulting from wounding. Similarly, the proportion of wounded birds was examined for pheasant (6%), mallard (15%) and wood pigeon (3%) (Noer *et al* 2006). Lead shot, which is embedded in the tissue by wounding, will normally be encapsulated, and lead from such shot is not spread in the tissue/body (Sanderson *et al* 1998).

A fundamental theory behind the study was that the source of lead in the game is lead shot from hunting: either shot that is ingested by the birds, or that has been injected as a result of the killing shot or previous wounding. Both possibilities should be considered given the background that, since 1996, the use of lead shot has been prohibited for hunting in Denmark, while a number of alternative materials have been introduced. These materials, for example bismuth and tin, may contain lead and provide a source of the measured elevated lead levels in game meat.

Previously published studies suggest that the shot in the environment becomes inaccessible to food-seeking birds relatively quickly. For example, Anderson (2000) shows that shot ingested by waterfowl along one of the central flyways of North America (Mississippi Flyway), was found to be mainly non-lead shot within a few years of the ban on the use of lead shot (1991). Similarly, it can be assumed that shot spread from hunting in an agricultural landscape, will relatively quickly be unavailable for pheasants and other bird species feeding in this ecosystem.

If the source of elevated levels of lead in Danish birds is shot ingested from their habitat, it is therefore likely that such shot has been spread recently rather than before the ban on lead shot, which came into force in agricultural habitats in 1993 and in forests in 1996. If the source of lead is "shot-in" lead shot, this is a clear proof of the continued use and therefore illegal use of lead shot. An unpublished study by the Danish Academy of Hunting in 2007 showed that "shot-in" shot in six out of 36 pheasants and mallard gizzards was lead shot. This result suggests the continued use of lead shot for hunting in Denmark.

British surveys (Food Standards Agency 2007) describe measurement of lead content in "some" samples of pheasant, recording a mean of 0.23 mg Pb/kg and a maximum of 1.63 mg Pb/kg. It was concluded that one possible source was non-visible fragments of lead shot in the samples. There is no prohibition on the use of lead shot for pheasant hunting in Britain, but on the basis of the survey, authorities recommended the use of other types of shot.

### **1.3 Existing Danish data on lead levels**

Food Northern Region has made detailed results for the years 2003–2009 available. The studies include material from pheasant, mallard, wood pigeon, doves, deer and other animals (ostrich, cattle, pig, chicken, sheep and horse). During 2003–2007, a total of 1,246 samples were taken, of which 483 samples originated from wild animals, including 408 from the three bird species: pheasant, mallard and wood pigeon, with 250 of those being from pheasant. Out of the total of 1,246 samples, 58 exceeded the threshold lead limits set for each of the actual years. 57 of these were samples from wild animals, 51 from birds, and 38 from pheasant. During the years 2005–2007, the prevalence of pheasant with elevated lead levels were 20% or more.

## **2. Objective**

The study aimed to identify the source of elevated levels of lead found repeatedly in game birds.

## **3. Methods and materials**

The study employed four methods: 1. continued and expanded measurement of lead in game birds submitted to the slaughterhouse *Bjarne Frost Vildt* (mainly pheasants), combined with measurement of a control group; 2. analysis of shot in body and gizzards of the same pheasants and other birds; 3. measurement of contamination of lead shot embedded in samples and passing through game meat; and 4. measurement of lead in bismuth and the impact of erosion of shot during the grinding preparation.

### 3.1 Trace element analysis 2008

Measurement of trace element contents has been implemented as an extension and continuation of the measurements already conducted by Food Northern Region (Laboratory of Lystrup). Homogenized samples were dissolved in nitric acid and the trace element content was measured using ICP-MS Agilent 7500i (ICP-MS).

During the hunting season in 2008/2009, the laboratory team collected samples of 56 pheasants, 15 mallard, nine wood pigeon and 20 deer. This standard sampling followed the same procedure as previous years, and independently of this study. Preparation was undertaken by isolating 100–200 g breast meat, which was homogenized by grinding. 0.5 g was taken for the ICP-MS measurement.

As part of the study, this sample was supplied with 46 pheasants from six districts, which provided pheasants with elevated lead levels in 2007. The control group was sampled by the district staff at the turn of 2008/2009, and it was stressed that the selection should be independent of general hunts on the properties, using steel shot or, possibly, without the use of firearms. All birds were X-rayed. Trace element measurements following the standard procedure were made on five birds from the six properties, totaling 30 birds. The birds were subsequently dissected, and a total of 15 shot were isolated. X-ray photos were analyzed and shot counted and localized.

### 3.2 Analysis of gizzards

A total of 1,434 gizzards, including 614 from pheasant and 656 from mallard, and a smaller number from other dabbling ducks, geese and wood pigeon, were collected through Bjarne Frost Vildt, directly from hunting districts, from individual hunters and from birds used for monitoring of trace element content. Most gizzards were collected in Eastern Denmark. However, most of the mallard gizzards were collected in Jutland. The other dabbling ducks and geese were collected in West Jutland. The collected gizzards are not necessarily representative of all districts or country-wide in terms of incidence of shot materials used. Regarding pheasant gizzards from Bjarne Frost Vildt, the supply of game birds may have been affected by the pre-hunting season in 2008, where districts were aware of the general focus on lead shot, including this project. Gizzards with lead shot are therefore estimated to be under-represented, and the measured volume must be seen as a minimum level.

All gizzards were X-rayed and, samples containing shot were subsequently dissected and sorted according to the following procedure. Gizzards were inspected externally for shot holes, which were, wherever possible, marked with needle (Figure 1), after which the gizzard was opened and the contents washed out into a tray. The gizzards were then inspected for the shot holes on the inside, and shot was isolated in the gizzard content or dissected out of muscles. The shot was subsequently photographed, inspected and categorized using the following system (in which only non-magnetic and non-fragmenting shot were investigated for density and melting point). With this method of analysis, shot was categorized by reference to the origin (“shot-in” or “ingested”) and partly in relation to types of material. In each case it was not possible to determine whether the shot was shot-in or ingested. These are indicated as “?”.

- A. Located in the muscle, fragmented/deformed (checked on X-ray photo), shot holes: shot shot-in.
- B. Located in grit, small (<2 mm) worn/almond-shaped (checked on X-ray photo), polished, no shot holes: shot ingested.
  - 1. Magnetic: Steel or Hevishot products.
  - 2. Fragments: Bismuth
  - 3. Dark material, high density, chewable and combustible: tungsten matrix products.
  - 4. Dark material, high density, melting point of 280° C: lead
  - 5. Bright material, low specific gravity, melting point below 280° C: tin.

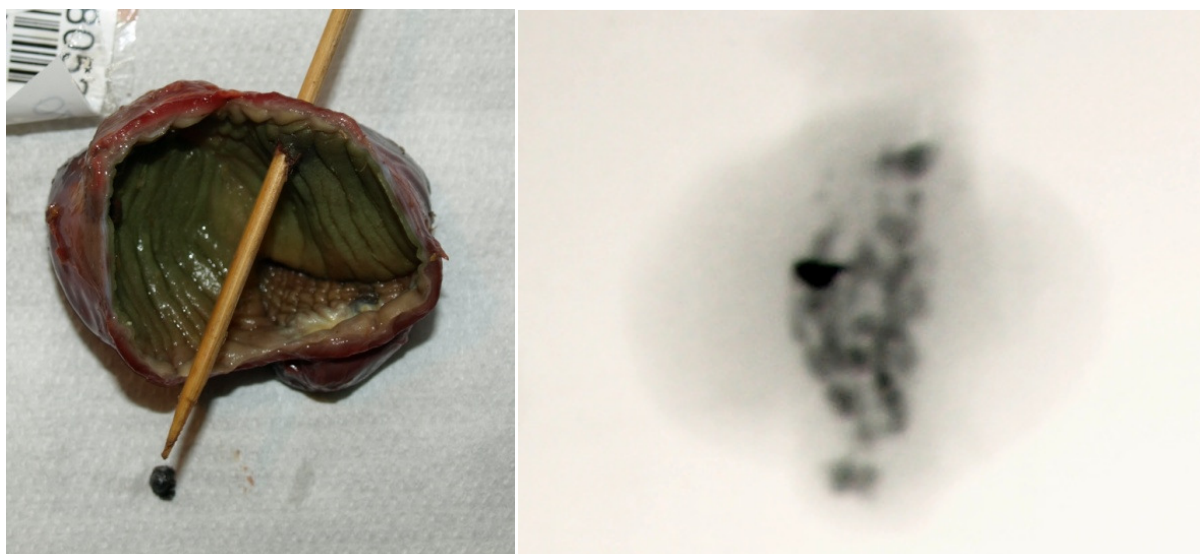


Figure 1. Gizzard of pigeon injected with lead shot. To the right is an X-ray photo of same gizzard, in which shots are seen with a deformation, which is typical of lead shot that hit grit.

### 3.3 Contamination by lead shot

To measure the level of contamination by lead shot embedded in the test sample and therefore ground in the preparation procedure, two 3.2 mm lead shot were placed in 150 g pheasant breast meat. Similarly, to measure the contamination of lead shot passing through the sample, a similar piece of pheasant breast meat was penetrated by six 3.2 mm lead shot, fired by a specially designed air gun. A control was constructed using meat from the same pheasant. The three samples were prepared uniformly and measured by ICP-MS.

### 3.4 Analysis of lead in bismuth shot and erosion

To measure content of lead in bismuth shot, three samples were used: one from six shot isolated from pheasants from one of the control districts; one from five shot isolated from an ordinary bismuth shot cartridge bought in a typical Danish retail gun store in 2009; and one similar bought in 2010. The samples were pulverized by use of non-lead tools and afterwards submitted to ICP-MS measurement.

To measure the impact of grinding procedure on shot, two bismuth and two lead shot were photographed and weighed and placed in a standard media of pheasant meat and exposed to a standard grinding procedure. Afterwards the remaining shot and visible fragments were isolated, photographed and weighed.

## 4. Results

### 4.1 Trace element analysis and control

The results of the standard lead content measurement of 56 pheasants, 15 mallard and nine wood pigeons is shown in Table 2. In terms of elevated lead levels, pheasant does not differ from the corresponding figures for 2000–2007 (Table 1).

	N	Min	Max	Mean	Deviation	Median
<b>Pheasants</b>	56	0.0001	42.2	0.950	5.650	0.027
<b>Mallard</b>	15	0.0046	1.27	0.110	0.320	0.022
<b>Wood pigeon</b>	9	0.0010	0.26	0.045	0.084	0.010

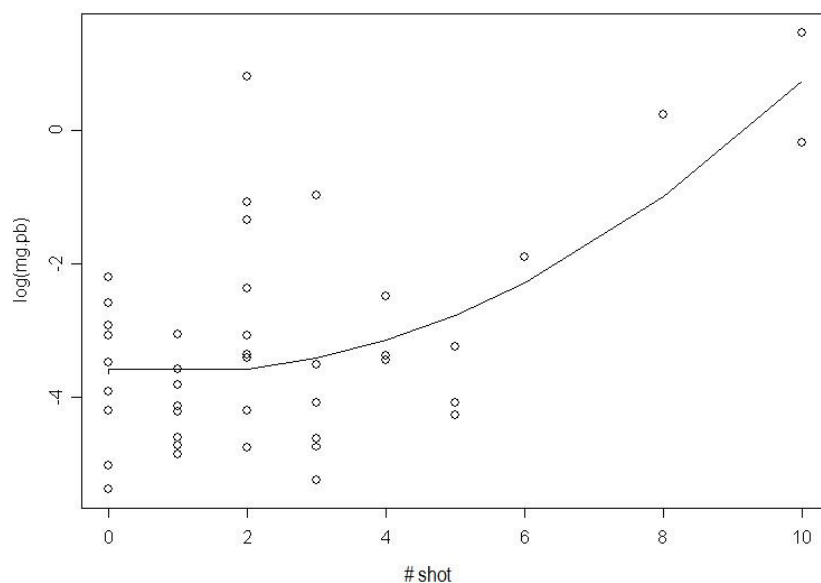
Table 2. The outcome of the Regional Food standard measurements in 2008. Unit: mg Pb/kg.

Against this, the result of the measurement of the control group of 30 pheasant are as follows. 25 had a lead concentration below the detection limit of 0.0033 mg Pb/kg. The lead content of the remaining five shot were: 0.0052, 0.0066, 0.0147, 0.0149, and 0.83 mg Pb/kg. In this sample there are no reported values of results below the detection limit (0.0033 mgPb/kg) and therefore there no numerical comparison can be made of the mean or median with the standard sample. However, a comparison of the number of results below 0.0033 mg Pb/kg in the two groups showed that eight (14.3%) out of 56 standard measurements, and 25 (83.3%) out of 30 in the control group, were below this value. The median of the five highest values in the standard group is 2.23 mg Pb/kg, while in the control group it was only 0.0147 mg Pb/kg. A statistical analysis of the material (non-parametric test (Wildcoxon Rangsum)) showed this difference to be statistically significant ( $p < 0.0001$ ). Against this background, it is concluded that the lead concentration in the standard group is significantly higher than in the control group.

Based on X-ray and partly on dissection it was possible to estimate the number of shot in the breast muscles of 73 birds (49 pheasants, 15 mallards and nine wood pigeons). Furthermore, a partial determination of shot types was made. X-ray photos cannot be used for a complete determination, but in cases where there is evidence of fragmented shot, they are categorized as bismuth shot. Shot deformed without being fragmented is likely to be lead or tin shot. Large and round shot are assumed to be steel shot. Localization and identification of shot by the use of X-ray photographs is a relatively inaccurate method. Hence, numbers of shot in the breast muscles cannot be taken as absolute figures, but rather as an index.

Dissection was only undertaken on the control group, since the remains of birds from standard samples were not preserved. No full dissection of birds from the control group was conducted, this being a very time consuming procedure, but 15 shot were isolated, of which two were bismuth (both from property # 4) and the rest, steel (4 mm) (all from the other properties). There is thus no indication that the control group was sampled using lead shot or had lead shot injected.

The lead levels and the number of shot in the breast muscles were correlated for 42 out of the 73 birds, as data below the detection limit were omitted for 31 birds, of which none contained shot. For the data above the detection limit, we used a logarithmic transformation of lead levels, and a regression on both the number of lead shot and the square of the number (Figure 2). The residuals of this model were confirmed by Kolmogorov–Smirnov testing for normality ( $p > 0.1$ ). The p-value for the effect of the number of shot (LR-test, F-test, usual multiple regression) on lead level is  $p < 0.0001$ . Accordingly, we concluded a statistically significant increase in lead levels was related to the amount of shot.



*Figure 2. The correlation between the estimated number of shot in the thoracic muscles and the measured lead levels (logarithmic) in mg Pb/kg.*

## 4.2 Shot in gizzards

Out of 1434 gizzards, using radiography, we detected shot in 296 (20.6%). From 292 of these, we isolated 449 pieces of shot (whole or fragmented) and categorized them by material and origin (ingested or shot-in). This is illustrated in Table 3 (all species), where the upper part indicates the distribution of all the shot, and the bottom shows the distribution of gizzards containing at least one shot. In several cases, shot of more than one type is found in the same gizzard, hence the difference between the number of investigated gizzard and totals. Tables 4 and 5 give the corresponding figures for pheasant and mallard, respectively.

Shot	Ingested	Shot-in	?	Total
Bismuth	144	85	2	231
Steel	55	100	2	157
Lead	27	25	4	56
Tin	0	5	0	5
Total	226	215	8	449
Gizzards with shot	Ingested	Shot-in	?	Total
Bismuth	56	74	2	132
Steel	28	83	2	113
Lead	18	22	4	44
Tin	0	3	0	3
Total	102	182	8	292

Table 3. Distribution of 449 shot taken from 263 of the 1434 collected gizzards. Top: all shot; bottom: distribution of gizzards with at least one shot.

Shot	Ingested	Shot	?	Total
Bismuth	84	40	1	125
Steel	27	26	0	53
Lead	17	15	1	33
Tin	0	5	0	5
Total	128	86	2	216
Gizzards with shot	Ingested	Shot	?	Total
Bismuth	24	38	1	63
Steel	7	24	0	31
Lead	10	12	1	23
Tin	0	3	0	3
Total	41	77	2	120

Table 4. Distribution of 216 shot taken from 108 of the 614 collected pheasant gizzards. Top: all shot; bottom: distribution of gizzards with at least one shot.

Shot	Ingested	Shot	?	Total
Bismuth	60	43	1	104
Steel	26	64	2	92
Lead	10	9	2	21
Tin	0	0	0	0
Total	96	116	5	217
Gizzards with shot	Ingested	Shot	?	Total
Bismuth	32	34	1	67
Steel	19	51	2	72
Lead	8	9	2	19
Tin	0	0	0	0
Total	59	94	5	158

Table 5. Distribution of 217 shot taken from 141 of the 656 collected mallard gizzards. Top: all shot; bottom: distribution of gizzards with at least one shot.

In one gizzard we found 36 ingested shot (11 bismuth, 4 lead, and 21 steel) (Figure 3).

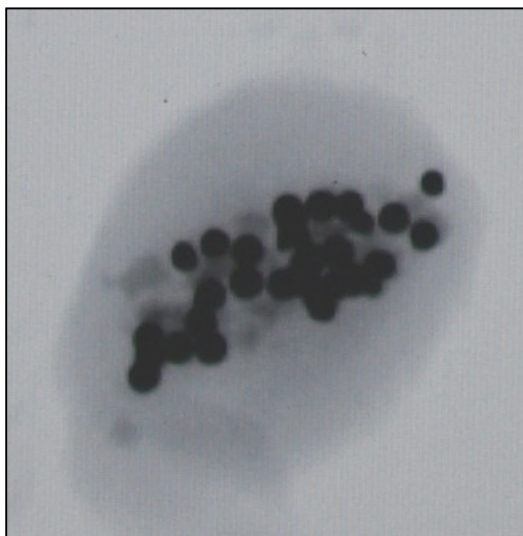


Figure 3. Pheasant gizzard with 36 ingested shot.

Figure 4 shows the overall distribution of ingested shot per gizzard, broken down into bismuth, steel and lead.

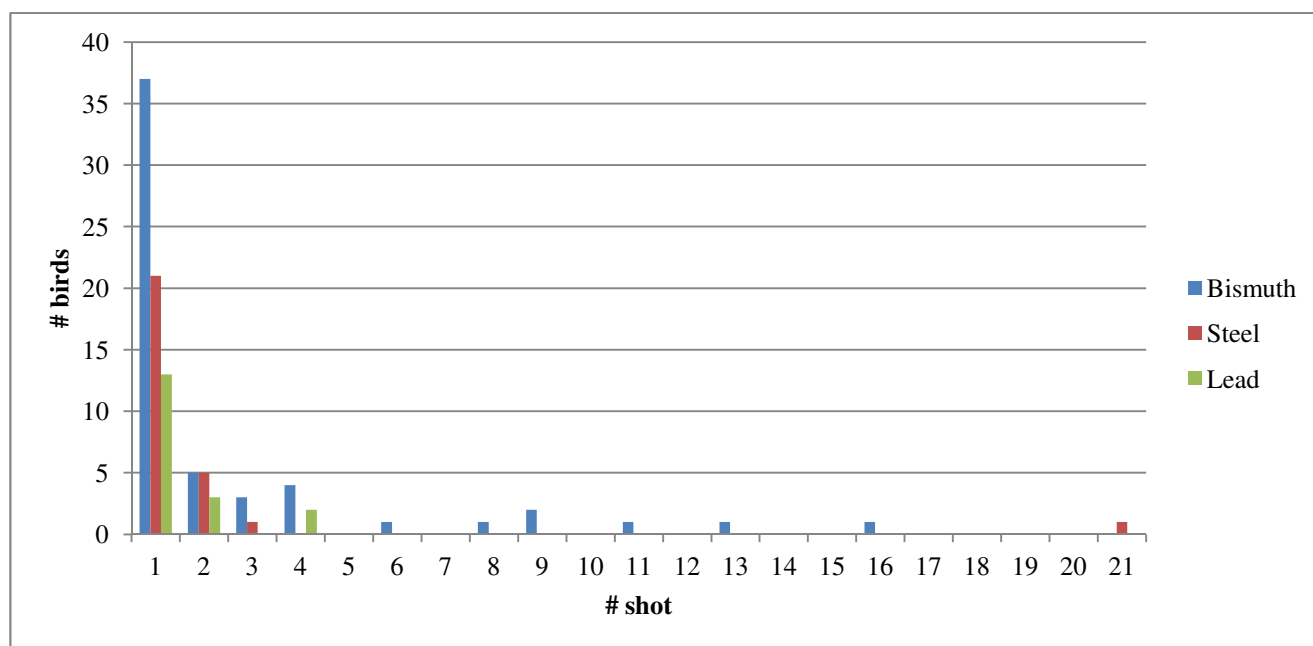


Figure 4. Breakdown of all ingested shot of bismuth, steel and lead (N=226).

#### 4.3 Contamination from lead shot

The level of lead in the piece of pheasant breast meat with two embedded lead shot was 810 mg Pb/kg, indicating a very large contamination by shot situated in the sample and ground during the preparation procedure. The level in the sample that was penetrated by six lead shot was 0.122 mg Pb/kg, thus slightly above the threshold limit. The level in the control measurement was below 0.0033 mg Pb/kg.

#### 4.4 Lead in bismuth and erosion by grinding

The level of lead in the three samples of bismuth shot is shown in Table 6. There are slight differences.

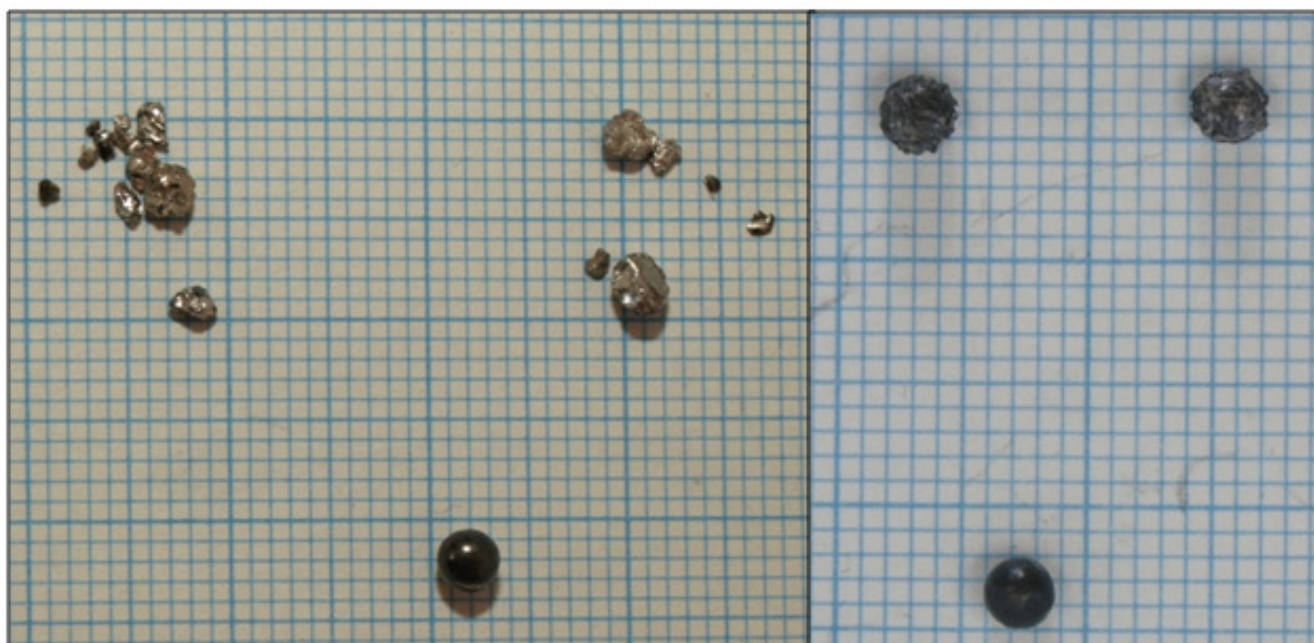
Bismuth shot sample	Lead level (mg Pb/kg)
Dissected from pheasant	6800
Bismuth shot retailed March 2009	3150
Bismuth shot retailed January 2010	950

*Table 6. Lead levels in three samples of bismuth shot.*

The erosion of bismuth and lead shot in the laboratory grinding preparation of samples is shown in Table 7. The grinding preparation causes fragmentation of bismuth shot, while the surface of lead shot becomes rough (Figure 5). These results indicate clearly the level of contamination that occurs during preparation of samples for the whole or fragmented shot.

Shot	Weight before (mg)	Weight after (mg)	Loss	%
Bi 1	146.9	133.3	13.6	9.3
Bi 2	132.6	101.1	31.5	23.8
Pb 1	127.6	123.6	4	3.1
Pb 2	152.1	149.7	2.4	1.6

*Table 7. Erosion of two bismuth and two lead shot by preparation of samples made using the standard method of The Food Region.*



*Figure 5. Top: shot after preparation of the sample (grinding). Bottom: shot before preparation of the sample. Left: bismuth. Right: Lead.*

## 5. Discussion

### 5.1 Lead in feed and food

One theory is that the measured lead levels in game meat originate from the rearing phase, or the period immediately after release. Sewage sludge has been suggested as a possible source. However, there are several factors in the study, which suggests that the source is *not* in the wider environment. Firstly, the high levels are found in species that typically are reared and released for shooting, mainly pheasant and mallard, and in other game species such as wood pigeon. The species differ significantly in terms of breeding habitat and foraging, and it is unlikely that these wild species are exposed to the same lead sources through feed or natural food items.

Another indication is that the elevated lead levels typically occur sporadically. A lead source in food would be expected to give more even levels, so that we would see more birds with slightly elevated lead levels and not, as in the present results, very variable levels in birds from the same area (indicated by the distribution and differences in mean and median in Table 1). Results from previous years (Food Region pers. comm.) show very variable levels, even between samples from the same bird, suggesting that the lead content is not uniformly distributed, as would be expected if the elevated levels of lead had been admitted through the digestive tract (also concluded in Scheuhammer 1998).

Thirdly, a comparison of the standard group from 2007 (N=89) and the control group in 2008 (N=30) (where the birds were all predominantly collected at properties with elevated lead levels in 2007), indicates that the lead source can be eliminated only by modifying the method of collection/instruction of shooters. Except for the five birds in the control group, which were shot with bismuth shot (property # 4), only one (4%) of the remaining 25 measurements was above the detection limit of 0.0033 mg Pb/kg. 77 out of 89 (80 %) birds from the standard measurement in 2007 was above this limit. This result does not exclude that lead sources may be in feed or natural food items. However, if this were a major source, one would expect the same high incidence of measurements in the control group in 2008.

### 5.2 Lead from ingested shot

As mentioned initially, it is known that both waterfowl and terrestrial species ingest shot by confusing them with food items or grit (e.g. Fisher *et al* 2006; Pain *et al* 2009). Through both field and laboratory studies it has been shown that ingestion of lead shot causes elevated levels of lead. For example, Schultz *et al* (2009) find significantly elevated levels of lead in the blood and liver of mourning doves (*Zenaida macroura*) which have ingested lead shot. There are also a number of similar studies of waterfowl, e.g. Longcore *et al* (1974), who find similar results in feeding studies with mallards. Daury (1993) concludes similarly by comparing American ducks from areas with and without hunting with lead shot. Custer *et al* (1984) find the same correlation in studies of American kestrel (*Falco sparverius*).

Ingested shot remaining in the gizzard will be eroded. The shape in this process is typically an "almond" form (see Figure 7), which is also described by e.g. Ringelman 1993. Shot of different materials decomposes at different rates (Mitchell 2001). Brewer (2003) shows that steel shot over a given period lose seven times more weight than tungsten-containing shot (Hevishot) during feeding trials with mallard. A snapshot of the distribution of shot types found in the gizzard does not therefore necessarily give an accurate picture of the ingestion rates or the availability in the birds' environment. Similarly, "toxic" shot may be underrepresented, as a certain amount of this type of shot (e.g. > 4 lead shot) will in most cases be lethal.

However, it is evident that the birds have ingested both bismuth, lead and steel shot, and that the recorded distribution probably reflects approximately the inclusion of shot. 6.7% of pheasant had ingested shot in their gizzards, including 3.9% bismuth shot, 1.6% lead and 1.1% steel shot. Consequently, it can be concluded that lead shot are in the birds' environment, which indicates continued use of lead shot for hunting, although we could not exclude that there is still shot available since the ban in 1996.

Neither tin nor tungsten shot were found, which is probably due to the limited use of these types of shot. For polymer-based tungsten shot, it is further known that they erode fairly quickly in a bird's gizzard (Mitchell 2001).

No ingested shot have been localized in the gizzard of birds that have been the subject of measurement of trace element content. Therefore, it has not been possible on this basis to relate the intake of shot to elevated lead levels, and therefore to confirm or exclude whether the ingestion of shot can be a source of the elevated lead levels. The link can be judged from the fact that 1.6% of the surveyed gizzards contained ingested lead shot. Breakdown by number of shot per gizzard is shown in Figure 6.

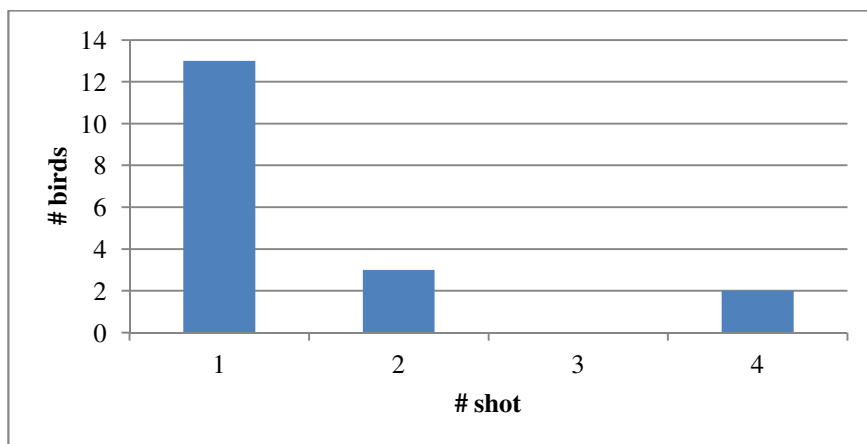


Figure 6. Distribution of number ( $N=19$ ) of lead shot, eaten by pheasants.

As mentioned in the methodology section, the collected gizzards used in this study were not necessarily representative and the prevalence of ingested lead shot must probably be seen as a minimum figure. Yet, numbers do not seem to explain the prevalence of elevated lead levels ( $> 0.1$  mg Pb/kg) which, in a number of years, was above 20%.

However, the measured levels of lead could well have arisen because the birds have ingested lead shot. A lead shot (diameter=3 mm) weighs approximately 140 mg. Assuming that such a shot erodes and is completely absorbed in a pheasant, which weighs 1 kg, the contamination is equivalent to a total lead content of 140 mg Pb/kg. Absorption of lead is not uniform in different organs and tissues. Concentration in muscles will be 30–50 times lower than concentrations in bone and kidney after both moderate and high lead intake in mallard (Longcore 1974). As the original size of the ingested lead shot is not known, their erosion in the gizzard cannot be calculated. The isolated lead shot weight ranges from ca. 120 mg to 20 mg, which indicates erosion similar to descriptions in previously published studies, which show an erosion of shot in the gizzard and consequent almond shaped shot (Figure 7).

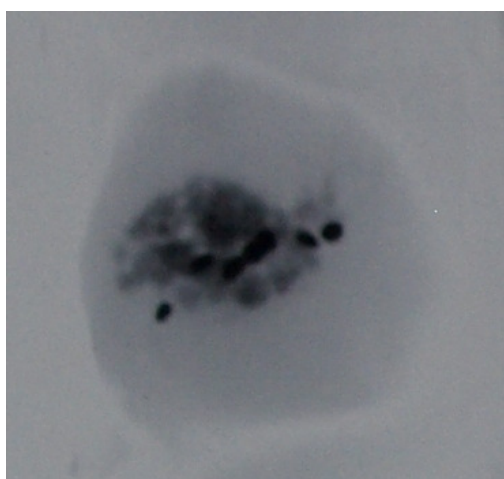


Figure 7. Pheasant gizzard with eroded lead shot. It is seen that shots lose their original round shape and adopt an “almond shape”.

A 50 % erosion and absorption of 3 mm lead shot will leave a 70 mg Pb/kg/shot in a whole pheasant. Longcore (1974) shows levels of 1.2 to 1.7 mg Pb/kg of lead in breast muscle in mallard that had absorbed approximately 300 mg of lead. Fimreit (1984) showed that absorption of 129 and 159 mg lead from lead shot did not raise lead levels in breast muscle above 0.1 mg Pb/kg in grouse, whereas an absorption of 222 and 257 mg resulted in levels of 0.5 and 0.7 mg Pb/kg, respectively.

Even taking into account that the concentration in muscle is significantly lower than the average concentration, 1–2 lead shot can cause values that correspond to some of the elevated levels measured in the Danish studies, but is unlikely to be the reason for the sporadically occurring very *highly* elevated values seen in the standard monitoring of lead levels in game meat.

A similar assessment can be made for bismuth shot. Bismuth shot investigated in this study turned out to have a certain level of lead, measured at 0.7 % in shot isolated from hunted pheasants. It is known from literature that bismuth shot may contain lead. Jayasinghe (2004) shows the correlation between measurements of bismuth and lead in samples from birds with ingested bismuth shot. A 3 mm bismuth shot with a lead content of 0.7 %, eroded and absorbed by 50%, will cause a lead content of 0.8 mg Pb/kg/shot in a whole pheasant. Taking into account that the inclusion of lead in muscles is significantly lower than average uptake, as discussed above, ingested bismuth shot does not seem to contribute markedly to elevated lead levels, even in birds ingesting large amounts of shot. Breakdown of ingested bismuth shot in the analyzed pheasant gizzards is shown in Figure 8. In one case, we found 16 ingested bismuth shot in a gizzard, but were most frequently found as single shots.

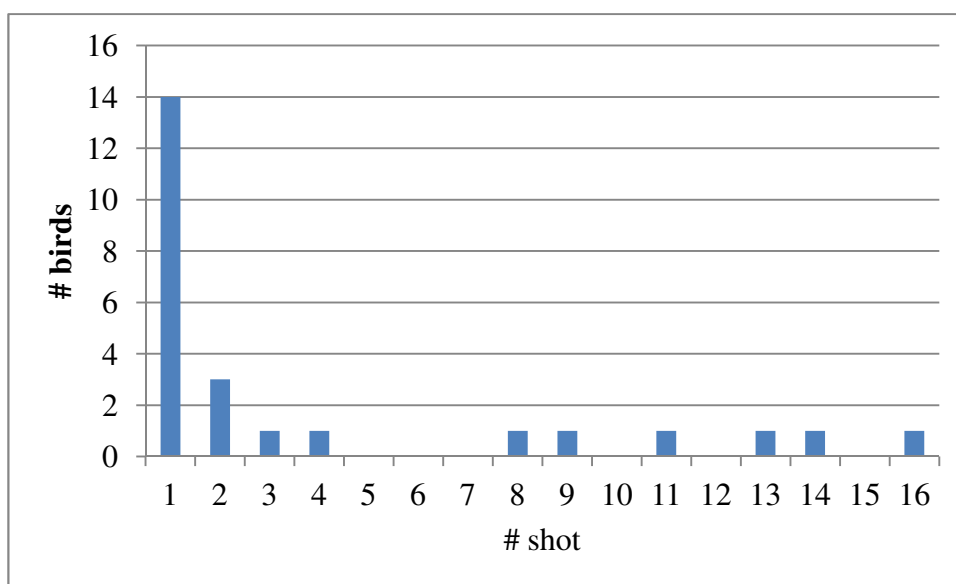


Figure 8. The breakdown of the number of bismuth shot (N=84) eaten by pheasants.

Based on this assessment and the measured levels of lead, it is estimated that ingested lead shot may be a source of some of the elevated values, but that ingested bismuth shot only slightly contributes to the elevated lead levels.

### 5.3 Lead from shot-in shot

As a result of the sampling and preparation methodology used in connection with ICP-MS measurements, there is a probability that whole shot, or fragments or traces of shot, are included in the sample. When the sample is grinded (homogenized), shot will erode/fragment, and the sample be contaminated. Homogenization is not complete and the outcome of the measurement will therefore depend on whether there is a high concentration of shot material in the 0.5 g meat, which is taken for further analysis. Inclusion of only 0.5 mg of lead (<0.4% of a shot) will affect the measurement results greatly (1,000 mg Pb/kg), as is seen in the controlled inclusion of two lead shot in a sample, resulting in 810 mg Pb/kg. Bismuth shot with a lead content of

1% also causes similar contamination of the sample. One fragment, for example of 5 mg bismuth shot, containing 0.05 mg of lead (1%), in a sample of 0.5 g, could lead to a lead level of 100 mg Pb/kg.

Whether the reason for the repeated elevated lead levels in standard monitoring is shot-in shot can be investigated on the basis of control measurements on the 30 pheasants taken out at the six properties where pheasants had significantly elevated lead levels in 2007. The results of this study suggest that the modification of the sampling methodology used for the control group causes a significant reduction in the measured lead levels, and that shot-in lead shot are a major source of elevated lead levels in birds.

Furthermore, the importance of shot-in shot can be discussed on the basis of dissected birds and gizzards. The entire study material, with the exception of a small number of the 30 pheasants in the control samples, was collected by using shotgun. This includes all 56 pheasants in the 2008 standard test that is applied during ordinary hunting.

Lead shot has been banned for use in hunting in Denmark since 1996, and a number of alternative shot materials have been marketed and are used today by Danish hunters. There are no precise statistics on the distribution of individual products, but steel shot has generally become popular for hunting in wetlands, and to some extent for upland game outside forests. Bismuth shot seems to be the dominant type of shot for hunting in the forests, where foresters in general do not allow the use of steel shot. Other products, such as tin and tungsten, may be available, but the price and other market-related reasons mean that their availability and use is sporadic.

When game is shot with a shotgun, it will be hit by a number of shot. At normal shooting distances, a bird of medium size, hit by the central parts of pattern, will typically be hit by 2–6 shot, some of which may pass through the bird, though the majority will be stopped by the muscles, organs, ligaments or bones. Figure 8 shows the distribution of shot in the 61 X-rayed hunted birds included in the study, and in which were recorded at least one shot.

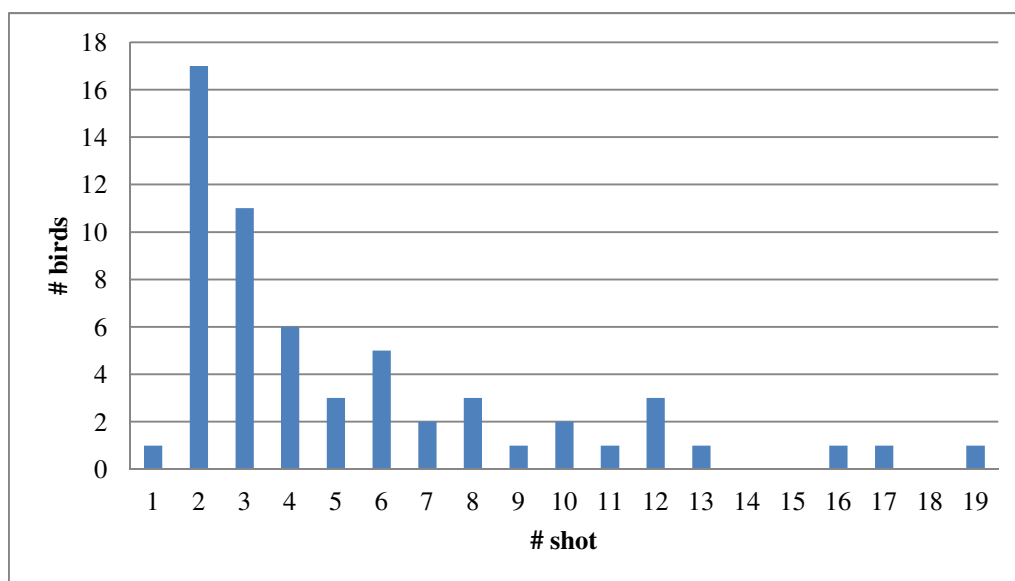


Figure 9. The distribution of shot in 61 birds bagged in the study (39 pheasants, 15 mallard and 7 wood pigeons).

An analysis of shot-in shot was made by radiography and dissection of all birds and collected gizzards (see Figure 1, 9 and 10). Radiography, as described in the methodology section, gave the possibility of distinguishing between types of shot: for example, in cases shot are clearly fragmented (bismuth). Similarly, shot type and material was determined by dissection and isolation of shot. In contrast to the analysis of ingested shot, the shot-in shot can be seen as an expression of the breakdown of the types used by hunters, although not necessarily representative of all districts and across the country.

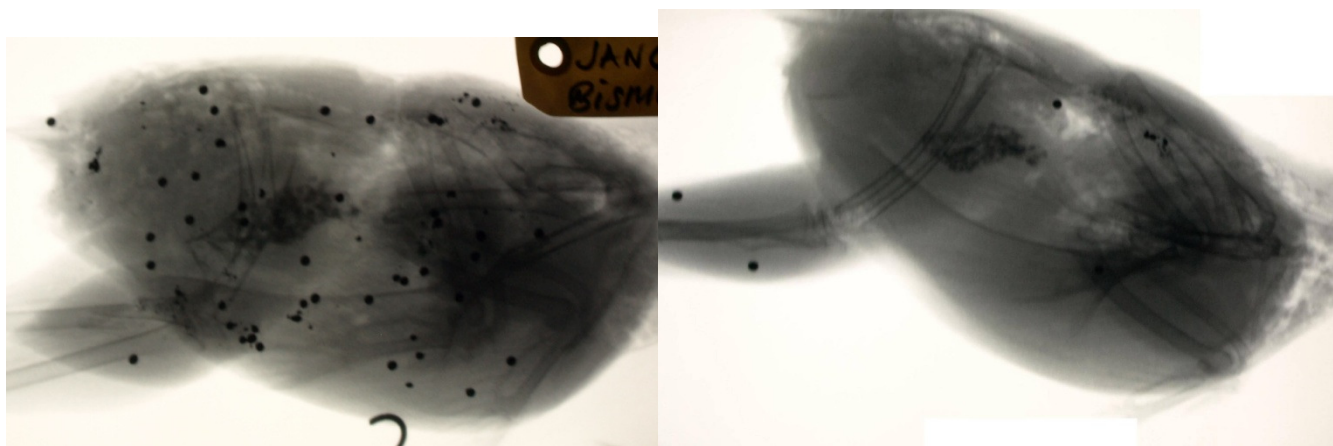


Figure 10. Pheasants with bismuth shot, which in some cases is clearly fragmented.

The results of this study show that, despite the ban on lead shot for hunting, lead shot is still used. Of the 77 pheasant gizzards with shot-in shot, 12 had lead shot (15.6%). For mallards there was lead shot in nine out of 94 gizzards, equivalent to 9.6%. Again, it must be emphasized that, because of the collection method, the findings are hardly representative of all districts or across the country, and are therefore probably minimum levels. In a somewhat lower sample-size from an unpublished study from 2007, six out of 36 shot-in shot in gizzards of pheasants and mallard were identified as lead shot, equivalent to 16.7%.

Because mallards are migratory birds, one might argue that deposits (lead) shot, could theoretically have come from wounding in other countries. Since most of the material were released mallards known to remain locally, it is not likely that wounding in other countries has contributed to the results.

The suspicion that lead shot is used for hunting in Denmark is confirmed by conversations with people who have direct contact with hunting management. Several districts have given information about discovery of empty cartridge cases, which corresponds to lead cartridges. The increased sales of lead cartridges in border regions in Germany and Sweden further suggest the illegal import and use of lead shot.

From the gizzard studies, it is estimated that between 10 and 20% of the hunted pheasants and mallard are taken with lead shot. In the somewhat lesser amount of material obtained for other species (N=6), there was included a single wood pigeon which was shot with lead shot. None of the gizzards from waterbirds, which originated from West Jutland (N=116), had shot-in (or ingested) lead shot.

An assessment of shot in whole birds suggests that about 33% of all shot are localized in the breast region, from which samples for lead measurements were taken. Experiments with the loading of lead shot in a sample showed that this can provide a very strong effect and shooting lead shot through pheasant meat also gives a measurable effect. This is further demonstrated by Johansen *et al* (2004) and Pain *et al* (2010).

Overall, these findings indicate that shot-in lead shot is a sporadically occurring source of contamination of samples for lead measurement. Deposited lead shot may be the cause of elevated values, which vary with repeated measurements of samples from the same bird. This corresponds to previously published results of U.S. studies. Scheuhammer (1998) concludes that the source of lead in breast muscles are lead shot or traces of lead shot, and that the values are highly dependent on where the sample is taken.

The calculations on the correlation between number of shot in the thoracic muscles and lead levels of the 71 birds also confirm the theory that the injected lead shot is a major source of elevated lead levels. Here was seen a clear correlation, probably due to the fact that the more shot that hit the bird, the greater the probability of shot or fragments of shot being included in the sample. As lead shot only fragments and erode to a limited extent, the probability increases that the material included in the sample is less. On the other hand, even small fragments of lead shot could result in a very high measurement. For bismuth shot, which may easily fragment on striking the bird, and particularly during the subsequent preparation of the sample, the likelihood of small pieces in the sample is relatively high. Quantitative estimates suggest that even relatively low lead levels in bismuth shot can explain some of the levels of lead seen in the standard monitoring.

The calculations are supplemented by a review of specific individual evaluations. In a single pheasant, which was part of the 2008 standard measurements, we measured a lead content of 42.2 mg Pb/kg, which is the highest value in the total material of 2008, and the second largest in the last four years of measurements on pheasant. X-ray photos of the bird shows one shot and fragments in the breast muscle, which appeared to indicate that bismuth or lead shot is the source. Since the bird is not preserved, it is no longer possible to use dissection to conduct an analysis of shot. Another pheasant, included in the control group from 2008, had no measurable lead content, but X-ray photograph indicates five shot in chest muscles. This bird was dissected, and all shot were found to be steel shot. Similarly, shot in birds with lead levels below the detection level were concluded to be non-lead or non-bismuth shot. Overall, we found that none of the birds (N=30), where the lead level was below the detection level, had lead or bismuth shot in the chest muscles.

The results suggest that the elevated lead levels in the standard monitoring predominantly derive from shot-in shot containing lead. Based on the available data, the importance of the respective lead and bismuth shot can only be assessed with caution. An evaluation of the prevalence of lead levels exceeding the 0.1 mg Pb/kg threshold limit over the years 2003–2010 is shown in Fig 11.

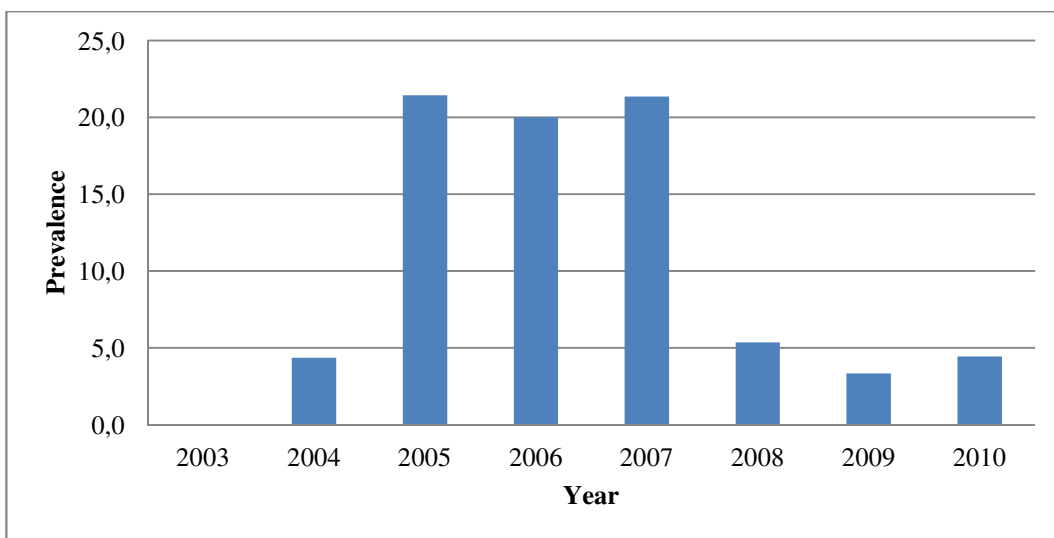


Figure 11. Prevalence of lead levels exceeding the 0.1 mg Pb/kg threshold limit for the years 2003–2010.

The very marked drop from 2007 to 2008 is most likely a consequence of the campaign to reduce the illegal use of lead shot that was launched before the 2008 hunting season. Also, awareness of this study may have played a role by making hunters either not use lead shot, or districts not delivering game to official slaughterhouses to avoid it being included in the standard measurements of lead content. As a consequence of the findings in this study, manufacturers in 2009 changed methodology and reduced the lead content of bismuth shot, which is also indicated in the measurement of the 2010-generation of bismuth shot, now containing 950 mg Pb/kg. However, this cannot explain the drop in prevalence of high lead levels from 2007 to 2008. We have focused specifically on the lead and bismuth shot, and not on tin shot, also believed to contain lead. Tin is part of bismuth shot and it cannot be excluded that lead in bismuth shot derives from added tin. There is no evidence that steel shot is a lead source.

## 6. Conclusion

There are several factors suggesting that the source of the measured excess of lead above the action limits is not found in bird food, natural food or in the surrounding environment. Firstly, excess lead is found in a variety of wildlife species with rather different breeding and foraging strategies. Secondly, control measurements on pheasants collected on properties that had significantly elevated lead levels in 2007, no longer showed elevated lead levels in 2008, although there had apparently been no changes in feed or environment. Thirdly, repeated measurements on samples from birds with high lead levels showed widely varying results and rarely confirmed the result of the initial measurement. This suggests that the lead content is not uniformly distributed throughout the tissue, as would be expected if the lead came through the bird's digestive system.

Similarly, there are a number of factors which suggest that the source of lead is associated with leaded ammunition. It is in this context demonstrated that bismuth shot contains lead, and the continued use lead shot for hunting means that lead shot is available for birds in the environment. The study did not indicate that ingestion of lead shot is the primary source of elevated lead levels.

Our study suggests that the major source of elevated lead levels is lead-containing shot that, during hunting, is shot into birds' muscle and thereby constitutes a very significant source of sporadically occurring elevated lead levels, when whole shot or fragments of metal from shot are included in the samples. Localization of shot indicates that about one third of the shot is located in the breast muscle from which the samples are collected. In experiments under controlled conditions, it is also shown that there may be erosion of shot during the laboratory preparation of samples, therefore explaining both the size and frequency of the measured lead levels.

## 7. Acknowledgements

Thanks to: Anne Sofie Hammer, National Veterinary Institute, Technical University of Denmark, and Inge Rokkjær, Food Northern Region, for assistance in data collection and comments on the report; Dick Dyreby, Nordic X-ray Technique, for the development of methodology and assistance for X-ray analysis of the gizzard; Eva Voigt Kanstrup for dissection and editorial assistance; Dick Potts (UK); David Stroud, JNCC (UK); Chris Franson, USGS National Wildlife Health Centre (US); and: Vernon Thomas, Guelph University (Canada) – all for technical data and input. Finally, thanks to 15. Juni Fonden for awarding a grant for the international publication of the work.

## 8. References

- Anderson, WL, Havera, SP & Zercher, BW (2000) Ingestion of lead and nontoxic shotgun pellets by ducks in the Mississippi Flyway. *Journal of Wildlife management*, 64(3):848–857.
- Brewer, L, Fairbrother, A, Clark, J & Amick, D (2003) Acute toxicity of lead, steel, and an iron-tungsten-nickel shot to mallard ducks (*Anas platyrhynchos*). *Journal of Wildlife Diseases*, 39(3): 638–648.
- Butler, DA, Sage, RB, Draycott, AH, Carroll, JP & Potts, D (2005) Lead exposure in ring-necked pheasants on shooting estates in Great Britain. *Wildlife Society Bulletin* 33(2):583–589.
- Custer, TW, Franson, JC & Pattee, OH (1984) Tissue lead distribution and hematologic effects in American kestrels (*Falco sparverius* L.) fed biologically incorporated lead. *Journal of Wildlife Diseases* 20 (1):39–43.
- Daur, RW, Schwab, FE & Bateman, MC (1993). Blood lead concentrations of waterfowl from unhunted and heavily hunted marshes of Nova-Scotia and Prince Edward Island, Canada. *Journal of Wildlife Diseases*, 29(4):577-581.
- Fimreite, N (1984) Effects of lead shot ingestion in willow grouse. *Bulletin of Environmental Contamination and Toxicology* 33(1):121-126.
- Fisher, I. J., Pain, D. J. and Thomas, V. G. (2006) A review of lead poisoning from ammunition sources in terrestrial birds. *Biol. Conserv.* 131: 421–432.
- Food Standards Agency (2007) UK Survey of Metals in a Variety of Foods. <http://www.food.gov.uk/multimedia/pdfs/fsismetals0107.pdf>.
- Jayasinghe, R, Tsuji, LJS, Gough, WA, Karagatzides, JD, Perera, D & Nieboer, E (2004) Determining the background levels of bismuth in tissues of wild game birds: a first step in addressing the environmental consequences of using bismuth shotshells. *Environmental Pollution*, 132(1):13–20.
- Johansen, P, Asmund, G & Rigt F (2004) High human exposure to lead through consumption of birds hunted with lead shot. *Environmental Pollution* 127(1):125–129.
- Longcore, JR, LN Locke, GE Bagley & R. Andrews (1974) Significance of lead residues in mallard tissues. US Fish and Wildlife Service Special Scientific Report - Wildlife No. 182

- Mitchell, RR, Fitzgerald, SD, Aulerich, RJ, Balander, RJ, Powell, DC, Tempelman, RJ, Sticle, RL Stevens, W. & Bursian, SJ (2001) Health effects following chronic dosing with tungsten-iron and tungsten-polymer shot in adult game-farm mallards. *Journal of Wildlife Diseases* 37(3): 451–458.
- Noer, H, Hartmann, P & Madsen, J (2006) Wounding af vildt. Konklusioner på undersøgelser 1997–2005. Danmarks Miljøundersøgelser. Faglig Rapport Nr. 569.
- Pain, DJ, Fisher, IJ & Thomas, VG 2009. A global update of lead poisoning in terrestrial birds from ammunition sources. In: Watson, RT, Fuller, M. P, & Hunt WG (Eds.) *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*. The Peregrine Fund, Boise, Idaho, USA.
- Pain, DJ, Cromie, RL, Newth, J, Brown, MJ, Crutcher, E, Hardman, P, Hurst, L, Mateo, R, Meharg, AA, Moran, AC, Raab, A, Taggart, MA & Green, RE (2010) Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. *PLoS ONE* 5(4):e10315. doi:10.1371/journal.pone.0010315.
- Ringelman, JK, Miller, MW & Andelt, WF (1993) Effect of ingested tungsten-bismuth-tin shot on captive mallards. *Journal of Wildlife Management* 57(4):725–732.
- Sanderson, GC, Anderson, WL, Foley, GL, Havera, SP, Skowron, LM, Brawn, JW, Taylor, GD & Seets, JW (1998) Effects of lead, iron, and bismuth alloy shot embedded in the breast muscles of game-farm mallards. *Journal of Wildlife Diseases* 34(4): 688–697.
- Scheuhammer, AM, Perrault, JA, Routhier, E, Braune, BM, Campbell, GD (1998) Elevated lead concentrations in edible portions of game birds harvested with lead shot. *Environmental Pollution* 102(2-3):251–257
- Schulz, JH, Gao, X, Millspaugh, JJ & Bermudez, AJ (2009) Acute lead toxicosis and experimental lead pellet ingestion in Mourning Doves. Extended abstract In: Watson, RT, Fuller, M P & Hunt WG (Eds.) *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*. The Peregrine Fund, Boise, Idaho, USA.

# PAPER 13

Kanstrup N, Balsby TJS, Thomas VG (2016). Efficacy of non-lead rifle ammunition for hunting in Denmark. European Journal of Wildlife Research 62:333-340  
doi:10.1007/s10344-016-1006-0

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

## Order Summary

Licensee:	Aarhus University
Order Date:	Mar 8, 2020
Order Number:	4784320991890
Publication:	European Journal of Wildlife Research
Title:	Efficacy of non-lead rifle ammunition for hunting in Denmark
Type of Use:	Thesis/Dissertation
Order Ref:	Efficacy
Order Total:	0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customercare@copyright.com](mailto:customercare@copyright.com)  
<https://myaccount.copyright.com>



## AUTHORS' CONTRIBUTIONS

Kanstrup N, Balsby TJS, Thomas VG (2016) Efficacy of non-lead rifle ammunition for hunting in Denmark European Journal of Wildlife Research 62:333-340  
doi:10.1007/s10344-016-1006-0

- Kanstrup N managed and conceptualized the project and publication, analyzed data, drafted, edited and revised the manuscript and acted as corresponding author.
- Balsby TJS ensured statistical analysis of data and undertook edition and critical commentary.
- Thomas VG undertook edition and critical commentary.

I hereby confirm this statement of the authors' contributions to the above mentioned paper.



Thorsten J. S. Balsby

Kanstrup N, Balsby TJS, Thomas VG (2016) Efficacy of non-lead rifle ammunition for hunting in Denmark European Journal of Wildlife Research 62:333-340 doi:10.1007/s10344-016-1006-0

- Kanstrup N managed and conceptualized the project and publication, analyzed data, drafted, edited and revised the manuscript and acted as corresponding author.
- Balsby TJS ensured statistical analysis of data and undertook edition and critical commentary.
- Thomas VG undertook edition and critical commentary.

I hereby confirm this statement of the authors' contributions to the above mentioned paper.

Vernon G. Thomas, Professor Emeritus, Department of Integrative Biology, University of Guelph, Guelph, Ontario N1G 2W1

Confirmed, April 2021



Niels Kanstrup

# Efficacy of non-lead rifle ammunition for hunting in Denmark

Niels Kanstrup<sup>1</sup> · Thorsten J. S. Balsby<sup>2</sup> · Vernon G. Thomas<sup>3</sup>

Received: 18 January 2016 / Revised: 18 March 2016 / Accepted: 28 March 2016  
© Springer-Verlag Berlin Heidelberg 2016

**Abstract** Lead has traditionally been used for making hunting ammunition. However, lead from spent hunting bullets has proven to be a health hazard for wildlife, ecosystems, and humans. The transition to use non-lead ammunition for hunting raises several concerns, especially *inter alia* the question of efficacy. This study examined whether non-lead rifle ammunition fulfills the demands of ethical and humane hunting by causing a rapid kill of hunted animals equivalent to lead rifle ammunition. A field sample of 657 hoofed animals, most red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*), were hunted under normal Danish conditions by sport hunters using commonly used rifle calibers. The efficiency of copper versus lead bullets was tested using flight distance after being hit as the primary response parameter. For red deer, we were not able to show any statistical significant difference between performance of non-lead and lead bullet. For roe deer, we found a small,

statistically significant, relation between flight distances and shooting distance for roe deer struck with non-lead bullets but not with lead bullets. However, this difference was not of such magnitude as to have any practical significance under hunting conditions. We conclude that in terms of lethality and animal welfare, non-lead ammunition within the tested range of bullet calibers can be recommended as an effective alternative to lead-core bullets.

**Keywords** Hunting · Lead-free · Copper · Bullets · Efficacy · Roe deer · Red deer

## Introduction

Since the invention of firearms, lead has been the preferred material for ammunition because lead is relatively cheap, is easy to extract, and make into bullets. Lead has a high density, enabling bullets to retain their kinetic energy, and has good ballistic properties because its softness confers a great ability to deform and expand inside the target. However, the development of non-lead products during the last two to three decades has shown that other materials can substitute for rifle bullets (Thomas 2013; Kanstrup 2015; Gremse et al. 2014). Furthermore, lead is a toxic heavy metal, and there is increasing concern about the risk of poisoning of scavengers that eat animals and their remains after being shot or wounded with lead ammunition (Watson et al. 2009; Haig et al. 2014; Nadjafzadeh et al. 2013; Golden et al. 2016). There is also a growing concern about the health risk to people who frequently eat game shot with lead bullets and being exposed to lead levels above recommended values (Knott et al. 2010; Pain et al. 2010; Bellinger et al. 2013; Knutsen et al. 2015).

Various types of non-lead rifle bullets are produced and marketed, copper and copper-zinc alloys being the most

**Electronic supplementary material** The online version of this article (doi:10.1007/s10344-016-1006-0) contains supplementary material, which is available to authorized users.

✉ Niels Kanstrup  
nk@danskjagtakademi.dk

Thorsten J. S. Balsby  
thba@bios.au.dk

Vernon G. Thomas  
vthomas@uoguelph.ca

<sup>1</sup> Danish Academy of Hunting, Skrejrupsvej 31, 8410 Rønne, Denmark

<sup>2</sup> Department of Bioscience, Aarhus University, Grenåvej 14, Building 8411, 8410 Rønne, Denmark

<sup>3</sup> Department of Integrative Biology, University of Guelph, Guelph, Ontario N1G 2W1, Canada

widely used alternatives (Thomas 2013; Kanstrup 2015). Introduction of non-lead hunting ammunition raises a number of issues including efficacy, toxicity, safety, availability, and price (Knott et al. 2009, 2010; Thomas 2015a, b). The efficacy of lead-free rifle bullets to produce rapid fatality has been demonstrated under controlled experimental situations (Grund et al. 2010) and when using ballistic soap to simulate animal tissue (Gremse et al. 2014). Trinogga et al. (2013) used a structural analysis of wound channels of hunted animals to compare the ballistic performance of lead-free and lead-core bullets to conclude that their killing efficacy was likely similar. However, it is the ability of sport hunters to use lead-free rifle bullets with confidence against an array of species that will influence their adoption of these lead-core substitutes, and ultimately, their acceptance of any government regulation requiring their use (Cromie et al. 2010). Thus, it is important to assess the efficacy of such lead-free bullets when used by conventional sport hunters under field hunting situations, in which uncontrolled conditions may apply. Knott et al. (2009) conducted such a preliminary field study in the UK on British deer which supported the use of non-lead bullets. Spicher (2008) reported that 95 % of 247 animals in Germany (mainly deer and wild boar (*Sus scrofa*)) were killed rapidly by a single shot made from non-lead material. The present study is the first large-scale test of the efficacy of non-lead, copper, rifle bullets' ability to safely and humanely kill hunted wild game animals with that of equivalent lead-core bullets when used by sport hunters. We compared the flight distance of animals struck by copper and lead bullets, while taking the shooting distance and bullet terminal strike energy into account in the analyses. The null hypothesis tested was that there is no difference in flight distance for animals shot with lead-core bullets compared to animals shot with copper bullets.

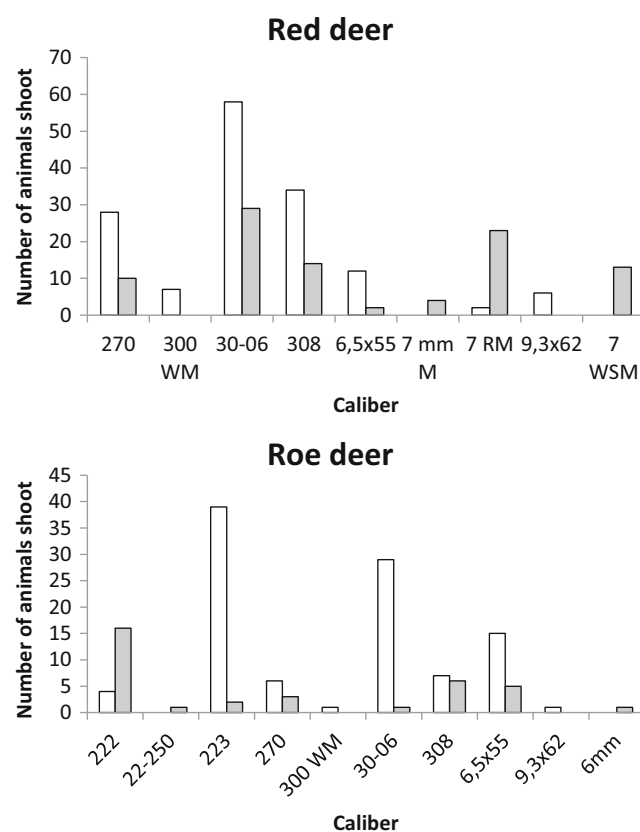
## Methods

### Sampling methodology

During three hunting seasons (years 2012–2014), 15 licensed and experienced Danish hunters collected data from 657 animals killed under customary hunting situations. Hunters were free to select the bullet caliber, bullet weight, and type consistent with accuracy from their rifles. Each rifle was sighted in to achieve accurate placement of bullets within shooting distances normal for that type of hunting. All hunters knew which type of bullet they fired (i.e., copper or lead-core) when each animal was killed. Ninety percent (591) of the data were taken from animals hunted in Denmark while the remaining 10 % (66) were taken in Sweden, Ireland, and Germany. Sixty-six percent (307) of the sample was red deer (*Cervus elaphus*), and 34 % (161) roe deer (*Capreolus*

*capreolus*). For the analyses in this paper, we only used the observations with frequently used calibers on red deer (224) and roe deer (133), which reduced the sample size to 357 observations.

The data were obtained from animals shot with commonly used firearms and cartridge calibers. The most common calibers used were 30-06, .308 WIN, 6.5×55, and .270 WIN (a total of 75 % of the sample), with the remaining being small calibers such as .222 REM and .223 REM, and large calibers, e.g., 9.3×62. Distribution of calibers used to hunt red and roe deer is shown in Fig. 1. Thirty percent of the overall sample were taken with lead bullets, 70 % with copper bullets. Twenty-five percent ( $n=33$ ) of the roe deer were taken with lead bullets and 75 % ( $n=100$ ) with copper bullet. The corresponding numbers for the red deer sample were 40 % ( $n=91$ ) and 60 % ( $n=133$ ). Hunters recorded for each animal shot the shooting distance, the animal's flight distance (the distance traveled by the shot animal before falling dead), movement of the animal at the time of shooting (standing, walking, running), location of the bullet's entry, bullet caliber, brand of ammunition, hunting area location, and date. Shooting and flight distances were estimated by each hunter

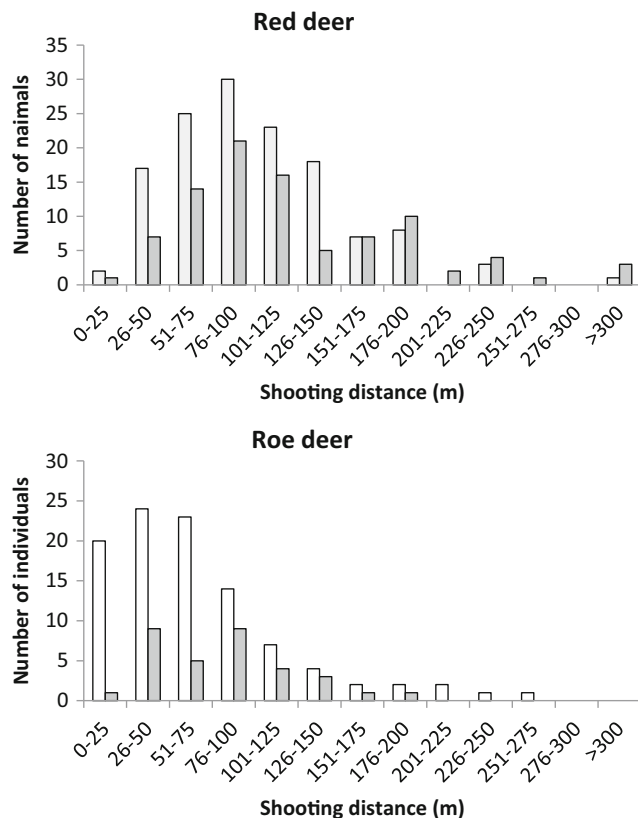


**Fig. 1** Number of animals shot with different rifle calibers and bullet material. White columns represent copper bullets and gray columns represent lead-core bullets. The rare calibers, omitted in the later analyses, were included in this figure. Red deer ( $N=242$ ) and roe deer ( $N=137$ )

either by eyesight, counting of measured steps, or use of electronic range finders. An estimate of the strike energy of the bullet was made based on the shooting distance, the mass, and muzzle velocity of the bullet as specified by the bullet's manufacturer. The estimate of strike energy assumed that the velocity of the bullet declined with 1 m/s per 1 m shooting distance, based on ballistic data given by a variety of rifle cartridge manufacturers. This calculation assumes that the correlation was linear within the range of shooting distances that were registered in this study. Shooting distances ranged from 7 to 380 m, with 80 % less than 100 m. Flight distances ranged from 0 to 1500 m, with 90 % <100 m (Fig. 2).

## Data analysis

The efficacy of the non-lead ammunition was tested in comparison with lead ammunition using flight distance as the criterion. To account for the variation in size of the animals in addition to the difference among bullet calibers, shooting distance, and flight distance, we analyzed data for red deer and roe deer in separate tests. We included only “one shot kills” of red and roe deer in the analyses because this is the best test of a single bullet's efficacy in producing a rapid death.



**Fig. 2** Number of red deer and roe deer shot at different shooting distance classes by copper bullets (white columns) and lead-core bullets (gray columns). Note that the statistics were made on the continuous shooting distance

Calibers which had been used less than 9 times for shooting roe deer and less than 13 for shooting red deer were omitted to enhance the robustness of the analyses. Hence, the calibers used in the calculations for roe deer were .222 REM, .223 REM, .270 WIN, 30-06, .308 WIN, and 6.5×55. Calibers used for red deer were .270 WIN, 7 MM RM, 7 MM WSM, 30-06, .308 WIN, and 6.5×55 (see supplementary material Table S1). The majority of the shots were shots placed in the heart and lung region. Data for a few shots placed in the abdomen were omitted from the analyses.

We used general linear mixed models and generalized linear mixed models (Littell et al. 2006) to test the influence of type of bullet material, movement of the animal at the time of shooting, strike energy, and shooting distance on flight distance. Due to collinearity issues, shooting distance and strike energy had to be tested in separate models. In the mixed model, we included covariates such as shooting distance or strike energy to reduce the effect of confounding variables in the dataset. To test the effect of bullet material (i.e., lead-core versus copper bullet), we included shooting distance, movement of the animal, and the interactions between shooting distance or strike energy and bullet material, and between movement of the animal and bullet material in the model. We used caliber as random effects as all shots taken with the same caliber would be expected to be more similar than shots made with other calibers, and hence the observations would not be equally independent. Each hunter has contributed multiple data points for the same species. These were considered independent observations as shooting distance and flight distance were rigorous measures that do not differ systematically between hunters, and the only factor that differed systematically was caliber, which was incorporated as a random factor. To illustrate the significant interaction effects, we used linear regressions. In all statistical tests assuming normal distribution, we tested for normality and homoscedasticity by examining probability plots and plots of residuals versus predicted values. The residuals for each test did not deviate from assumptions regarding normality and homoscedasticity. We used SAS ver 9.3 (SAS Institute, Cary, NC) to conduct all statistical analyses using proc mixed, proc glimmix, and proc glm. Statistical significance was accepted at  $p \leq 0.05$ .

## Results

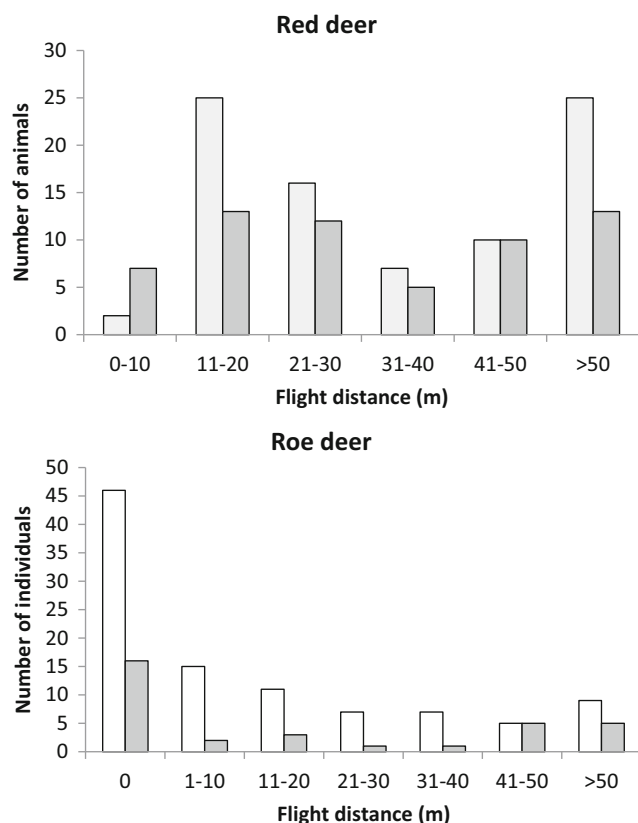
The original data set consisted of 137 roe deer and 242 red deer. However, after omitting data for the rarer calibers, the set consisted of 133 roe deer, of which 100 were shot with copper bullets and 33 shot with lead-core bullets, and 224 red deer, of which 133 were shot with copper bullets and 91 were shot with lead-core bullets. For these data, several parameters differed between roe and red deer. The use of calibers has

limited overlap (Fig. 1). For red deer, shooting distances were significantly larger than for roe deer (Fig. 2, Mixed model  $F_{1,365} = 10.97$ ,  $p = 0.001$ ). Likewise, flight distances for red deer were significantly longer for red deer than for roe deer (Fig. 3, generalized linear model assuming Poisson distribution  $F_{1,364} = 195.6$ ,  $p < 0.001$ ), and longer flight distances occurred more frequently for red deer than for roe deer. Due to these differences between roe deer and red deer, the two species data sets were analyzed separately (Fig. 4).

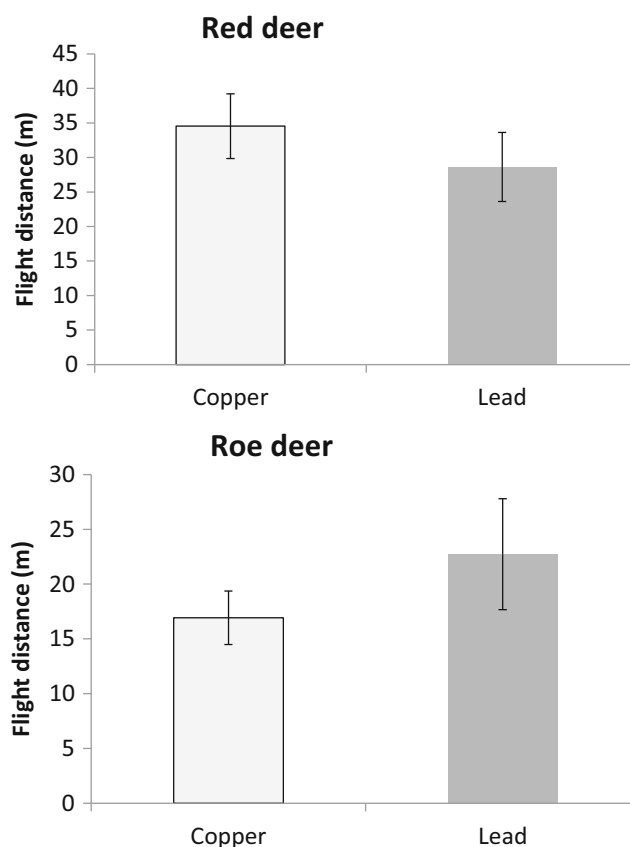
Shooting distances did not differ between copper bullets and lead-core for roe deer (General linear model  $F_{1,131} = 2.06$ ,  $p = 0.151$ ). For red deer, the shooting distance was significantly larger with lead-core bullets (125 m) than for copper bullets (105 m) (General linear model  $F_{1,223} = 5.87$ ,  $p = 0.016$ ).

### Effect of bullet material and shooting distance on the flight distance

The bullet material did not have an effect on the flight distance, although there was a statistically insignificant tendency for roe deer to show longer flight distances when



**Fig. 3** Numbers of red deer and roe deer for each flight class distance shot with copper bullets (white columns) and lead-core bullets (gray columns). Note that the statistics were made on the continuous distance



**Fig. 4** Flight distance (mean  $\pm$  SE) for red deer and roe deer shot with either lead-core (gray) or copper (white) bullets. Only the frequently used calibers were used for this estimate

shot with lead bullets compared to copper bullets (Table 1). However, the bullet material may have importance, as both the interaction effect between bullet material and shooting distance, and the interaction between bullet material and animal movement showed significant effects on flight distance for roe deer (Table 1).

The interaction effect between animal movement and bullet material was significant for roe deer. The pair wise comparison showed that flight distance was significantly larger for animals that were standing compared to animals that were walking when they were shot (least square means difference  $t_{96} = 2.50$ ,  $p = 0.014$ ). The pair wise comparison relating to bullet material was not significant, but indicated a larger flight distance for copper compared to lead-core bullets for both walking and standing roe deer (least square means difference, standing  $t_{96} = 1.68$ ,  $p = 0.097$ ; walking  $t_{96} = 1.81$ ,  $p = 0.073$ ). The significant interaction between shooting distance and bullet material suggests that the effect of shooting distance relative to flight distance differs between bullet materials. To illustrate these relations for each material, we tested the relation between shooting distance and flight distance for lead-core and copper bullets separately. The flight distance for roe deer shot with copper bullets increased significantly with increasing shooting distance, whereas the

**Table 1** Test for effect of bullet material, movement of the animal at the time of shooting, and shooting distance on the flight distance of roe deer and red deer. The data were analyzed using a mixed model with caliber as a random effect

	Red deer			Roe deer		
	<i>df</i>	<i>F</i>	<i>p</i>	<i>df</i>	<i>F</i>	<i>p</i>
Shooting distance	1, 209	1.34	0.249	1, 96	1.94	0.167
Material	1, 209	1.67	0.198	1, 96	3.33	0.071
Movement	2, 209	0.27	0.760	2, 96	2.07	0.132
Material $\times$ movement	2, 209	0.89	0.413	1, 96	5.49	0.021
Shooting distance $\times$ material	1, 209	0.02	0.890	1, 96	9.38	0.003

relation between flight distance and shooting distance was not significant for lead-core bullets (Fig. 5, General linear model, copper bullet:  $R^2=0.048$ ,  $F_{1,98}=4.89$ ,  $p=0.029$ , slope=0.102; lead-core bullet:  $R^2=0.063$ ,  $F_{1,31}=2.10$ ,  $p=0.158$ , slope=-0.164). For red deer, there were no significant effects of bullet material, movement of the animal, shooting distance, and their interaction effects (Table 1, Fig. 6). Copper bullets, however, tended to result in longer, but statistically insignificant, flight distances than lead-core bullets (Fig. 4). Flight distances for red deer tended to increase with shooting distance, but this relation was not significant (Table 1).

#### Effect of terminal strike energy and bullet material on flight distance

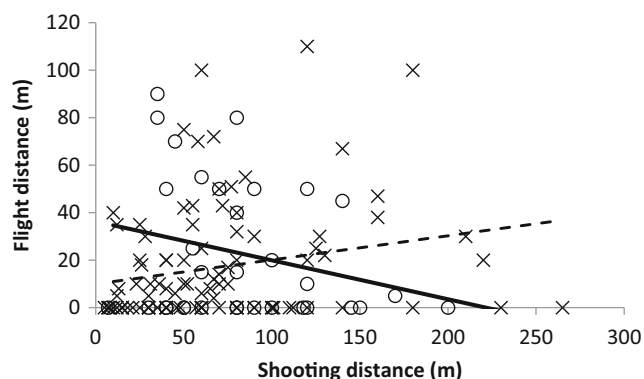
Bullet material did not have any effect on flight distance when combined with strike energy within the tested range of strike energy (approximately 2500 to 5000 J). Neither strike energy, bullet material, nor the interaction between them showed significant effects on the flight distance for roe deer and red deer (Table 2). There was no significant relation between

flight distance and impact energy for either lead-core or copper bullets for roe deer and red deer (Table 2).

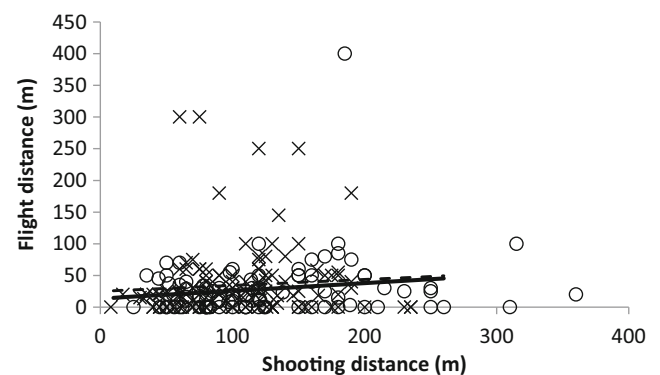
#### Discussion

The results of this realistic comparison using actual hunters under prevailing hunting conditions affirms the efficacy of copper bullets in producing rapid incapacitation, of red and roe deer. The result is consistent across a range of practicing recreational hunters and a range of different bullet brands, calibers, and bullet types. The flight distances observed for both deer species struck by copper bullets was largely less than 50 m, reflective of rapid death and assured retrieval of the shot animal. This field comparison of the two bullet types indicates that a transition to non-lead rifle ammunition can be undertaken with no adverse consequences to the hunters and hunted given the array of non-lead ammunition already available. Two field comparisons, one in the UK Knott et al. (2009), and the present Danish study, endorse the practicality of this transition.

What constitutes an effective and humane kill in a hunting context is not defined in Danish hunting regulations, but it is



**Fig. 5** Relation between shooting distance and flight distance for roe deer shot with lead (circles) and copper (crosses) bullets. The lines represent the regression for the relationships: broken line denotes copper bullets; solid line for lead-core bullets. Regression for copper bullets:  $R^2=0.05$ , slope=0.102,  $t_{98}=2.21$ ,  $p=0.029$ , intercept=9.98,  $t=2.53$ ,  $p=0.013$ . Regression for lead-core bullets,  $R^2=0.06$  slope=-0.164,  $t_{31}=1.45$ ,  $p=0.158$ , intercept=36.3,  $t=3.42$ ,  $p=0.002$



**Fig. 6** Relation between shooting distance and flight distance for red deer shot with lead (circles) and copper (crosses) bullets. The lines represent the regression for the relationships. Regression for copper:  $R^2=0.006$ , slope=0.09,  $t_{131}=0.92$ ,  $p=0.360$ , intercept=24.9,  $t=2.15$ ,  $p=0.033$ . Regression lead:  $R^2=0.030$ , slope=0.122,  $t_{89}=1.66$ ,  $p=0.101$ , intercept=13.4,  $t=1.29$ ,  $p=0.202$

**Table 2** Test for effect of strike energy and material on flight distance for roe deer and red deer. The data were analyzed with a mixed model with caliber as a random effect

	Red deer			Roe deer		
	<i>df</i>	<i>F</i>	<i>p</i>	<i>df</i>	<i>F</i>	<i>p</i>
Strike energy	1, 201	1.71	0.193	1, 96	0.01	0.941
Material	1, 201	0.33	0.564	1, 96	3.89	0.052
Movement	2, 201	0.53	0.589	2, 96	0.61	0.544
Material $\times$ movement	2, 201	1.07	0.345	1, 96	3.08	0.083
Strike energy $\times$ material	1, 201	0.85	0.357	1, 96	2.49	0.118

implicit that the demands of animal welfare require killing the quarry as rapidly as possible and avoiding prolonged suffering (Aebischer et al. 2014). Given this consideration, we regard the flight distance to be a valid criterion, as flight distance in most cases will reflect the time from the animal is hit until it dies (“time to death”). Furthermore, flight distance is a variable that is relatively easy to measure.

The flight distance is dependent on major variables such as body size of the animal, hitting point, shooting distance, rifle caliber, bullet mass and velocity, and bullet type and construction. The question is whether this dependence is more or less pronounced for non-lead ammunition compared with lead-core ammunition (Caudell et al. 2012). The expansion and fragmentation of bullets is regarded as a fundamental property to ensure that the bullet delivers its energy and creates sufficient injury to vital sections of the body to cause rapid death (Caudell 2013). Therefore, lead-core bullets are traditionally designed to expand and fragment, whereas lead-core bullets designed not to expand (e.g., full metal jacket bullets) are not allowed for hunting. Non-lead bullets fragment much less than lead-core bullets (Grund et al. 2010; Cruz-Martinez et al. 2015). However, non-lead bullets are designed to either expand (most types) or fragment into a few sections thus creating adjacent tissue injury in addition to the injury caused by the bullet in the prime wound channel. A typical expanding copper bullet will, on entering the animal, double its diameter and achieve a mushroom shape (Fig. 7,

right), and despite that almost no bullet mass is lost as fragments, will have a dramatic physiological impact provided that the expansion is released in a depth that ensure injury to vital organs.

In our comparison of lead versus copper bullets, there was a tendency for copper bullets to result in longer flight distances for red deer. However, the trend did not show statistical significance. For roe deer, we found a statistically significant increase of flight distance with shooting distance for copper bullets, but not for lead bullets. In addition, we found that the main factor for material differed significantly between non-lead and lead bullets. This difference was not related to precision of bullet strike, choice of caliber, or other variables. However, the difference between copper and lead-core bullets become important only at shooting distances beyond 100 m, at which flight distances for roe deer shot with copper bullets become larger than those shot with lead-core bullets. Because shooting distances above 100 m are rarely seen in a practical Danish hunting context, this finding does not disqualify the use of copper bullets. Also for red deer, we found an overall statistical significant correlation between flight distance and shooting distance, but with no difference between lead-core and copper bullets.

In the present study, lead-core and copper bullets did not differ in efficacy when accounting for shooting distance and strike energy for red deer. For roe deer, the flight distance increased with shooting distance for copper but not for lead-core bullets. One reason for this could be the lower strike energy in the smaller bullets used for roe deer hunting. However, neither strike energy nor the interaction between strike energy and bullet materials had a significant effect on flight distance for roe deer. The energy in the bullet therefore seems an unlikely explanation for the positive relation between shooting distance and flight distance. It is more likely that the ballistic behavior of the bullet upon impact changes with the strike velocity, which especially for small copper bullets declines faster with increasing shooting distance. It is well known that lead bullets have a larger propensity to fragment upon hitting the animal compared to copper bullets (Caudell et al. 2012; Grund et al. 2010; Thomas 2015a). This could explain the observed difference in flight distance, which

**Fig. 7** *Left:* 9 g lead-core bullet (caliber 6.5 $\times$ 55) before and after shooting through water jars. Residual bullet weight is 5.9 g, and approximately 3 g of lead particles and fragments will potentially contaminate the carcass. *Right:* 17.5 g copper bullet (caliber 9.3 $\times$ 62) with a mass reduction of <1 % after passing through similar testing equipment



although being statistically significant is of minor importance under the observed normal hunting conditions.

It is expected that increased impact energy of bullets would reduce flight distance. Gremse and Rieger (2012) show such a relation for impact energies up to 2500 J, but increases beyond 3000 J did not provide any further shortening of the flight distance. In the present study, we have too few impact energy values below 2500 J to conduct a similar analysis. But for impact energy values beyond 3000 J, we cannot demonstrate that increased impact energy resulted in reduced flight distance, either for copper or for lead-core bullets. This suggests that the impact energy of copper bullets is not a limitation of their efficacy, as there is no real difference from the classical lead projectiles. These results show that the impact energy can be seen as a measure of effectiveness only to a certain extent. Gremse and Rieger (2012) indicate that, apart from the critical vital point of impact, the decisive factor for killing ability is the bullet's ability to transform its energy into power and to release it at the right depth in the animal body. Hence, the ballistic behavior of the bullet upon hitting the animal is more important than the bullet material, which is also supported by Gremse and Rieger (2012) and Gremse et al. (2014). This indicates the need of ongoing development of bullet design independently of the material used, especially as it relates to bullet deformation and fragmentation within the animal body (Fackler et al. 1984; Sellier and Kneubuehl 1994; Caudell et al. 2012).

## Conclusion

The results of this study and the general experience of the participating hunters indicate that there is no consistent and significant difference between the efficacy of lead-core and copper bullets for hunting roe and red deer under normal field hunting conditions. These results are in accordance with the studies of Spicher (2008), Knott et al. (2009, 2010), and Gremse and Rieger (2012), which, also, could not detect any major difference between the efficacy of lead-core and copper bullets. The tested copper bullets have an efficacy similar to lead-core ammunition and meet all efficacy requirements for ammunition used in traditional hunting in Denmark. From a lethality and animal welfare point of view, the different brands of non-lead ammunition within the range of bullet calibers and types tested under the reported field conditions can be recommended as an alternative to lead-core ammunition. However, there is a continuous need to develop non-lead ammunition to satisfy not only an environmental demand but also to improve efficacy, and thereby the ethical sustainability of recreational hunting. Finally, development of hunter education programs and best practice guidance in order to further enhance hunting efficacy is recommended independently of the choice of bullet material.

**Acknowledgments** We thank the many hunters who took the time to provide all the data we requested. We also thank 15. Juni Fonden, Arboretet, Kirkegårdsvej 3A, DK-2970 Hørsholm for funding all stages of this project. The grant was given for the 3-year study period 2013–2015 (grant number 2013-A-88).

**Compliance with ethical standards** All of the hunters who participated in the study were fully licensed under Danish law, were experienced hunters, who killed deer according to prevailing ethical hunting standards.

## References

- Aebischer NJ, Wheatley CJ, Rose HR (2014) Factors associated with shooting accuracy and wounding rate of four managed wild deer species in the UK, based on anonymous field records from deer stalkers. *PLoS ONE* 9(10), e109698. doi:10.1371/journal.pone.0109698
- Bellinger DC, Burger J, Cade TJ, Cory-Slechta DA, Finkelstein M, Hu H, Kosnett M (2013) Health risks from lead-based ammunition in the environment. *Environ Health Perspect* 121:A178–A179. doi:10.1289/ehp.1306945
- Caudell JN, Stopak SR, Wolf PC (2012) Lead-free, high-powered rifle bullets and their applicability in wildlife management. *Human Wildlife Interact* 6(1):105–111
- Caudell JN (2013) Review of wound ballistic research and its application to wildlife management. *Wildl Soc Bull* 37(4):824–831. doi:10.1002/wsb.311
- Cromie RL, Loram A, Hurst L, O'Brien M, Newth J, Brown MJ, Harradine JP (2010) Compliance with the environmental protection (restrictions on use of lead shot) (England) Regulations 1999. Report to Defra, Bristol, p 99
- Cruz-Martinez L, Grund MD, Redig PT (2015) Quantitative assessment of bullet fragments in viscera of sheep carcasses as surrogates for white-tailed deer. *Human Wildlife Interact* 9(2):211–218
- Fackler ML, Surinchak JS, Malinowski JA, Brown RE (1984) Bullet fragmentation: a major cause of tissue disruption. *J Trauma-Injury Infection Critical Care* 24(1):35–39
- Golden NH, Warner SE, Coffey MJ (2016) A review and assessment of spent lead ammunition and its exposure and effects to scavenging birds in the United States. *Revs Environment Contam Toxicol* 237:123–191. doi:10.1007/978-3-319-23573-8\_6
- Gremse C, Rieger S (2012) Ergänzende Untersuchungen zur Tötungswirkung bleifreier Geschosse. Bundesanstalt für Landwirtschaft und Ernährung (BLE) BMELV – Förderkennzeichen 09HS023. [http://www.bmel.de/SharedDocs/Downloads/Landwirtschaft/Wald-Jagd/BLE-Forschungsbericht-Jagdmunition.pdf?\\_\\_blob=publicationFile](http://www.bmel.de/SharedDocs/Downloads/Landwirtschaft/Wald-Jagd/BLE-Forschungsbericht-Jagdmunition.pdf?__blob=publicationFile).
- Gremse F, Krone O, Thamm M, Kiessling F, Tolba RH, Rieger S, Gremse C (2014) Performance of lead-free versus lead-based hunting ammunition in ballistic soap. *PLoS ONE* 9(7), e102015. doi:10.1371/journal.pone.0102015
- Grund MD, Cornicelli L, Carlson LT, Butler EA (2010) Bullet fragmentation and lead deposition in white-tailed deer and domestic sheep. *Human Wildlife Interact* 4:257–265
- Haig SM, D'Elia J, Smith-Eagles C, Fair JM, Gervais J, Herring G, Rivers JW, Schultz JH (2014) The persistent problem of lead poisoning in birds from ammunition and fishing tackle. *Condor* 116:408–428. doi:10.1650/CONDOR.14-36.1
- Kanstrup N (2015) Non-lead rifle ammunition—availability in Danish gun stores. Report 1508–2. Danish Academy of Hunting. 8 p. [http://www.danskjagtakademi.dk/fileadmin/user\\_upload/NK/Bly/](http://www.danskjagtakademi.dk/fileadmin/user_upload/NK/Bly/)

[150820\\_Blyfri\\_riffelammunition\\_forhandlerundersoegelse\\_RAPPORT.pdf](#).

- Knott J, Gilbert J, Green RE, Hoccom DG (2009) Comparison of the lethality of lead and copper bullets in deer control operations to reduce incidental lead poisoning: field trials in England and Scotland. *Conserv Evidence* 6:71–78
- Knott J, Gilbert J, Hoccom DG, Green RE (2010) Implications for wildlife and humans of dietary exposure to lead from fragments of lead rifle bullets in deer shot in the UK. *Sci Total Environ* 409:95–99. doi:[10.1016/j.scitotenv.2010.08.053](#)
- Knutsen HK, Brantsæter A-L, Alexander J, Meltzer HM (2015) Associations between consumption of large game animals and blood levels in humans in Europe: the Norwegian experience. In: Delahay RJ, Spray CJ (eds) *The Oxford Lead Symposium. Lead ammunition: understanding and minimizing the risks to human and environmental health*. Edward Grey Institute, Oxford, pp 44–50
- Littell RC, Milliken GA, Stroup WA, Wolfinger RD, Schabenberger O (2006) *SAS for mixed models*, second edn. SAS Institute Inc, Cary
- Nadjafzadeh M, Hofer H, Krone O (2013) The link between feeding ecology and lead poisoning in white-tailed sea eagles. *J Wildl Manage* 77(1):48–57. doi:[10.1002/jwmg.440](#)
- Pain DJ, Cromie RL, Newth J, Brown MJ, Crutcher E, Hardman P, Hurst L, Mateo R, Meharg AA, Moran AC, Raab A, Taggart MA, Green RE (2010) Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. *PLoS ONE* 5(4), e10315. doi:[10.1371/journal.pone.001031](#)
- Sellier K, Kneubuehl BP (1994) *Wound ballistics and the scientific background*. Elsevier, Amsterdam, p 479
- Spicher V (2008) Experiences with lead-free rifle ammunition under field hunting conditions. In: Krone O (ed) *Lead poisoning of sea eagles: causes and approaches to solutions—the transition to lead-free rifle ammunition*. Leibniz Institut für Zoo- und Wildtierforschung, Berlin, pp 81–90 (In German)
- Thomas VG (2013) Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. *AMBIO* 42:737–745. doi:[10.1007/s13280-012-0361-7](#)
- Thomas VG (2015a) Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In: Delahay RJ, Spray CJ (eds) *The Oxford Lead Symposium. Lead ammunition: understanding and minimizing the risks to human and environmental health*. Edward Grey Institute, Oxford, pp 85–97
- Thomas VG (2015b) Lead-free rifle bullets: product availability, and issues concerning use in USA. In: Kanstrup N (ed) *Efficiency and other aspects of transition from lead to non-lead rifle ammunition*. Dansk Jagtakademi, Danish Hunters' Association and 15, Juni Fonden, Aarhus
- Trinogga A, Fritsch G, Hofer H, Krone O (2013) Are lead-free hunting rifle bullets as effective at killing wildlife as conventional bullets? A comparison based on wound size and morphology. *Sci Total Environ* 443:226–232. doi:[10.1016/j.scitotenv.2012.10.084](#)
- Watson RT, Fuller M, Pokras M, Hunt WG (eds) (2009) *Ingestion of lead from spent ammunition: implications for wildlife and humans*. The Peregrine Fund, Boise, 383

# PAPER 14

Kanstrup N, Fox AD, Balsby TJS (2020). Toxic lead gunshot persists accessible to waterbirds after a 33-year ban on their use. Science of The Total Environment:136876 doi:<https://doi.org/10.1016/j.scitotenv.2020.136876>

## RIGHTS:



**Toxic lead gunshot persists accessible to waterbirds after a 33-year ban on their use**  
Author: Niels Kanstrup, Anthony D. Fox, Thorsten Johannes Skovbjerg Balsby  
Publication: Science of The Total Environment  
Publisher: Elsevier  
Date: 20 April 2020  
© 2020 Elsevier B.V. All rights reserved.

Please note that, as the author of this Elsevier article, you retain the right to include it in a thesis or dissertation, provided it is not published commercially. Permission is not required, but please ensure that you reference the journal as the original source. For more information on this and on your other retained rights, please visit: <https://www.elsevier.com/about/our-business/policies/copyright#Author-rights>

[BACK](#) [CLOSE WINDOW](#)

## AUTHORS' CONTRIBUTIONS

Dear Niels

I hereby confirm the following contribution to the article of which I am an author:

Kanstrup N, Fox AD, Balsby TJS (2020) Toxic lead gunshot persists accessible to waterbirds after a 33-year ban on their use Science of The Total Environment:136876 doi:<https://doi.org/10.1016/j.scitotenv.2020.136876>

- Kanstrup, N managed and conceptualized the project, drafted the manuscript, processed and analysed data, edited and revised the manuscript and served as corresponding author.
- Fox AD undertook critical review and commentary.
- Balsby TJS ensured statistical data analysis and undertook critical review and commentary.
- All authors approved the final revised manuscript.

Yours sincerely



Professor Anthony D. Fox  
Department of Bioscience  
Aarhus University  
Kalø  
Grenåvej 14  
DK-8410 Rønde  
Denmark

I hereby confirm the following contribution to the article of which I am an author:

Kanstrup N, Fox AD, Balsby TJS (2020) Toxic lead gunshot persists accessible to waterbirds after a 33-year ban on their use Science of The Total Environment:136876  
doi:<https://doi.org/10.1016/j.scitotenv.2020.136876>

- Kanstrup, N managed and conceptualized the project, drafted the manuscript, processed and analysed data, edited and revised the manuscript and served as corresponding author.
- Fox AD undertook critical review and commentary.
- Balsby TJS ensured statistical data analysis and undertook critical review and commentary.
- All authors approved the final revised manuscript.



Thorsten J. S. Balsby

Confirmed, March 2021



Niels Kanstrup



# Toxic lead gunshot persists accessible to waterbirds after a 33-year ban on their use

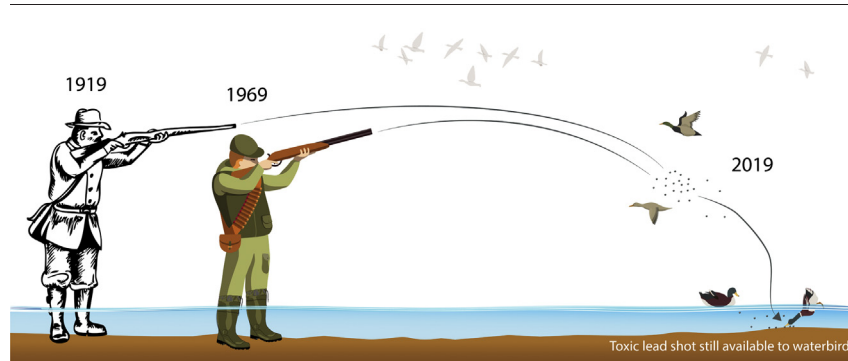
Niels Kanstrup\*, Anthony D. Fox, Thorsten Johannes Skovbjerg Balsby

Aarhus University, Department of Bioscience, Grenåvej 14, DK-8410 Rønde

## HIGHLIGHTS

- Lead shot was banned over Danish wetlands in 1986 to reduce poisoning of waterbirds.
- Lead shot accessible to birds in resampled wetlands did not differ in 2019 to late 1970s.
- Low settlement and corrosion rates of shot pellets explain pellet persistence in soils.
- Replacement non-toxic steel shotgun pellets corrode and disappear.
- Accumulated lead shot creates an enduring global toxic legacy.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

### Article history:

Received 21 November 2019  
Received in revised form 21 January 2020  
Accepted 21 January 2020  
Available online 22 January 2020

Editor: Filip M.G. Tack

### Keywords:

Hunting  
Lead shot  
Shot settlement  
Steel shot  
Waterbirds

## ABSTRACT

Use of lead shot for hunting was banned under legislation on 26 Ramsar sites in Denmark from 1986, based on evidence of poisoning in waterbirds ingesting lead shot and high lead shot pellet densities in Danish wetland sediments caused by intensive hunting. To assess the fate of lead shot from hunting prior to 1986 and the degree to which such shot remains available to waterbirds, this study replicated the survey of shot pellet densities in substrates in Ringkøbing Fjord undertaken in the late 1970s. 287 shotgun pellets (282 lead, five steel) were recovered from 123 sediment samples at four locations, equivalent to a mean of 127 pellets  $m^{-2}$  in the top 20 cm of the sediment at the four locations, in certain hot spots equating to  $>250$  kg lead  $ha^{-1}$ , broadly similar to densities found in the 1970s. Possible explanations were given for the persistence of such high lead shot densities despite  $>30$  years of regulation, during which time steel shot has been widely used as the alternative to lead. Field experiments showed that steel shot corroded in the marine environment, which likely contributes to lower steel shot densities found in this study. It is concluded that lead gunshot pellet dispersal and accumulation in natural ecosystems remains as a persistent and irreversible hazard to wildlife and ecosystems. Based on these Danish experiences, it is urgently recommended that international and national bodies in countries where hunting with lead shot continues recognise these results and act to prevent the accumulation of this toxic metal.

© 2020 Elsevier B.V. All rights reserved.

## 1. Introduction

It has long been recognised that expended lead shot deposited into wetland sediments by hunters is ingested by waterbirds as food or grit, causing sub-lethal effects and widespread mortality especially to dabbling duck species (e.g. Bellrose, 1959; Wetmore, 1919). Danish

\* Corresponding author.  
E-mail address: [nk@bios.au.dk](mailto:nk@bios.au.dk) (N. Kanstrup).

1970s studies showed increasing evidence of the lethal lead poisoning of waterbirds, e.g. Mute Swan (*Cygnus olor*), caused by shot ingestion (Clausen and Wolstrup, 1979; Kanstrup et al., 2018; Pedersen and Meltofte, 1979) and the accumulation of high densities of lead shot in wetlands as a result of concentrated local shooting intensity (Eskildsen, 1980; Pedersen, 1978; Pedersen and Meltofte, 1979). These results led to a ban on hunter's use of lead shot on the 26 declared Ramsar sites (wetlands designated to be of international importance under the Ramsar Convention) in Denmark in 1985 (effective from 1 August 1986). By 1996, Danish legislation banned all use, trade and possession of lead shot cartridges, motivated largely by the need to efficiently enforce the regulation of lead shot over wetlands, but also by a broader national policy to phase-out all lead compounds in the environment wherever possible (Kanstrup, 2018).

Despite 33 years of legislation to regulate the use of lead shot, there have been few studies of the effect of these changes in law, until very recent studies of compliance (Kanstrup, 2012; Kanstrup and Balsby, 2019a) lessons learned (Kanstrup, 2018) and nature conservation benefits (Kanstrup and Balsby, 2019b). To date, there has been no attempt to measure the rate of disappearance of lead shot pellets in wetlands since regulation and determine the current availability of lead shot to waterbirds in wetlands. Kanstrup and Balsby (2019b) considered this as a "population" of dispersed shotgun pellets ( $P_d$ ) available in the environment to birds. This population can be regarded as analogous to other populations with its overall instantaneous size determined by the balance between "recruitment" (addition of new pellets to the substrate from hunting, excretion by birds, and accumulation of dead organisms that have accumulated pellets) and "mortality" (pellets that becoming inaccessible by sinking deeper into sediment layers, pellets that corrode into fragments too small to constitute a problem, and shot ingested and thereby removed by birds). Recruitment depends almost exclusively on hunting intensity, i.e. numbers of shots fired and thus new gunshot pellets dispersed. "Mortality" is more complex. Shot may sink slowly through the substrate, but this varies with local conditions. Sediment movement may bury pellets as seen in Spanish wetlands, but equally can expose them (Mateo et al., 1997). Studies investigating pellet degradation in natural environments have demonstrated that lead gunshot pellets remain unchanged for considerable periods of time, estimating complete decomposition of particulate lead likely takes tens or hundreds of years (Jørgensen and Willems, 1987; Mateo et al., 1997; Rooney et al., 2007; Scheuhammer and Norris, 1996; Takamatsu et al., 2010). However, decomposition depends on inter alia temperature, moisture, substrate chemistry and biotic functions (Rooney et al., 2007; Sullivan et al., 2012). Generally, studies demonstrate that dispersed lead shot may remain available to waterbirds for decades after deposition (Flint, 1998; Flint and Schamber, 2010; Mateo et al., 2000; Tavecchia et al., 2001). Finally, the fraction removed by birds, gleaned during their feeding activity in the upper horizons of sediments either as potential prey or for use as gizzard grit remains unknown and unquantified.

Due its history of phasing out lead shot for hunting, Denmark provides excellent opportunities for investigating the consequences of regulation, particularly to establish the current availability of lead shot in wetland substrates more than three decades after the ban. Wetlands subject to earlier investigations of substrate lead gunshot pellet densities are of special interest as they provide a potential baseline for comparison with contemporary densities to determine the fate of lead shot in wetland substrates (i.e. to determine mortality in  $P_d$ ).

In this study, wetland sediments were resampled in Ringkøbing Fjord, a large wetland in Western Jutland (Ramsar International No. 141, Natura 2000 Site Code DK00CY163) and popular waterbird hunting area. The site is non-tidal, rather sheltered, being well protected against storm-ravage and thus exposed to low sedimentation/erosion rates. This applies in particular to the sampling locations in the present study where the water is brackish (salinity 0.3–0.5%). In the late 1970s, lead shot densities were determined at nine locations around

the fjord (Eskildsen, 1980; Pedersen, 1978; Pedersen and Meltofte, 1979), of which we here resurvey four previously surveyed sites (Fig. 1). In addition, experiments with steel shotgun pellets to test their rate of degradation relative to lead were undertaken.

## 2. Materials and methods

### 2.1. Measuring contemporary densities of shot in sediment

Sediment cores were taken during August–September 2017 and July 2018, when water depth over the four substrate sampling locations (Loc1: 55.871013°N 8.207484°E; Loc2: 55.877153°N, 8.244359°E; Loc3: 55.881197°N, 8.277147°E, Loc4: 55.972646°N, 8.273392°E) varied from 20 to 50 cm. At each location, two to three stations (13 in total) were selected and a total of 123 samples were taken. Sampling used a circular corer (diameter 15 cm; cross-sectional area 177 cm<sup>2</sup>) designed and used to extract and collect above and below ground plant biomass to quantify food sources for herbivorous birds. The corer was forced into the sediment to a depth of 20 cm and each sediment core (volume 3534 cm<sup>3</sup>) extracted. To assess any vertical gradient in shot density, shot types, or shot sizes, cores were divided into an upper (0–10 cm) and lower layer (10–20 cm) each of which were sieved separately, except at Loc3. Each core subsample was washed through a 50 × 50 cm sieve (mesh size 2 mm) and shot retained in the sieve was identified visually from grit. Extracted shot was labelled and stored according to location, station, sample, and top or bottom layer. Gunshot pellet type (lead/steel) was determined by magnetism and gravity (see (Kanstrup and Balsby, 2019b)) and each weighed to the nearest mg. Shot size was assessed to the nearest tenth millimetre from the average of the max and min diameter of each shot.

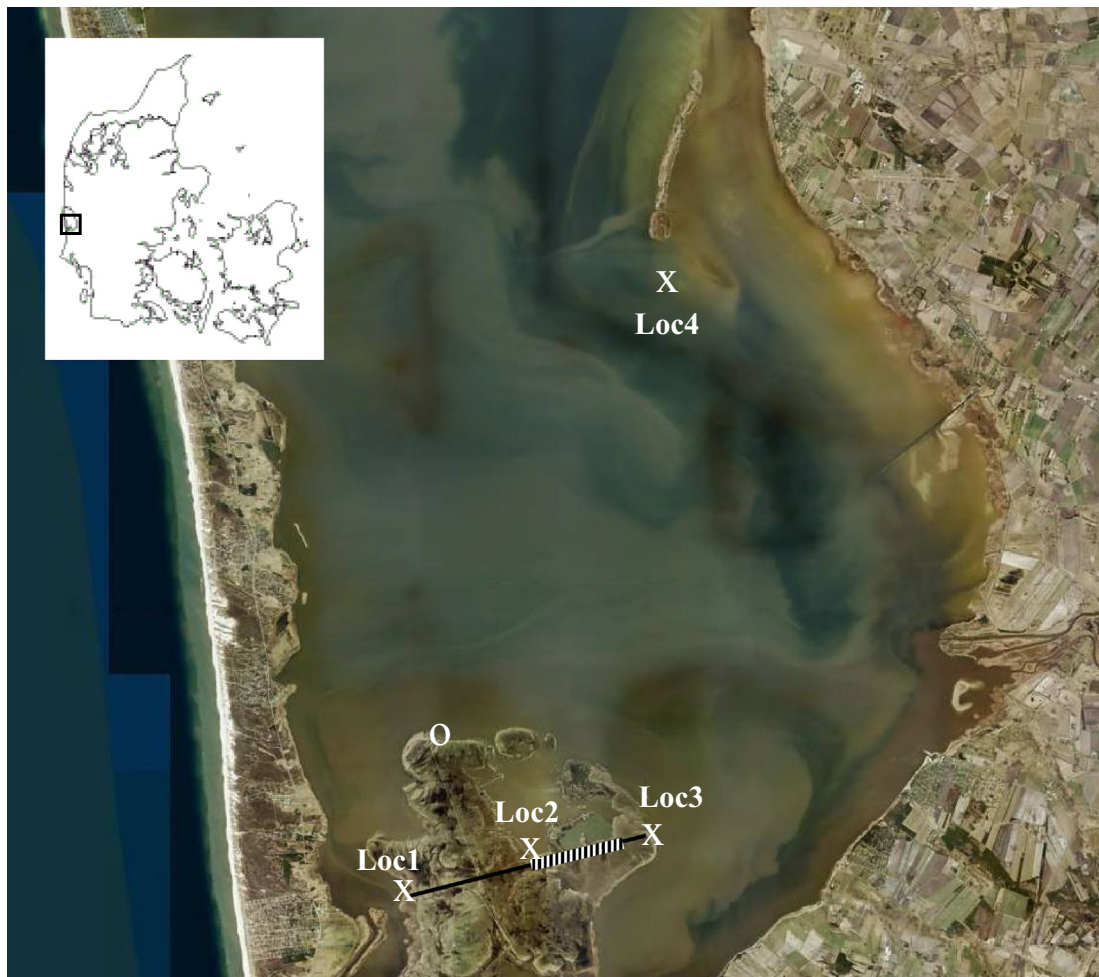
### 2.2. Corrosion of steel shot

To determine rates of degradation of dispersed steel shot, a sample of 150 gunshot pellets (average mass: 178 (172–184) mg) was placed at a location close to "the harbour" north of the Tipper House (Fig. 1) on 1 November 2018. This location was chosen because salinity and sediment were representative of the wetland and because hunting had been prohibited here since 1928, thus there was no risk of interference with previous remnants of steel shot from hunting. To ensure that these shot pellets matched shot from a typical hunting event, they had been fired into a water tank before retrieval and seeding out in the study area. In parallel, a laboratory test was undertaken by placing two steel gunshot pellets in sealed plastic container of 0.5 l medium consisting of sediment (half) and water (half) from the southern part of Ringkøbing Fjord, stored at room temperature, from which the shot were removed and weighed at regular intervals. In the field test, ten shot pellets were collected using a powerful magnet on 24 September 2019 and weighed. The remaining dispersed steel shot were left untouched in the sediment for sampling to assess future degradation.

### 2.3. Statistics

It was tested if the number of shot differed between locations and layers as well as for the interaction between location and layer, to test if the layering of shot differed between sites. A repeated measures design was used as top and bottom layers were taken in coupled samples. The number of shot followed a Poisson distribution, thus these data were analysed with a generalized linear mixed model.

To test for differences in the weight of the lead shot in the two layers at the three locations where layering had been registered, the weight was square root transformed and a general linear model was used. One outlier (a lead pellet weighing 781 mg) was excluded from the calculations. A general linear model was used to test the difference between the historical and the current observations for the two locations (Loc2 and Loc3) for which estimates for individual stations were



**Fig. 1.** Inset map shows location of the southern Ringkøbing Fjord study area on the Danish west coast (rectangle). The four sampling locations, Loc1: Tipperne West; Loc2: Tippersande; Loc3: Tipperne East; Loc4: Klægbanken (see geo-positions in text) are shown on the main aerial photograph. The black line indicates the border ("the line") between Værnengene and Tipperne reserve. Vertical bars indicate the 1.5 km and 400 m wide hunting zone used in the given example of intensive hunting (see text and Fig. 2). O: Location for the steel shot for the corrosion experiment.

available. The residuals for both general linear models did not deviate from assumptions regarding normal distribution and homoscedasticity. Weight estimates were always given as mean  $\pm$  SE. SAS ver 9.4 were used to conduct the analyses using proc glimmix and proc glm.

### 3. Results

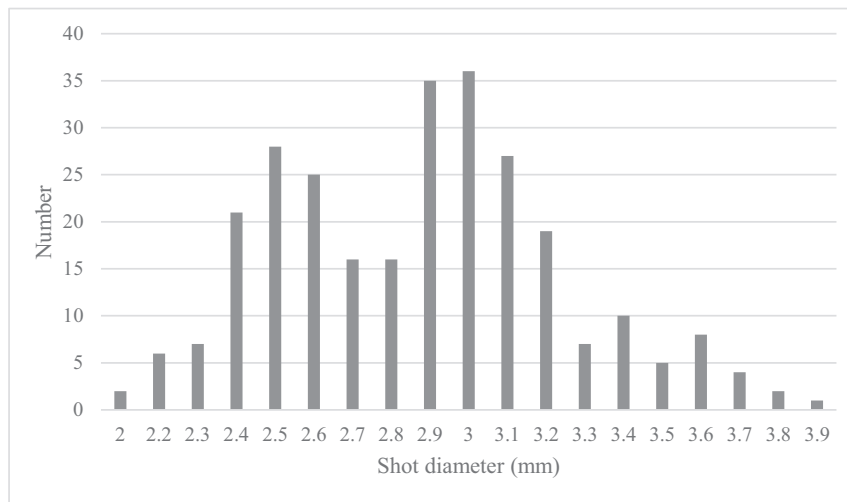
From the 123 samples, 287 gunshot pellets were collected, of which 282 were lead and five steel shot. No other pellet types were found. This corresponds to an overall average of 130 shot  $m^{-2}$  at the four locations. Table 1 shows the shot numbers and densities differentiated by locations, stations, lead/steel shot and top/bottom sample. Overall, average

shot densities at the Locations ( $N = 4$ ) varied from 41.3 to 204.1 shot  $m^{-2}$  (lead) and 0.0 to 5.7 shot  $m^{-2}$  (steel) and between Stations ( $N = 13$ ) average shot densities varied from 17.0 to 327.7 shot  $m^{-2}$  (lead) and 0.0 to 11.3 shot  $m^{-2}$  (steel). Shot densities differed significantly between sampling locations (Table 1, generalized linear mixed model  $F_{3,120} = 12.43, p < .001$ ), with Loc2 showing the highest densities followed by Loc3 and Loc1 and Loc4 with lowest densities. All posthoc pairwise comparisons showed significant differences except Loc3 relative to Loc2 and Loc1 (Table S1).

The lead shot pellets showed a significant layering effect (generalized linear model  $F_{1,120} = 5.19, p = .024$ ); densities in the 0–10 cm (top) layer had approximately twice the density compared to the

**Table 1**  
Densities of shot at the four sampling locations. The historical values for lead shot densities originate from (Pedersen and Møltøfte, 1979). T = Top; B=Bottom.

Location	Stations	Samples	Density (shot $m^{-2}$ ) lead			Density (shot $m^{-2}$ ) steel			Density (shot $m^{-2}$ ) lead + steel			Historical lead	Change (%)
			T	B	T + B	T	B	T + B	T	B	T + B		
Loc1	2	20	33.9	79.1	113.0	2.8	0.0	2.8	36.7	79.1	115.8	183.7	−38
Loc2	4	36	154.0	50.1	204.1	0.0	0.0	0.0	154.0	50.1	204.1	166.8	+22
Loc3	2	23	–	–	189.1	–	–	5.7	–	–	194.7	88.3	+114
Loc4	5	44	29.1	12.3	41.3	2.3	0.0	2.3	31.3	12.3	43.6	53.3	−22
Totals	13	123	83.9	41.3	125.2	2.2	0.0	2.2	86.0	41.3	127.3		+76



**Fig. 2.** Frequency distribution of lead shot pellets by diameter recovered from sediment cores. One outlier (5.6 mm) was omitted for clarity.

10–20 cm (bottom) layer. All steel shot pellets were found in the top layer. Layering also differed between locations as indicated by the significant interaction between location and layers (generalized linear mixed model  $F_{3,120} = 6.08, p = .0007$ ). Here the post-hoc pairwise comparisons revealed significant differences in layering at three locations, but not at Loc4 (Table S2).

The total weight of the sampled lead shot was 37.5 g, equivalent to  $17.0 \text{ g m}^{-2}$  ( $170 \text{ kg ha}^{-1}$ ). The corresponding numbers for steel shot were 0.4 g,  $0.18 \text{ g m}^{-2}$  ( $1.8 \text{ kg ha}^{-1}$ ). Average weight of lead shot was 137 mg (min 15 mg, max 781 mg), for steel shot 165 mg (min 51 mg, max 169 mg).

The weight of single lead shot found at the four locations did not differ significantly (general linear model  $F_{3,267} = 2.04, p = .1091$ ). Lead shot in the top layer ( $134.5 \pm 4.8 \text{ mg}$ ) weighed significantly less than shot in the bottom layer ( $181.0 \pm 14.1 \text{ mg}$ ) (general linear model  $F_{1,126} = 12.91, p = .0005$ ).

The measured diameter of sampled shot varied from 2.0 to 5.6 mm for lead and 2.4 to 3.6 for steel (Fig. 2). For lead shot, sizes showed a bi-modal frequency distribution with peaks around 2.5 and 3.0 mm. These correspond well to the traditional choice of lead shot sizes for waterbird hunting, i.e. US7 (2.5 mm) for small ducks and US5 (3.0 mm) for bigger ducks and geese.

### 3.1. Current and historical densities

Comparing current densities with the results of the historical densities of lead shot showed no clear pattern. At two locations, current densities exceeded historical densities, and two locations showed the opposite trend (Table 1). At Loc2 and Loc3, the study had access to raw data from the historical study (average densities  $166.8 \text{ shot m}^{-2}$  and  $88.3 \text{ shot m}^{-2}$ , respectively). Although the current lead shot densities at Loc2 and Loc3 ( $204.1 \text{ shot m}^{-2}$  and  $189.1 \text{ shot m}^{-2}$ ) were markedly higher than historical densities (22% and 144%) this difference was not statistically significant (general linear model  $F_{1,16} = 1.95, p = .182$ ). Densities were not statistically significantly different at Loc2 and Loc3 (general linear model  $F_{1,16} = 2.14, p = .163$ ).

### 3.2. Degradation of steel shot

In September 2019, ten of the steel shot pellets placed in sediment the previous November were retrieved and weighed. The average weight of shot pellets in this sample was 148 mg (range 113–161), which corresponds to an average mass loss over 11 months of 30 mg (equivalent to  $19\% \text{ year}^{-1}$ ) compared to the initial weight. The

minimum and maximum weight loss of a single shot was 11 mg and 71 mg, respectively. Measurements from the laboratory test also showed that steel shot lost weight, although at a slower rate. From the starting weight of 155 mg at the start of the experiment on 16 April 2018, the two shot had both lost 2 mg by 12 November 2018, and 5 and 6 mg each by 7 August 2019. In broad terms, this corresponds to 3–4% weight loss per year.

## 4. Discussion

A mean of 127 lead shot pellets  $\text{m}^{-2}$  was found in the top 20 cm of sediments at four locations and a maximum of  $>250 \text{ kg lead ha}^{-1}$  in some areas (compared to 53.3 to  $183.7 \text{ shot m}^{-2}$  in the 1970s Table 1), 33 years after lead shot was made illegal for hunting. Lead shot densities  $>100 \text{ shot m}^{-2}$  in the upper 20 cm of wetland sediments have been reported from France and Spain, and between 10 and 50 shot  $\text{m}^{-2}$  are found in most sampled wetlands from the UK (Mateo, 2009). Extreme densities ( $>2000 \text{ shot m}^{-2}$ ) in Danish wetlands have been measured near clay target shooting ranges, but varied from 0 to  $183.7 \text{ shot m}^{-2}$  in hunted wetland areas (Pedersen and Møltefte, 1979).

The results of this present study showed shotgun pellet densities varied within and between sampling locations, a feature of historical studies (Eskildsen, 1980), reflecting highly variable local hunting intensities which greatly affects shot recruitment rate to a specific sampling point. Popular shooting hides (typically associated with high bird densities) subject the immediate area to intensive pellet deposition. In Ringkøbing Fjord, the zone between the Tipperne Reserve (no hunting) and the hunting area Værnengene (hereafter called: “the line”, Fig. 1) is one such example. The zone immediately south of the reserve is highly attractive to hunters because waterbirds move along or across this 4.4 km long line flying in or out from the reserve. Hunting is concentrated in the sections with reed beds which provide cover for hunters, mostly the 1.5 km stretch south of Tippersande and Tippepold (Figs. 1 and 3), where hunting is very intensive (up to 30+ guns at 50 m intervals), inevitably concentrating shotgun pellet dispersal in a non-random pattern. If this estimated (but realistic) level of hunting along the line (Fig. 3) is taken into account and we assume shots are fired in all directions, the deposition of pellets will occur in a 60 ha zone equidistant on both sides of the hunting line out to c. 200 m (Chugh, 1982). If each hunter fires ten rounds, each containing 200 pellets, i.e. a total of 60,000 pellets for all 30 hunters, this equates to a daily deposition of  $0.08 \text{ shot m}^{-2}$  over the entire zone. Average shotgun pellet densities at the four sampling locations was around  $170 \text{ kg lead shot ha}^{-1}$ ,

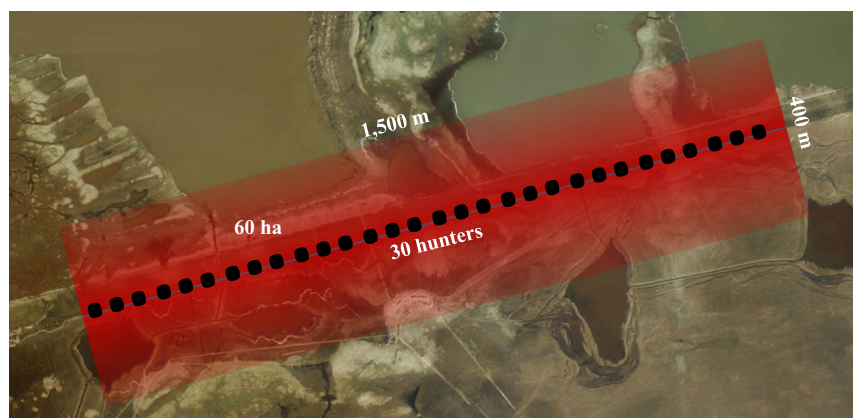


Fig. 3. The hotspot hunting zone used in the example, see text.

peaking at  $256.6 \text{ kg shot ha}^{-1}$  at Loc2, equivalent to  $15.4 \text{ t}$  of metallic lead in the  $60 \text{ ha}$  hotspot hunting zone (Fig. 3).

Hunting is permitted from 1 September to 31 December (c. 120 days) often with two hunting episodes per day (dawn and dusk flights), although weather and presence of waterbirds affect hunting intensity. Hunting adding  $0.08 \text{ shot m}^{-2}$  per episode may be limited to just a few days, but just 12 such hunting events will contribute an extra gunshot pellet per  $\text{m}^{-2}$ . Studies in the same area demonstrated average deposition rates of  $3.5$  to  $14.6 \text{ shot m}^{-2} \text{ year}^{-1}$  during 1986–1988 (Meltøfte, 1994).

Our study suggested a 22% increase in lead shot density at Loc2 since the 1970's (although not statistically significant). The lead shot ban came into force in this area in 1986, so there was a period after the 1970s studies until implementation of regulation, when lead shot deposition took place, adding to earlier densities. Compliance with the 1986 ban was unlikely to have been immediate, for example, 96% of shots fired at Værnengene in the hunting seasons 1986–1988 were illegal lead shot (Meltøfte, 1994). Police checks and other observations showed that compliance in Denmark, more generally, was far from complete in the first years following lead regulation for hunting (Kanstrup and Balsby, 2019a). To our knowledge, there have been no recent police checks or compliance level monitoring of the use of lead shot in the area. Seven plastic cartridge shells and 23 plastic wads sampled in the area during the 2018–2020 hunting seasons found only a single very worn shell (i.e. not fired recently) from a lead shot cartridge (based on text on the cartridge). Four shells originated from steel shot cartridges (according to the printed text on the shell) and another was unidentifiable. All 23 wads originated from steel shot cartridges. This small sample indicates almost complete compliance with the lead shot ban. The present densities at Loc3 also seem to be higher than the historical levels, potentially for the same reasons as at Loc2. At the other two locations, our data indicated that the current levels of accessible pellets were lower than historical levels, perhaps due to the uncertainty about the exact positions sampled in the 1970 studies, especially in the case of Loc4.

Regardless of these sources of error, the results demonstrate the persistence of high lead pellet densities in sediments highly accessible to waterbirds (i.e. highest densities in the top 10 cm), decades after the total ban on lead shot for hunting. In French wetlands, the rate of descent of shot was influenced by plant composition and the physical characteristics of sediments: most shot remained within the top 2 cm two years after seeding in heavy clay soils (Pain, 1991) compared to less shot remaining in surface layers of sites with much looser soil textures. UK shot settlement experiments showed slow rates of pellet movement in five out of six study plots (Mudge, 1984). In the present study, shot in the top 10 cm sediment were smaller than shot in the 10–20 cm layer, suggesting that shot size may affect settlement rates,

larger and heavier shot descending more rapidly than smaller and lighter shot, an interpretation supported by other studies (Beer and Stanley, 1965; Bellrose, 1959; Low and Studinski, 1967; Nelson, 1965; Pain, 1991).

Hunting at Værnengene has always been very popular among local and tourist hunters since the 1920s (although of varying intensity (Meltøfte, 1994)), hence shot densities are expected to be very high. Three of our sampling locations lay between Værnengene and the Tipperne reserve, where the  $177.6 \text{ shot m}^{-2}$  found was lower than expected if calculated from 1986 to 1988 annual exposure levels ( $3.5$ – $14.6 \text{ shot m}^{-2} \text{ year}^{-1}$  from (Meltøfte, 1994), which would correspond to only 12 to 51 years of hunting exposure, given that the area has been exposed to lead shot deposition for at least 70 years. The 1986–1988 deposition rates may have been higher than the average for the whole period due to higher hunting intensity in this period (suggested by counts of shots carried out at that time, Meltøfte, 1994). Loss of lead shot as they sink in the sediment or are ingested by waterbirds also occurs (Kanstrup and Balsby, 2019b). We lack data on lead shot turnover rates in Ringkøbing Fjord or other Danish wetland sediments, but elsewhere studies indicate that particulate lead decomposition takes tens or hundreds of years. Lack of difference between 1970s and contemporary sediment lead shot densities (despite the banning of lead shot in 1986) demonstrates the very slow rate of disappearance of lead shot in this habitat in this locality, confirmed by the good correspondence between lead shot sizes found in this study and those traditionally used by hunters, suggesting a lack of erosion or dissolution, supported by other studies elsewhere (Beer and Stanley, 1965; Low and Studinski, 1967; Pain, 1991). The continued accessibility of these pellets to waterbirds and their undiminished toxicity in the upper layers of the substrate gives considerable cause for concern, given the importance of this site to staging and wintering waterbirds.

Since the lead shot phase-out, steel shot has become the most popular alternative shot type for hunting in Denmark (Kanstrup, 2018). Our (albeit limited) sample of cartridge plastic components and communication with local hunters indicate that steel shot is now generally used for all hunting at Værnengene, so it was puzzling to find relatively low densities of steel shot in our samples (total five pellets). Based on deposition rates of several shots  $\text{m}^{-2} \text{ year}^{-1}$  (e.g. at Loc2) the accumulated density of steel shot is predicted to be higher, at least 20 years of hunting only with steel shot. A buffer zone established in 1979 moved the hunting line 50 m southwards, potentially reducing shot deposition since that time within the reserve, reducing exposure to lower deposition rates of steel compared to lead shot (because steel was introduced ten years after the buffer zone the establishment). Steel shot (unlike lead) corrodes rapidly in the marine environment, contributing to the more rapid disappearance rate ("mortality") of steel shot compared to lead. Steel shot of the sizes used most commonly for hunting (3.5 mm,

180 mg) lost mass to corrosion under experimental conditions at a rate of 17% in 11 months. Assuming a constant linear extrapolation of this rate, steel shot will therefore disappear in 5–6 years. Hence, steel shot has a shorter lifetime than lead shot, and therefore does not accumulate at the same rate over the years. This contributes to explaining the low densities of steel shot compared to lead shot found in this study, but does not explain the low density of steel shot observed (likely the result of the introduction of the buffer zone as mentioned above).

## 5. Conclusions

Lead-based gunshot pellets dispersed over a wetland remains a toxic hazard to wildlife and ecosystems over decades. In this study, lead shot densities were found to be comparable with those measured 40 years ago, and 33 years after regulation of the use of lead shot for hunting in the study area. At a hunting hotspot, present densities of lead shot exceeded 200 shot  $m^{-2}$  corresponding to >250 kg shot  $ha^{-1}$ . Most shot was in the upper 10 cm of the sediment, thus still accessible to waterbirds. Steel shot (the main non-toxic alternative to lead) has a shorter lifetime than lead shot and does not accumulate at the same rate over time. Based on these Danish experiences, international and national bodies in countries where lead shot continues to be used when hunting over wetlands are urgently recommended to recognise the consequences of these results and act to restrict the adverse impact of such continued accumulation of this toxic metal on natural resources elsewhere.

## CRedit authorship contribution statement

**Niels Kanstrup:** Conceptualization, Methodology, Validation, Investigation, Writing - original draft, Writing - review & editing. **Anthony D. Fox:** Writing - review & editing. **Thorsten Johannes Skovbjerg Balsby:** Formal analysis, Writing - review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

We thank 15. Juni Fonden, Arboretet, Kirkegårdsvej 3A, DK–2970 Hørsholm for financial support to the lead ammunition research program run by Aarhus University and Danish Academy of Hunting in which this project was included.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2020.136876>.

## References

Beer, J.V., Stanley, P., 1965. Lead poisoning in the Slimbridge wildfowl collection. *Wildfowl Trust. Ann. Rep.* 16, 30–34.

- Bellrose, F.C., 1959. Lead poisoning as a mortality factor in waterfowl populations. *Illinois Nat. Hist. Survey Bull.* 27 (3), 1–288.
- Chugh, O.P., 1982. Maximum range of pellets fired from a shotgun. *Forensic Sci. Int.* 19, 223–230. [https://doi.org/10.1016/0379-0738\(82\)90082-2](https://doi.org/10.1016/0379-0738(82)90082-2).
- Clausen, B., Wolstrup, C., 1979. Lead poisoning in game from Denmark. *Dan. Rev. Game Biol.* 11 (2), 1–33.
- Eskildsen, J., 1980. Tætheden af blyhagl i lavvandede vestjyske fjordområder. *Naturhistorisk Museum, Aarhus.*
- Flint, P.L., 1998. Settlement rate of lead shot in tundra wetlands. *J. Wildl. Manag.* 62 (3), 1099–1102.
- Flint, P.L., Schamber, J.L., 2010. Long-term persistence of spent lead shot in tundra wetlands. *J. Wildl. Manag.* 74, 148–151.
- Jørgensen, S., Willems, M., 1987. The fate of Lead in soils: the transformation of lead pellets in shooting-range soils. *Ambio* 16, 11–15.
- Kanstrup, N., 2012. Lead in Game Birds in Denmark: Levels and Sources. *Danish Academy of Hunting (Article 12–1).*
- Kanstrup, N., 2018. Lessons learned from 33 years of lead shot regulation in Denmark. *Ambio* 48, 999–1008. <https://doi.org/10.1007/s13280-018-1125-9>.
- Kanstrup, N., Balsby, T.J.S., 2019a. Danish pheasant and mallard hunters comply with the lead shot ban. *Ambio* 48, 1009–1014. <https://doi.org/10.1007/s13280-019-01152-7>.
- Kanstrup, N., Balsby, T.J.S., 2019b. Ingested shot in mallards (*Anas platyrhynchos*) after the regulation of lead shot for hunting in Denmark. *Eur. J. Wildlife Res.* 65, 42. <https://doi.org/10.1007/s10344-019-1278-2>.
- Kanstrup, N., Swift, J., Stroud, D.A., Lewis, M., 2018. Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47, 846–857. <https://doi.org/10.1007/s13280-018-1042-y>.
- Low, J.B., Studinski, G., 1967. Lead shot, its settlement, oxidation, and general availability to waterfowl. *BSF & W. Utah Coop. Wildl. Res. Unit Spec. Rep.*
- Mateo, R., 2009. Lead poisoning in wild birds in Europe and the regulations adopted by different countries. Paper Presented at the Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans, Conference, Boise Idaho <https://science.peregrinefund.org/legacy-sites/conference-lead/PDF/0107%20Mateo.pdf>.
- Mateo, R., Martínez-Vilalta, A., Guitart, R., 1997. Lead shot pellets in the Ebro delta, Spain: densities in sediments and prevalence of exposure in waterfowl. *Environ. Poll.* 96, 335–341. [https://doi.org/10.1016/S0269-7491\(97\)00046-8](https://doi.org/10.1016/S0269-7491(97)00046-8).
- Mateo, R., Bonet, A., Dolz, J., Guitart, R., 2000. Lead shot densities in a site of grit ingestion for Greylag geese *Anser anser* in Doñana Spain. *Ecotox. Environ. Restor.* 3, 76–80.
- Meltofte, H., 1994. Hunting registration on Værnengene, West Jutland, 1928–1990. *Dansk Orn. Foren. Tidsskr.* 88, 23–32.
- Mudge, G.P., 1984. Densities and settlement rates of spent shotgun pellets in British wetland soils. *Environ. Poll. (Series B)* 8, 299–318.
- Nelson, D., 1965. Lead Shot. Its Settlement, Oxidation, and General Availability to Waterfowl Vol no 13. Utah Cooperative Wildlife Research Unit, Utah State University.
- Pain, D.J., 1991. Lead shot densities and settlement rates in Camargue marshes, France. *Biol. Conserv.* 57, 273–286. [https://doi.org/10.1016/0006-3207\(91\)90073-I](https://doi.org/10.1016/0006-3207(91)90073-I).
- Pedersen, B.D., 1978. Forekomst af blyhagl i vestjyske fladvandsområder. *Fredningsstyrelsen, Miljøministeriet, København.*
- Pedersen, B.D., Meltofte, H., 1979. Occurrence of lead shot in wetlands of Western Jutland, Denmark, and in the gizzards of Danish ducks. *Dansk Orn. Foren. Tidsskr.* 73, 257–264.
- Rooney, C.P., McLaren, R.G., Condron, L.M., 2007. Control of lead solubility in soil contaminated with lead shot: effect of soil pH. *Environ. Poll.* 149, 149–157. <https://doi.org/10.1016/j.envpol.2007.01.009>.
- Scheuhammer, A.M., Norris, S.L., 1996. The ecotoxicology of lead shot and lead fishing weights. *Ecotoxicology* 5, 279–295. <https://doi.org/10.1007/bf00119051>.
- Sullivan, T., Gittel, N., Basta, N., Jardine, P., Schadt, C., 2012. Firing range soils yield a diverse array of fungal isolates capable of organic acid production and Pb mineral solubilization. *Appl. Environ. Microb.* 78 (17), 6078–6086.
- Takamatsu, T., Murata, T., Koshikawa, M.K., Watanabe, M., 2010. Weathering and dissolution rates among Pb shot pellets of differing elemental compositions exposed to various aqueous and soil conditions. *Arch. Environ. Con. Tox.* 59, 91–99. <https://doi.org/10.1007/s00244-009-9449-x>.
- Tavecchia, G., Pradel, R., Lebreton, J.-D., Johnson, A.R., Mondain-Monval, J.-Y., 2001. The effect of lead exposure on survival of adult mallards in the Camargue, southern France. *J. Appl. Ecol.* 38, 1197–1207. <https://doi.org/10.1046/j.0021-8901.2001.00684.x>.
- Wetmore, A., 1919. Lead Poisoning in Waterfowl. 793. United States Department of Agriculture Bulletin, pp. 1–12.

# PAPER 15

Kanstrup N, Balsby TJS (2019). Danish pheasant and mallard hunters comply with the lead shot ban Ambio 48:1009-1014 doi:10.1007/s13280-019-01152-7

## RIGHTS:

Thank you for your order!

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

### Order Summary

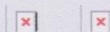
Licensee: Aarhus University  
Order Date: Mar 8, 2020  
Order Number: 4784260764242  
Publication: AMBIO  
Title: Danish pheasant and mallard hunters comply with the lead shot ban  
Type of Use: Thesis/Dissertation  
Order Ref: Comply  
Order Total: 0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customer care@copyright.com](mailto:customer care@copyright.com)  
<https://myaccount.copyright.com>



## AUHORTS' CONTRIBUTIONS

Kanstrup N conceptualized and managed the project, processed and analyzed data, drafted, revised and finalized the manuscript.

Balsby TJS undertook statistical data processing, analyzed data, edited the manuscript and approved the final manuscript.

Confirmed, April 2021

Niels Kanstrup

Thorsten Johannes Skovbjerg Balsby



# Danish pheasant and mallard hunters comply with the lead shot ban

Niels Kanstrup , Thorsten Johannes Skovbjerg Balsby

Received: 14 November 2018 / Revised: 9 January 2019 / Accepted: 17 January 2019

**Abstract** Denmark implemented a total ban on the use of lead shot for hunting and clay target shooting in 1996. Compliance was not studied systematically until recently. However, sporadic police checks and individual studies indicated that compliance was far from complete in the early years after regulation. To assess current levels of compliance with Danish regulations, we purchased 730 carcasses of pheasants (*Phasianus colchicus*) and mallards (*Anas platyrhynchos*) and a further 690 mallard gizzards were obtained from > 14 shooting events distributed across > 10 local authority districts throughout East and West Denmark in the 2016/2017 and 2017/2018 hunting seasons. All carcasses and gizzards were subject to radiography and those that contained shot were examined, pellets removed by dissection and identified to shot type. In all, 3589 pellets (intact or fragmented) were found in 1420 carcasses/gizzards, of which 799 pellets (some fragmented) were identified. Among the sample of pheasants with embedded shot ( $N = 447$ ), 1.8% (in 2016) and 2.2% (in 2017) were lead shot. Among 148 mallards in 2017 with embedded shot, 3.1% had lead shot. None of the 2017 mallard gizzards had embedded lead shot. We conclude that Danish pheasant and mallard shooters mostly comply with the lead shot regulations. Steel was the most used non-lead alternative. The majority of ingested shot was non-lead, indicating that lead shot is not generally available to pheasant and mallard and suggesting compliance with regulations in recent years/decades. The study showed that the possibility to predict the metal composition of shot pellets from X-ray images alone was highly inaccurate, confirming the necessity of necropsy to determine shot type.

**Keywords** Ammunition · Bismuth shot · Compliance · Hunting · Poisoning · Steel shot

## INTRODUCTION

Lead introduced into the environment from hunting ammunition puts the health of birds and other wildlife at risk, as well as the health of humans, who frequently consume hunted game (Arnemo et al. 2016; Pain et al. 2019). Waterbirds ingest shot along with grit and food. Ingested lead shot retained in the gizzard causes poisoning. Against this background, Denmark banned the use of lead shot for hunting and target shooting. Lead shot was initially regulated for clay target shooting in the early 1980s, followed by a ban on the use of lead shot for hunting in Ramsar sites in 1986, wider regulation in 1993, and a total phase-out in 1996 (Kanstrup 2019).

Police checks and other observations showed that compliance was far from complete in the first years following regulation. There was evidence of non-compliance even after the complete ban on the use, trade and possession of lead shot in Denmark in 1996. In 2012, 15.6% of pheasant gizzards ( $N = 77$ ) and 9.6% of mallard gizzards ( $N = 94$ ) from Danish shoots had embedded lead shot (Kanstrup 2012). Based on sampling and identification of plastic litter from hunting ammunition, Kanstrup and Balsby (2018) found lead cartridge remnants in between 10 and 20% of all such remains associated with Danish maritime hunting.

Several other countries have introduced regulations on lead shot, but mostly partial bans restricting hunting with lead shot in certain wetlands or hunting of specific bird taxa (waterbirds) (Mateo and Kanstrup 2019, unpubl. results). Despite the fact that many national regulations have been in force for more decades, and that international fora, e.g., The African Eurasian Waterbird Agreement have emphasized the importance of enforcement procedures and monitoring to ensure effectiveness of lead shot regulations,

there is a dearth of information regarding compliance with such legislation. With a few exceptions, compliance monitoring procedures are notably lacking or feeble (Kanstrup et al. 2018).

Compliance levels with hunting regulations, including the ban on use of lead ammunition, cannot be generalized across the entire hunting community, but requires assessment according to hunting and hunter type. In a Danish context, these fall into five categories: (i) “guest hunters”—hunters who are invited to or pay to attend a social hunting arrangement, (ii) “syndicate hunters”—hunters belonging to an established group of hunters, (iii) “club hunters”—hunters associated with a club with rented hunting rights on private or public land, (iv) “single hunters”—hunters who hunt solitarily or in small groups often on their own land, and (v) “coastal hunters”—mostly solitary hunters using the free hunting rights that exist within the Danish maritime fishery territory.

Denmark does not employ special rangers to police hunters and ensure compliance with hunting legislation. Responsibility for control lays with the police, who are permitted to carry out checks on a regular basis or via ad hoc raids. Illegal hunting may be reported by the public, visitors to hunting areas or by hunters in the same area. Although police reports offer a mechanism to monitor compliance, these have never been analysed systematically in Denmark.

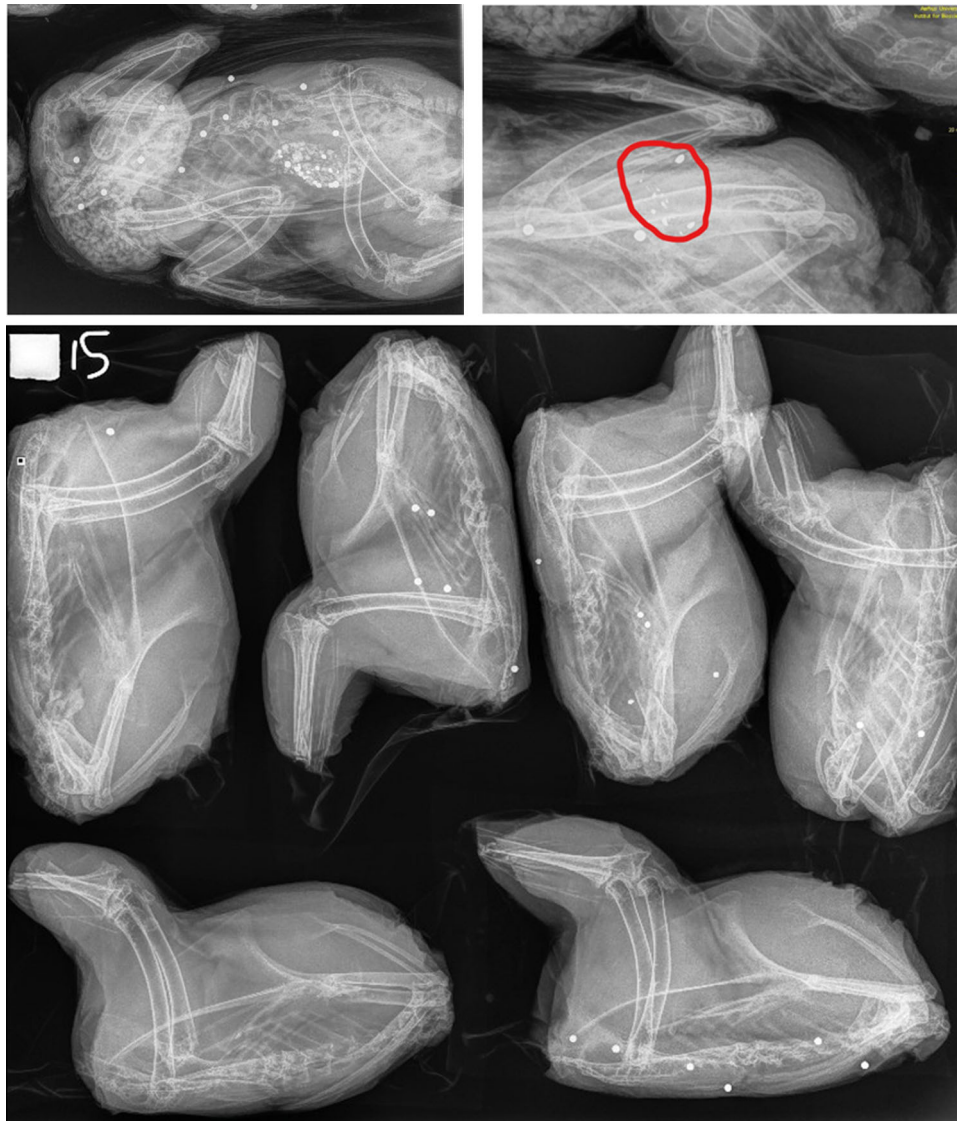
In this study, based on the identification of shot types found in shot birds, we evaluate compliance in a primary element of Danish hunting tradition, i.e., game shooting of pheasant and mallard, which is a part of (i) “guest hunters” above, comprising *c.*50% of the total annual hunting harvest in Denmark (Bregnballe et al. 2002). Our hypothesis is that game shooters in general comply with the lead shot regulations. As a part of the study we also evaluate the accuracy of predicting the metal composition of shot pellets from X-ray images alone.

## MATERIALS AND METHODS

We purchased 200 pheasant carcasses from a food retail store. All were plucked and ready-for-sale, i.e., carcasses without head/neck, wings, tarsi, intestines and organs and all originated from an unknown number of shooting events/local authority districts in South-East Zealand (personal information from the wholesale dealer). All were shot during the 1 October 2016–31 January 2017 hunting season. Furthermore, a sample of 328 pheasants and 202 mallards was purchased from a Danish game-handling establishment, which originated from hunting districts in Jutland during the 1 October 2017–31 January 2018 season. The birds were either ready-for-sale (120 mallards) or

discarded birds/remains of birds (82 mallards, all 328 pheasants). All mallards were plucked, lacking head/neck, wings, tarsus, intestines and organs. The pheasant carcasses were almost intact as only the breast meat had been removed for food processing purposes. From the same establishment, we purchased 690 mallard gizzards. The sample of birds from Jutland originated from 14 shooting events distributed between 10 different districts. The typical number of participating hunters in such shooting event was 14 (Jesper Petersen. Gamekeeper at Mattrup Estate. Mattrupvej 3, DK-8765 Klovborg. E-mail: mail@mattrup.dk), and hence the material from Jutland represents the harvest from approximately 200 different hunters, although some hunters may have participated in more than one shooting event. The selection of districts was random and no districts had advance knowledge of the sampling.

All bird carcasses and gizzards were X-rayed, typically 5–6 birds/40–50 gizzards per plate. A total of 149 X-rays plates were exposed, see the examples shown in Fig. 1. After X-ray, all birds and gizzards without pellets were discarded. Birds and gizzards with pellets were analysed systematically. Based on the X-rays, the numbers of pellets per bird were counted and analysed according to size, deformation and fragmentation and on the basis of these characteristics, we predicted the shot type. All birds and gizzards were subject to necropsy and pellets removed. Pellets in gizzards were identified as embedded or ingested depending on presence of wound channels. To minimize laboratory time, we did not remove all pellets but assumed one pellet would be indicative of the material of all pellets in each bird, unless other pellets were very easily located and removed. This could introduce a small degree of error, as some birds may carry shot and survive. However, in our sample of young released mallards we presume that the prevalence of birds with embedded shot from previous hunting occasions is low. In cases of birds containing different pellet sizes, we removed at least one shot of each shot size. In certain cases, pellets could not be found within reasonable time. In these cases, the material was judged on the X-ray evaluation, but only if the X-ray data were clearly indicative, e.g., obviously fragmented pellets (bismuth shot, 7 occasions) or large shot (steel shot, 3 occasions). This approach may lead to some shot misidentification and introduce a small margin of error. It is, however, unlikely that the distribution of shot types in the X-ray sample differ from the extracted sample, so the X-ray sample is unlikely to affect the conclusions. If pellets could not be found and X-rays gave no clear data, identification was abandoned. The sample of mallard gizzards was subject to a more detailed analysis with emphasis on identifying the types of ingested shot (Kanstrup and Balsby 2019, unpubl. results).



**Fig. 1** Examples of X-ray output. Top, left: Pheasant carcass from the 2017 sample with 11 embedded steel shot, 17 ingested bismuth shot and 1 ingested steel shot. Top, right: Pheasant carcass with a fragmented bismuth shot (in red circle). Plate 15: Top row: No 1, 2 and 4: Predicted to be steel shot (due to low deformation and no fragmentation) but identified as bismuth shot. 3. Predicted to be bismuth shot (due to rather small size) but identified as lead shot. Bottom row right: Predicted to be steel (due to large size, low deformation and no fragmentation), and identified as steel shot

Excised pellets were identified based on magnetism, fragmentation tendency and specific gravity. Magnetic pellets were identified as “steel”. Non-magnetic pellets which fragmented when subject to controlled hammering were identified as “bismuth”. Non-magnetic and non-fragmenting pellets deforming when subject to controlled hammering were identified as “lead”. All “lead” pellets were checked to have a specific gravity  $> 10 \text{ g/cm}^3$ , to exclude tin and zinc shot. Other studies use more sophisticated methods to identify shot material, including electron microscopy (Cromie et al. 2010). However, given the few possible shot types our simple methodology seems sufficiently accurate. To assess the accuracy of prediction of shot material from X-ray images only, we compared the positively identified material

with the X-ray “prediction”. The likelihood of identifying the material correctly using X-rays was tested using a generalized linear model with a binomial distribution with least square means as post hoc tests. The test was calculated using proc genmod in SAS 9.4 (SASInstitute, Cary, NC).

## RESULTS

### Embedded shot types in total sample

In total, 3589 shot were found in 1420 carcasses/gizzards. Of these, we removed and identified 799. Among 447 pheasants with embedded shot, 1.8% (in 2016) and 2.2%

(in 2017) were lead pellets. Of the 148 mallards with embedded shot in 2017, 3.1% contained lead shot. None of the mallard gizzards from 2017 had (embedded) lead shot. Table 1 shows the overall findings of the analysis of embedded shot in the samples of pheasants and mallards.

Steel shot was the by far most frequent non-lead alternative accounting for > 80% in the 2017 samples, although substantially lower in the 2016 pheasant sample. In 27 incidences, shot type could not be determined.

### Ingested shot

Of the 328 pheasants from the 2017 hunting season, 6 (1.8%) had ingested steel or bismuth shot in the gizzard, of which two contained combinations of steel and bismuth (Table 2). No pheasants in this sample had ingested lead shot.

Of 690 mallard gizzards, 9.6% had ingested shot in different combinations of steel, bismuth and lead. The prevalence and occurrence of shot in general were higher than in previous Danish and other studies. However, prevalence of lead shot was markedly lower, and the ingestion of non-lead shot exceeded the levels of ingested lead shot by a factor of 10. (Kanstrup and Balsby 2019, unpubl. results).

**Table 1** The total study sample of pheasant and mallards ( $N = 1420$  analysed for shot pellets). <sup>a</sup>Plucked, without head/neck, wings, tarsus, intestines and organs. <sup>b</sup>Discarded carcasses without breast meat. <sup>c</sup>Gizzards without proventriculus. Numbers in bold give the prevalence of birds with embedded lead shot, i.e., the level of “non-compliance”

Sample	Pheasant 2016 <sup>a</sup>	Pheasant 2017 <sup>b</sup>	Mallard 2017 <sup>a</sup>	Mallard gizzards 2017 <sup>c</sup>
<i>N</i>	200	328	202	690
Shot found on X-ray	966	1.773	735	115
Shot removed	241	298	155	105
Birds/gizzards with embedded shot (%)	171 (85.5)	276 (84.1)	148 (73.3)	106 (15.4)
Shot material	Number of birds (%)	Number of birds (%)	Number of birds (%)	Number of gizzards (%)
Steel	96 (56.1)	239 (86.6)	124 (84.4)	101 (95.3)
Bismuth	65 (38.0)	20 (7.2)	7 (4.4)	5 (4.7)
Lead	<b>2 (1.2)</b>	<b>6 (2.2)</b>	<b>5 (3.1)</b>	<b>0 (0)</b>
Steel and bismuth	2 (1.2)	1 (0.4)	0 (0.0)	0 (0)
Bismuth and lead	<b>1 (0.6)</b>	<b>0 (0.0)</b>	<b>0 (0.0)</b>	<b>0 (0)</b>
Unknown	5 (2.9)	10 (3.6)	12 (8.1)	0 (0)

**Table 2** Distribution of ingested shot types among the 6 pheasants having ingested shot

Pheasant no.	Steel	Bismuth
1	96	3
2		3
3	2	
4	1	17
5	3	
6		3

### Prediction of shot type from X-ray

The comparison between the predicted and identified shot types in 568 pheasant and mallard carcasses is presented in Table 3. Carcasses with combinations of other shot types and cases where the shot type could not be assessed (“unknown”) are not included.

Table 3 shows that in no case was prediction of shot types 100% correct. The composite metal significantly affected the likelihood of a correct classification (generalized linear model with binomial distribution  $\chi^2_{22} = 34.7$ ,  $p < 0.001$ ). The three pairwise comparisons all showed significance (least square means  $z > 3.01$ ,  $p < 0.003$ ) with lead being the material hardest to identify correctly by X-ray. Prediction of steel shot tended to be more reliable than prediction of bismuth shot. Lead shot is the most difficult to predict with a success rate of only 36.4%, with almost equal probability of confusion with bismuth and steel.

## DISCUSSION

### Compliance

Our findings showed that there was less than 3.5% use of lead shot by mallard and pheasant hunters. Lowest

**Table 3** Difference between predicted and identified shot type in the total sample from pheasant and mallard carcasses. Figures in bold indicate the probability of predicting the actual shot type correctly

		Predicted			
		Steel	Bismuth	Lead	Total
Identified	Steel	448 ( <b>94.5</b> )	12 (14.5)	3 (27.3)	463
	Bismuth	20 (4.2)	68 ( <b>81.9</b> )	4 (36.4)	92
	Lead	6 (1.3)	3 (3.6)	4 ( <b>36.4</b> )	13
	Total	474	83	11	568

compliance was found in the 2017 mallard sample (3.1% were shot with lead shot). In the 2017 pheasant sample, 2.2% were shot with lead shot. In this sample, most birds shot with lead originated from the same batch, i.e., from the same shooting event, potentially killed by a few hunters. Hence, the levels of detected non-compliance could result from a very few hunters out of several hundred that contributed to the material.

Historical data indicated lower levels of compliance (see Introduction) so the high compliance found in this survey is likely to reflect a continuing trend among Danish pheasant and mallard hunters towards compliance with the ban on lead shot and therefore demonstrates a reduction in toxicological risk to wildlife, ecosystems and consumers. Compared to studies elsewhere (e.g., 77% of 109 ducks shot illegally with lead shot in English wetlands following a lead ban for shooting wildfowl in 1999, Cromie et al. 2015), Danish levels of non-compliance are negligible. This may be a consequence of the very strict Danish approach that regulates not only the use of lead shot for all hunting but also any trade and possession of lead shot. Such an approach is obviously much more powerful than the partial bans, which are the most common type of regulation in other countries, including the UK.

As well as finding a low prevalence of embedded lead pellets in our sample, the lack of ingested lead shot in 328 pheasant gizzards in 2017 sample indicated that non-lead shot predominated among shot pellets available to birds as grit in their immediate environment. This represents further evidence of compliance with the lead shot regulations in recent years, confirming the conservation benefit of phasing out lead shot for hunting purposes, as also described for mallard in Kanstrup and Balsby (2019, unpubl. results). The difference in the prevalence of ingested shot between pheasants (1.8%) and mallards (9.6%) was likely due to their contrasting feeding behaviour, feeding and shooting locations.

The data show that steel shot was by far the most frequently used non-lead alternative, although bismuth still played a role. The higher prevalence of steel in 2017 compared to the 2016 pheasant sample may be due to the Danish Forest Association and Danish Tree Industries lifting their non-statutory requirement for the use of specially approved non-steel “forest shot” for hunting in forests prior to the 2017 hunting season.

There is a long tradition of many forms of hunting in Denmark and compliance with legislation may vary between them: thus the results presented here may not be strictly representative of all forms of hunting. In this study, our material originated from game dealers, directly or indirectly. The suppliers of shot game to such dealers are typically shooting districts, which support release programmes of game birds which are subject to single days of

driven game shoots for invited guests and groups of paying hunters. Such one-day shoots are normally very well organized, with prior instructions to participants on shooting safety, regulations and codes of conduct. In many cases, participants might be subject to control by the organizers or eventually the police. Under such circumstances, compliance levels with hunting regulations, including the lead shot ban, may be greater than in situations where hunters hunt on their own under less public and “visible” circumstances, subject to less instruction, scrutiny and control. Hence, our results may over-represent levels of compliance with the lead shot regulation compared to other categories of hunting and hunters. However, the two investigated species, pheasant and mallard, are highly representative of hunting in Denmark. The total annual bag of the two species accounts for more than half of the bag of all species. At the same time, up to half of the pheasant bag and more than half of the mallard bag originate from shooting of released birds (Bregnballe et al. 2002). Our analysis of a sample of birds from the game districts therefore comes from a representative proportion of the total annual harvest of these species in Denmark; hence, our conclusions concerning compliance with lead shot regulations, in terms of quantity, can be considered as broadly representative of hunting in Denmark in general.

Our sample came from at least 10 different hunting districts, all suppliers to game-handling establishments. The selection of districts was random and no districts had advance knowledge of the study and sampling. Therefore, neither the districts nor the participating hunters had any background knowledge that might result in adjustments to their behaviour, and we have no reason to believe that the results do not reflect compliance with the lead shot ban among the investigated group of shooters during the study hunting seasons.

### Prediction of shot type from X-ray

In financial terms, such studies involve three major costs: (i) purchase of bird carcasses, (ii) X-ray costs and (iii) necropsy laboratory time to localize and remove shot for identification. The latter could be reduced significantly, if shot could be identified from X-ray images alone. In this study, predictions were made based on shot size (hunters normally use larger steel and bismuth shot than lead shot), deformation and fragmentation (lead shot tends to deform without much obvious fragmentation, whereas bismuth typically fragments in an obvious way, Fig. 1). However, the results confirmed the inaccuracy of such an approach, even given accumulated experience from repeated observations by laboratory staff. The data show that steel and bismuth shot tend to be over-predicted and lead shot under-predicted, confirming necropsy is necessary, i.e., that

pellets need to be isolated and subject to examination based on magnetism, fragmentation and specific gravity to confirm their composition.

## CONCLUSION

We conclude that almost all Danish pheasant and mallard shooters comply with current lead shot regulations. Based on data from shot birds originating from more than 10 shooting districts in different geographical regions (Jutland and South-East Zealand), we found that levels of compliance were high. Among 447 pheasants with embedded shot, 2.0% had lead pellets. Among 148 mallards with embedded shot, 3.1% contained lead shot. In a sample of 690 mallard gizzards, we found no (embedded) lead shot. Steel was the most used non-lead alternative. Most ingested shot was of non-lead types, suggesting that lead shot was generally inaccessible to mallard and pheasant in this study and supports the conclusion of good compliance in recent years/decades. These results demonstrate the conservation gains of phasing out lead shot for hunting. Prediction of shot types from X-ray images alone was insufficient to identify shot to metal composition, which requires necropsy for confirmation.

**Acknowledgements** We thank 15. Juni Fonden, Arboretet, Kirkegårdsvej 3A, DK-2970 Hørsholm for the grant given to the Danish Academy of Hunting for the study period 2017–2018. Not least, we are grateful to Klosterhedens Vildt who assisted with collection of test samples, to Tony Fox for helpful comments to previous drafts, and to Annija Užule for useful assistance with necropsy of bird carcasses.

## REFERENCES

- Armeno, J.M., O. Andersen, S. Stokke, V.G. Thomas, O. Krone, D.J. Pain, and R. Mateo. 2016. Health and environmental risks from lead-based ammunition: Science versus socio-politics. *Eco-Health* 13: 618.
- Bregnballe, T., T. Asferg, I. Clausager, H. Noer, P. Clausen and T.K. Christensen 2002. Vildtbestande, jagt og jagttider i Danmark—en biologisk vurdering af jagtens bæredygtighed som grundlag for jagttidsrevisionen 2003. Faglig Rapport fra DMU nr. 428. 225 pp.
- Cromie, R.L., A. Loram, L. Hurst, M. O'Brien, J. Newth, M.J. Brown, and J.P. Harradine. 2010. *Compliance with the environmental protection (Restrictions on Use of Lead Shot) (England) Regulations 1999*, 2010. Bristol: Defra.
- Cromie, R., J. Newth, J. Reeves, M. O'Brien, K. Beckmann, and M. Brown. 2015. The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult. In Delahay, eds. R.J. and C.J. Spray. *Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health*. Oxford, UK: Edward Grey Institute, The University of Oxford.
- Kanstrup, N. 2012. Lead in game birds in Denmark: levels and sources Danish Academy of Hunting, 2012-02-1. [Link](#).
- Kanstrup, N. 2019. Lessons learnt from 33 years regulation of lead shot in Denmark. In *Lead in hunting ammunition: Persistent problems and solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue. <https://doi.org/10.1007/s13280-018-1125-9>.
- Kanstrup, N., and T.J.S. Balsby. 2018. Plastic litter from shotgun ammunition on Danish coastlines—amounts and provenance. *Environmental Pollution* 2018: 601–610. <https://doi.org/10.1016/j.envpol.2018.02.087>.
- Kanstrup, N., J. Swift, D. Stroud, and M. Lewis. 2018. Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47: 846–857. <https://doi.org/10.1007/s13280-018-1042-y>.
- Pain, D.J., R. Mateo and R.E. Green. 2019. Effects of lead from ammunition on wildlife: a review and update. In *Lead in hunting ammunition: Persistent problems and solutions*, eds. N. Kanstrup, V.G. Thomas, and A.D. Fox, *Ambio* vol. 48, Special Issue.

## AUTHOR BIOGRAPHIES

**Niels Kanstrup** (✉) is a Danish biologist, scientist and hunter. He works with sustainability of hunting and focuses particularly on the issue of lead in hunting ammunition.

*Address:* Institute for Bioscience – Kalø, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark.

e-mail: [nk@bios.au.dk](mailto:nk@bios.au.dk)

**Thorsten Johannes Skovbjerg Balsby** is a Danish biologist and senior scientist with particular expertise in biostatistics, animal behavior and population biology.

*Address:* Institute for Bioscience – Kalø, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark.

e-mail: [thba@bios.au.dk](mailto:thba@bios.au.dk)



# PAPER 16

Kanstrup N, Balsby TJS (2019). Ingested shot in mallards (*Anas platyrhynchos*) after the regulation of lead shot for hunting in Denmark. *European Journal of Wildlife Research* 65 doi:10.1007/s10344-019-1278-2

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

### Order Summary

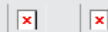
Licensee: Aarhus University  
Order Date: Mar 8, 2020  
Order Number: 4784261353417  
Publication: European Journal of Wildlife Research  
Title: Ingested shot in mallards (*Anas platyrhynchos*) after the regulation of lead shot for hunting in Denmark  
Type of Use: Thesis/Dissertation  
Order Ref: Mallard  
Order Total: 0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customer@copyright.com](mailto:customer@copyright.com)  
<https://myaccount.copyright.com>



## AUHTORS' CONTRIBUTIONS

Kanstrup N conceptualized and managed the project, processed and analyzed data, drafted, revised and finalized the manuscript.

Balsby TJS undertook statistical data processing, analyzed data, edited the manuscript and approved the final manuscript.

April 2021

Niels Kanstrup

Thorsten Johannes Skovbjerg Balsby



# Ingested shot in mallards (*Anas platyrhynchos*) after the regulation of lead shot for hunting in Denmark

Niels Kanstrup<sup>1</sup> · Thorsten Johannes Skovbjerg Balsby<sup>1</sup>

Received: 6 December 2018 / Revised: 22 March 2019 / Accepted: 8 April 2019  
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

## Abstract

Since 1986, lead-based gunshot has been banned inter alia for hunting in ponds with the release of mallards (*Anas platyrhynchos*) in Denmark. To assess whether ingestion of gunshot by this common waterbird has changed as a result of this regulation, we purchased 690 mallard gizzards from ten Danish hunting districts with a program for the rearing and release of mallards for shooting purposes. After X-ray examination, embedded and ingested shot were removed by dissection and subjected to type classification. Of the 690 gizzards, 66 (9.6%) had ingested shot in different combinations of steel, bismuth and lead. The prevalence and occurrence of shot in general were higher than in previous Danish and other studies. However, prevalence of lead shot was markedly lower, and the ingestion of non-lead shot exceeded the levels of ingested lead shot by a factor 10. The result demonstrated that lead shot has become less available over time, although it is still present despite the ban of lead-based ammunition in habitats of released mallards in 1986. Our study proves the hypothesis that mallards have switched from ingesting lead to steel shot due to the change of shot types for hunting in their habitat and indirectly demonstrates that the Danish phase-out of lead shot for hunting has led to decreased levels of waterbird poisoning. No gizzards were detected with embedded lead shot, which demonstrated a full compliance with the lead shot regulation in this sample.

**Keywords** Ammunition · Gunshot · Lead poisoning · Non-toxic shot · Waterbirds

## Introduction

The first regulation of lead ammunition for waterbird hunting in Denmark was established in 1985, coming into force by 1st August 1986. It implied a ban of the use of lead shot for hunting in the Danish Ramsar sites (at that time, 26) and in ponds with the rearing and release of mallards (*Anas platyrhynchos*) for hunting. The background for the regulation was an increasing evidence that waterbirds ingested shot along with grit and food and thereby were exposed to lead poisoning. This problem had been the subject of several Danish studies (e.g. Clausen and Wolstrup 1979; Mølte and Petersen 1979; Eskildsen 1980) supported by the evidence from abroad, not

least from the USA, where the problem had been identified in the 1950s (Bellrose 1959). Lead poisoning from ingestion of gunshot causes elevated mortality (Pain 1996; Watson et al. 2009) and severe risk of sub-lethal impacts (Newth et al. 2016; Ecke et al. 2017). Densities of lead gunshot may be several hundreds per square meter (Mølte and Petersen 1979; Eskildsen 1980; Mateo 2009). Lead shot remains for considerable periods of time, and the complete decomposition of particulate lead likely takes tens or hundreds of years (Scheuhammer and Norris 1996; Rooney et al. 2007).

The selection of Ramsar sites in the Danish regulation was due to these areas' special international importance as staging and wintering areas for waterbird populations. The emphasis on ponds with the rearing and release of mallards was motivated by the evidence showing that the risk of waterbirds to ingest lead shot was particularly high in areas that serve both as feeding areas for birds and where the fall-down of shot from intense hunting is concentrated in rather small areas (Clausen and Wolstrup 1979).

Until recently, the compliance with the Danish regulation of lead shot for hunting has not been studied systematically. Sporadic police controls have indicated that the compliance

✉ Niels Kanstrup  
nk@bios.au.dk

Thorsten Johannes Skovbjerg Balsby  
thba@bios.au.dk

<sup>1</sup> Department of Bioscience, Institute for Bioscience – Kalø, Aarhus University, Grenåvej 14, DK-8410 Rønde, Denmark

was far from complete in the first years after the regulation. Even after the complete ban of the use, trade and possession of lead shot in Denmark in 1996, there were examples of non-compliance (Kanstrup 2012). Today, compliance is investigated more systematically, inter alia through collections and analyses of shot pheasants and mallards (Kanstrup and Balsby 2019). A part of the material for this study was a sample of gizzards ( $N=690$ ) from mallards collected at a Danish game-handling establishment (slaughterhouse). The purpose of this sample was twofold: (1) to analyse the types of embedded shot to assess compliance with the lead shot ban and (2) to analyse the types of ingested shot to evaluate to which degree non-lead types have replaced lead shot as a result of the regulation. The present study deals with the second purpose.

## Materials and methods

A total of 690 gizzards from shot mallards were collected at a Danish game-handling establishment. The gizzards originated from 15 shoots at ten different Danish districts located primarily in the Western part of Denmark (Jutland) with professional game management, including a program for the rearing and release of mallards for shooting purposes. The districts and involved hunters had no information about the sampling and therefore no premonition of the research. The gizzards mainly originated from mallards shot in September and October 2017 and a minor part originated from November 2017.

All gizzards were X-rayed, and gizzards with shot were subjected to a closer examination, including inspection of the position of the shot, shot size and shape, and assessed via the X-ray image. Gizzards with shot were examined for potential wound channels and then dissected. All shot in the muscular tissues of gizzards were categorised as “embedded”. Shot in the grit were categorised as “embedded” or “ingested”, depending on the presence of the wound channel and the size, shape and signs of wear. Removed shot were analysed to define the shot material according to Kanstrup (2012). Prevalence, incidence of shot levels and occurrence were calculated.

The terms used in the study are shown in Table 1.

## Statistics

Three earlier studies provided counts of the numbers of lead shot found in gizzards of mallards, including the incidence of shot levels. We compared these observations of the incidence of shot levels with the findings of the current study, using a generalised linear model with an overdispersed Poisson distribution for birds with ingested shot and tested if the distribution differed between the four studies. Our model thus included the number of shot in a gizzard, the study and the interaction between these two fixed variables.

**Table 1** Terms used

Prevalence: The percentage (%) of sampled birds with one or more ingested shot ( $= 100 (N - N_0)/N$ , where $N$ is the number of birds and the index gives the number of shot).
Incidence ( $i$ ) of shot levels: The number of gizzards with 0 ( $i_0$ ), 1 ( $i_1$ ) 2 ( $i_2$ ), 3 ( $i_3$ ), etc. ingested shot.
Occurrence: The average number of ingested shot per bird in the total sample ( $= (\sum_{i=0}^{i=\max} Ni)/N$ ).
Density: The number of available shot per square unit in habitat.
$P_d$ : The population (pool) of dispersed shot in a habitat.
$P_i$ : The population (pool) of ingested shot in a gizzard.

The gizzards in the current study originated from 15 shoots. To test whether the incidence of shot levels differed between the shoots, we used a generalised linear model assuming a Poisson distribution with overdispersion of zeros. The generalised linear models were conducted in SAS 9.4 (SAS Institute, Cary, NC) using proc. glimmix.

To test if the sample of mallards in our study had ingested shot from the same population of shot as the one they had been shot with, we tested if these two distributions differed, using a chi-square test.

## Results

Of the 690 gizzards examined, 161 (23.3%) had shot, 106 (15.4%) had embedded shot, of which 101 (95.2%) gizzards had steel, and the remaining five (4.8%) had bismuth shot. Hence, no gizzards were detected with embedded lead shot which demonstrated a full compliance with the lead shot regulation in this sample. However, 66 (9.6%) gizzards had ingested shot in different combinations of steel, bismuth and lead (Table 2).

Overall, 81.8% of the gizzards with ingested shot had only one ammunition type, with steel shot being by far the most common (75.8%), while 16.6% had a mixture of steel/lead or steel/bismuth, with the former combination being the most common. In one gizzard (1.5%) with a total of 36 ingested shot, all three types were found; however, 34 of the shot were steel shot. Of the gizzards with ingested shot, 18.1% had lead shot. Of all 221 ingested shot, 87.8% were steel, 2.7% were bismuth and 9.5% were lead shot. The average number of shot per gizzard was 3.3. The maximum number found in one gizzard was 42, of which all were steel shot.

Table 3 shows the incidence of various ingested shot levels in the 66 gizzards.

More than half of the gizzards had only one ingested shot, and the incidence declined with increasing shot levels (Fig. 1). Less than 10% had more than six shot. Bellrose (1959), Clausen and Wolstrup (1979) and Lumeij et al. (1989)

**Table 2** Types of shot in gizzards with ingested shot

	No of gizzards (%)	No of shot				
		Fe	Bi	Pb	Total	Average
Fe	50 (75.8)	124			124	2.5
Bi	2 (3.0)		2		2	1.0
Pb	2 (3.0)			4	4	2.0
Fe + Bi	2 (3.0)	11	3		14	7.0
Fe + Pb	9 (13.6)	25		16	41	4.6
Fe + Bi + Pb	1 (1.5)	34	1	1	36	36.0
Total	66 (100)	194	6	21	221	3.3

*Fe* iron/steel, *Bi* bismuth, *Pb* lead

conducted similar studies on mallards; however, these studies only involved ingested lead shot as non-lead shot were not yet available or used by hunters at that time. Bellrose (1959) investigated a sample of 17,066 gizzards from mallards bagged in North America in the period from 1938 to 1953, of which 1159 (6.79%) had ingested shot. Clausen and Wolstrup (1979) examined 3149 gizzards of mallards bagged in Denmark in 1975, of which 77 (2.4%) had ingested lead shot (up to 58 in one gizzard). Lumeij et al. (1989), investigating a sample of 2859 mallards, found that 67 (2.3%) had ingested lead shot (up to 16). Figure 1 compares the incidences of shot levels ( $i_0$  not included) in these three historical studies and in the present study. The data demonstrated a common pattern in the incidence of shot levels in the four studies covering a period of 60 years. Ingestion of one shot ( $i_1$ ) was by far the most frequent incidence ( $i_0$  not included). Among birds with shot, the frequency of the single incidences of shot levels decreased significantly with the increasing incidence (Fig. 1, generalised linear model  $F_{1,20} = 6.91$ ,  $p = 0.016$ , slope =  $-0.52$ ). The slopes for the curves did not differ significantly among studies, as indicated by the non-significant interaction

between number of incidences and study (Fig. 1, generalised linear model  $F_{3,20} = 0.17$ ,  $p = 0.918$ ). Overall, the studies differed significantly (Fig. 1, generalised linear model  $F_{3,20} = 4.34$ ,  $p = 0.016$ ); however, this only reflected that some studies had larger samples than others. For this reason, post hoc pairwise comparisons were not made for differences between studies.

Prevalence differed markedly between the 16 sample batches in our study (Fig. 2, generalised linear model  $F_{15,45} = 2.20$ ,  $p = 0.0088$ ), varying from 0 (batch 14) to 36% (batch 9). However, only batch 9 differed significantly from some of the other batches (0, 1, 4, 5, 7, 8, 10 (least square means  $t_{145} \geq 2.11$ ,  $p \leq 0.037$ )). All other pairwise comparisons showed no significant differences (least square means  $t_{145} \leq 1.64$ ,  $p \geq 0.104$ ).

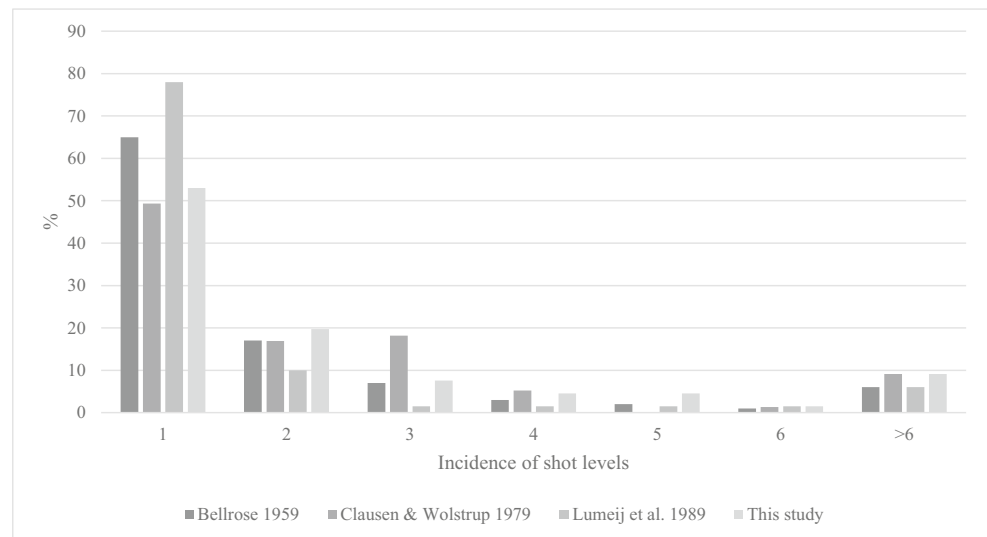
The test of distribution of ingested and embedded shot types showed that these categories differed significantly, with a higher rate of lead shot in the ingested shot compared to embedded shot (chi-square test  $\chi^2_3 = 17.8$ ,  $p < 0.001$ ). This demonstrates that ingested and embedded shot originate from different populations of shot.

**Table 3** Incidence of shot levels

No of shot	No of gizzards									
	No mix			Fe + Bi		Fe + Pb		Fe + Bi + Pb		
	Fe	Bi	Pb	Fe	Bi	Fe	Pb	Fe	Bi	Pb
1	32	2	1	0	1	4	5	0	1	1
2	11	0	0	1	1	2	3	0	0	0
3	1	0	1	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0	0
5	3	0	0	0	0	1	1	0	0	0
6	1	0	0	0	0	2	0	0	0	0
> 6	1	0	0	1	0	0	0	1	0	0
SUM	50	2	2	2		9		1		

*Fe* iron/steel, *Bi* bismuth, *Pb* lead

**Fig. 1** Incidence of shot levels in three historical studies and in the present study



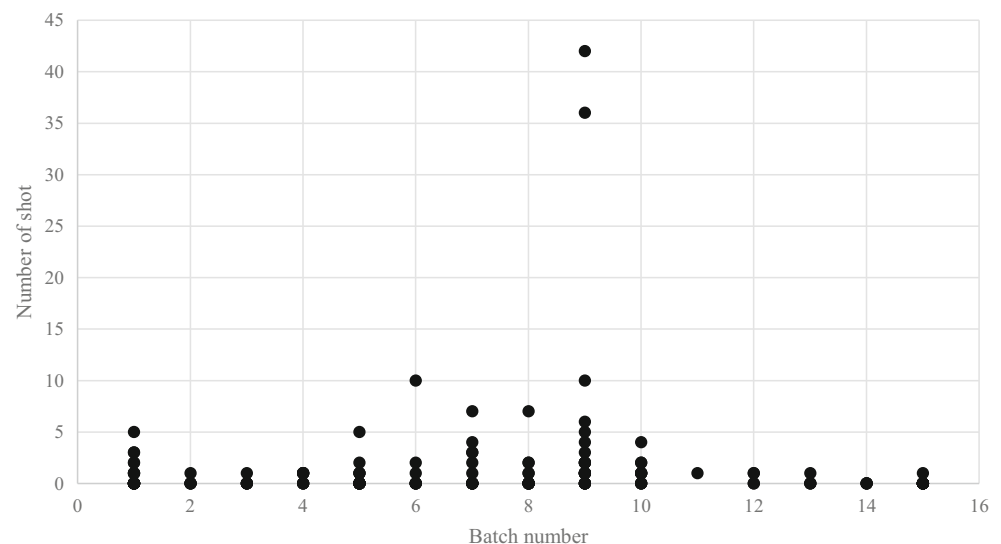
## Discussion

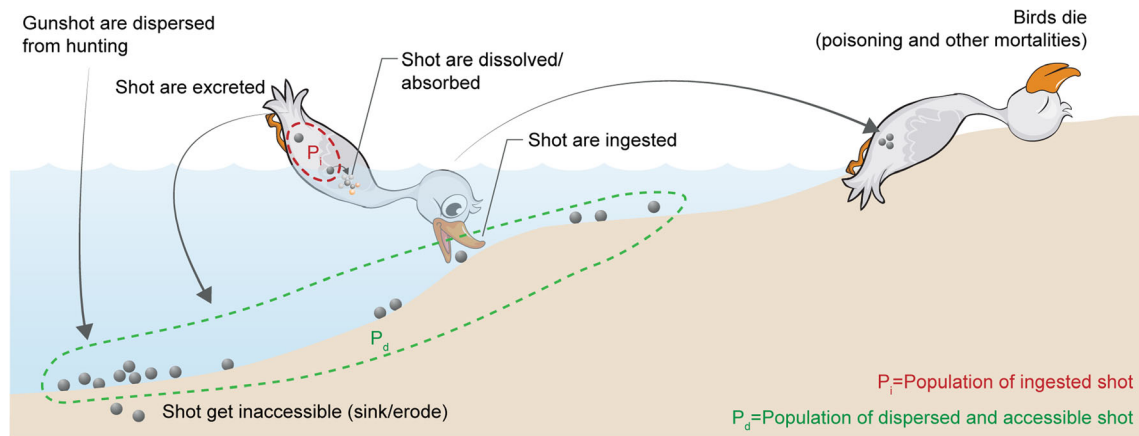
In this study, we made three overall findings: (1) the prevalence and occurrence of ingested shot in our sample exceeded the levels in comparable studies from Denmark and abroad; (2) the levels of ingested non-lead shot exceeded those of ingested lead shot by a factor of 10; and (3) ingested shot types differed from embedded shot types.

Gunshot are dispersed from hunting in natural habitats, e.g. wetlands, and retained in the soil/sediment, where they represent a “population” ( $P_d$ , Fig. 3) that is accessible for waterbirds. This population increases with dispersal rates from hunting (reproduction) and decreases with rates of shot that sink into the sediment, corrode/dissolve (Jorgensen and Willems 1987; Takamatsu et al. 2010) or are ingested by birds (mortality).

The population dynamics of shot in soil and sediment ( $P_d$ ) is poorly investigated. The most thoroughly investigated parameter concerning shot in soil/sediment is shot density, typically in the upper 20-cm layer, which can be assessed by simple field samples. It varies between zero to several hundreds of (lead) shot per square meter (Eskildsen 1980; Mateo 2009). The reproduction depends on the hunting regime, while mortality depends on the physical/chemical characteristics of the environment and the shot material used. Lead shot are known to remain as “shot” for considerable periods of time, and the complete decomposition of particulate lead likely takes tens or hundreds of years under most conditions (Jorgensen and Willems 1987; Scheuhammer and Norris 1996; Rooney et al. 2007; Takamatsu et al. 2010). Shot will sink slowly through the soil, with rates affected by soil characteristics. The degradation of lead from gunshot depends

**Fig. 2** Number of ingested shot per gizzard distributed in the 15 different batches in the sample





**Fig. 3** Demonstration of the connection and flow between the two “populations” of gunshot:  $P_d$  = dispersed and accessible shot;  $P_i$  = ingested shot retained in the bird’s gizzards

on inter alia temperature, moisture, soil chemistry and biotic functions (Rooney et al. 2007; McLaren et al. 2009; Sanderson et al. 2012; Sullivan et al. 2012) and is therefore highly site-specific. Flint (1998), investigating various experimentally seeded wetland types, found that most (lead) shot were still within the top 4 cm of the sediment 3 years after deposition. Tavecchia et al. (2001) estimated a half-life of lead shot in the first 0–6 cm, thus available to waterfowls, of 46 years, with complete settlement after 66 years in French marchlands. Flint and Schamber (2010) found that 10 years after seeding experimental plots on temporal tundra wetlands with four lead shot, about 10% remained in the top 6 cm and > 50% in the top 10 cm; based on this, it will likely require > 25 years for lead shot to become unavailable to waterbirds in such ecosystems. Kanstrup (unpublished) found, for some plots, high densities of lead shot in Danish wetland habitats where lead shot has been banned for hunting since 1986. There is a general paucity of knowledge about turnover rates of steel and other non-lead shot in natural habitats. Steel shot may, due their lower specific gravity, sink at a slower rate than lead shot. On the other hand, steel (iron) shot can rust and thereby disappear at higher rates than lead and other more stable metals.

Avifauna ingest dispersed gunshot in both wetlands and terrestrial habitats (Pain 1996; Pain et al. 2009). Ingested shot is retained as grit or food in the bird’s gizzard, but may be quickly excreted. Most commonly, ingested shot is mechanically eroded and dissolved by the stomach acids, and the salts formed are absorbed into the blood and enter metabolic processes. Shot in the bird’s digestive tract can be regarded as a population, too ( $P_i$ , Fig. 3), with the ingestion rate being an analogue to reproduction and the excretion/absorption an analogue to mortality. Ingestion rate (a mortality factor for  $P_d$ ) depends on shot densities, density of natural grit and food items and ecological behaviour of the bird species (Mateo 2009). Mortality rates of ingested shot correlate with physical and chemical conditions in the digestive tract, the shot

material and with other characteristics (Brewer et al. 2003). Cook and Trainer (1966) found for Canada goose (*Branta canadensis*) that lead pellets appeared to erode at a constant rate regardless of the number in the gizzard. The largest lead pellet volume (66%) was eroded within the first 3 days after exposure, and it took approximately 45 days for the remaining volume to disappear. Kerr et al. (2010) found for the bobwhite quail (*Colinus virginianus*) that most (lead) pellets were absorbed or excreted within 14 days of gavage, independent of the dose. Plouzeau et al. (2011) showed for young mallards fed with a single (lead) shot that less than 20% of all shot were found on X-rays at day 21 and none remained at day 28, with a mean retention time in the gizzard of  $12.85 \pm 1.34$  days for all treated groups. Holladay et al. (2012) found for domestic pigeons that shot retention decreased by roughly 50% per week for the first 4 weeks as pellets were either absorbed or excreted; from week 5, the number of pellets was no longer diminished.

In field studies, there are two primary parameters for  $P_i$ ; one is the prevalence, i.e. the percentage of birds in a sample that have one or more ingested shot in the digestive tract. Mateo (2009) found that prevalence in general varied between zero and 50%, while for Northern European populations of mallards, the average prevalence was assessed at 3.6% ( $N = 8683$ ) (Mateo 2009). In the present study ( $N = 690$ ), the prevalence was 9.6%. However, the population of ingested shot may also be assessed by the occurrence. In Bellrose (1959), Clausen and Wolstrup (1979) and Lumeij et al. (1989), the occurrence was 0.17 ( $N = 17,066$ ), 0.08 ( $N = 3149$ ) and 0.07 ( $N = 2859$ ) shot per bird, respectively. In our study, occurrence was 0.32 shot per bird ( $N = 690$ ), hence much larger than in similar studies.

The prevalence and occurrence of ingested shot in gizzards are influenced by different variables. The density of shot in the birds’ feeding area and the accessibility of shot are primary factors. Species have different feeding behaviours and choices of food and grit items; hence, some species are more

susceptible than others. Mallards are generally regarded to be at a rather high risk (Mateo 2009), but single populations are exposed to different levels depending on inter alia the local hunting regime. It is common that mallards reared for hunting purposes are released in the ponds and lakes where the hunting takes place. Feeding may take place nearby or at the same spots where guns are located during the shoot. This causes a very pronounced overlap between feeding areas and areas with fall-down of gunshot, hence a significant likelihood of foraging birds to ingest shot. The large prevalence (36.0%) and occurrence (2.4) of ingested shot in birds from batch 9 in our study is likely due to these birds having foraged in a habitat with a high density of shot. Also, 98% of the ingested shot in birds from this Batch were steel shot, which indicates that the source is not a historical population of lead shot, but of steel shot from intensive hunting in recent years.

Multiple studies have shown that just a few lead shot ingested by birds cause lethal poisoning (Arnemo et al. 2016; Watson et al. 2009; Delahay and Spray 2015) or sub-lethal impacts leading to animal suffering, changed behaviour and reduced survival (Vallverdú-Coll et al. 2015; Newth et al. 2016; Ecke et al. 2017). The toxicity of non-lead shot such as steel, bismuth and tungsten based shot has been well investigated, and ingestion of these shot types causes no harm to birds (Sanderson et al. 1997, Mitchell et al. 2001a, b, c, Thomas et al. 2009, Thomas 2015). However, some alternative shot types, e.g. zinc, are acutely toxic to waterfowl (Levengood et al. 1999).

Twelve (1.7%) of the total gizzard samples in this study ( $N = 690$ ) had one or more ingested lead shot, with a maximum of five shot in one gizzard. This is much lower than the prevalence of lead shot found in other studies (see above) and indicates that the density and accessibility of lead shot in the habitats of these mallards are relatively low. Our results support the findings by Anderson et al. (2000), who examined the extent to which ingested non-lead (steel and bismuth) shotgun shot replaced lead shot in ducks harvested in the Mississippi Flyway during the 1996 and 1997 hunting seasons (fifth and sixth year after the American conversion to non-toxic shot in wetlands). The prevalence of ingested shot was 8.9% for mallards ( $N = 15,147$ ), and 68% of gizzards with ingested shot had only non-lead shot; the ingestion of more than two toxic pellets declined by as much as 78%. Anderson et al. (2000) estimated that non-toxic shot reduced mortality from lead poisoning in Mississippi Flyway mallards by 64%. Similarly, Mateo et al. (2014) showed that lead shot ingestion in mallards decreased from a pre-ban prevalence value of 30.2 to 15.5% in the post-ban period in the Ebro delta in Spain. Huck et al. (2016), investigating female northern pintail (*Anas acuta*) specimens collected at the Texas coast, found that shot (lead and non-toxic combined) ingestion rates were similar to those found prior to the lead shot ban; however, lead shot ingestion rates were considerably lower, suggesting that lead was becoming less available over time.

The high prevalence of ingested steel shot in our study demonstrates that steel shot is available in high densities in the birds' feeding areas. The gizzards with ingested bismuth shot (7.5% of gizzards with ingested shot) reflect that some hunters use this type, as also seen in a sample of embedded shot (Kanstrup and Balsby 2019). The prevalence of ingested lead shot (18.1% of gizzards with ingested shot) shows that lead shot are still available in the birds' habitats decades after the ban, as also demonstrated by Flint and Schamber (2010) and Huck et al. (2016). The source may be shot dispersed illegally after the ban (for release ponds for mallards in 1986). However, our data support the assumption that hunters who shoot released mallards in general respect the legislation or at least have done so in recent time. Mallard is a migratory species, so in theory, ingested shot could originate from other feeding areas on the migratory route. However, released mallards, as in our study, are mostly sedentary and only make few and short movements between wetlands in the vicinity of the ponds where they are released and fed.

Due to the toxicity of lead shot, it is expected (and the primary rationale behind the legislation) that the gradual replacement of lead shot by non-toxic shot in natural habitats, resulting from a phase-out of lead shot for hunting, will save birds from getting lead-poisoned and thereby over time removes this extra source of mortality and sub-lethal suffering. However, multiple factors must be considered. Prevalence is dependent on the ingestion rate and the time the shot is retained in the gizzard, which may differ among shot types. Ingestion rates are related to densities of accessible shot in the habitat, which depend on dispersal from hunting, but also on the time the shot are retained and stay available in the habitat. As steel (iron) shot have other physical properties than lead shot, including the ability to corrode quickly, they may not accumulate in the environment in the same way as lead shot. On the other hand, shot made from hard metals such as steel may persist gizzard erosion longer than shot made of lead and bismuth. This may cause prolonged retention time in the gizzards. In conclusion, the prevalence of ingested shot depends on numerous factors that differ among shot types. Therefore, we cannot precisely calculate the conservation gain of phasing out lead shot based on our data. However, our study proves the hypothesis that mallards have switched from ingesting lead to steel shot due to the change of shot types for hunting in their habitat, as also seen in other studies (Anderson et al. 2000; Mateo et al. 2014). With reference to all the strong evidence that lead shot are toxic, whereas steel shot are non-toxic, our data indirectly demonstrates that the Danish phase-out of lead shot for hunting has led to decreased levels of waterbird poisoning and, subsequently, to reduced mortality and sub-lethal impacts caused by ingestion of lead shot. The exact levels can only be assessed by more thorough studies to achieve a better understanding of the turnover of different shot types in the habitat as well as in the digestive system of waterbirds.

## Conclusions

Waterbirds and other bird taxa ingest gunshot in confusion with grit or food. The regulation-imposed shift from lead to non-lead gunshot for hunting in Denmark over the last decades is reflected in a shift of shot types ingested by mallards. Out of 221 ingested shot from 690 mallard gizzards collected during the 2017 hunting season, we found that 87.8% were steel, 2.7% were bismuth and 9.5% were lead shot. The shot ingestion indicators (prevalence and occurrence) were higher than those found prior to the lead shot ban; however, lead shot levels were considerably lower, suggesting that lead shot are becoming less available over time, although still present despite the ban of lead shot in habitats of released mallards since 1986.

Due to the toxicity of lead shot, this study suggests that the gradual replacement of lead shot by non-toxic shot in natural habitats, resulting from the phase-out of lead shot for hunting, has saved birds from acquiring lead poison and thereby, over time, has reduced this extra source of mortality and sub-lethal suffering.

**Acknowledgements** We thank Klosterhedens Vildt, who helped with the purchase of study samples.

**Funding information** We thank 15. Juni Fonden, Arboretet, Kirkegårdsvej 3A, DK-2970 Hørsholm for the grant given to the Danish Academy of Hunting for the study period 2018–2019.

## References

- Anderson WL, Havera SP, Zercher BW (2000) Ingestion of lead and non-toxic gunshot pellets by ducks in the Mississippi flyway. *J Wildl Manag* 64:848–857. <https://doi.org/10.2307/3802755>
- Armeno JM, Anderson O, Stokke S, Thomas VG, Krone O, Pain DJ, Mateo R (2016) Health and environmental risks from lead-based ammunition: science versus socio-politics. *EcoHealth* 13:618–622. <https://doi.org/10.1007/s10393-016-1177-x>
- Bellrose FC (1959) Lead poisoning as a mortality factor in waterfowl populations. *Bulletin Illinois Natural History Survey* 7 27(3):233–288
- Brewer L, Fairbrother A, Clark J, Amick D (2003) Acute toxicity of lead, steel, and iron-tungsten-nickel shot to mallard ducks (*Anas platyrhynchos*). *J Wildl Dis* 39(3):638–648. <https://doi.org/10.7589/0090-3558-39.3.638>
- Clausen B, Wolstrup C (1979) Lead poisoning in game from Denmark. *Danish Review of Game Biology* 11(2)
- Cook RS, Trainer DO (1966) Experimental lead poisoning of Canada geese. *J Wildl Manag* 30(1):1–8
- Delahay RJ, Spray CJ (eds) (2015) Proceedings of the Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, The University of Oxford, Oxford
- Ecke F, Singh NJ, Armeno JM, Bignert A, Helander B, Berglund AMM, Borg H, Bröjer C, Holm K, Lazzone M, Miller T, Nordström Å, Räikkönen J, Rodushkin I, Ägren E, Hörmfeldt B (2017) Sublethal lead exposure alters movement behavior in free-ranging golden eagles. *Environ Sci Technol* 51:5729–5736. <https://doi.org/10.1021/acs.est.6b06024>
- Eskildsen J (1980) Tætheden af blyhagl i lavvandede vestjyske fjordområder. Naturhistorisk Museum 1980
- Flint PL (1998) Settlement rate of lead shot in tundra wetlands. *J Wildl Manag* 62(3):1099–1102
- Flint PL, Schamber JL (2010) Long-term persistence of spent lead shot in tundra wetlands. *J Wildl Manag* 74(1):148–151
- Holladay JP, Nisanian M, Williams S, Tuckfield RC, Kerr R, Jarrett T, Tannenbaum T, Holladay SD, Sharma A, Gogal RM Jr (2012) Dosing of adult pigeons with as little as one #9 lead pellet caused severe  $\delta$ -ALAD depression, suggesting potential adverse effects in wild populations. *Ecotoxicology* 21(8):2331–2337. <https://doi.org/10.1007/s10646-012-0989-x> <https://www.ncbi.nlm.nih.gov/pubmed/22903291/>
- Huck NR, Ballard BM, Fedynich AM, Kraai KJ, Castro ME (2016) Shot ingestion by wintering female northern pintails (*Anas acuta*) in the Texas Coastal Plain, 2012–14. *J Wildl Dis* 52(1):118–121. <https://doi.org/10.7589/2015-02-050>
- Jorgensen SS, Willems M (1987) The fate of lead in soils: the transformation of lead pellets in shooting range soils. *Ambio* 16:11–15
- Kanstrup N (2012) Lead in game birds in Denmark: levels and sources. Danish Academy of Hunting. Article: 2012–1
- Kanstrup N, Balsby TJS (2019) Danish pheasant and mallard hunters comply with the lead shot regulation. *Ambio*. In: Kanstrup N, VG Thomas and AD Fox. Lead in ammunition: persistent problems and solutions. *Ambio* vol. 48, Special Issue
- Kerr R, Holladay S, Jarrett T, Selcer B, Meldrum B, Williams S, Tannenbaum L, Holladay J, Williams J, Gogal R (2010) Lead pellet retention time and associated toxicity in northern bobwhite quail (*Colinus virginianus*). *Environ Toxicol Chem* 29(12):2869–2874. <https://doi.org/10.1002/etc.355>
- Levengood JM, Sanderson GC, Anderson WL, Foley GL, Skowron LM, Brown PW, Seets JW (1999) Acute toxicity of ingested zinc shot to game-farm mallards. *Illinois Natural History Survey Bulletin* 36:1–36
- Lumeij JT, Hendriks H, Timmers A (1989) The prevalence of lead shot ingestion in wild mallards (*Anas platyrhynchos*) in the Netherlands. *Vet Q* 11(1):51–55. <https://doi.org/10.1080/01652176.1989.9694196>
- Mateo R (2009) Lead poisoning in wild birds in Europe and the regulations adopted by different countries. In: Watson RT, Fuller M, Pokras M, Hunt WG (eds) Ingestion of lead from spent ammunition: Implications for wildlife and humans. The Peregrine Fund, Boise
- Mateo R, Vallverdú-Colla N, López-Antia A, Taggart MA, Martínez-Haroac M, Guitart R, Ortiz-Santaliestra ME (2014) Reducing Pb poisoning in birds and Pb exposure in game meat consumers: the dual benefit of effective Pb shot regulation. *Environ Int* 63:163–168. <https://doi.org/10.1016/j.envint.2013.11.006>
- McLaren R, Rooney C, Condron L (2009) Control of lead solubility in soil contaminated with lead shot: effect of soil moisture and temperature. *Soil Res* 47(3):296–304
- Meltofte H, Petersen BD (1979) Forekomst af blyhagl i vestjyske vådområder samt i kråsen hos danske ænder. *DOFT* 73:265–272
- Mitchell RR, Fitzgerald SD, Auerlich RJ, Balander RJ, Powell DC, Templeman RJ, Sickie RL, Stevens W, Bursian SJ (2001a) Health effects following chronic dosing with tungsten-iron and tungsten-polymer shot in adult-game farm mallards. *J Wildl Dis* 37:451–458. <https://doi.org/10.7589/0090-3558-37.3.451>
- Mitchell RR, Fitzgerald SD, Auerlich RJ, Balander RJ, Powell DC, Templeman RJ, Cray C, Stevens W, Bursian SJ (2001b) Hematological effects and metal residue concentrations following chronic dosing with tungsten-iron and tungsten polymer shot in adult game-farm mallards. *J Wildl Dis* 37:459–467. <https://doi.org/10.7589/0090-3558-37.3.459>

- Mitchell RR, Fitzgerald SD, Auerlich RJ, Balander RJ, Powell DC, Templeman RJ, Stevens W, Bursian SJ (2001c) Reproductive effects and ducking survivability following chronic dosing with tungsten-iron and tungsten-polymer shot in game-farm mallards. *J Wildl Dis* 37:468–474. <https://doi.org/10.7589/0090-3558-37.3.468>
- Newth JL, Rees EC, Cromie RL, McDonald RA, Bearhop S, Pain DJ, Norton GL, Deacon C, Hilton GM (2016) Widespread exposure to lead affects body condition of free-living whooper swans *Cygnus cygnus* wintering in Britain. *Environ Pollut* 209:60–67. <https://doi.org/10.1016/j.envpol.2015.11.007>
- Pain DJ (1996) Lead in waterfowl. In: Beyer WM, Heinz GH, Redman-Norwoo AW (eds) *Environmental contaminants in wildlife: interpreting tissue concentrations*. Lewis Publishers, Boca Raton, pp 251–262
- Pain DJ, Fisher IJ, Thomas VG (2009) A global update of lead poisoning in terrestrial birds from ammunition sources. In: Watson RT, Fuller M, Pokras M, Hunt WG (eds) *Ingestion of lead from spent ammunition: implications for wildlife and humans*. The Peregrine Fund, Boise. <https://doi.org/10.4080/ilsa.2009.0108>
- Plouzeau E, Guillard O, Pineau A, Billiald P, Berny P (2011) Will leaded young mallards take wing? Effects of a single lead shot ingestion on growth of juvenile game-farm mallard ducks *Anas platyrhynchos*. *Sci Total Environ* 409(12):2379–2383. <https://doi.org/10.1016/j.scitotenv.2011.03.012>
- Rooney CP, McLaren RG, Condron LM (2007) Control of lead solubility in soil contaminated with lead shot: Effect of soil pH. *Environ Pollut* 149(2):149–157. <https://doi.org/10.1016/j.envpol.2007.01.009>
- Sanderson GC, Anderson WL, Foley GL, Duncan KL, Skowron LM, Brawn JD, Seets JW (1997) Toxicity of ingested bismuth alloy shot in game-farm mallards: chronic health effects and effects on reproduction. *Illinois Natural History Survey Bulletin* 35(4):217–252
- Sanderson P, Naidu R, Bolan N, Bowman M, McLure S (2012) Effect of soil type on distribution and bioaccessibility of metal contaminants in shooting range soils. *Sci Total Environ* 438:452–462
- Scheuhammer AM, Norris SL (1996) The ecotoxicology of lead shot and lead fishing weights. *Ecotoxicology* 5(5):279–295. <https://doi.org/10.1007/BF00119051>
- Sullivan TS, Gittel NR, Basta N, Jardine PM, Schadt CW (2012) Firing range soils yield a diverse array of fungal isolates capable of organic acid production and Pb mineral solubilization. *Appl Environ Microbiol* 78(17):6078–6086
- Takamatsu T, Murata T, Koshikawa MK, Watanabe M (2010) Weathering and dissolution rates among Pb shot pellets of different elemental compositions exposed to various aqueous and soil conditions. *Arch Environ Contam Toxicol* 59:91–99
- Tavecchia G, Pradel R, Lebreton JD, Johnson AR, Mondain Monval JY (2001) The effect of lead exposure on survival of adult mallards in the Camargue, southern France. *J Appl Ecol* 38(6):1197–1207
- Thomas VG (2015) Elemental tungsten, tungsten-nickel alloys and shot-gun ammunition: resolving issues of their relative toxicity. *Eur J Wildl Res* 62(1):1–9. <https://doi.org/10.1007/s10344-015-0979-4>
- Thomas VG, Roberts MJ, Harrison PTC (2009) Assessment of the environmental toxicity and carcinogenicity of tungsten-based shot. *Ecotoxicol Environ Saf* 72:1031–1037. <https://doi.org/10.1016/j.ecoenv.2009.01.001>
- Vallverdú-Coll N, López-Anita A, Martínez-Haro M, Ortiz-Santaliestra ME, Mateo R (2015) Altered immune response in mallard ducklings exposed to lead through maternal transfer in the wild. *Environ Pollut* 205:350–356. <https://doi.org/10.1016/j.envpol.2015.06.014>
- Watson RT, Fuller M, Pokras M, Hunt WG (eds) (2009) *Ingestion of lead from spent ammunition: Implications for wildlife and humans*. The Peregrine Fund, Boise

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



# PAPER 17

Thomas VG, Pain DJ, Kanstrup N, Green RE (2020). Setting maximum levels for lead in game meat in EC regulations: an adjunct to replacement of lead ammunition. *Ambio* 49, pages 2026–2037. doi:<https://doi.org/10.1007/s13280-020-01336-6>

## RIGHTS:

### Open access

## AUTHORS' CONTRIBUTIONS

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above, of which I am first author, was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Prof. Emeritus Vernon Thomas  
Department of Integrative Biology, College of Biological Science, University of Guelph,  
Guelph, Ontario N1G 2W1, Canada

Email: [vthomas@uoguelph.ca](mailto:vthomas@uoguelph.ca)

\*\*\*

Thomas VG, Pain DJ, Kanstrup N, Green RE (2020) Setting maximum levels for lead in game meat in EC regulations: an adjunct to replacement of lead ammunition *Ambio*  
doi:<https://doi.org/10.1007/s13280-020-01336-6>

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Deborah Pain

Professor Deborah Pain

[dp596@cam.ac.uk](mailto:dp596@cam.ac.uk)

<https://www.zoo.cam.ac.uk/directory/debbie-pain>



UNIVERSITY OF  
CAMBRIDGE  
Department of Zoology

Rhys E. Green  
Professor of Conservation Science

*Conservation Science Group, Downing Street, Cambridge CB2 3EJ, UK*

email: [reg29@cam.ac.uk](mailto:reg29@cam.ac.uk)

Web: <http://www.zoo.cam.ac.uk/zoostaff/green.htm>

Phone: 01223 762840 (direct line) Fax: 01223 336676

14 April 2021

Aarhus University  
Denmark

To Whom it may Concern

This letter is to confirm that Niels Kanstrup made substantial contributions to this paper, of which I am a co-author.

Thomas VG, Pain DJ, Kanstrup N, Green RE (2020 (Paper 22)) Setting maximum levels for lead in game meat in EC regulations: an adjunct to replacement of lead ammunition Ambio doi:<https://doi.org/10.1007/s13280-020-01336-6>

Niels Kanstrup's contribution was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Professor Rhys E. Green

Confirmed, April 2021

Niels Kanstrup



# Setting maximum levels for lead in game meat in EC regulations: An adjunct to replacement of lead ammunition

Vernon G. Thomas, Deborah J. Pain, Niels Kanstrup,  
Rhys E. Green

Received: 9 December 2019 / Revised: 11 December 2019 / Accepted: 29 February 2020

**Abstract** Each year, hunters from 12 of the 27 European Union (EU) countries and the UK shoot over 6 million large game mammals, 12 million rabbits and hares and over 80 million birds. They support an international game meat market worth over 1.1 thousand million Euros. Animals shot with lead ammunition frequently contain lead fragments in the carcass which contaminate meals made from game meat with concentrations of lead substantially above the maximum allowable level (ML) set by European Commission Regulation EC1881/2006 for meat from domesticated animals. This poses a health risk to frequent consumers of wild-shot game meat, with children and pregnant women being particularly vulnerable. Total replacement of lead rifle and shotgun ammunition with available non-toxic alternatives is needed for all hunting in EU nations to prevent exposure of humans and wildlife to ammunition-derived lead and to allow the depletion of the long-term environmental legacy of lead from spent ammunition. We propose that EC1881/2006 is amended to incorporate an ML for game meats as a supplementary measure to the replacement of lead ammunition. This would harmonise food safety standards for lead in meats traded across and imported into the EU.

**Keywords** Europe · Game meat · Hunting · International trade · Regulation · Scavengers

## INTRODUCTION

Modern European hunting results in game meat that is consumed either by hunters, their families or associates and enters the retail market place and restaurants (Schulp et al. 2014). The trade in game meat is large (FAO 2018), both within and among European nations, and between Europe

and other countries. This trade generates large revenues (Schulp et al. 2014; FAO 2018) that offset the costs of maintaining habitats on shooting estates. Human consumption of wild game meat is increasing, including the UK (BASC 2018, 2019), reflecting a preference for ‘un-farmed’ meat and the promotion of wild game as a healthy alternative to other meats (Taggart et al. 2011). Campaigns to promote game meat consumption are active in the UK (BASC 2019; CA 2019), as is the Danish promotion of game meat in schools (DJA 2019).

Lead ammunition frequently leaves tiny fragments of lead dispersed widely through the meat of both large game shot with bullets (Hunt et al. 2009) and birds and other small game shot with lead gunshot pellets (Pain et al. 2010). This source of lead is biologically available (Green and Pain 2012) and is not easily removed, especially from the flesh of small game animals (Green and Pain 2019). It thus poses a health risk to those who frequently consume game shot with lead ammunition and to children and pregnant women who are especially vulnerable to the effects of lead (Pain et al. 2010; Green and Pain 2012, 2019; Knutsen et al. 2015). There is a large and growing awareness of the effects of ammunition-derived dietary lead on human health and well-being and their associated societal impacts and costs (Delahay and Spray 2015; Kanstrup et al. 2019; Pain et al. 2019a). Non-lead substitutes for lead shotgun and rifle ammunition have been developed and are available to European hunters (Thomas 2015; Thomas et al. 2016), but no European-wide regulation exists to require their use for game hunting (Mateo and Kanstrup 2019).

European Commission Regulation (Council Directive 92/5/EEC) concerns the procurement and handling of game meat (Bertolini et al. 2005), but does not mention the use of lead ammunition in taking wild game. European

Commission Regulation EC1881/2006 sets maximum levels (MLs) of lead allowed in traded meats from domesticated bovine animals, sheep, pigs and poultry, but also from less frequently eaten meats from wild animals, including cephalopods and bivalve molluscs. However, no ML has been set for lead in game meat. The European Commission is aware of the elevated lead levels found in game animals (EFSA 2010, 2012), and the food standards or safety agencies of a number of European Union (EU) nations have issued new advice intended to reduce or eliminate health risks associated with the consumption of lead-contaminated game meat. This is intended for frequent consumers and vulnerable pregnant women, women of pregnancy age and children (Knutsen et al. 2015; ANSES 2018; Gerofke et al. 2018, 2019). However, this increase in awareness and the provision of health advice has not resulted in EU or any national regulations concerning lead MLs in game meat.

The present paper supplements the reviews of ECHA (2018), Pain et al. (2019a, b) and Green and Pain (2019) of the effects of lead ammunition use on human and wildlife health, and the analysis of Gerofke et al. (2019) on the sources and consequences of lead in game meat in Germany. We indicate the scale of game hunting and trade in Europe, and the health risks posed by lead from frequent ingestion of wild-shot game meat. We then describe the advantages of amending the European Commission Regulation that sets the ML for lead in domestic meat so that it includes meat from wild game animals. In particular, we argue that this action would complement and facilitate the essential transition to non-lead ammunition for European hunting, which would benefit people, wildlife and domestic animals (Pain et al. 2019a).

## HUNTING AND TRADE IN GAME ACROSS THE EUROPEAN UNION

Most game hunting in Europe is conducted on privately owned lands and game meat trade occurs via private agencies. Statistics on the numbers of animals killed each season, by species, and by region are obtained by voluntary questionnaires or statutory reporting (for birds). The Birds Directive 2009/147/EC sets the framework for hunting legislation across the EU. This specifies how, when and where 82 bird species may be hunted legally and requires the provision of data on hunting bags at regular intervals. In terms of voluntary questionnaires, FAO (2018) reported data collected from United Nations Economic Commission for Europe (UNECE) countries using a questionnaire survey in 2016 and 2017. The objective of this FAO pilot study was to improve knowledge and understanding of game meat production and trade. Game was taken to

comprise all hunted birds and mammals, such as partridge (*Perdix perdix* and *Alectoris* spp.), pheasant (*Phasianus colchicus*), hare (*Lepus europaeus*), deer including roe deer (*Capreolus capreolus*), red deer (*Cervus* spp.), fallow deer (*Dama dama*) and European elk (*Alces alces*), wild boar (*Sus scrofa*) and chamois (*Rupicapra rupicapra*) that are available for consumption, but the study excluded farmed game (mostly deer and wild boar). The study focussed particularly on game species that use forested or forest associated habitats. Although reporting requirements for birds are mandatory under the Birds Directive, data provided both from this survey and voluntary schemes varied substantially in coverage and quality.

The fresh weight of game killed and its traded value (FAO 2018) are presented in Tables 1 and 2. These figures represent only the most important mammalian and avian game species and came from those countries that replied most fully to the questionnaires. We recommend that FAO (2018) is consulted for information on hunted species of lesser economic importance to the game trade. The data in Tables 1 and 2 are annual means averaged across recent annual reports. The numbers vary from year to year because of variation in wild game recruitment patterns, hunter effort and market economic conditions. The 13 EU countries that replied to the survey on numbers of animals killed have 5 465 000 hunters, representing 82% of the 6 667 770 hunters in the EU 28 in 2010 (FACE 2010). Assuming that a similar number of mammals are killed per hunter by the remaining 18% of hunters gives an estimated annual kill across the EU of 6 282 841 large mammals (3 species of deer plus wild boar) and 12 269 575 brown hares and rabbits.

Data on numbers of birds killed in the EU are sparse in FAO (2018). Hirschfeld et al. (2019) found that almost 52 million birds (51 808) were reported as shot annually in the EU, but these data excluded the UK, Greece, Ireland and the Netherlands, where 20% of shooters are reported to live (FACE 2010). In the UK, Green and Pain (2015) used available data to make a conservative estimate of 28.1 million birds shot annually, although these data are from a decade ago and numbers shot are likely to have increased, along with increases in numbers of released gamebirds (primarily pheasants and red-legged partridges *Alectoris rufa*). Adding the UK figure to that of Hirschfeld et al. (2019) gives a total of c.80 million birds shot in the EU, but excluding Greece, Ireland and the Netherlands. These latter three countries contain 9.2% of the total number of hunters in the EU (FACE 2010). If we assume that a similar average number of birds are shot per hunter in these countries, this suggests that about 88 million birds are shot per year. This is not dissimilar to the totals given in the FAO (2018) voluntary questionnaire. FAO data showed that 12 EU countries with 4 665 000 hunters (in 2010:

**Table 1** Annual numbers of wild mammals shot in 13 EU countries<sup>a,b</sup> and tonnage of game produced. Data are taken from FAO (2018) and represent the most important game species hunted

Species	Annual kill (number of countries that reported)	Annual tonnage (assumed weight of individual animals in kg)
Roe deer <i>Capreolus capreolus</i>	2 294 324 (13)	45 886 (20)
Red deer <i>Cervus elaphus</i>	480 464 (12)	72 070 (150)
Fallow deer <i>Dama dama</i>	156 032 (12)	9362 (60)
Wild boar <i>Sus scrofa</i>	2 218 687 (11)	155 308 (70)
Brown hares <i>Lepus europaeus</i>	2 039 436 (11)	7750 (3.8)
Rabbit <i>Oryctolagus cuniculus</i>	8 016 884 (7)	16 033 (2)
Total mammal kill	15 205 827	306 409

<sup>a</sup>Croatia, Czech Republic, Finland, France, Germany, Ireland, Italy, Lithuania, Luxembourg, Poland, Spain, Sweden, UK. The 13 countries that replied to the survey have 5 465 000 hunters (82%) of the 6 667 770 in the EU 28 as of 2010 (FACE 2010). Assuming that a similar number of mammals are killed per hunter by the remaining 18% of hunters, this gives an estimated kill of 6 282 841 large mammals and 12 269 575 brown hares and rabbits

<sup>b</sup>The total kill of birds approaches 88 million in the EU, from the data of Hirschfeld et al. (2019) and Green and Pain (2015: for the UK) extrapolated to include all EU countries (see text). Data from FAO (2018) on bird kills were too sparse from many countries to allow reasonable representation

**Table 2** The annual tonnage and traded values of game meat reported by six EU nations in FAO (2018). These numbers refer to the principal species of mammals and birds involved in the game markets. The values in US\$ were converted to Euros using the exchange factor 0.908

Six nations reporting trade data <sup>a</sup>	Traded quantity in tonnes/y		Traded value in million Euros/y	
	Imports	Exports	Imports	Exports
	70 881	127 696	178.22	298.36

<sup>a</sup>Croatia, Finland, Lithuania, Poland, Spain, Sweden

The 6 EU countries that reported trade data have 1 771 000 hunters (26.56%) of the 6 667 770 reported in the EU in 2010 (FACE 2010). Assuming a direct relationship between the numbers of hunters and the level of export trade gives an estimated export trade value in excess of 1123 million Euros a year for the whole of the EU

FACE 2010) reported shooting 38 766 554 birds of selected species. To this we can add UK figures of 800 000 hunters shooting 28.1 million birds (FACE 2010; Green and Pain 2015) giving a total of 5 465 000 million hunters (82% of total hunters) shooting 66 866 554 birds. Extrapolating this to the total number of EU hunters in 2010: 6 667 770 (FACE 2010) gives a total of 81 544 000 birds hunted. This may be an underestimate given that not all species were reported and numbers have increased in the UK, but is broadly similar to the estimate of Hirschfeld et al. (2019) for the EU.

Despite the reporting limitations inherent in the FAO (2018) survey, the results indicate a large annual kill of mammals (Table 1) and birds as indicated above. Fewer countries reported trade data. Data in Table 2 are based on the principal mammal and bird species traded, which are deer and boar, waterfowl, pheasant and other non-wetland gamebirds. The annual traded values of the EU imports and exports are large (Table 2; FAO 2018). The 6 EU countries

that reported trade data have 1 771 000 hunters (26.56%) of the 6 667 770 reported in the EU in 2010 (FACE 2010). By assuming a direct relationship between the numbers of hunters and the level of export trade, extrapolation of the 298 363 005 Euros reported by those 6 countries (Table 2) gives an estimated export trade value in excess of 1123 million Euros a year for the whole of the EU. This is unlikely to be precise as there may not be a direct relationship between the number of hunters and the level of trade, but this gives a broad idea of the overall value of trade in the most important species.

## HEALTH PROBLEMS POSED BY LEAD FRAGMENTS FROM AMMUNITION IN GAME MEAT

Lead hunting bullets are designed to expand on entering an animal, and many small lead fragments can be released



**Fig. 1** Radiograph of a roe deer shot with a single unbonded lead rifle bullet, showing the extent of the bullet's fragmentation and the distance of fragments' spread from the entry site. Most of the small fragments would not likely be removed prior to butchering and retail sale, thereby exposing the consumer. Photo credit, Oliver Krone, Leibniz Institute for Zoo and Wildlife Research, Berlin, Germany

from the bullet's core (Fig. 1). The extent of fragmentation depends on the type of bullet, its terminal velocity and the tissues penetrated, especially bone (Dobrowolska and Melosik 2008; Trinogga et al. 2019). Unbonded jacketed lead bullets fragment more than costlier bonded jacketed bullets. While it is common practice for hunters and game handlers to remove flesh around the point of bullet's entry, small distant fragments are likely to evade removal and, ultimately, be consumed by humans. Non-lead rifle bullets are designed not to fragment, thus avoiding contamination of the carcass. Copper, which has very low toxicity compared to lead, is frequently used for non-lead bullets, and research has indicated that this does not present a health risk (Krone et al. 2019). Lead gunshot often remains in birds until prepared for cooking, or even after cooking. Multiple shot may be found in both the vital and the non-vital parts of the body, including small fragments produced when pellets strike hard tissues (Fig. 2). While intact shot are visible, many are not removed prior to cooking, which could increase the solubilisation and availability of lead to humans (Mateo et al. 2007).

Removal of lead shot and bullet fragments is impractical in small game animals like gamebirds (Green and Pain 2019) and results in discarding of a considerable quantity of meat in large game animals. In Norway, discarding meat close to wound channels results in approximately 200 tonnes of contaminated meat being discarded annually, representing a loss of around 3 million Euros (Kanstrup et al. 2018). The experimental removal of whole shot and large fragments of lead gunshot to simulate what consumers would do at the table still results in lead levels in



**Fig. 2** X-ray of a woodpigeon illustrating four gunshot and numerous small radio-dense fragments. Radio-dense fragments may trace the passage of shot through the bird; some fragments are close to bone suggesting fragmentation on impact, others are not. Reproduced from Fig. 1 of Pain et al. (2010)

meat that are, on average, more than an order of magnitude higher than the EC MLs set for the meat of domestic animals (Pain et al. 2010; Lindboe et al. 2012). Many waterfowl ingest spent lead shot whose lead is absorbed and deposited in the organs (primarily liver and kidney) and the skeleton. Other birds may carry throughout life lead shot embedded in tissues from prior hunting encounters (Pain et al. 2019b). Even though such birds may be killed later by hunters using non-lead shot, these birds may enter markets with lead levels exceeding current EC MLs for meat and offal, especially in the livers and kidneys (Guitart et al. 2002). The only pragmatic solution to this problem is the appropriate labelling of retailed waterfowl carcasses that alert consumers to a potential health risk from lead. In large mammals killed with lead-based rifle bullets, the lead contamination may vary considerably throughout the carcass. Animals killed with a single heart–lung shot may have bullet fragments widely dispersed through thoracic meat (e.g. Hunt et al. 2009; Fig. 1), but meat from the hind quarters may be lead-free (Gerofke et al. 2018). Mincing the meat from the thoracic region would homogenise the lead within the retailed product (Lindboe et al. 2012; Vogt and Tysnes 2015).

This issue is not unique to Europe and arises wherever hunters use lead ammunition (Pain and Green 2019; Thomas et al. 2019). The health risk to humans increases with the annual consumption of contaminated game meat (Taggart et al. 2011; Green and Pain 2012, 2015), the type of game eaten (e.g. mammals vs. birds), and with the vulnerability of the consumer to the effects of dietary lead (especially children and pregnant women).

## THE HUMAN AND SOCIETAL COST OF LEAD EXPOSURE FROM GAME MEAT CONSUMPTION

While absorbed lead affects most body systems in humans, critical effects were considered by the Panel on Contaminants in the Food Chain (CONTAM Panel) of the European Food Safety Authority (EFSA) to be developmental neurotoxicity in young children and cardiovascular effects and nephrotoxicity in adults (EFSA 2010). Children and foetuses are particularly sensitive to dietary exposure and are considered to be the most vulnerable group. This is both because they absorb a higher proportion of the lead ingested, and because children's developing brains are especially susceptible to the effects of chronic lead exposure, even when blood lead concentrations indicate a low level of exposure (Lanphear et al. 2005; Budtz-Jørgensen 2010; EFSA 2010).

Pain et al. (2019a) estimated the economic costs of reduced IQ in those children deemed at risk from ingestion of lead from ammunition in the diet. Such a calculation requires an estimate of the numbers of children exposed to sufficient dietary lead from ammunition to result in blood lead levels associated with reduced IQ. A 1 point (1%) reduction in IQ was considered significant at a population level by EFSA (2010). In the UK, it has been estimated that 4000–48 000 children were at risk from incurring a one point or more reduction in IQ as a result of their level of exposure to dietary lead from game meat (Green and Pain 2015). Another survey in the UK by the British Association for Shooting and Conservation and the Countryside Alliance (BASC/CA) found that, in the UK shooting community alone, 9000 (midpoint of 5500–12 500) young (8 years or younger) children consume at least one game meal per week averaged over the year (reported in LAG 2014). As this level of consumption generally exceeds the amount of dietary lead exposure associated with a 1 point reduction in IQ (Green and Pain 2012, 2015), it seems probable that at least 10 000 children in the UK are at risk. Pain et al. (2019a) assumed that the ratio of children at risk in the UK relative to the number of UK hunters would be similar across the EU. This gave an estimate of 83 000 or more children across the EU27 who may be at risk of an IQ reduction of 1 point.

The societal costs of reduced IQ have been estimated in various ways by different authors and relate to impacts on academic achievement and/or decreased productivity in later life (e.g. Schwartz 1994; Grosse et al. 2002; ECHA 2011; Bierkens et al. 2012; Monahan et al. 2015). Using the range of values from the last three of these studies, Pain et al. (2019a) estimated that the consumption of lead shot game by the cohort of children 8 years old or younger within the EU was linked to a potential loss in IQ worth €322 million to €830 million. This equates to an annualised

(i.e. ongoing and cumulative) cost to society of €40 million–€104 million for every year that lead-contaminated game continues to be consumed at current levels. The authors considered that the actual cost may be higher than estimated because some children will be exposed to more lead from game than is associated with a 1 point reduced IQ, with greater concomitant risks, and also because some studies indicate that in some EU countries, more people may be 'high-level' consumers of game, relative to the national number of hunters, than in the UK (see Pain et al. 2019a).

We are unaware of other attempts to monetise the possible health effects associated with elevated blood lead from consumption of lead shot game. Increased blood lead levels are associated with increased risk of cardiovascular disease and of chronic kidney disease (EFSA 2010) and may contribute to antisocial behaviour and increased crime rates (e.g. Campbell et al. 2018; Sampson and Winter 2018), with related costs to both the individuals concerned and society in general. Based on a 2008 survey on blood lead concentrations in French children aged one to 6 years old, Pichery et al. (2011) estimated the monetary benefits in terms of avoided national costs if threshold values for lead toxicity above 15 µg/L, 24 µg/L and 100 µg/L were introduced, at €22.72 thousand million, €10.72 thousand million and €0.44 thousand million, respectively. It is notable that more people appear to eat game frequently and be 'high-level' consumers than might previously have been supposed. Green and Pain (2019), by extrapolating from UK surveys and reviewing studies from elsewhere, estimated this to be approximately 5 million people (1% of the population) in the EU. In some EU countries, this has been estimated to be several times higher (e.g. 3% in Italy: Ferri et al. 2017).

## IMPACTS OF LEAD AMMUNITION INGESTION ON SCAVENGERS

Hunters customarily discard the organs and entrails of killed animals in the field. These entrails frequently contain lead bullet fragments, and the gut piles are often eaten by avian and mammalian scavengers (Stokke et al. 2017; Hampton et al. 2018). At least 5–6 million gut piles from deer and boars may be discarded annually throughout Europe (based on Table 1) and pose a lead exposure risk to scavengers. Whole animals shot by hunters may be left in the field, either deliberately as pests, or accidentally, when not retrieved. Waterfowl hunting, for example, is often accompanied by large unintentional crippling losses when birds are hit but not retrieved (Falk et al. 2006). These carcasses are eventually fed on by scavengers which may then ingest the shot or bullet fragments. These sources of

lead exposure are additional to those from discarded gut piles.

The toxic effects of dietary lead on scavenging species are well documented (Golden et al. 2016; Krone 2018). Pain et al. (2019b) indicated that many species of scavenging and predatory raptors (Old and New World vultures, eagles, hawks, falcons, and owls) are susceptible to this form of lead exposure. Toxic effects in raptors range from overt mortality to abnormal behaviour (Ecke et al. 2017; Pain et al. 2019b). This form of lead exposure occurs globally and probably affects every European scavenging raptorial species (Krone 2018; Pain et al. 2019b). Exposure to ammunition-derived lead is a threat to at least nine species of raptor globally classified as threatened or near threatened with extinction (Krone 2018; Pain et al. 2019b). Apex predatory mammals such as bears (*Ursus* spp.) also scavenge the remains of large game animal kills and so may also be at risk (Legagneux et al. 2014). The voluntary use of non-lead rifle ammunition in some parts of the USA has been related to reductions in lead exposure and ingestion by raptors (Kelly et al. 2011). A similar change would probably have beneficial effects were it introduced in Europe. Preventing lead exposure and toxicosis in scavenging species has been the main justification for passing federal laws requiring the use of non-lead shot for hunting waterfowl throughout the USA (1991) and Canada (1999) (Thomas et al. 2019). In 2019, California became the first state jurisdiction to require non-lead hunting shotgun and rifle ammunition for all types of hunting throughout the state, mainly to prevent lead exposure of several raptorial species (Thomas et al. 2019). Any regulation of lead use intended to protect human health would have a simultaneous and positive effect on the health of all scavenging species, especially raptors.

## POTENTIAL EFFECTS OF AN AMENDMENT OF EUROPEAN COMMISSION REGULATIONS DEALING WITH LEAD IN MEAT

Although exposure of humans to elevated levels of dietary lead derived from ammunition has been known for decades, this exposure pathway is absent from the Alimentarius Code of Practice on reducing exposure to lead in food (Codex Alimentarius 2004) and no ML for lead in human foodstuffs derived from wild-shot game animals is set in the Codex Alimentarius General Standard for Contaminants and Toxins (Codex Alimentarius 2018). It is difficult to understand why the ammunition route of exposure to dietary lead has not been mentioned within Codex Alimentarius and why MLs have not been set for game, given that levels of exposure in frequent consumers of game meat shot with lead ammunition are high.

This important exposure route needs to be acknowledged (Taggart et al. 2011) and health-protective measures put in place. Taggart et al. (2011) noted the large discrepancy between what is legally considered to be safe in terms of lead content of European foods and what is actually present in wild game meats. EC Regulation 1881/2006 does not set MLs of lead in game meats (EC 2006). This may have been because the committees setting these levels assumed (1) that lead projectiles would remain intact, and therefore present little risk to consumers who would remove projectiles from food at the table and/or (2) that relatively few people eat wild game frequently. Recent research has shown that neither of these assumptions is correct. Firstly, because lead bullets and gunshot pellets often fragment on impact leaving behind tiny lead particles, their removal is not practical in small game animals like gamebirds (Green and Pain 2019). In large game animals like deer, shot with bullets, removal of contaminated tissue results in considerable meat wastage. After removal of large visible lead fragments in gamebirds prior to cooking, lead levels in the meat were still on average, more than an order of magnitude above the EU MLs set for the muscle of domestic livestock and poultry (Pain et al. 2010). Even meals made from gamebirds with no visible lead pellets or large fragments in the carcass often had lead concentrations considerably higher than the MLs set for other meats. Secondly, food standards generally aim to protect specific consumer groups as well as the general public. Many who frequently consume wild game are likely to be sport and subsistence hunters and their families and friends. In some countries, such as the UK and Denmark, game animals, especially gamebirds, are often given to employees of game shoots and consumed by them and their families. This represents a form of occupational exposure to lead, which, while strictly regulated in other contexts, is not in the case of game shooting. Some people may consume game for health reasons and it is widely promoted as such in the UK. Although many recipes for game are given in websites and literature promoting the consumption of game, most do not include information on removing lead-contaminated tissues. Green and Pain (2019) suggested that the numbers of people who frequently consume wild game are higher than previously assumed, perhaps about 1% of the population of the EU (c. 5 million people). Those choosing to eat game for ethical or health reasons could purchase it from retailers where a lead ML could be applied.

It might be thought that testing game meat for lead would be difficult because lead from ammunition is unevenly distributed across the tissues of wild-shot animals, so that multiple samples would need to be analysed for comparison with the ML. Additionally, if large lead fragments were present, the lead levels would be

misleadingly high. However, protocols are readily available in which large particles of ammunition are removed prior to analysis to simulate culinary practices (Pain et al. 2010).

The relevant MLs of lead of concern in European Commission Regulation (EC) 1881/2006, Setting Maximum Levels of Certain Contaminants in Foodstuffs, Annex, Section 3, Metals, Lead, are as follows:

Section 3.1.3. Meat (excluding offal) of bovine animals, sheep, pigs and poultry (0.10 mg/kg).

Section 3.1.4. Offal of bovine animals, sheep, pigs and poultry (0.50 mg/kg) (EC 2006).

We consider below the effects of amending these Sections to:

Section 3.1.3. Meat (excluding offal) of bovine animals, sheep, pigs, poultry and wild game mammals and birds (0.10 mg/kg).

Section 3.1.4. Offal of bovine animals, sheep, pigs, poultry and wild game mammals and birds (0.50 mg/kg).

This amendment would harmonise the regulations across all domestically reared and wild game animals within the EU. It would, if passed, apply to all EU nations and other countries across which wild game meat and meat products are traded commercially. Establishing an EC ML for lead in traded game meat would require means to both monitor and enforce the regulation. We propose that the same monitoring and lead testing procedures used for domestically reared meat could be applied to commercial wild game. The consumers of game meat obtained from retail outlets, such as restaurants, shops and supermarkets, would be affected by the lead content of the portions served or bought, rather than the lead content of the entire carcass. This would have implications for the scale of monitoring and testing of the meat from large game animals, but for gamebirds, the lead content of the whole animal bought or served is usually the issue.

## DISCUSSION

The exclusion of wild game from European Commission lead regulations is paradoxical given the large annual kill of game in Europe and its associated markets. The proposed amendment to harmonise lead regulations for game meat with domesticated meat would, if enacted, reduce human lead exposure from marketed game. Simultaneously, lead ingestion by scavengers would be reduced by hunters' use of non-lead ammunition.

The use of lead ammunition is now recognised as unsustainable (Kanstrup et al. 2018). The transition to use of non-lead shotgun and rifle ammunition is not hampered by the availability of lead substitutes (Thomas 2015; Thomas et al. 2016; Kanstrup and Thomas 2019), their

effectiveness (Kanstrup et al. 2016; Stokke et al. 2019) or their cost (Thomas 2015; Kanstrup and Thomas 2019). Availability of both types of ammunition is dependent upon demand, which, in turn, depends upon legislation regulating the ammunition types that may be used for hunting (Thomas 2015). In some countries, the increased human consumption of wild game reflects a preference by some for 'unfarmed' meat. This provides an opportunity for the hunting community to promote the strategy of supplying society with natural products. Setting a ML for lead in game would enhance both food safety and the sustainability of hunting.

The transition to non-toxic shot in Europe is occurring slowly and has been driven largely by concerns about lead exposure to wetland bird species which ingest spent lead shot. Lead shot use is restricted legally in 23 European countries, not all of which are EU Member States (Mateo and Kanstrup 2019). The extent of the restriction varies. In Denmark, it is illegal to possess lead shot cartridges, so all hunters and target shooters use non-lead shot. The Netherlands also bans use of lead shot for hunting and shooting. Many nations, including those banning lead shot use over wetlands, still allow lead shot to be used for non-wetland game hunting. Legislation requiring the use of non-lead rifle bullets has not been passed at the national level in any European country, and only Germany requires such ammunition to be used in several regions (Mateo and Kanstrup 2019). Regulations also restrict the use of lead ammunition in at least an additional 10 countries beyond Europe (Stroud 2015; Mateo and Kanstrup 2019), including the USA and Canada, and the use of all types of lead ammunition for hunting has been banned throughout California State (AB 711 2013).

An EU-wide restriction on the use of lead gunshot for shooting in and over wetlands was proposed by the European Chemicals Agency under REACH<sup>1</sup> at the request of the European Commission (ECHA 2018; SEAC 2018), primarily to protect waterbirds and harmonise measures taken across the EU. An ECHA Annex XV Investigation Report (ECHA/PR/18/14 2018) contended that further measures could be considered, extending the restriction to all shooting, to protect both human health and predatory and scavenging birds. At the request of the Commission, ECHA is now preparing a broader restriction proposal on the placing on the market and use of lead in ammunition used in both wetlands and other terrains (ECHA 2019).

In their Investigation Report (ECHA 2018), ECHA concluded that "the most effective manner to deal with lead is at the source, i.e. through a regulatory action on the use of lead ammunition. Other measures (setting maximum

<sup>1</sup> The EU's Regulation, Evaluation, Authorisation and Restriction of Chemicals.

lead levels in game meat) are protective for human health, but would not be protective enough for scavengers and raptors. Additionally, such a limit value would not protect hunters that consume their own meat.” While agreeing with most of these conclusions, we contend that setting MLs is needed in addition to the replacement of lead ammunition and that these measures are complementary. A ban on the use of lead ammunition would provide a harmonised level of protection to raptors and scavengers and would remove ammunition-derived lead from the meat of wild-shot game animals traded freely within the EU’s single market. However, a ban on the use of lead ammunition alone would not harmonise lead safety standards in traded domestic and game meats within the EU, nor deal with the issue of game meat that is imported into the EU. The setting of MLs for lead in game within Regulation 1881/2006 would achieve both, and additionally provide some level of health-protective compliance monitoring, were a ban on lead ammunition implemented. Achieving this goal would also alert other global jurisdictions about the need for health-protective international food safety standards.

The risks from exposure to elevated dietary lead are global, affecting subsistence communities in some of the most remote regions on earth, such as the Peruvian Amazon (Cartró-Sabaté et al. 2019), sport shooting communities in the EU and across the world, and urban consumers who purchase wild game. We therefore encourage the Joint FAO/WHO Expert Committee on Food Additives (JECFA) to include this issue on its subsequent agendas.

While international regulation requiring the replacement of lead ammunition with non-toxic alternatives is urgently needed, it is not yet in place. Should the setting of MLs precede such a ban, it would simultaneously reduce exposure of wild birds to lead ammunition. However, the setting of MLs, while in our view desirable, would not alone be sufficiently protective to wildlife and might not protect the majority of people at risk who frequently consume game. Hunters could continue using lead ammunition to kill animals for their personal consumption, thereby exposing them and their families to lead remnants in the game meat. While Table 1 indicates the numbers of animals killed annually, it does not reveal the numbers consumed only by hunters and their families. However, it is assumed that the majority of ‘high level’ or frequent consumers of game are hunters, their families and associates as illustrated by studies from the UK (LAG 2014; Green and Pain 2015) and other countries (e.g. in Italy, Ferri et al. 2017). In the UK, where game is commonly sold in supermarkets and other retail outlets, game sales have been reported to be increasing year on year for the last 5 years to 2018, with a 5% increase in 2018 (BASC 2019) as a result of game meat promotion campaigns. Nonetheless, it

remains widely assumed that across the EU the majority of game consumed in the country of origin is consumed locally by hunters and their associates. However, this obviously does not apply to traded game meat.

Despite a lack of national and international regulation setting standards for lead in game meat, there have been recent examples of trade-initiated voluntary restrictions on lead ammunition. Forest Enterprise England (FE—an executive agency of The Forestry Commission, a UK Government Department) requires their staff to use non-lead ammunition for deer and boar culling from 2016. This decision resulted from evidence that lead from lead ammunition contaminates carcasses and that FE’s marketing position could be seriously damaged if they continued to put lead-contaminated meat into the human food chain when proven alternatives exist. Forest Enterprise Scotland is also transitioning to lead-free ammunition to shoot deer and feral pigs.<sup>2</sup> Together, these forestry agencies put over 900 tonnes of venison into the human food chain annually. In 2019, the UK supermarket Waitrose, the largest national retailer of game meat, indicated that, as of the 2020/2021 season, it would sell only game meat that was killed with non-lead ammunition (Barkham 2019; Waitrose 2019). Other UK supermarkets have also indicated that they will act similarly.

## CONCLUSIONS

The risks arising from the use of lead ammunition are incurred by wild animals, humans and the environment, and there is a great need to replace lead ammunition with non-toxic alternatives. The lead contamination of game meat is an important issue in Europe because game meat is both eaten locally and traded globally. Setting MLs of lead in harmony with EC regulations on lead in meat and offal from domesticated animals is critical to complement the regulated use of lead-free ammunition and protect all people in the EU who purchase and regularly consume game meat. This change can be achieved by an amendment of existing regulations on the EC MLs of lead in meat. An EC action on MLs would also stimulate setting international standards applicable to game meats imported into the EU. MLs would also provide a monitoring mechanism for Member States to measure compliance with eventual bans on the use of lead ammunition. Substitutes for all types of lead ammunition are available and in use in various European jurisdictions and pose no economic barrier to

<sup>2</sup> <https://markavery.info/2017/12/06/forest-enterprise-nontoxic-ammunition/>.

<https://markavery.info/2018/12/20/lead-free-venison-from-scotland/>.

their use. Current initiatives of the EC on lead reduction from ammunition are highly appropriate. If realised, they portend benefits to the health of humans and wildlife species that ingest lead (Mateo et al. 2014), and the soils and waters of the environment that receive so much discharged lead each year.

**Acknowledgements** Funding for this paper was provided by the personal resources of the authors.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

## REFERENCES

- AB 711. 2013. Assembly Bill 711, Rendon. Hunting: Nonlead ammunition. Chapter 742. An act to amend Section 3004.5 of the Fish and Game Code, relating to hunting. [http://leginfo.ca.gov/faces/billNavClient.xhtml?bill\\_id=201320140AB711](http://leginfo.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB711).
- ANSES. 2018. *AVIS de l'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail relatif au "risque sanitaire lié à la consommation de gibier au regard des contaminants chimiques environnementaux (dioxines, polychlorobiphényles (PCB), cadmium et plomb)"*. Avis de l'ANSES Saisine n° 2015-SA-0109. Maisons-Alfort Cedex: ANSES. <https://www.anses.fr/fr/content/consommation-de-gibier-sauvage-agir-pour-r%C3%A9duire-les-expositions-aux-contaminants-chimiques>. Accessed Jan 2019.
- Barkham, P. 2019. Waitrose stops sales of birds shot with lead as experts call for UK ban. Studies highlight risk to health of humans and wildlife from toxic particles in meat. *The Guardian Monthly*, 29 July 2019 14.14 BST Last modified on Mon 29 July 2019 20.10 BST. <https://www.theguardian.com/business/2019/jul/29/experts-call-for-ban-on-lead-shot-as-waitrose-overhauls-sale-of-game>.
- BASC. 2018. <https://basc.org.uk/blog/uncategorized/game-sales-soar/>.
- BASC. 2019. <https://basc.org.uk/blog/press-releases/press-releases-press-releases/game-sales-bucking-the-trend/>.
- Bertolini, R., G. Zgrabic, and E. Cuffolo. 2005. Wild game meat: Products, markets, legislation and processing countries. *Veterinary Research Communications* 29: 97–100. <https://doi.org/10.1007/s11259-005-0029-x>.
- Bierkens, J., J. Buekers, M. Van Holderbeke, and R. Torfs. 2012. Health impact assessment and monetary valuation of IQ loss in pre-school children due to lead exposure through locally produced food. *Science of the Total Environment* 414: 90–97. <https://doi.org/10.1016/j.scitotenv.2011.10.048>.
- Budtz-Jørgensen, E. 2010. *An international pooled analysis for obtaining a benchmark dose for 2 environmental lead, exposure in children*. Scientific/Technical Report submitted to EFSA. [www.efsa.europa.eu](http://www.efsa.europa.eu).
- CA. 2019. <https://basc.org.uk/blog/uncategorized/game-sales-soar/>; <https://basc.org.uk/blog/press-releases/press-releases-press-releases/game-sales-bucking-the-trend/>.
- Cartró-Sabaté, M., P. Mayor, M. Orta-Martínez, and A. Rosell-Melé. 2019. Anthropogenic lead in Amazonian wildlife. *Nature Sustainability* 2: 702–709. <https://doi.org/10.1038/s41893-019-0338-7>.
- Campbell, P.M., E. Corneau, D. Nishimura, E. Teng, and D. Ekoualla. 2018. Cost–benefit analysis for a lead wheel weight phase-out in Canada. *Science of the Total Environment* 637: 79–90. <https://doi.org/10.1016/j.scitotenv.2018.04.414>.
- Codex Alimentarius. 2004. Code of Practice for the prevention and reduction of lead contamination in foods. CAC/RCP 56-2004. <http://www.codexalimentarius.org/standards/list-of-standards/>.
- Codex Alimentarius. 2018. General standard for contaminants and toxins in food and feed CXS 193-1995. Adopted in 1995. Revised in 1997, 2006, 2008, 2009. Amended in 2010, 2012, 2013, 2014, 2015, 2016, 2017, 2018. Rome: Food and Agriculture Organisation.
- Delahay, R.J., and C.J. Spray, eds. 2015. *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and minimising the risks to human and environmental health*. Oxford: Edward Grey Institute, The University of Oxford.
- DJA. 2019. Rønde: Danish Hunting Academy. [https://www.jaegerforbundet.dk/media/3015/vildt\\_kogebog\\_til\\_tryk\\_270115.pdf](https://www.jaegerforbundet.dk/media/3015/vildt_kogebog_til_tryk_270115.pdf).
- Dobrowolska, A., and M. Melosik. 2008. Bullet-derived lead in tissues of the wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*). *European Journal of Wildlife Research* 54: 231–235. <https://doi.org/10.1007/s10344-007-0134-y>.
- EC. 2006. European Commission Regulation EC 1881/2006. Setting maximum levels for certain contaminants in foodstuffs. Official Journal of the European Union EC 1881/2006 (20.12.2006), L364/365–L364/324. <http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1442063437890&uri=CELEX:32006R1881>.
- ECHA. 2011. Committee for Risk Assessment Committee (RAC) for Socio-economic Analysis (SEAC), background document to the opinions on Annex XV dossier proposing restrictions on lead and its compounds in jewellery. <http://echa.europa.eu/documents/10162/ab0bba9c-29f8-41e2-bcd9-42af796088d2>. Accessed Nov 2018.
- ECHA. 2018. A review of the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle. Annex XV. Investigation Report Version Number 1.4. Helsinki: European Chemicals Agency.
- ECHA. 2019. Request from the European Commission to the European Chemicals Agency to prepare a restriction proposal on the placing on the market and use of lead in ammunition (gunshot and bullets) and of lead in fishing tackle conforming to the requirements of Annex XV to REACH. 16 July 2019. [https://echa.europa.eu/documents/10162/13641/rest\\_lead\\_ammunition\\_COM\\_request\\_en.pdf/f607c957-807a-3b7c-07ae-01151001d939](https://echa.europa.eu/documents/10162/13641/rest_lead_ammunition_COM_request_en.pdf/f607c957-807a-3b7c-07ae-01151001d939).
- Ecke, F., N.J. Singh, J.M. Arnemo, A. Bignert, B. Helander, A.M.M. Berglund, H. Borg, C. Bröjer, et al. 2017. Sublethal lead exposure alters movement behavior in free-ranging golden eagles. *Environmental Science and Technology* 51: 5729–5736. <https://doi.org/10.1021/acs.est.6b06024>.

- European Food Safety Authority, EFSA. 2010. Scientific Opinion on Lead in Food. EFSA Panel on contaminants in the food chain (CONTAM). *EFSA Journal* 2010: 1570.
- European Food Safety Authority, EFSA. 2012. Lead dietary exposure in the European population. *EFSA Journal* 10: 28831.
- FACE. 2010. *Hunters in Europe in FACE Annual Report 2009–2010*.
- Falk, K., F. Merkel, K. Kampp, and S.E. Jamieson. 2006. Embedded lead shot and infliction rates in common eiders *Somateria mollissima* and king eiders *S. spectabilis* wintering in southwest Greenland. *Wildlife Biology* 12: 313–321.
- FAO. 2018. *Game meat. Production and trade in the ENECE region*. Rome: Food and Agricultural Organization of the United Nations.
- Ferri, M., L. Baldi, S. Cavallo, R. Pellicanò, and G. Brambilla. 2017. Wild game consumption habits among Italian shooters: Relevance for intakes of cadmium, perfluorooctanesulphonic acid, and <sup>137</sup>cesium as priority contaminants. Food Additives and Contaminants Part A. *Chemistry Analysis Control Exposure and Risk Assessment* 34: 832–841. <https://doi.org/10.1080/19440049.2017.1293303>. Epub 2017 March 8.
- Gerofke, A., E. Ulbig, A.C. Martin, C. Müller-Graf, T. Selhorst, C. Gremse, M. Spolders, H. Schaffit, et al. 2018. Lead content in wild game shot with lead or non-lead ammunition: Does state of the art consumer health protection require non-lead ammunition? *PLoS ONE* 13: e0200792. <https://doi.org/10.1371/journal.pone.0200792>.
- Gerofke, A., A. Martin, D. Schlichting, C. Gremse, and C. Müller-Graf. 2019. Heavy metals in game meat. In *Chemical hazards in foods of animal origin*, ed. F.J.M. Smulders, I.M.C.M. Rietjens, and M.D. Rose, 585–609. Wageningen: Wageningen Academic Publishers. [https://doi.org/10.3920/978-90-8686-877-3\\_24](https://doi.org/10.3920/978-90-8686-877-3_24).
- Golden, N.H., S.E. Warner, and M.J. Coffey. 2016. A review and assessment of spent lead ammunition and its exposure and effects to scavenging birds in the United States. In *Reviews of environmental contamination and toxicology*, ed. W. de Voogt, vol 237, 123–191. [https://doi.org/10.1007/978-3-319-23573-8\\_6](https://doi.org/10.1007/978-3-319-23573-8_6).
- Green, R.E., and D.J. Pain. 2012. Potential health risks to adults and children in the UK from exposure to dietary lead in gamebirds shot with lead ammunition. *Food and Chemical Toxicology* 50: 4180–4190. <https://doi.org/10.1016/j.fct.2012.08.032>.
- Green, R.E., and D.J. Pain. 2015. Risks of health effects to humans in the UK from ammunition-derived lead. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimizing the risks to human and environmental health*, eds. R.J. Delahay and C.J. Spray, 27–43. Oxford: Edward Grey Institute, The University of Oxford.
- Green, R.E., and D.J. Pain. 2019. Risks to human health from ammunition-derived lead in Europe. *Ambio* 48: 954–968. <https://doi.org/10.1007/s13280-019-01194-x>.
- Grosse, S.D., T.D. Matte, J. Schwartz, and R.J. Jackson. 2002. Economic gains resulting from the reduction in children's exposure to lead in the United States. *Environmental Health Perspectives* 110: 563–569. <https://doi.org/10.1289/ehp.02110563>.
- Guitart, R., J. Serratos, and V.G. Thomas. 2002. Lead poisoned waterfowl in Spain: A significant threat for human consumers. *Environmental Health Research* 12: 301–309. <https://doi.org/10.1080/0960312021000056410>.
- Hampton, J.O., M. Laidlaw, E. Buenz, and J.M. Arnemo. 2018. Heads in the sand: Public health and ecological risks of lead-based bullets for wildlife shooting in Australia. *Wildlife Research* 45: 287–306. <https://doi.org/10.1071/WR17180>.
- Hirschfeld, A., G. Attard, and L. Scott. 2019. Bird hunting in Europe: An analysis of bag figures and the potential impact on the conservation of threatened species. *British Birds*. [https://britishbirds.co.uk/article/bird-hunting-in-europe-an-analysis-of-](https://britishbirds.co.uk/article/bird-hunting-in-europe-an-analysis-of-bag-figures-and-the-potential-impact-on-the-conservation-of-threatened-species/)
- <https://doi.org/10.1007/s13280-019-01170-5>
- Hunt, W.G., R.T. Watson, J.L. Oaks, C.N. Parish, K.K. Burnham, R.L. Tucker, J.R. Belthoff, and G. Hart. 2009. Lead bullet fragments in venison from rifle-killed deer: Potential for human dietary exposure. *PLoS ONE* 4: e5330. <https://doi.org/10.1371/journal.pone.0005330>.
- Kanstrup, N., and V.G. Thomas. 2019. Availability and prices of non-lead gunshot cartridges in the European retail market. *Ambio* 48: 1039–1043. <https://doi.org/10.1007/s13280-019-01151-8>.
- Kanstrup, N., T.J.S. Balsby, and V.G. Thomas. 2016. Efficacy of non-lead rifle ammunition for hunting in Denmark. *European Journal of Wildlife Research* 62: 333–340. <https://doi.org/10.1007/s10344-016-1006-0>.
- Kanstrup, N., J. Swift, D.A. Stroud, and M. Lewis. 2018. Hunting with lead ammunition is not sustainable: European perspectives. *Ambio* 47: 846–857. <https://doi.org/10.1007/s13280-018-1042-y>.
- Kanstrup, N., V.G. Thomas, and A.D. Fox (eds.). 2019. Lead in hunting ammunition: Persistent problems and solutions. Special Issue. *Ambio* 48:923–1098.
- Kelly, T.R., P.H. Bloom, S.G. Torres, Y.Z. Hernandez, R.H. Poppenga, W.M. Boyce, and C.K. Johnson. 2011. Impact of the California lead ammunition ban on reducing lead exposure in golden eagles and Turkey vultures. *PLoS ONE* 6: e17656. <https://doi.org/10.1371/journal.pone.0017656>.
- Knutsen, H.K., A.-L. Brantsaeter, J. Alexander, and H.M. Meltzer. 2015. Associations between consumption of large game animals and blood lead levels in humans in Europe: The Norwegian experience. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimizing the risks to human and environmental health*, eds. R.J. Delahay and C.J. Spray, 44–50. Oxford: Edward Grey Institute, The University of Oxford.
- Krone, O. 2018. Lead poisoning in birds of prey. In *Birds of prey: Biology and conservation in the XXI century*, ed. J.H. Saratola, 251–272. Springer. [https://doi.org/10.1007/978-3-319-73745-4\\_11](https://doi.org/10.1007/978-3-319-73745-4_11).
- Krone, O., N. Kenntner, N. Ebner, C.A. Szentiks, and S. Dänicke. 2019. Comparing erosion and organ accumulation rates of lead and alternative lead-free ammunition fed to captive domestic ducks. *Ambio* 48: 1065–1071. <https://doi.org/10.1007/s13280-019-01183-0>.
- LAG. 2014. Minutes of the 11th Lead Ammunition Group (LAG) meeting: 16 April 2014: Agenda item 11.2. [http://www.leadammunitiongroup.org.uk/wp-content/uploads/2015/07/LAG\\_meeting\\_minutes\\_11\\_1600414.pdf](http://www.leadammunitiongroup.org.uk/wp-content/uploads/2015/07/LAG_meeting_minutes_11_1600414.pdf). Accessed 01 Feb 2019.
- Lanphear, B.P., R. Hornung, J. Khoury, K. Yolton, P. Baghurst, D.C. Bellinger, R.L. Canfield, K.N. Dietrich, et al. 2005. Low-level environmental lead exposure and children's intellectual function: An international pooled analysis. *Environmental Health Perspectives* 113: 894–899. <https://doi.org/10.1289/ehp.7688>.
- Legagneux, P., P. Suffice, J.-S. Messier, F. Lelievre, J.A. Tremblay, C. Maisonneuve, R. Saint-Louis, and J. Bêty. 2014. High risk of lead contamination for scavengers in an area with high moose hunting success. *PLoS ONE* 9: e111546. <https://doi.org/10.1371/journal.pone.0111546>.
- Lindboe, M., E.N. Henrichsen, H.R. Høgåsen, and A. Bernhoft. 2012. Lead concentration in meat from lead-killed moose and predicted human exposure using Monte Carlo simulation. *Food Additives and Contamination* 29: 1052–1057. <https://doi.org/10.1080/19440049.2012.680201>.
- Mateo, R., and N. Kanstrup. 2019. Regulations on lead ammunition adopted in Europe and evidence of compliance. *Ambio* 48: 989–998. <https://doi.org/10.1007/s13280-019-01170-5>.

- Mateo, R., M. Rodríguez-de la Cruz, D. Vidal, M. Raglero, and P. Camarero. 2007. Transfer of lead from shot pellets to game meat during cooking. *Science of the Total Environment* 372: 480–485. <https://doi.org/10.1016/j.scitotenv.2006.10.022>.
- Mateo, R., N. Vallverdú-Coll, A. López-Antia, M.A. Taggart, M. Martínez-Haro, R. Guitart, and M.E. Ortiz-Santaliestra. 2014. Reducing Pb poisoning in birds and Pb exposure in game meat consumers: The dual benefit of effective Pb shot regulation. *Environment International* 63: 163–168. <https://doi.org/10.1016/j.envint.2013.11.006>.
- Monahan, M., K. Boelaert, K. Jolly, S. Chan, P. Barton, and T.E. Roberts. 2015. Costs and benefits of iodine supplementation for pregnant women in a mildly to moderately iodine-deficient population: A modelling analysis. *The Lancet: Diabetes and Endocrinology* 3: 715–722. [https://doi.org/10.1016/S2213-8587\(15\)00212-0](https://doi.org/10.1016/S2213-8587(15)00212-0).
- Pain, D.J., and R.E. Green. 2019. Risks from lead ammunition: Correspondence. *Nature Sustainability*. <https://doi.org/10.1038/s41893-019-0406-z>. Published online 14 Oct 2019.
- Pain, D.J., R.L. Cromie, J. Newth, M.J. Brown, E. Crutcher, P. Hardman, L. Hurst, R. Mateo, et al. 2010. Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. *PLoS ONE*. <https://doi.org/10.1371/journal.pone.0010315>.
- Pain, D.J., I. Dickie, R.E. Green, N. Kanstrup, and R. Cromie. 2019a. Wildlife, human and environmental costs of using lead ammunition: An economic review and analysis. *Ambio* 48: 969–988. <https://doi.org/10.1007/s13280-019-01157-2>.
- Pain, D.J., R. Mateo, and R.E. Green. 2019b. Effects of lead from ammunition on birds and other wildlife: A review and update. *Ambio* 48: 935–953. <https://doi.org/10.1007/s13280-019-01159-0>.
- Pichery, C., M. Bellanger, D. Zmirou-Navier, P. Glorennec, P. Hartemann, and P. Grandjean. 2011. Childhood lead exposure in France: Benefit estimation and partial cost–benefit analysis of lead hazard control. *Environmental Health* 10: 44. <https://doi.org/10.1186/1476-069X-10-44>.
- Sampson, R.J., and A.S. Winter. 2018. Poisoned development: Assessing childhood lead exposure as a cause of crime in a birth cohort followed through adolescence. *Criminology* 56: 269–301. <https://doi.org/10.1111/1745-9125.12171>.
- SEAC. 2018. *Lead gunshot restriction in wetlands*. Committee for Socioeconomic Analysis. <https://echa.europa.eu/-/rac-adopts-13-proposals-for-harmonized-classification-and-labelling-and-seac-adopts-the-restriction-proposal-on-lead-in-gunshot>.
- Schulp, C.J.E., W. Thuiller, and P.H. Verburg. 2014. Wild food in Europe. A synthesis of knowledge and data of terrestrial wild food as an ecological service. *Ecological Economics* 105: 292–305. <https://doi.org/10.1016/j.ecolecon.2014.06.018>.
- Schwartz, J. 1994. Societal benefits of reducing lead exposure. *Environmental Research* 66: 105–124. <https://doi.org/10.1006/enrs.1994.1048>.
- Stokke, S., S. Brainerd, and J.M. Arnemo. 2017. Metal deposition of copper and lead bullets in moose harvested in Fennoscandia. *Wildlife Society Bulletin* 41: 98–106. <https://doi.org/10.1002/wsb.731>.
- Stokke, S., J.M. Arnemo, and S. Brainerd. 2019. Unleaded hunting: Are copper bullets and lead-based bullets equally effective for killing big game? *Ambio* 48: 1044–1055. <https://doi.org/10.1007/s13280-019-01171-4>.
- Stroud, D.A. 2015. Regulation of some sources of lead poisoning: A brief review. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimizing the risks to human and environmental health*, eds. R.J. Delahay and C.J. Spray, 8–26. Oxford: Edward Grey Institute, The University of Oxford.
- Taggart, M.A., M.M. Reglero, P.R. Camarero, and R. Mateo. 2011. Should legislation regarding maximum Pb and Cd levels in human food also cover large game meat? *Environment International* 37: 18–25. <https://doi.org/10.1016/j.envint.2010.06.007>.
- Thomas, V.G. 2015. Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In *Proceedings of the Oxford Lead Symposium. Lead ammunition: Understanding and minimizing the risks to human and environmental health*, eds. R.J. Delahay and C.J. Spray, 85–97. Oxford: Edward Grey Institute, The University of Oxford.
- Thomas, V.G., C. Gremse, and N. Kanstrup. 2016. Non-lead rifle hunting ammunition: Issues of availability and performance in Europe. *European Journal of Wildlife Research* 62: 633–641. <https://doi.org/10.1007/s10344-016-1044-7>.
- Thomas, V.G., N. Kanstrup, and A.D. Fox. 2019. The transition to non-lead sporting ammunition and fishing weights: Review of progress and barriers to implementation. *Ambio* 48: 925–934. <https://doi.org/10.1007/s13280-018-1132-x>.
- Trinogga, A.L., A. Courtiol, and O. Krone. 2019. Fragmentation of lead-free and lead-based hunting rifle bullets under real life hunting conditions in Germany. *Ambio* 48: 1056–1064. <https://doi.org/10.1007/s13280-019-01168-z>.
- Vogt, G., and E.A. Tysnes. 2015. *Lead in minced beef from Norwegian hunted game, Elg (Alces alces)*. Moss: Eurofins Food and Feed Testing, Norway AS.
- Waitrose. 2019 (July 31st). Animal Welfare: Lead shot pledge. [https://www.waitrose.com/home/inspiration/about\\_waitrose/the\\_waitrose\\_way/waitrose\\_animal\\_welfarecommitments.html](https://www.waitrose.com/home/inspiration/about_waitrose/the_waitrose_way/waitrose_animal_welfarecommitments.html).

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## AUTHOR BIOGRAPHIES

**Vernon G. Thomas** is a Professor Emeritus specialising in the transfer of scientific knowledge to conservation policy and law, especially in the issue of lead exposure and toxicity in wildlife and humans.

*Address:* Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, ON N1G 2W1, Canada. e-mail: vthomas@uoguelph.ca

**Deborah J. Pain** (✉) is an Honorary Professor in the School of Biological Sciences, University of East Anglia, and an Honorary Research Fellow in the Department of Zoology, University of Cambridge. Her research interests include diagnosing the causes of declines in threatened bird species and developing and testing practical and policy solutions to reverse them. She has an interest in ecotoxicology, particularly lead poisoning from ammunition, on which she has worked since the early 1980s.

*Address:* Department of Zoology, University of Cambridge, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK. e-mail: pain.debbie@gmail.com

**Niels Kanstrup** is a Biologist, Scientist and Hunter, and is an Adjunct Senior Scientist at Aarhus University, Department of Bioscience. He has worked with the Danish Hunters' Association, been the President of the CIC Migratory Bird Commission and is a Member of the AEW Technical Committee. Throughout his career, he has focused on the sustainability of hunting, particularly the issue of lead in hunting ammunition.

*Address:* Department of Bioscience, Aarhus University, Grenåvej 14, Rønde, 8410 Aarhus, Denmark. e-mail: nk@bios.au.dk

**Rhys E. Green** is an Honorary Professor of Conservation Science in the Department of Zoology at the University of Cambridge. His research interests include the effects of human activities on population size and demographic rates of wild species. He uses statistical and simulation models fitted to data on these effects to devise

practical interventions that land managers can use to reduce negative effects on wild species so as to improve their conservation status.

*Address:* Department of Zoology, University of Cambridge, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK.  
e-mail: [reg29@cam.ac.uk](mailto:reg29@cam.ac.uk)

# PAPER 18

Kanstrup N, Balsby TJS (2018). Plastic litter from shotgun ammunition on Danish coastlines - Amounts and provenance. *Environmental Pollution* 237:601-610  
doi:10.1016/j.envpol.2018.02.087

## RIGHTS:



Plastic litter from shotgun ammunition on Danish coastlines – Amounts and provenance

Author: Niels Kanstrup, Thorsten J.S. Balsby

Publication: *Environmental Pollution*

Publisher: Elsevier

Date: June 2018

© 2018 Elsevier Ltd. All rights reserved.

Please note that, as the author of this Elsevier article, you retain the right to include it in a thesis or dissertation, provided it is not published commercially. Permission is not required, but please ensure that you reference the journal as the original source. For more information on this and on your other retained rights, please visit: <https://www.elsevier.com/about/our-business/policies/copyright#Author-rights>

BACK

CLOSE WINDOW

### AUTHORS' CONTRIBUTIONS

Kanstrup N conceptualized and managed the project, processed and analyzed data, drafted, revised and finalized the manuscript.

Balsby TJS undertook statistical data processing, analyzed data, edited the manuscript and approved the final manuscript.

Confirmed, April 2021

Niels Kanstrup

Thorsten Johannes Skovbjerg Balsby



# Plastic litter from shotgun ammunition on Danish coastlines – Amounts and provenance<sup>☆</sup>

Niels Kanstrup <sup>a, b, \*</sup>, Thorsten J.S. Balsby <sup>a</sup>

<sup>a</sup> Department of Bioscience, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark

<sup>b</sup> Danish Academy of Hunting, Denmark

## ARTICLE INFO

### Article history:

Received 11 January 2018

Received in revised form

23 February 2018

Accepted 27 February 2018

### Key words:

Ammunition

Hunting

Litter

Marine

Plastic

Sustainability

## ABSTRACT

Plastic litter in the marine environment is a major global issue. Discarded plastic shotgun ammunition shells and discharged wads are an unwelcome addition and feature among the top ten litter items found on reference beaches in Denmark.

To understand this problem, its scale and origins, collections were made by volunteers along Danish coastal shorelines. In all 3669 plastic ammunition items were collected at 68 sites along 44.6 km of shoreline. The collected items were scored for characteristic variables such as gauge and length, shot type, and the legibility of text, the erosion, and the presence of metallic components. Scores for characteristics were related to the site, area, and season and possible influences discussed.

The prevalence of collected plastic shotgun litter ranges from zero to 41 items per 100 m with an average of 3.7 items per 100 m. Most ammunition litter on Danish coasts originates from hunting on Danish coastal waterbodies, but a small amount may come from further afield. North Sea coasts are the most distinctive suggesting the possible contribution of long distance drift as well as the likelihood that such litter can persist in marine habitats for decades.

The pathway from initial discard to eventual wash-up and collection depends on the physical properties of plastic components, marine tides and currents, coastal topography and shoreline vegetation.

Judging from the disintegration of the cartridge and the wear and decomposition of components, we conclude that there is a substantial supply of polluting plastic ammunition materials that has and will accumulate. These plastic items pose a hazard to marine ecosystems and wash up on coasts for many years to come. We recommend that responsible managers, hunters and ammunition manufacturers will take action now to reduce the problem and, thereby, protect ecosystems, wildlife and the sustainability of hunting.

© 2018 Elsevier Ltd. All rights reserved.

## 1. Introduction

Marine pollution by plastic litter is a major global environmental issue. Macro plastic items are a cosmetic and aesthetic problem that causes serious harm to marine animals that try to eat them (Lusher et al. 2013; Wilcox et al. 2015) or which become entangled by them (Laist 1997). Micro plastic particles or beads created by the decomposition of macro plastic items are ingested by small animals and filter-feeders, then accumulate up food chains and create hazards for ecosystems, other wildlife and human

health. The issue is more thoroughly described in Derraik 2002, Thevenon et al. 2014, UNEP 2016, and Lamb et al. 2018.

Shotgun ammunition cartridges used for hunting are an additional unwelcome source of plastic litter in the marine environment. Empty cartridge shells cases (in the following called shells) may not be picked up by the hunter who fired them, or they may be irretrievably ejected into the sea on firing and not recovered. Plastic wads that serve to separate the propellant from the shot load, are invariably lost down-range when a shot is fired. Uncollected plastic shells and wads are distinct but avoidable sources of macro plastic pollution that in the later stages of decomposition break down into harmful micro plastic particles or beads (Andrady 2011).

Hunting in modern society is a valued recreational activity that benefits from broadly favorable but not uncritical political and public perceptions. Any avoidable negative impact on the natural

<sup>☆</sup> This paper has been recommended for acceptance by Maria Cristina Fossi.

\* Corresponding author. Department of Bioscience, Aarhus University, Grenåvej 14, 8410 Rønde, Denmark.

E-mail addresses: [nk@bios.au.dk](mailto:nk@bios.au.dk) (N. Kanstrup), [thba@bios.au.dk](mailto:thba@bios.au.dk) (T.J.S. Balsby).

environment, ecosystems and human health, risks undermining the perception of hunting and threatens its long-term sustainability.

Denmark's widespread coastal habitats located centrally on the Western European migratory bird flyway support a long-established tradition of waterbird hunting. The hunting takes place on open waterbodies from specially designed small boats as well as from adjacent private and state lands. Residents in Denmark enjoy a free right to hunt on such open salt and brackish waters known as the "the fishery territory". The total annual harvest of waterbirds in Denmark is approximately 800,000 (Christensen et al. 2017). Some 150,000<sup>1</sup> of these are taken during the free hunting on coastal salt and brackish water bodies. Based on the annual harvest and an estimated number of cartridges fired per bagged bird (estimated here at four<sup>2</sup>) we estimate a total annual discharge of some 600,000 cartridges while hunting in Danish coastal salt and brackish water bodies.

Denmark banned the use of lead shot for all hunting in coastal ecosystems in 1993, and steel shot is now the commonly preferred alternative.

A shotgun cartridge consists of a plastic cartridge shell containing the powder and the shot load. The cartridge's brand name and some specification details (cartridge type, gauge, shot size and shot type if not lead) are usually printed on the shell. When lost to the environment and subjected to abrasion the printed information becomes increasingly illegible and disappears over time. Cartridges that have lost all such marking cannot be identified and the only recordable indicator is its gauge and length. In some instances head marks may be stamped on the shell. The cartridge shell has a metallic base, commonly known as "the brass" which is, notwithstanding, mostly made from iron. A metallic primer is situated at the centre of the brass's baseplate. The gradual loss of printing and metal features provides clues to the length of time a cartridge shell has been subjected to abrasion and wear. The powder and shot are separated by a wad (also known as a shot cup). Wads come in different designs but they are insufficiently distinctive to enable them to be linked to a brand or type of cartridge. Wads have no labelling. Their gauge can however be recorded and the wad construction is indicative of the shot material used.

The predominant plastic material used for production of shells and wads used for hunting in wetlands is low density polyethylene (LDPE). This may show signs of abrasion but takes long time to break down completely. The shell plastic is colored, mostly black, red, blue or green, but colors cannot be used for identification. Wads are usually white/greyish.

Responsible hunters in normal circumstances take care to collect their empty cartridges after shooting and later discard them.

However, empty cartridges may sometimes be lost into the environment. The use of semiautomatic and pump action guns may accentuate this loss. The wads are invariably dispersed with the shot load and lost.

Systematic analysis of the plastic litter from hunting ammunition collected by volunteers in coastal habitats sheds light on its scale and provenance, and can help inform programs to counteract further dispersal. It may also contribute to wider understanding of movements and turnover of other plastic waste in marine habitats and ecosystems.

The principal objective of this study is to evaluate the amount and provenance of plastic waste from hunting ammunition washing up on Danish beaches. For this, we use litter characteristics (*inter alia* quantity, shot type, and wear) and relate this to site and season. We analyse possible movements of the litter types, and, finally, present some management perspectives for reduction of this pollution.

## 2. Materials and methods

### 2.1. Collection and registration of litter

From 2010 to 2017, volunteers associated with the Danish Nature Protection Society, as well as local clubs and individuals, collected shotgun ammunition litter from 68 sites along 44.9 km of Danish coastline. From 2010 to 2014 the collection was limited to two stretches of coast in the East Kattegat (Begrtrup Bay and Ebeltoft Bay). In 2015 the collection was extended to 66 additional sites (Fig. 1). Based on the adjacent waterbodies we grouped each site as belonging to one of six areas with at least three collections within each area, except one with only one site (Roskilde).

For each collection, wads and shells found were retrieved and in most cases collection date, collector's name, site name, stretch length, and total number of plastic items in each batch was recorded. Items were registered individually and the following data, so far as possible, were recorded:

**Shells:** their gauge, brand, type, other text (labelling), text wear index (TW) (group 1 to 5, see caption Fig. 3), brass erosion index (BE) (group 1 to 5, see caption Fig. 3), presence of plastic bottom, and presence of primer. If possible, cartridges were categorised as "steel shot", "lead shot", "bismuth" or "unknown" depending on printed text, if present, or other indicative characteristics.

**Wads:** their gauge and design for use with "steel shot" or "lead shot" based on three distinguishing characteristics: volume of the shot cup, the construction and splitting of the cup wall, and design of the buffer forming the wad base. Remains of rusty pellets embedded in the wad cup base could also sometimes confirm a steel shot categorisation. Wads for bismuth or other soft shot types are the same as wads for lead shot, but due to *inter alia* price we expect that the use of bismuth for coastal hunting is negligible.

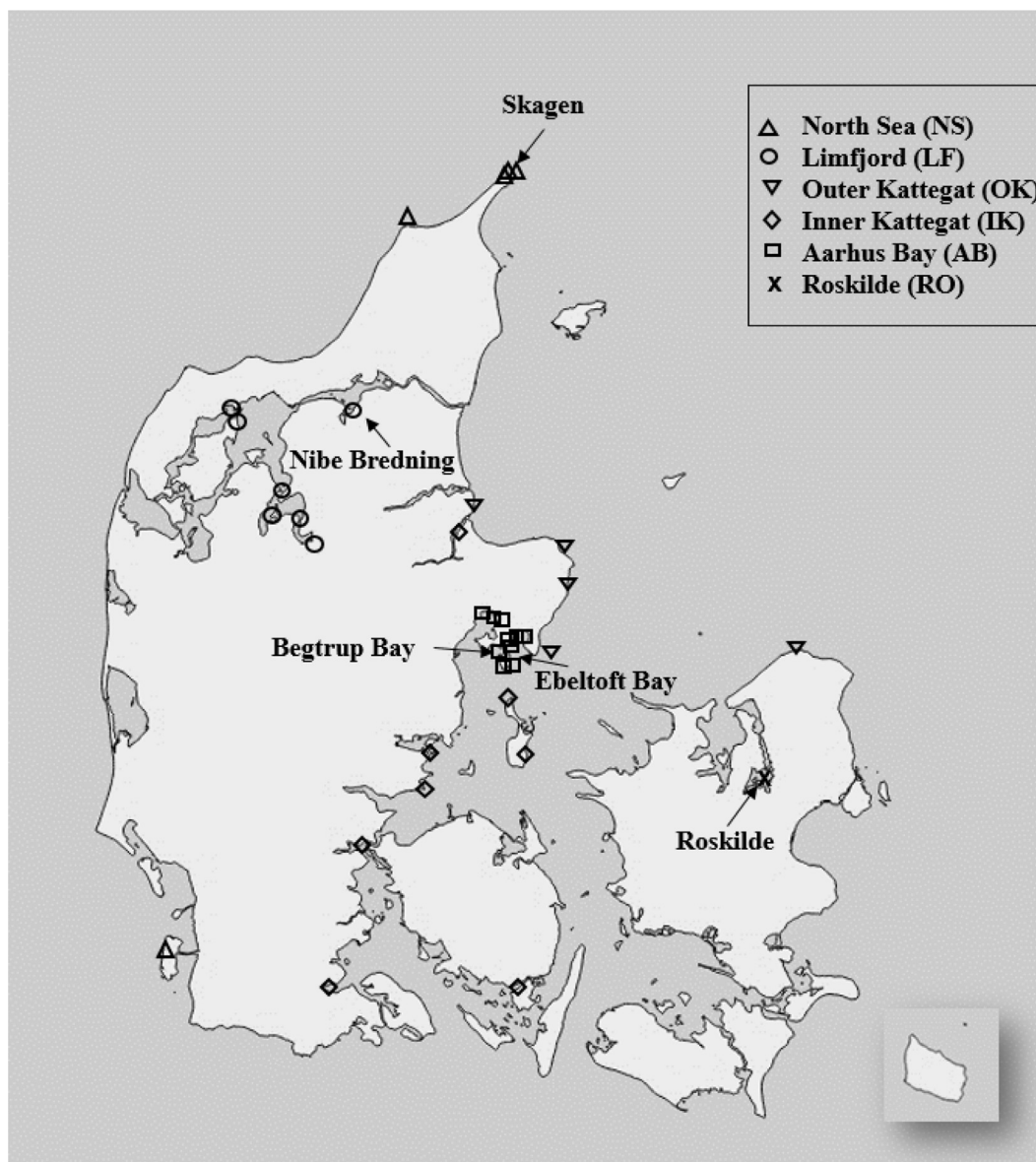
One single project staff (leading author Niels Kanstrup) carried out all registrations and categorisations centrally.

### 2.2. Metrics of litter samples and cartridge

The weight and volume of samples of empty cartridge shells and wads was measured, and mean weights and specific gravity calculated. In addition, the weight of components (shell plastic, shell metal, wad plastic, powder, and shot) of unfired standard cartridges was measured.

<sup>1</sup> The Danish waterbird wing survey programme was used to make this estimation after consultation with Aarhus University, Bioscience, Kalø. This programme suggests that some 10% of the dabbling duck and goose harvest is taken under hunting forms that relate to the free hunting right at sea. To this, we added the total harvest of all diving ducks and coot. On this background we suggest an overall estimation of 150,000 birds taken annually under the regime of the free hunting right on the Danish fishery territory.

<sup>2</sup> Noer et al. 1998 found for Danish duck hunters an average cartridge consumption at 3.6 per bagged duck (total 240 shots fired). The same study found for Eider Duck hunting a cartridge consumption at 2.5 per bagged bird (total 141 shots fired). However, this did not include shots to kill wounded birds. Noer et al. 2001 found for two groups of Danish duck hunters (dusk hunting) a cartridge consumption at 2.63 resp. 4.05 per harvested bird (total 390 shots fired). For goose hunting in Denmark the study referred to much higher levels of cartridge consumption, up to 8.0 (1996 estimates) and 8.7 (1997 estimates) depending on hunting form (shooting crossing birds or decoying). On this background and based on common practical experience we suggest a level of 4 shots per harvested birds as an average of the many different hunting forms that relate to the free hunting right on the Danish fishery territory.



**Fig. 1.** Collection sites. Sites were organised in six different “areas” marked with symbols. Names with arrows refer to sites mentioned in the text.

### 2.3. Controlled wear and corrosion experiment

To assess the rates of wear of text and corrosion of the brass a sample of 10 empty steel shot cartridges were suspended (anchored on ropes and lines) 25 m from the shoreline at 1 m depth in Begtrup Bay (approx. 2% salinity). This experiment started in 2015 and was extended in October 2016 by tethering 80 empty cartridges of five assorted steel and lead shot cartridge brands in the same locality. The amounts of wear and erosion were evaluated by frequent inspection, measurement of weights and observation of erosion until January 2018.

### 2.4. Statistics

We used a generalised linear model to test if the measures of wear and erosion of shells and the characteristics for the shells differed between the six areas. Measures of wear and erosion used an ordinal scale with up to five points for each, and hence we used a multinomial or a binomial distribution. We used least square

means to conduct *post hoc* pairwise tests.

To determine whether occurrence of litter showed a periodic pattern and whether such pattern differed between cartridge shells compared to wads we recorded occurrence of litter per 100 m in January–March, April–June, and July–December. We used this division of the year as it provided a reasonable number of observations in each period. As the percentage was calculated for each site, we did not need to correct for site effects, but “area” was included as a random variable. We used a mixed model to test this. In addition, we used a random effects model to test if the seasonal variance in occurrence differed for shells and wads. All statistical analyses were conducted in SAS 9.4 (SASInstitute, Cary, NC) using *proc genmod* and *proc glm*.

## 3. Results

### 3.1. Density of shotgun plastic litter

The study involved 68 sites where systematic collections were

made on shorelines with lengths between approximately 100 and 7000 m (total 44.6 km). In all 3669 pieces of plastic shotgun cartridge litter (2153 shells and 1516 wads) were collected. In some instances, collection was repeated on the same stretch. When repeated collections were excluded, the total number of “first time” collections were 53 covering a total stretch of 39.5 km producing 1468 plastic items or an average of 3.7 items/100 m coastline. Fig. 2 shows the distribution of densities on unrepeated (“first time”) collections.

### 3.2. Characteristics of litter

Most shells were 12 gauge (97.2%) and the remainder (2.8%) were of smaller gauge (16, 20 or 36 gauge). 90.0% of the shells were 70 mm chamber length. 3.3% were shorter (65 or 67 mm) and 6.7% were longer (75, 76 or 89 mm).

The majority (81.5%) of the shells showed a high degree of wear (TW groups 4 & 5). Surface text could be fully or partially distinguished on the remaining 18.5% (TW groups 1 to 3) (Fig. 3a). The

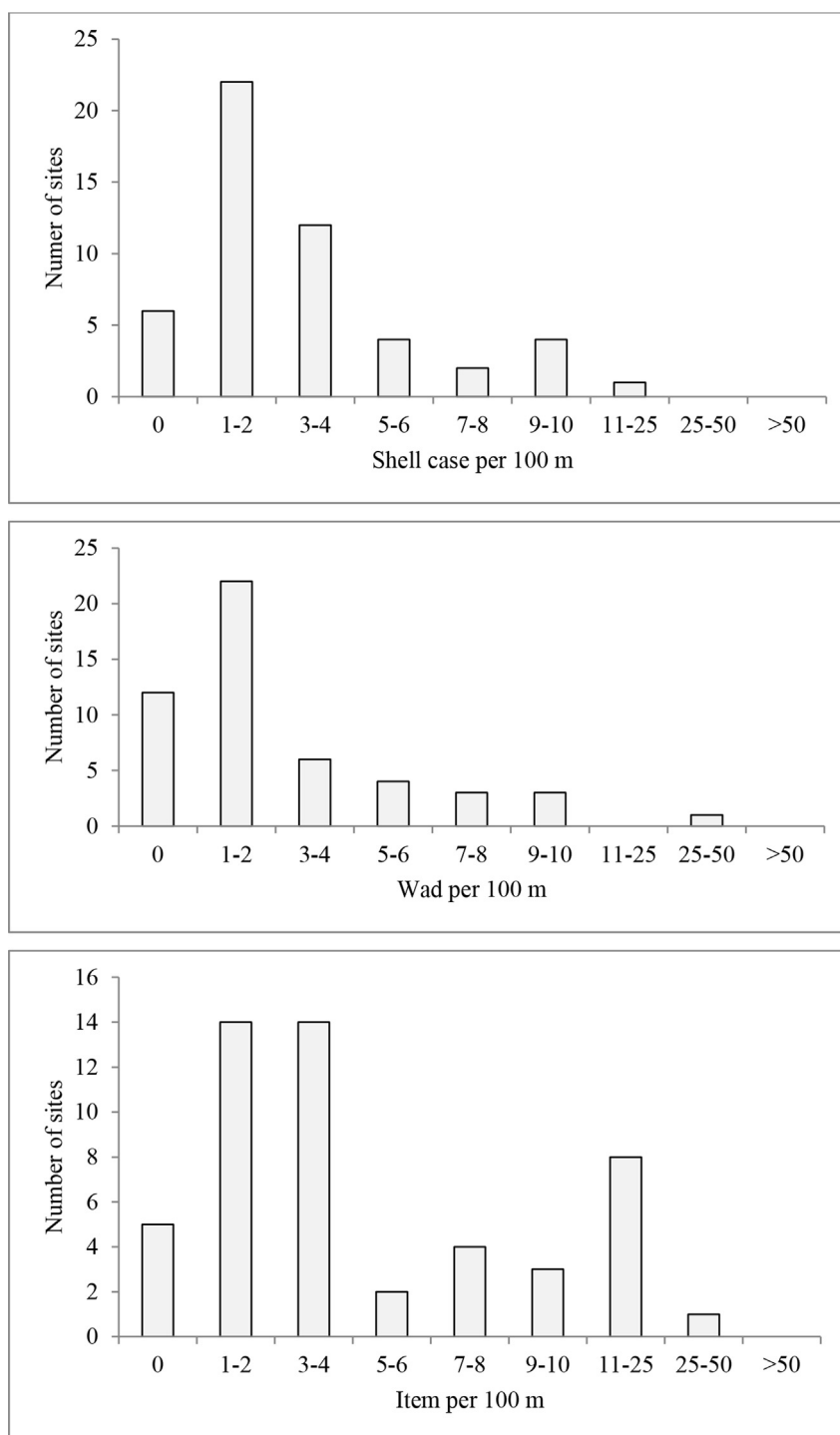
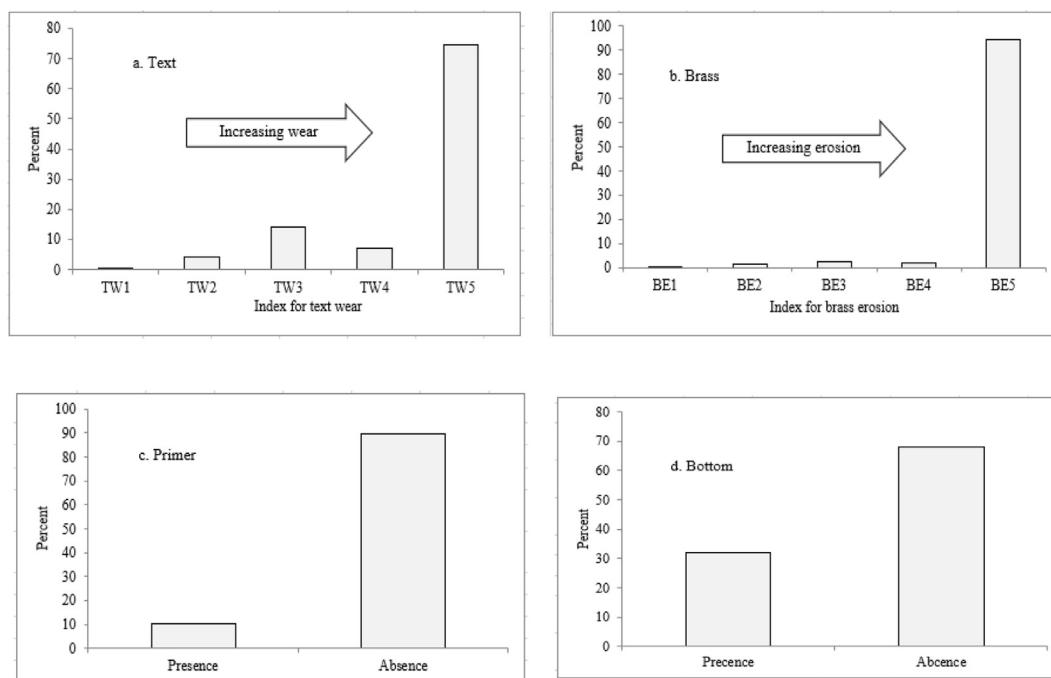


Fig. 2. Number of sites with different densities (number per 100 m), total 1468 items (only “first time” collection sites).



**Fig. 3.** Distributions of measures of: a. text wear (TW1 = intact text, TW5 = no text), b. brass erosion (BE1 = intact brass, BE5 = no brass), c. Presence/absence of primer, d. Presence/absence of bottom.

brass had completely disappeared (BE5) from 94.1% of the shells (Fig. 3b). Correspondingly, the primer was absent in 89.7% (Fig. 3c). The bottom of the shell was absent in 68.5% (Fig. 3d). Among all shells cases, 8.6% were categorised as “steel” and 13.8% as “lead”, whereas 77.6% were indeterminate (“unknown”). One single shell could be determined to originate from a bismuth shot cartridge.

The majority (99.1%) of wads were from gauge 12 cartridges, with gauges 16, 20 and 28 (and one gauge 10) making up the remainder. Among the wads, 82.8% were judged to originate from steel shot cartridges and 17.2% from lead shot cartridges. The abrasive marine environment also causes wear to wads, but wear characteristics for wads showed minor variation so further analysis was not done.

### 3.3. Area differences

The four measures of wear and corrosion (text, brass, primer and bottom) and the three measures of cartridge type (gauge, length and shot type) differed between areas in most shells (Table 1).

The North Sea area's samples differed from all the other areas showing greater text wear, fewer bottoms present and a higher proportion of long or normal length cartridges (see supplementary material, Table S1). For text wear, presence of primer and shot type

the *post hoc* pairwise comparisons showed significant differences among the four other areas (i.e. excluding the North Sea) (Table S1). For text wear, Outer Kattegat (OK) showed more erosion than other areas (except North Sea (NS)), and Aarhus Bay (AB) showed less text wear than other areas. Presence of primers differed between all areas except for North Sea. Shells from the areas Aarhus Bay (AB) and Inner Kattegat (IK) had more shells with retained primers than Limfjord (LF) and Outer Kattegat (OK). Limfjord (LF) had the lowest presence of primers. Most shot-type observations from shells were classified as “unknown”, hence this material is less conclusive.

From the collected wads, the average steel to lead shot ratio was 85:15. The North Sea (NS) sample showed the lowest steel to lead ratio (Fig. 4) but this was not statistically significant (General linear model  $\chi^2_3 = 1.83$ ,  $p = 0.608$ ). 99.1% of the wads originated from gauge 12 cartridges.

### 3.4. Seasonal pattern

The percentage of wads relative to the total number of collected items (i.e. wads and shells together) per 100 m differed between seasons (General linear model  $F_{3,69} = 8.43$ ,  $p < 0.0002$ ). Post hoc pairwise comparisons showed that the percentage of wads found in January–March was significantly higher than found in other periods (least square means  $p \leq 0.0032$ ). The percentage of wads differed significantly between the three seasons (Fig. 5, Mixed model  $F_{2,45} = 5.60$ ,  $p = 0.0067$ ). The period from July–December showed significantly lower percentages than the periods January–March and April–June (Least means square  $t_{45} \geq 2.18$ ,  $p \leq 0.035$ ).

The variance in the number of shells and wads per 100 m differed between the three seasons (Random effects mixed model, wads:  $F_{2,59} = 5.58$ ,  $p = 0.006$ ; shells:  $F_{2,59} = 3.61$ ,  $p = 0.033$ ).

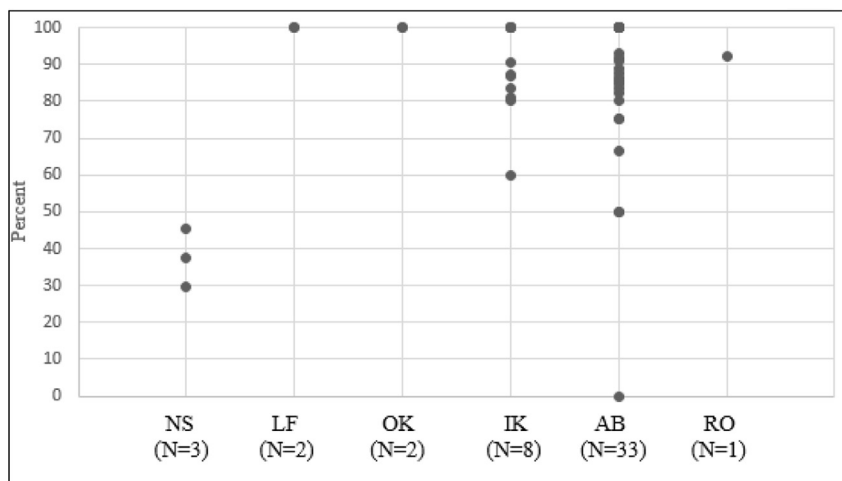
### 3.5. Shot sizes

The shot size could be determined for 312 (17%) of all collected

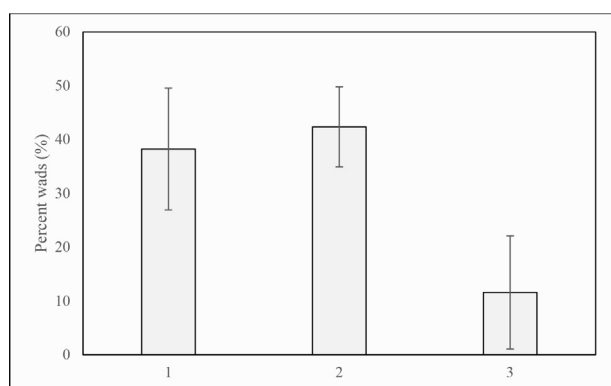
**Table 1**

Test of difference between the areas with various measures of corrosion of shotgun shells. We used a generalised linear model with a multinomial or binomial distribution to test differences between areas.

	df	Chi-square	p
Text wear	4	355.9	<0.0001
Brass erosion	4	87.1	<0.0001
Primer (present/absent)	4	199.4	<0.0001
Bottom (present/absent)	4	102.0	<0.0001
Shot type (Lead, steel or unknown)	4	236.6	<0.0001
Gauge (normal or different)	4	16.1	0.0028
Length (short, normal or long)	4	37.4	<0.0001



**Fig. 4.** Percentage of wads originating from steel shot cartridges showed per collection site distributed on areas. Sites with zero wads are not included. North Sea (NS) has the lowest steel shot percentage, but the difference is not statistically significant ( $p = 0.608$ ).



**Fig. 5.** Percentage of wads relative to total number of items per 100 m distributed on the three annual seasons, 1 = January–March, 2 = April–June, 3 = July–December. Estimates are least mean squares.

shells. 39.7% originated from US shot size 3 (3.5 mm) and 77.8% from cartridges with shot size 2–5 (3.75–3 mm).

### 3.6. Metrics of shotgun ammunition and litter

Average metrics of the main components of a selection of standard 12 gauge shotgun cartridges for chamber length 70 mm is shown in Table 2. Metrics vary with gauge and chamber length, solidity of wad etc. Magnum loads (e.g. gauge 12/76) may contain up to 30% more powder and shot. However, the weight of the plastic components was not significantly greater.

**Table 2**

Basic metric data for cartridge components of standard shotgun ammunition gauge 12/70 with a 30 g steel shot load.

		Weight (g)	Volume (cm <sup>3</sup> )	Spec. gravity (g/cm <sup>3</sup> )
Shell	Plastic	4.3	4.6	0.93
	Metal	3.3		
Shell total		7.6	5.1	1.49
Wad (steel shot)	Plastic	3.1	3.3	0.94
	Powder	3.1		
	Shot load	30		
Cartridge		43.8		

Given the estimated annual consumption of 600,000 cartridges, these data indicated an annual dispersal of plastic wads during the free hunting in coastal habitats of some 1860 kg. The total amount of plastic from shells in the equivalent number of shotgun cartridges would be 2580 kg of which an unknown but not negligible proportion was inadvertently lost in the natural environment during hunting.

### 3.7. Wear and corrosion

Fig. 6 shows the weight loss of samples of shotgun shells tethered in a typical Danish marine environment (Begtrup Bay), a *Littorina* coast (salinity 2%). The samples showed a weight loss that was not linear over time. For most types of cartridge including both steel and lead shells, the weight reduced by some 50% to approximately 4–5 g over 460 days. At this weight the shell began to become positively buoyant and may float. The measurements were supplemented by a visual inspection of the wear and corrosion. Shells lost text after 47 to 113 days depending on brand. After 460 days all brass metal parts had disappeared on all five brands. However, the primer was still left in four of the five brands. Based on weight loss trends, we estimated that shells would achieve a weight to refloat after approximately 18 months of exposure.

## 4. Discussion

The dispersal pathway from the location of initial wad discharge and empty cartridge case discard on a given hunting or shooting day to the place where they eventually come to rest (Fig. 7) is multifactorial and needs consideration. Depending on weather conditions (waves) discarded shells may float for a short while, but when swamped by waves they sink and will thereafter be embedded in sediment or driven by bottom and tidal currents. The wads are positively buoyant and remain floating at the surface. The sunken shells, if not filled with silt and embedded in marine sediments, refloat once the metal parts (brass and primer) have corroded sufficiently (in our study after approximately 18 months). The plastic litter's ability to float seems to be of some importance to the eventual location of wash-up. Of the 2153 shells collected during the study 2027 (94.1%) had lost their metal components (brass and primer). This points to the possibility that the brass had corroded away sufficiently for the shell to refloat. Shells retaining a small amount of metal and having a specific gravity greater than 1 g/cm<sup>3</sup>

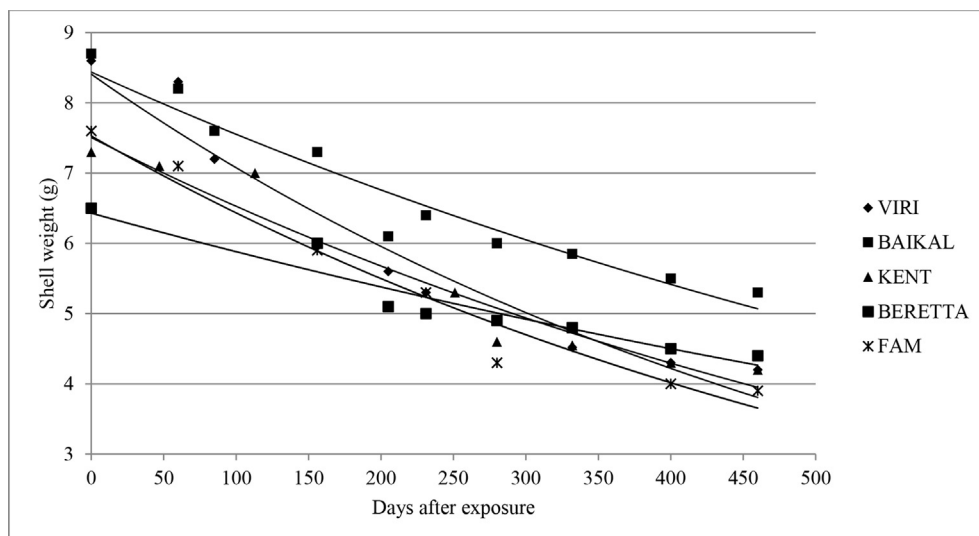


Fig. 6. Weight of samples of shotgun shells from five brands tethered in Begtrup Bay from October 2016 to January 2018.

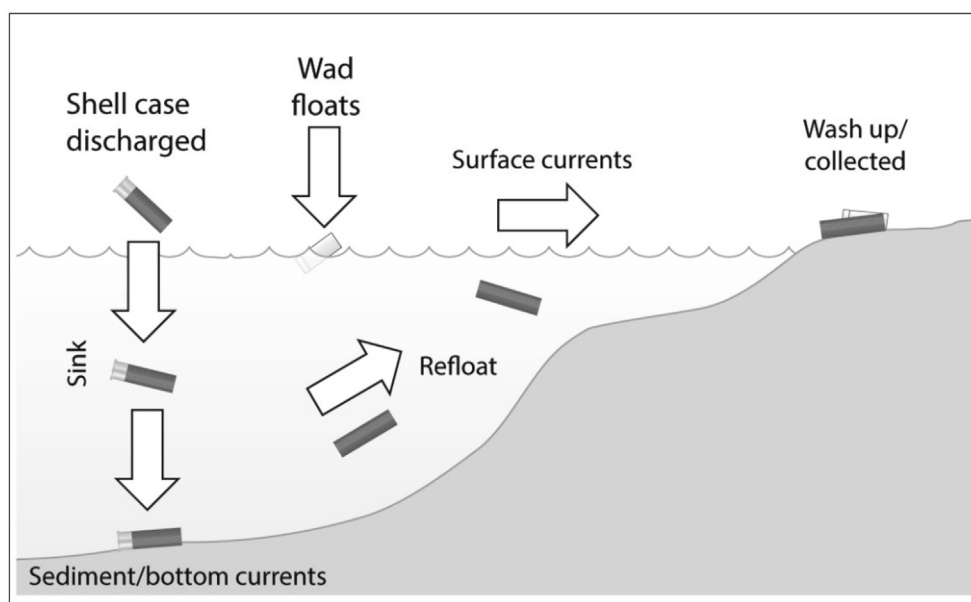


Fig. 7. The flow of ammunition litter when dispersed during hunting in coastal areas. Shells may be retrieved by the hunter and disposed of with household garbage.

were unlikely to wash up. Floating litter follows surface currents dependent on wind conditions, tide etc. The likelihood of litter washing up on a given shoreline depends on multiple vectors and influences including near-coast currents, wind, tide, and shoreline topography and vegetation. Washed-up litter may become embedded in the shore sediment or hidden by saltmarsh vegetation, dead seaweed and other detritus. The likelihood of discovery and ultimate collection depends on intensity of search, experience of volunteer collectors, and the intrinsic visibility of the litter. Colorful litter (typically shells) are more easily found than relatively small white/grey items (typically wads). This may explain why the number of collected shells was greater than the number of wads, although the opposite could be expected as shells sink and hunters cannot retrieve the wads. Another possible explanation is that some of especially the older shells in our sample may originate from a period when shells were made from plastic whilst the wads were made from felt.

#### 4.1. Amounts

On some of the investigated coastal stretches, we found up to 41 pieces of shotgun plastic litter per 100 m, which is almost one per every second meter. The average density was 3.7 items per 100 m (total 37.8 km). Given the number and total length of investigated coast stretches we consider that this amount of pollution substantial. Strand et al. 2016 place cartridge shells and wads (OSPAR Code 43 = “shotgun cartridges”) among the top ten items in the North Sea/Skagerrak and the Baltic Sea/Inner Danish waters, based on 2015-data from the Danish reference beaches.

Overall the sites differed significantly in number of shells and wads per 100 m and on some stretches (total 4.9 km of the 44.9 km) we found no ammunition litter. A basic condition for ammunition litter wash-up is its presence in the nearby waterbodies, as demonstrated by research and monitoring programs and campaigns (McCord, pers. comm., Rame Peninsular Beach Care 2017,

Strand et al. 2016). However, there were regional differences, as certain coastal waters are not exposed to the direct disposal of ammunition litter from local hunting. This seemed to be the case for the Danish North Sea coast, where hunting is far from intensive. Nonetheless, high densities of hunting litter were found there (Skagen). It is likely that the origin of it is not local but connected to movements of North Sea and Atlantic currents.

Similar to this Danish study, Shetland colleagues in 2017 collected a sample of 84 pieces of shotgun ammunition litter on a 70 m stretch at Burwick located on the west coast of mainland Shetland. This was a higher density than found at any Danish site. Shetland colleagues suggested that the hunting tradition at Shetland does not indicate local discharge and that the litter may have an Atlantic, perhaps transatlantic origin. The high density found on this shoreline was probably due to onshore currents and prevailing winds that increased the wash-up of plastic litter of all kinds including that from ammunition (McCord, pers. comm.).

Marine, tidal and estuarine currents influence the likelihood of litter washing up. The high density of ammunition litter collected at Skagen may have been due to local sea currents at the confluence of the Skagerrak and Kattegat (just as coastal circulations were suspected to have contributed to the findings at Burwick, Shetland). This rationale is supported by Strand et al. 2015 who demonstrated that the general circulation of the currents in the North Sea and Skagerrak, which includes the Atlantic Gulf Stream waters, passes Shetland and continues along the Norwegian coast.

Shoreline profile and topography combine with tidal movements and the saltmarsh vegetation to filter and retain litter and influence the degree to which plastic items remain on the shoreline. Cartridge shells and wads are normally found with other (plastic) litter in wash-up zones with short vegetation, and/or along the tideline fringe where there is dead algal, seaweed and other detritus.

The orientation of the shoreline to prevailing wind direction plays a role. Forty seven percent of the total cartridge litter sample was collected in Begtrup Bay. This was probably due not only to the relatively long and intensive collection effort, but also to the shoreline conditions which favoured wash-up. This shore is located on the east of Aarhus Bay where hunting from boats is notably intensive and the dispersal of ammunition litter correspondingly high. The prevailing wind direction is onshore from the west and the shoreline is thereby exposed to wash-up. Begtrup Bay has a steep and narrow intertidal zone with a characteristic intermittent fringing of seaweeds and short, stiff retentive vegetation. At Nibe Bredning on the other hand, where waterbird hunting from boats and adjacent land is similarly intensive, very few items of plastic ammunition litter were found. A possible cause may be that the shoreline here is often covered by dead and stranded eel grass (*Zostera marina*) that could hide any stranded litter items.

Some of the above-mentioned influences may be seasonal, due for example to different tidal and estuarine currents as well as wind conditions. There was a clear seasonal difference in the wash-up of cartridge shells compared to wads. This was probably due to different physical characteristics affecting their dispersal. Shells sink and get embedded in sediment or follow bottom currents until sufficient corrosion of the brass makes them buoyant again, whereas the wads float and disperse more quickly in surface currents.

#### 4.2. Provenance

A central question is the extent to which ammunition litter comes from local hunting activities and there are several ways to look at this.

We have estimated that the annual dispersal of plastic wads

into Danish coastal waters is some 600,000 pieces. Since wads float they are likely to wash up on shorelines nearby in Denmark or in neighbouring countries depending on dispersal site and sea currents. If all 600,000 were to wash up on Danish shorelines it would amount to some 7 wads per 100 m of coastline, given a total coast length of approximately 8500 km (Geodætisk Institut, 2017). This is far greater than the average density of wads collected during this study (1.7 wads per 100 m). This comparison must also take account of the likelihood that wads will have accumulated over multiple years and are not the product of the immediately preceding or current hunting seasons. Although this is, admittedly, a very rough estimation the potential dispersal of wads in terms of quantity is consistent with the collected wads to originate from hunting in Denmark. It should also be noted that 82.8% of the collected wads were estimated to have come from steel shot cartridges. This supports the likelihood that the main source is hunting in the Danish territory, as neighbouring countries have not regulated against lead shot for open sea hunting.

Tracing the origins of cartridge shells was more complex. It was possible to determine the brands and types of some shells collected. These were consistent with their source being Danish as the brands are typical for types that have been marketed in Denmark in recent decades. Additionally, 97.2% of cartridge cases were 12 gauge, which corresponds with experience that hunters are unlikely to use gauges smaller than 12 gauge for coastal hunting (Simonsen, pers. comm.). Shot sizes found in the collected material were those commonly used for coastal hunting in Denmark.

Of the total sample of cartridge shells (2153) the shot material type could be ascertained in only 23%, of which 9% were steel and 14% were lead. These figures were consistent with the view that most shells stem from steel shot cartridges shells dispersed in Denmark, if combined with a contribution of lead shot shells dispersed before their prohibition in 1993 and some illegal use thereafter. The likelihood of some continued illegal use was indicated by the fact that a considerable number of the identified lead shot shells had readable printing similar to those with less than one year's corrosion as indicated by our controlled trial (including the same brands, e.g. Baikal). However, the picture was complicated by several changes related to both the types of ink used as well as the printing techniques used by most modern cartridge manufacturers, where there was a general tendency towards less durable printing on shells compared to older types (Larsen, personal comm.). This change in printing technology overlapped with the introduction of non-lead shot types. It was therefore reasonable to suspect that steel shot cartridges were under-represented in the above proportions and over-represented in the sample of non-identified shells.

The North Sea (Skagen) samples showed significant differences in most of the key characteristics, e.g. wear, corrosion, prevalence of small calibers, and shot type (shells). Although not statistically significant, the Skagen wad samples had a higher lead to steel ratio compared to all other samples (Fig. 4). In one of the Skagen samples, we found a single gauge 10 cartridge wad. This gauge is not legal in Denmark and this isolated finding could possibly suggest that some of the litter may originate from neighbour countries that allow such calibres. These special characteristics suggest that some of the North Sea (NS) litter may not all originate from Denmark but possibly from other countries as North Sea (NS) current systems may have carried ammunition litter to Danish coasts. This finding corresponds with findings of litter on North Sea (NS) coasts in the Shetlands that was unlikely to have originated from local sources (McCord pers. comm.).

#### 4.3. Age and fate of ammunition litter

Cartridge shells and wads are made from LDPE, though wads for some types of non-toxic shot may be produced from high density polyethylene (HDPE). These plastics are not biodegradable under normal environmental conditions. Ultra violet light and other physical impacts stimulate degradation, but even with such exposure breakdown can take hundreds of years. With no exposure such plastic items may persist indefinitely.

From this perspective, it is possible that some of our samples of ammunition litter might have originated from dispersal at the very beginning of production of modern shotgun cartridges with plastic some 50 years ago. The level of text and metal corrosion confirmed that the shells in general were older than one year, but an absolute age estimation of the material was not possible or when it had been dispersed. However, due to solid labelling of shells (melting combined with painting) we identified some cartridge types that have not been produced since the 1980's, for example cartridges produced by HK (Hærens Krudtværk); a legendary Danish factory that stopped production in the 1960's. We also identified rather large numbers of the Russian brand "Baikal" (e.g. one type "Baikal Super") and the Czech brand "SB" (Sellier & Bellot, particularly the type "Plastik") that previously were popular among Danish hunters but which have not been on the Danish market since the lead shot ban in the mid 1990's. Such old cartridges could have been stock-piled by hunters and not used until recently. However, it is possible that a significant share of the cartridge shells was dispersed many years ago. This suggests that much plastic ammunition litter has accumulated in the marine environment for decades and will remain a further accumulating source of plastic pollution for many years to come.

Plastic compounds used for the manufacture of cartridge components do not degrade at a significant rate, and the final fate of the litter from hunting ammunition and other sources is worth considering. The most plausible option is that shells and wads will in time be covered over and layered in sediments – either at the sea bottom or along the intertidal shoreline. Here they may rest unchanged for centuries unless exposed by shoreline erosion. Some items may remain floating for many years and be subject to erosion and wear due to contact with rocks and stones, and become micro plastic particles and beads. The roughness of the coast may speed this process, as indicated by the difference in wear and corrosion we found in litter from Danish west and east coasts. Any micro plastic residues may be ingested by invertebrate life (to their detriment) and accumulated in filter feeders and predators (to their detriment also) at higher trophic levels.

#### 4.4. Management

Compared to the other sources of plastic litter in natural habitats and ecosystems, litter from hunting ammunition could be regarded as a relatively minor hazard that can be disregarded. However, plastic ammunition litter features high on lists of litter types found on the Danish reference beaches where litter has been monitored. We believe that hunters in general, once made aware of the scale and duration of problem for which they are responsible, will dismiss any such *laissez faire* attitude. We therefore suggest that responsible managers and hunters will consider the following points.

First, hunters must do more to retain/retrieve empty shotgun shells during hunting so as to discard them later with their household waste. This is a simple question of attitude and respect for existing codes of conduct, but the evidence suggests there is more to be done, including a campaign to ensure greater effort and compliance by all.

Regulatory and civil society actions could support such a campaign, for example through implementation of a deposit system for used empty cartridges, as known for other potential waste items e.g. plastic or glass bottles. Hunters and their clubs could also initiate or get actively involved in existing beach clean-up programmes.

Wads require a different approach as hunters cannot retrieve wads when hunting. The only way to prevent dispersal of wad-plastic is to switch away from plastic to wads made from marine biodegradable or soluble materials that are not harmful in the marine environment. Technology for this is already in place and several products are available on the market and used in a variety of cartridges. However, progress is driven by user-demand as well as by forward-looking, innovative cartridge manufacturers and loaders developing improved and profitable biodegradable wads that meet technical, environmental and health standards.

Owners of private and state hunting land request increasingly hunters to use non-plastic wads. As for hunting in public areas such as the Danish fishery territory a switch from plastic to biodegradable wads will need a clear management strategy led by hunters, their organisations and governmental bodies.

#### 5. Conclusion

Litter from hunting ammunition is a significant source of plastic pollution in nature, and in some Danish coastal areas one of the most common single types of macro pollution. Samples from different areas show various levels of wear and corrosion, which indicates the likelihood of extended length of time since dispersal. Gauge, shot type, and other characteristics also differ between areas indicating that plastic litter occurs in different "populations", with North Sea being the most distinct.

Most ammunition litter on Danish coasts originates from hunting on Danish coastal waterbodies. The North Sea samples may provide some exceptions that suggest that ammunition litter may have come from neighboring countries or even further afield.

Judging from the likely age of the litter collected and slow decomposition rates of plastic, a substantial quantity of plastic ammunition litter will expose coastal habitats to a harmful source of pollution for many years to come.

We recommend responsible managers and hunters to take action now to help reverse this problem and thereby safeguard ecosystems, wildlife and the sustainability of hunting.

#### Acknowledgments

We thank 15. Juni Fonden, Arboretet (2016-A-67), Kirkegårdsvej 3A, DK-2970 Hørsholm for the grant given to the Danish Academy of Hunting for the study period 2016–2018. We are very grateful to John Swift, John Swift Consultancy, Higher Wych, Malpas, Cheshire, SY14 7JS, UK, for his valuable linguistic and technical comments that improved earlier drafts. We thank also colleagues from the hunting and ammunition trade society in Denmark, discussions with whom have helped develop our thinking on this subject. Not least, we are grateful to volunteers who ensured the collection of plastic items.

#### Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.envpol.2018.02.087>.

#### References

Andrady, A.L., 2011. Microplastics in the marine environment. *Mar. Pollut. Bull.* 62

- (8), 1596–1605. August 2011, Available at: <http://www.sciencedirect.com/science/article/pii/S0025326X11003055?via%3DiHub>.
- Christensen, T.K., Balsby, T.S., Mikkelsen, P., Lauritzen, T., 2017. Vildtudbyttestatistik og Vingeundersøgelsen for Jagtsæsonerne 2015/16 Og 2016/17. Institute for Bioscience, p. 8. Available at: [http://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater\\_2017/Notat\\_Vildtudbyttestatistik\\_2016\\_TK\\_MIS.pdf](http://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2017/Notat_Vildtudbyttestatistik_2016_TK_MIS.pdf).
- Derraik, José G.B., 2002. The Pollution of the marine Environment by Plastic Debris: a Review. Available at: <http://www.sciencedirect.com/science/article/pii/S0025326X02002205>.
- Geodætisk Institut, 2017. Danmarks Areal, Folketal Og Kystlinje. Available at: <https://www.dst.dk/pukora/epub/upload/22259/headword/dk/400.pdf>.
- Lamb, J., Willis, B.L., Fiorenza, E.A., Couch, C.S., Howard, R., Rader, D.N., True, J.D., Kelly, L.A., Ahmad, A., Jompa, J., Harvell, C.D., 2018. Plastic waste associated with disease on coral reefs. *Science* 359, 460–462 (2018). Available at: <http://science.sciencemag.org/content/359/6374/460>.
- Laist, D.W., 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe, J.M., Rogers, B.D. (Eds.), *Marine Debris: Sources, Impacts and Solutions*. Springer, Berlin, pp. 99–141. Available at: [http://plastics.earthmind.net/files/ART\\_Laist\\_1997.pdf](http://plastics.earthmind.net/files/ART_Laist_1997.pdf).
- Lusher, A.L., McHugh, M., Thompson, R.C., 2013. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Mar. Pollut. Bull.* 2013. Feb 15 67 (1–2), 94–99. <https://doi.org/10.1016/j.marpolbul.2012.11.028>. Epub 2012 Dec 27.
- Noer, H., Madsen, J., Hartmann, P., Kanstrup, N., Kjær, T., 1998. Anskydning Af Vildt. Status for Undersøgelser 1997–1998. Danmarks Miljøundersøgelser, p. 61. Technical Report DMU, nr. 233. With an English summary. Available at: [http://www.dmu.dk/1\\_viden/2\\_Publikationer/3\\_fagrapporter/rapporter/FR233.pdf](http://www.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR233.pdf).
- Noer, H., Hartmann, P., Madsen, J., Christensen, T.K., Kanstrup, N., Simonsen, N.H., 2001. Anskydning Af Vildt. Status for Undersøgelser 2001. Danmarks Miljøundersøgelser, p. 45. Technical Report DMU, nr. 367. With an English summary. Available at: [http://mst.dk/media/113999/anskydning\\_af\\_vildt\\_2001.pdf](http://mst.dk/media/113999/anskydning_af_vildt_2001.pdf).
- Rame Peninsular Beach Care, 2017. Webpage: <http://www.ramepbc.org/the-plastic-problem/shooting-and-marine-litter/>.
- Strand, J., Tairova, Z., Metcalfe, R. d'A., 2016. Status on beach Litter Monitoring in Denmark 2015. Amounts and Composition of marine Litter on Danish Reference Beaches. Aarhus University, DCE – Danish Centre for Environment and Energy, p. 42. Scientific Report from DCE – Danish Centre for Environment and Energy No. 177. Available at: <http://dce2.au.dk/pub/SR177.pdf>.
- Strand, J., Tairova, Z., Danielsen, J., Hansen, J.W., Magnusson, K., Naustvoll, L.-J., Sørensen, T.K., 2015. Marine Litter in Nordic Waters. Nordic Council of Ministers 2015. Available at: <http://norden.diva-portal.org/smash/get/diva2:824655/FULLTEXT01.pdf>.
- Situation Analysis Report. In: Thevenon, F., Carroll, C., Sousa, J. (Eds.), 2014. *Plastic Debris in the Ocean: the Characterization of Marine Plastics and Their Environmental Impacts*. IUCN, Gland, Switzerland, p. 52. Available at: <https://portals.iucn.org/library/sites/library/files/documents/2014-067.pdf>.
- UNEP, 2016. *Marine plastic Debris and Microplastics – Global Lessons and Research to Inspire Action and Guide Policy Change*. United Nations Environment Programme, Nairobi.
- Wilcox, C., Van Sebille, E., Hardesty, B.D., 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. *Proc. Natl. Acad. Sci.* 112 (38), 11899–11904. Available at: <http://www.pnas.org/content/112/38/11899>.

## Personal communications

- Grioghair McCord, Business Support Officer at KIMO International, Robert Gordon University, Lerwick, Shetland Islands, UK.
- Nils Juul Larsen. Director of Hunting & Outdoor at Rapala VMC Corporation.
- Niels Henrik Simonsen, Wetland hunting expert and consultant, Danish Hunters' Association, Molsvej 34, 8410 DK-Rønde.



# PAPER 19

Thomas VG, Gremse C, Kanstrup N (2016). Non-lead rifle hunting ammunition: issues of availability and performance in Europe. European Journal of Wildlife Research 62:633-641 doi:10.1007/s10344-016-1044-7

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

### Order Summary

Licensee: Aarhus University  
Order Date: Mar 8, 2020  
Order Number: 4784340385280  
Publication: European Journal of Wildlife Research  
Title: Non-lead rifle hunting ammunition: issues of availability and performance in Europe  
Type of Use: Thesis/Dissertation  
Order Ref: Non-toxic rifle  
Order Total: 0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customer@copyright.com](mailto:customer@copyright.com)  
<https://myaccount.copyright.com>



## AUTHORS' CONTRIBUTIONS

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above, of which I am first author, was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Prof. Emeritus Vernon Thomas  
Department of Integrative Biology, College of Biological Science, University of Guelph,  
Guelph, Ontario N1G 2W1, Canada  
Email: [vthomas@uoguelph.ca](mailto:vthomas@uoguelph.ca)

Confirmed, March 2021

Niels Kanstrup

# Non-lead rifle hunting ammunition: issues of availability and performance in Europe

Vernon G. Thomas<sup>1</sup> · Carl Gremse<sup>2</sup> · Niels Kanstrup<sup>3</sup>

Received: 31 May 2016 / Revised: 9 August 2016 / Accepted: 22 August 2016  
© Springer-Verlag Berlin Heidelberg 2016

**Abstract** Non-lead hunting rifle bullets were developed to make superior quality ammunition, and the need to reduce lead exposure of wildlife and humans. European and US hunters' concerns about non-lead bullets involve perceptions of availability, costs, efficacy, accuracy, toxicity, and barrel fouling. These concerns are politically powerful and, if not addressed, could thwart greater use of non-lead ammunition. Product availability (i.e. that which is made) of non-lead rifle ammunition in a wide range of calibres is large in Europe and is suited for all European hunting situations. At least 13 major European companies make non-lead bullets for traditional, rare, and novel rifle calibres. Local retail availability is now a function of consumer demand which relates, directly, to legal requirements for use. Costs of non-lead and equivalent lead-core hunting bullets are similar in Europe and pose no barrier to use. Efficacy of non-lead bullets is equal to that of traditional lead-core bullets. Perceptions of reduced accuracy and greater barrel fouling must be addressed by industry and hunter organizations and, if verified, resolved. Non-lead bullets are made in fragmenting and non-fragmenting versions,

but there is no advice to hunters yet given on the use of these two bullet types. The non-toxicity of ingested metallic copper, the principal component of non-lead bullets, is scientifically well-established.

**Keywords** Bullets · Ballistics · Concerns · Efficacy · Fragmenting · Fouling

## Introduction

A growing body of scientific evidence indicates that a transition to non-lead (synonymous with lead-free) rifle bullets is advisable to reduce lead exposure in wildlife and humans from ingested lead in spent hunting ammunition (Krone and Hofer 2005; Watson et al. 2009; Delahay and Spray 2015; Kanstrup et al. 2016a). What began in the state forests of Germany and, now, a total ban on use of lead-based ammunition in three German states (Gremse and Rieger 2015) has spread (beginning 2019) to California, USA, as a practice to protect endangered birds of prey, especially the California condor (*Gymnogyps californianus*) (Thomas 2013). The rationale for this transition is based on reducing lead exposure in scavenging species of wildlife (Berny et al. 2015; Helander et al. 2009; Madry et al. 2015; Nadjafzadeh et al. 2013) and humans who consume game meat containing lead bullet fragments (Dobrowolska and Melosik 2008; Fachehoun et al. 2015; Knutsen et al. 2015). Non-lead bullets were developed, initially, to produce non-fragmenting, high quality expanding ammunition capable of deep penetration. Over 30 US companies manufacture, or load, non-lead bullets into rifle ammunition, as do 13 of the major European arms companies, and there is international trade in these products (Thomas 2013). Most companies produce loaded cartridges by assembling

✉ Vernon G. Thomas  
vthomas@uoguelph.ca

Carl Gremse  
carl.gremse@hnee.de

Niels Kanstrup  
nk@danskjagtakademi.dk

<sup>1</sup> Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, Ontario N1G 2W1, Canada

<sup>2</sup> Leibniz-Institute for Zoo and Wildlife Research, Berlin, and Eberswalde-University, Wildlife Department, Schicklerstrasse 5, 16225 Eberswalde, Germany

<sup>3</sup> Danish Academy of Hunting, Skrejrupsvej 31, 8410 Rønne, Denmark

components made by others: only a few major companies make all of the components for their rifle cartridges.

Compared to the different types of lead-core rifle ammunition, little has been written about the transition to, and use of, non-lead bullets in hunting, despite the advertising claims of manufacturers. Consequently, concerns have arisen among hunters and their representative organizations about the mandatory use of non-lead bullets (Epps 2014). These concerns are mainly oral, anecdotal, statements made at government-public hearings on the possible adoption of non-lead ammunition in hunting, or listed in survey questions to hunters (Chase and Rabe 2015). While these concerns are not based on the scientific literature, they are able to influence public attitudes and the course of government policy.

This paper addresses the principal and valid concerns of European hunters about using non-lead rifle ammunition that are impediments to making this transition. They pertain, mainly, to the retail availability and prices of lead substitutes in Europe; their accuracy and efficacy in killing game humanely; whether to use fragmenting or non-fragmenting non-lead types; toxic concerns of copper-based bullets; and issues of greater barrel fouling.

## Definition of non-lead bullets

There are no international or national regulations that define the composition of non-lead bullets. California states only that they contain less than 1 % by mass of lead (California Department of Fish and Wildlife 2015a). They are, currently, made from solid pure copper or gilding metal (approx. 95 % copper and approx. 5 % zinc) and may include inserts made from tin or tungsten alloys (Oltrogge 2009; Paulsen et al. 2015). Lead-core<sup>1</sup> and non-lead bullets do not have identical properties, despite both having the same surface material of copper. Copper has a density of 8.96 g/cm<sup>3</sup>, but the lead-antimony core of a bullet is approximately 11.0 g/cm<sup>3</sup>, so lead-core bullets have a density approx. 20 % greater than copper bullets. Thus, for a given rifle calibre, and given bullet mass and shape, non-lead bullets are longer, which in some cases will demand a faster twist in the rifle barrel to achieve a sufficient stabilization to ensure accuracy. They also need to be driven at a higher velocity to achieve the same ballistic effects as the equivalent lead-core bullet (Thomas 2013). Non-lead bullets are designed to be expanding and may be made as either fragmenting<sup>2</sup> or non-fragmenting types. The production of non-lead bullets is currently represented mainly

by US companies who either make and/or load non-lead rifle ammunition (California Department of Fish and Wildlife 2015a) and a growing number (Table 1) of European ammunition makers who offer lines of non-lead bullets for stalking and driven game hunting.

## Availability of non-lead rifle ammunition in Europe

As of 2014, all of the major US rifle ammunition makers featured non-lead rifle ammunition, both centre-fire and rim-fire, in an array of popular calibres. These same companies<sup>3</sup> also produced non-lead slugs for shotguns, bullets for muzzle-loading rifles, non-lead bullets in bulk for hand-loaders (Thomas 2013), and export to European-Scandinavian markets (Knott et al. 2009). In 2013, 37 US and foreign on-line ammunition distributors collectively advertised non-lead ammunition in 51 different rifle calibres (Thomas 2013). Although no European country has yet regulated the use of non-lead rifle ammunition for all hunting on a national basis, the principal 13 European rifle ammunition makers have already developed their own brands. This is in response to the ongoing demand for and evaluation of non-lead rifle ammunition in Germany (Gremse and Rieger 2015), and possibly, for export into the growing North American market. The European ammunition makers may also be preparing their business for possible future European state-wide transitions to non-lead ammunition and are developing their own non-lead products to have an established market presence. The levels of production can always be geared up to future projected demand.

The major companies, Blaser, Brenneke, Fiocchi, Geco, Lapua, Norma, Rottweil, RWS, Sako, Sellier & Bellot, Sax, Sauvestre, Schnetz, and Hornady International, list calibres suitable for hunting every European game species and for every commonly used rifle (Table 1). A large range of rifle calibres (.223 to .500 Jeffrey) is listed across these 13 companies (Table 1), and they are made for both bolt-action and break-action rifles. Thus, the product availability (i.e. that which is manufactured, as opposed to what is commonly available at the retail level) of non-lead rifle ammunition is not limiting in Europe. The bullets in these non-lead calibres are listed as either fragmenting or non-fragmenting, and the company RWS lists both types of bullets in its catalogue (Table 1). For the hunting of very large (e.g. African plains) game, the companies Sako, Sauvestre, and Sax also offers a line of non-lead bullets in calibres from 9.3 × 74R to .500 Jeffrey (Table 1). The company Schnetz offers lead-free ammunition in calibres that are not commonly used for hunting (Table 1) and so precludes the obsolescence of rarer European calibres and older rifles during a potential transition.

<sup>1</sup> A lead-core bullet has a copper (or gilding metal) jacket that surrounds the lead-alloy core which extends to an open tip in semi-jacketed bullets (conventional ammunition).

<sup>2</sup> The anterior part of fragmenting bullets breaks into three to four large pieces on entry, penetrating adjacent tissues, while the residual part of the bullet continues along its initial route of entry.

<sup>3</sup> Barnes Bullets LLC, Hornady, Federal, Remington, and Winchester.



Regulation will be the most important factor determining both the product availability and, especially, the local retail availability of non-lead ammunition, besides influencing competitive prices (Thomas 2015). This was the case when the US federal government banned nationally the use of lead shotgun ammunition for waterfowl hunting in 1991 and ushered in the rapid transition to the mandatory use of lead-free shot. However, it is interesting to note the large product availability of non-lead bullets among the 13 European companies (Table 1) even though there is, comparatively, very little regulation requiring their use in European hunting.

### **Non-lead bullets are made in fewer bullet weights per calibre**

This concern arises, partly, from the lower density of copper and gilding metal non-lead bullets compared to equivalent lead-core bullets, resulting in their being of greater length. The constraint applies across all calibres and means that non-lead bullets have to be seated deeper in the cartridge case to prevent their extending into the rifled bore of the barrel. Thus, makers may not produce the largest mass non-lead bullets per rifle calibre. For example, lead-core bullets of 150 grains (9.72 g) mass, and heavier, are typical for the calibre .270 Winchester, but non-lead copper bullets are available mainly in 130 grains (8.42 g) and less. This does not preclude the use of non-lead bullets of this mass, consistent with energy delivered and shooting distance. However, a given bullet mass may be excluded by national regulation setting the minimum allowable bullet mass, e.g. in Denmark, where 9.0 g (138.9 grains) is legally required to hunt deer larger than roe deer. Hence, for this reason, or if hunters insist on using heavier mass non-lead bullets, they need to use ammunition and rifles of larger calibre.

Another factor relates to only the most commonly used non-lead bullet weights and shapes being made currently, and in smaller production batches or runs, in the absence of an established, regulated, market for non-lead bullets. This could result in the appearance of scarcity and unavailability of preferred bullet weights and types to hunters.

### **Costs of non-lead rifle ammunition**

Hunters commonly feel that costs play a large role in this form of recreation and that any increase in the projected price of ammunition may cause them to leave the sport. This fear was amplified by a report commissioned for the US hunting/shooting community (Southwick Associates Inc 2014). This concern also relates to a regulated requirement for use, and to the local demand factor. Small retailers cannot compete with large specialty stores on a volume of sales/price basis.

Similarly, it may cost more to import a particular, uncommon, brand or calibre and bullet type from a distant supplier. Purchase of ammunition on-line may result in lower costs (where allowed) compared to local store purchases. However, concerns about the cost of rifle ammunition used in hunting are exaggerated, especially when related to the total cost of rifle hunting (see Thomas (2015) for a UK comparison). A comparison of prices for lead-core and non-lead rifle ammunition was presented in Thomas (2013). That study compared the retail prices of nine commonly used calibres (from .223 to .416) of assembled rifle ammunition in different weights, types, and brands available across the USA. It found that prices for the two types of ammunition were generally comparable, and where the non-lead products cost more, the relatively small increase was not enough to deny purchase and use. The same result applies to bulk purchase of bullets for ammunition hand-loaders: lead-core and non-lead bullets cost about the same at the retail level. An economy of scale effect is likely to lower the price of non-lead ammunition further, as more hunters adopt this ammunition. A regulated use of non-lead rifle ammunition in hunting would increase an economy of scale effect across the most widely used bullet calibres. Kanstrup (2015) concluded that non-lead rifle ammunition is largely available in all normal calibres (particularly  $6.5 \times 55$ , 308 Win. and 30–06) in Danish hunting stores at prices comparable to equivalent lead products. The lowest range of availability was found in the small calibres ( $<6$  mm). In Germany, Gremse and Rieger (2012) found non-lead rifle ammunition in adequate supply across the range of hunting calibres typically used, with ammunition for small calibres ( $\leq 6$  mm) being offered mostly by specialty manufacturers. Pricing comparisons in Germany mirror the conclusions of Thomas (2013).

The above consideration applies only to ammunition used in hunting. Rifle target shooters may fire many more rounds during training and practice, and should the price of their selected non-lead ammunition exceed that of the lead equivalent, an extra cost is realized, unless economy of scale effects eventually render differences slight or non-existent.

### **Performance of non-lead rifle bullets fired through traditional rifle barrels**

#### **Accuracy of bullets**

The accuracy of a rifle bullet (i.e. the technical ability of the rifle in combination with the actual cartridge to achieve a consistent hitting point independently of the shooters' skills) is a product of an array of different factors including length, quality and state of the rifle barrel, the pressure and speed of the powder burning, the velocity of the bullet, and not least how the bullet is introduced to and led by the rifling of the barrel. Most of these factors apply equally to lead-core and

non-lead bullets. However, due to their lower density, copper bullets contain a greater volume to achieve an equal bullet mass; hence, they are longer than equivalent lead types. This effect is more pronounced (second power) for small calibres than for greater calibres. It may be counteracted by reducing bullet weight which, again, may result in a need for higher velocity to satisfy demands for striking power.

A longer and/or lighter bullet creates two basic challenges. The first is to avoid increasing the total length of the cartridge and prevent the bullet from extending into the rifling of the barrel. This is normally solved by seating the bullet deeper in the cartridge case and/or using more pointed bullets to ensure that the bullet still has sufficient “free bore”, which is crucial for pressure and accuracy. The second concerns the barrel rifling twist rate, which is key to stabilizing the bullet and optimizing accuracy. The twist rate is designed to stabilize the range of bullets and their respective velocities used in a particular calibre, and, in most existing rifles, is designed for lead-core bullets. The twist rate is normally expressed as the number of inches per turn (e.g. 10 ipt—also noted as 1:10 in the literature). Twist rates in hunting rifles range from approx. 1:6 to approx. 1:14. The twist in a rifle barrel of a given length is designed to stabilize the range of bullets normally used in that particular calibre. The basic rule is that, at the same velocity in the same calibre, longer bullets require lower (faster) twist rates than shorter bullets of the same weight. A change from using lead-core bullets to non-lead bullets may therefore challenge the twist construction of the particular rifle. This is particularly the case in small calibres and most pronounced in older rifle models. The twist in a given rifle cannot be modified. However, change of the barrel is a realistic solution; hence, the rifle can be modified to optimized use of non-lead ammunition. In a Danish case (Niels Kanstrup, personal testing and observation, 2016) and rifle (Sako cal. .222 REM, Twist Rate 1:16) that regularly showed great accuracy with lead-core bullets, the rifle was tested for accuracy at 100 m with non-lead bullets. In no case was the accuracy acceptable, and non-lead bullet groupings were 10.0+ cm in diameter. The stabilization was unacceptable and could not be improved by changing bullet shape or powder loads. The barrel was changed to a Lothar Walther barrel .222 REM Twist Rate 1:9 and tested. Stabilization and accuracy were then found acceptable (Table 2). Total price for the change is 650 Euros.

The bullet spin rate is an essential factor determining accuracy. It is undesirable to spin a bullet faster than necessary, as this can reduce accuracy and increase pressure, barrel wear, and the strain on the bullet jacket resulting in fouling.

Professional gun smiths can give the needed advice on the optimal twist rate based on the formula,

$$TW = \frac{3.5 \sqrt{V} D^2}{L}$$

where

TW	Twist rate [inches per turn]
V	Muzzle velocity [feet per second]
D	Diameter (cal.) [inches]
L	Total bullet length [inches], (Miller 2006)

### Perceptions of increased barrel fouling from non-lead bullets

Every copper-jacketed bullet fired from a barrel leaves some copper residue (fouling) on the rifling of the barrel. It builds up with every bullet fired and, if not removed, may interfere with bullet placement accuracy and pressure. This applies also to non-lead bullets, and some shooters report greater copper fouling with these bullets than with similar lead-core bullets, thus requiring more frequent barrel cleaning.

Copper fouling is already recognized by different makers of non-lead bullets who have created shallow rings in the mid-posterior section of the bullet into which copper is displaced during its contact with the rifling. In this way, copper build-up is theoretically reduced. This is a feature of the non-lead bullets made by Barnes Bullets, Hornady, RWS, Cutting Edge Bullets, and others. The last-named company actually reduces the length of the bullet's region that engages the rifling, both to increase velocity and to reduce the amount of copper fouling in barrels. The nature of the material used to make the non-lead bullet may vary among companies. Thus, “pure copper”, “annealed copper”, “gilding metal”, and “brass” are listed as choice materials to enhance ballistic performance. Annealing copper softens the metal made hard by shaping in die-made (swaged) bullets. Perhaps the greater extent of fouling (if real) can be attributed to the different metal types used. By way of comparison, the composition of non-lead bullets should be compared to the material used for jackets of lead-core bullets, for which metal fouling affecting accuracy does not appear to be a concern. In theory, the pure copper surface of non-lead bullets and that of copper-jacketed lead-core bullets should leave the same amount of fouling in a given barrel. The same consideration applies to bullets made from copper-zinc alloys (gilding metals).

Repeated firing with non-lead bullets during range practice can be expected to produce copper residue in the barrel bore, and it is customary to remove it after such practice. Under typical European hunting conditions in which a hunter uses a sighted-in rifle with a cleaned bore, many cartridges are not expected to be fired during a day's hunt, so the issue of extensive barrel fouling and reduced accuracy may not arise. This may be a simple issue of raising awareness and instructing hunters in proper gun maintenance. In the German field studies (Gremse and Rieger 2012), the average bag per person per

**Table 2** Bullet grouping diameters for .222 Rem calibre lead-core and copper bullets fired from a Sako rifle after re-barrelling with a Lothar Walther barrel, twist rate 1:9. Grouping diameters are the means of three consecutive shots. Cartridges were hand loaded with the same primers, but varying amounts of Norma 200 rifle powder. Shooting distance was 100 m. The data show that the Lothar Walther barrel produced equally acceptable bullet groupings with copper or lead-core bullets. Results show that small diameter groups with the small calibre Barnes copper bullets can be produced, and that accuracy is influenced by powder charge

Barrel type	Barnes TSX 55 grain Copper bullets	Sierra 55 grain Lead-core bullets
Lothar Walther Twist rate 1:9	18 grains Norma 200 Velocity 877 m/s Group size 20 mm	19.0 grains Norma 200 Velocity 865 m/s Group size 25 mm
	18.5 grains Norma 200 Velocity 870 m/s Group size 37 mm	19.5 grains Norma 200 Velocity 860 m/s Group size 21 mm
	19.0 grains Norma 200 Velocity 877 m/s Group size 34 mm	

year was between 3.2 and 11.2 animals. Regular gun care during the hunting seasons and a thorough cleaning twice a year have become the norm during these 6-year-field trials with over 1300 participants. These practices have shown themselves suited to ensure rifle accuracy.

### Complete penetrance of shot animals by non-lead bullets: the “through and through”

Lead-core bullets frequently loose lead (often about 50 % of the initial mass (Grund et al. 2010)) from the anterior region of the bullet as their anterior region expands (or “mushrooms”) during penetration. This effect is greater if the bullet strikes bone, and if the bullet’s lead core is “unbonded” as opposed to “bonded”. In the latter case, fusion of the lead core to the copper jacket results in a greater retention of the lead core during expansion. The recent development of lead-core bullets has emphasized “bonding” so that less lead is lost during penetration, resulting in greater bullet retained mass and greater penetration depth. The lead fragments that are released travel throughout the body and continue to wound tissues at some distance (approx. 30 cm diameter (Hunt et al. 2006)) from the entry point and away from the bullet’s initial trajectory (Caudell 2013; Gremse et al. 2014). Some hunters view this bullet core fragmentation as a positive adjunct to a swift kill (Caudell et al. 2012) and view negatively the performance of bullets that pass through the entire animal intact (a “through and through”). However, an exit wound with the consequent blood trail may allow easier pursuit of a wounded animal (Gremse and Rieger 2012).

The depth of penetration of an expanding bullet is a simple function of its energy at the point of entry relative to the total resistance provided by the carcass along the route of penetration. This applies to both lead-core and non-lead bullets. Lead-core bullets that loose much of their mass during penetration will dissipate fragments and their energy within the adjacent tissues and are so less inclined to exit the body. Much of the rationale behind the development of expanding non-lead bullets was to enhance bullet mass retention during entry to maximize depth of penetration and increase the amount of wounding in vital regions. Some of the modern types of non-lead bullets are constructed to retain 95+ % of their initial mass during penetration (e.g. Barnes TSX and TTSX, Nosler E-tip, Hornady, and RWS HIT) (Grund et al. 2010; Gremse et al. 2014). Non-lead bullets are now made in both fragmenting and non-fragmenting types (Table 1), with the non-fragmenting type designed to reduce the incidence of complete penetration.

### Use of fragmenting versus non-fragmenting non-lead bullets

Lead-free, non-fragmenting, bullets are designed not to disintegrate during passage through animal tissues, despite expansion of the anterior region. Bullet manufacturers in the USA and Europe (Table 1) now produce non-lead bullets whose anterior region is engineered to fragment deliberately into four to six large pieces upon entry. Each piece assumes its own trajectory in the animal and continues to wound, while the intact posterior remnant of the bullet continues along its initial trajectory. These bullets are advertised for their lethality, presumably by providing a bullet that behaves in much the same way as unbonded lead-core bullets. Trinogga et al. (2013) evaluated the performance of three partially fragmenting, non-lead bullets (RWS Bionic Yellow, Moeller KJG, and Reichenberg HDBoH) used to kill German game. Their results showed the same killing efficiency as traditional lead-core bullets and the non-fragmenting non-lead bullets (Barnes TSX and Lapua Naturalis). However, the wounds caused by the partially fragmenting bullets were smaller in diameter than the wounds made by the non-fragmenting bullets. An analysis carried out for this review paper on bullet performance data obtained from German field trials using 5842 hunter reports with non-lead, non-fragmenting bullets ( $n = 2892$ ) and non-lead, fragmenting bullets ( $n = 2950$ ) showed the average distance run by the targeted animal to be significantly higher for non-fragmenting bullets compared to fragmenting bullets (24.1 m versus 21.9 m; two-tailed  $t = 2.18$ ;  $p = 0.02929$ ;  $df = 5743$ ). This difference, while statistically significant at the 5 % level, had no practical relevance in German hunting practices.

Table 1 indicates the array of fragmenting and non-fragmenting bullets that are available in Europe. For the hunter desiring to use non-lead bullets, there is need to understand the ballistic advantages of using non-fragmenting or fragmenting bullet types, regardless of bullet calibre, bullet mass, and profile. This is where the hunting and ammunition industry should take the initiative in explaining under what circumstance each could be used to greatest effect. Another concern related to consumption of game meat is the question of fragmenting bullets leaving metal fragments in the carcass, which could abrade the mucosa and gingiva of animals and humans that ingest them. Nadjafzadeh et al. (2015) concluded from studies on white-tailed sea eagles (*Haliaeetus albicilla*) that only pure deforming non-fragmenting bullets are suited to prevent ingestion of bullet fragments. In this respect, expanding, but non-fragmenting, non-lead bullets are preferred to fragmenting types.

### Lethality of non-lead bullets

The immediate lethality of a given bullet depends on where and at what angle it strikes the animal (determined by the shooter and dependent on his experience and shooting skills), the mass of the animal as a determinant of its physical size, and its terminal energy (determined by bullet construction and by the shooter's choice of ammunition and shooting distance) (Gremse 2015). The present paper cannot deal with the first three parameters. However, it can assess the relative performance of expanding non-lead bullets that retain much of their mass and their ability to kill animals outright. British wild red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) were shot using either Barnes non-lead TSX bullets or traditional lead-core bullets in a comparative study (Knott et al. 2009). These authors reported that there was no significant difference between the two bullet types in terms of accuracy or observed killing power. This result was supported by the study of Trinogga et al. (2013), in which German wild deer and boar were shot with non-fragmenting non-lead bullets made by Barnes and Lapua. These authors found these bullet types as effective in killing as traditional lead-core bullets when used by German hunters. The maximum cross-sectional areas of the wound channels were independent of the type of bullet used, whether lead-core or non-lead, as was the gross morphology of the wound. Kanstrup et al. (2016b) performed an extensive comparison of the efficacy of traditional lead-core bullets and non-fragmenting copper bullets for taking roe and red deer under field conditions by Danish hunters. There was no practical difference in the performance of the two bullet types in producing rapid, one-shot, kills, based on the distances run by deer after being struck. In a lab study using ballistic soap as the target, Gremse et al. (2014) found that the Barnes TSX bullets showed very similar

ballistic behaviours as traditional lead-core bullets across all measured parameters, except for their much lower fragmentation. Thus, if the shot is taken responsibly, non-lead fragmenting and non-fragmenting bullets are able to produce rapid and humane kills.

### The non-toxicity of ingested non-lead bullet components

There is no national or international regulative process for determining the non-toxicity of lead bullet substitutes. The US Fish and Wildlife Service legal process of toxicity evaluation applies only to lead gunshot substitutes used for the hunting of migratory waterfowl in the USA (USFWS US Fish and Wildlife Service 1997). Only California has stipulated a maximum content of 1 % lead by mass in non-lead bullets (California Department of Fish and Wildlife 2015b). The non-toxicity of ingested metallic copper pellets to birds and mammals has been established scientifically (Thomas et al. 2007; Thomas and McGill 2008; Franson et al. 2013). The levels of copper residues remaining in carcass and meat of wild European game killed with non-lead bullets have been measured by Irschik et al. (2013) and Schuhmann-Irschik et al. (2015) and shown to pose no health risks to humans. Paulsen et al. (2015) measured the amount of metals released from fragmenting non-lead bullets under simulated conditions of meat storage and human ingestion. These authors compared the release of copper, iron, zinc, tin, and aluminium to recommended daily maximum intake levels for humans and reported that the amounts of these metals released were below the limits set by health agencies. Thus, there is no risk of metal toxicosis should birds or mammals ingest copper pieces released from spent non-lead bullets.

Paulsen et al. (2015) did indicate that one brand of non-lead bullet, Bionic Black, made by the company RWS, contained 1.9 % lead by mass, so exceeding the 1 % maximum level set by California. The other brands of non-lead bullets in the same study were found not to contain lead.

### Actions suggested for the ammunition industries, hunting organizations, and governments

- Evaluate concerns of poorer “impact groupings” with non-lead bullets particularly in small calibres. If real, then determine their cause, especially as it may relate to twist rates of rifle barrels (Caudell 2013).
- Evaluate concerns of greater copper residues (fouling) in barrels from using non-lead bullets. If they are valid, relate to impact group size, and the composition of metal(s) used to make various non-lead bullets. Provide information to hunters on proper barrel maintenance.

- Provide information to hunters on the optimal non-lead bullet choice for accuracy and lethality for common calibres, including the use of fragmenting versus non-fragmenting bullets for hunting, and recommended twist rates for rifle barrels.
- Regulation has to be the basis of any transition to use of lead-free bullets and the basis of regulatory enforcement and hunter compliance. Regulation provides the ammunition makers with the assurance of markets for the new products, and leads to greater availability as manufacturers meet new demands that otherwise might not exist.

**Acknowledgments** We thank the reviewers for their constructive comments and improvements to this paper. We acknowledge the support to N. Kanstrup from 15 Juni Fonden, Arboretet, Kirkegårdsvej 3A, DK-2970 Hørsholm (grant number 2013-A-88). Research of C. Gremse was supported by the German Federal Ministry for Food and Agriculture, Rochusstraße, 1, 53123 Bonn (grant number 09HS023), the State of Mecklenburg West Pomerania Ministry for Agriculture, Environment and Consumer Protection, and the State of Brandenburg Ministry of Rural Development, Environment and Agriculture. Lars Thune Anderson kindly performed the shooting tests with copper and lead-core bullets detailed in Table 2.

#### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Funding** The authors are not funded by any ammunition maker, government department, university, or agency promoting an end to use of lead ammunition.

## References

- Berny P, Vilagines L, Cugnasse J-M, Mastain O, Chollet J-Y, Concour G, Razin M (2015) Vigilance poison: illegal poisoning and lead intoxication are the main factors affecting avian scavenger survival in the Pyrenees (France). *Ecotoxicol Environ Saf* 118:71–82. doi:10.1016/j.ecoenv.2015.04.003
- California Department of Fish and Wildlife (2015a) Certified nonlead ammunition information. URL: <http://www.dfg.ca.gov/wildlife/hunting/lead-free/certifiedammo>.
- California Department of Fish and Wildlife (2015b) Nonlead certification information for ammo manufacturers. URL: <http://www.dfg.ca.gov/wildlife/hunting/lead-free/certification.html>
- Caudell J (2013) Review of wound ballistic research and its applicability to wildlife management. *Wildl Soc Bull* 37:824–831. doi:10.1002/wsb.311
- Caudell JN, Stopak SR, Wolf PC (2012) Lead-free, high-powered rifle bullets and their applicability in wildlife management. *Human-Wildl Interact* 6:105–111
- Chase L, Rabe MJ (2015) Reducing lead on the landscape: anticipating hunter behavior in absence of a free nonlead ammunition program. *PLoS ONE* 10(6):e128355. doi:10.1371/journal.pone.128355
- Delahay RJ, Spray CJ (eds) (2015) Proceedings of the Oxford lead symposium. Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, Oxford
- Dobrowolska A, Melosik M (2008) Bullet-derived lead in tissues of the wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*). *Eur J Wildl Res* 54:231–235. doi:10.1007/s10344-007-0134-y
- Epps CW (2014) Considering the switch: challenges of transitioning to non-lead hunting ammunition. *Condor* 116:429–434. doi:10.1650/CONDOR-14-78.1
- Fachehoun RC, Lévesque B, Dumas P, St-Louis A, Dubé M, Ayotte P (2015) Lead exposure through consumption of big game meat in Quebec, Canada: risk assessment and perception. *Food Addit Contam* 32:1501–1511. doi:10.1080/19440049.2015.1071921
- Franson JC, Lahner LL, Meteyer CU, Rattner BA (2013) Copper pellets simulating oral exposure to copper ammunition: absence of toxicity in American kestrels (*Falco sparverius*). *Arch Environ Contam Toxicol* 62:145–153. doi:10.1007/s00244-011-9671-1
- Gremse C (2015) “Tierschutz im Jagdbetrieb” (in German). The German Veterinary Society (DVG) Friedrichstraße 17, 35392 Gießen, Germany. Summary in English pg. 90. ISBN 978-3-86345-300-8
- Gremse C, Rieger S (2012) Bericht zu Entscheidungshilfenvorhaben “Ergänzende Untersuchungen zur Tötungswirkung bleifreier Jagdgeschosse (09HS023) In German., Federal Ministry for Food and Agriculture, Available at <https://www.researchgate.net/publication/271190631>
- Gremse C, Rieger S (2015) Lead from hunting ammunition in wild game meat: research initiatives and current legislation in Germany and the EU. In: Delahay RJ, Spray CJ (eds) Proceedings of the Oxford lead symposium. Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, Oxford, pp 51–57
- Gremse F, Krone O, Thamm M, Kiessling F, Tolba RH, Rieger S, Gremse C (2014) Performance of lead-free versus lead-based hunting ammunition in ballistic soap. *PLoS ONE* 9(7):e.102015. doi:10.1371/journal.pone.0102015
- Grund MD, Cornicelli L, Carlson LT, Butler EA (2010) Bullet fragmentation and lead deposition in white-tailed deer and domestic sheep. *Human-Wildl Interact* 4:257–265
- Helander B, Axelsson H, Borg H, Holm K, Bignert A (2009) Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden. In: *Sci Total Environment* 407:5555–5563. doi:10.1016/j.scitotenv.2009.07.027
- Hunt WG, Burnham W, Parish CN, Burnham KK, Mutch B, Oaks JL (2006) Bullet fragments in deer remains: implications for lead exposure in avian scavengers. *Wildl Soc Bull* 34:167–170
- Irschik I, Bauer F, Sager M, Paulsen P (2013) Copper residues in meat from wild artiodactyls hunted with two types of rifle bullets manufactured from copper. *Eur J Wildl Res* 59:129–136. doi:10.1007/s10344-012-0656-9
- Kanstrup N (2015) Non-lead rifle ammunition—availability in Danish gun stores. Report 1508–2. Danish Academy of Hunting, Rønde
- Kanstrup N, Thomas VG, Krone O, Gremse C (2016a) The transition to non-lead rifle ammunition in Denmark: national obligations and policy considerations. *AMBIO* 45:621–628. doi: 10.1007/s13280-016-0780-y
- Kanstrup N, Balsby TJS, Thomas VG (2016b) Efficacy of non-lead rifle ammunition for hunting in Denmark. *Eur J Wildl Res* 62(3):333–340. doi: 10.1007/s10344-016-1006-0
- Knott J, Gilbert J, Green RE, Hoccom DG (2009) Comparison of the lethality of lead and copper bullets in deer control operations to reduce incidental lead poisoning; field trials in England and Scotland. *Conservation Evidence* 6:71–78
- Knutsen HK, Brantsæter AL, Alexander J, Meltzer HM (2015) Associations between consumption of large game animals and blood lead levels in humans in Europe: the Norwegian experience. In: Delahay RJ, Spray CJ (eds) Proceedings of the Oxford lead

- symposium. Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, Oxford, pp 44–50
- Krone O, Hofer H (2005) Bleihaltige Geschosse in der Jagd–Todesursache von Seeadlern? Institute for Zoo and Wildlife Research, Berlin
- Madry MM, Kraemer T, Kupper J, Naegeli H, Jenny H, Jenni L, Jenny D (2015) Excessive lead burden among golden eagles in the Swiss Alps. *Environ Res Lett* 10:034003. doi:[10.1088/1748-9326/10/3/034003](https://doi.org/10.1088/1748-9326/10/3/034003)
- Miller D (2006) Where did Grennhill's twist rule come from? *Int J Impact Eng* 32(11):1786–1799. doi:[10.1016/j.ijimpeng.2005.06.001](https://doi.org/10.1016/j.ijimpeng.2005.06.001)
- Nadjafzadeh M, Hofer H, Krone O (2013) The link between feeding ecology and lead poisoning in white-tailed eagles. *J Wildl Manag* 77:48–57. doi:[10.1002/jwmg.440](https://doi.org/10.1002/jwmg.440)
- Nadjafzadeh M, Hofer H, Krone O (2015) Lead exposure and food processing in white-tailed sea eagles and other scavengers: an experimental approach to simulate lead uptake at shot mammalian carcasses. *Eur J Wildl Res* 61:763–774. doi:[10.1007/s10344-015-0953-1](https://doi.org/10.1007/s10344-015-0953-1)
- Oltrogge V (2009) Success in developing non-lead, expanding-nose centre fire bullets. In: Watson RT, Fuller M, Pokras M, Hunt WG (eds) Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, pp 310–315. doi:[10.4080/ilsa.2009.0305](https://doi.org/10.4080/ilsa.2009.0305)
- Paulsen P, Bauer F, Sager M, Schumann-Irschik I (2015) Model studies for the release of metals from embedded rifle bullet fragments during simulated meat storage and food ingestion. *Eur J Wildl Res* 61:629–633. doi:[10.1007/s10344-015-0926-4](https://doi.org/10.1007/s10344-015-0926-4)
- Schuhmann-Irschik I, Sager M, Paulsen P, Tichy A, Bauer F (2015) Release of copper from embedded solid copper bullets into muscle and fat tissues of fallow deer (*Dama dama*), roe deer (*Capreolus capreolus*), and wild boar (*Sus scrofa*) and effect of copper content on oxidative stability of heat-processed meat. *Meat Sci* 108:21–27. doi:[10.1016/j.meatsci.2015.05.008](https://doi.org/10.1016/j.meatsci.2015.05.008)
- Southwick Associates Inc (2014) Effects of the ban on traditional ammunition for hunting in California on hunting participation and associated economic measures. Prepared for the national shooting sports foundation. Fernandina beach, Florida
- Thomas VG (2013) Lead-free rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. *AMBIO* 42:737–745. doi:[10.1007/s13280-012-0361-7](https://doi.org/10.1007/s13280-012-0361-7)
- Thomas VG (2015) Availability and use of lead-free shotgun and rifle cartridges in the UK with reference to regulations in other jurisdictions. In: Delahay RJ, Spray CJ (eds) Proceedings of the Oxford lead symposium. Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, Oxford, pp 85–95
- Thomas VG, McGill IR (2008) Dissolution of copper and tin from sintered tungsten-bronze shot in a simulated gizzard, and an assessment of their potential toxicity to birds. *Sci Total Environ* 394:283–289. doi: [10.1016/j.scitotenv.2008.01.049](https://doi.org/10.1016/j.scitotenv.2008.01.049)
- Thomas VG, Santore R, McGill IR (2007) Release of copper from sintered tungsten-bronze shot under different pH conditions and its potential toxicity to aquatic organisms. *Sci Total Environ* 374:71–79. doi: [10.1016/j.scitotenv.2006.10.004](https://doi.org/10.1016/j.scitotenv.2006.10.004)
- Trinogga A, Fritsch G, Hofer H, Krone O (2013) Are lead-free hunting rifle bullets as effective at killing wildlife as conventional bullets? A comparison based on wound size and morphology. *Sci Total Environ* 443:226–232. doi:[10.1016/j.scitotenv.2012.10.084](https://doi.org/10.1016/j.scitotenv.2012.10.084)
- USFWS (US Fish and Wildlife Service) (1997) Migratory bird hunting: revised test procedure for nontoxic shot approval procedure for shot and shot coatings. *Fed Register* 62(320):63607–63615
- Watson RT, Fuller M, Pokras M, Hunt WG (eds) (2009) Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise

## PAPER 20

Kanstrup N (2006). Non-toxic shot - Danish experiences. *Waterbirds around the world*. Eds. G.C. Boere, C.A. Galbraith & D.A. Stroud. The Stationery Office, Edinburgh, UK. P. 861.

### RIGHTS:

Open access.

# Waterbirds around the world

A global overview of the conservation, management and research of the world's waterbird flyways

*Edited by G.C. Boere, C.A. Galbraith and D.A. Stroud*

*Assisted by L.K. Bridge, I. Colquhoun, D.A. Scott,  
D.B.A. Thompson and L.G. Underhill*



landbouw, natuur en  
voedselkwaliteit



SCOTTISH EXECUTIVE



© Scottish Natural Heritage 2006

First published in 2006 by The Stationery Office Limited  
71 Lothian Road, Edinburgh EH3 9AZ, UK.

Applications for reproduction should be made to Scottish Natural Heritage,  
Great Glen House, Leachkin Road, Inverness IV3 8NW, UK.

British Library Cataloguing in Publication Data  
A catalogue record for this book is available from the British Library

ISBN 0 11 497333 4

Recommended citation:

Boere, G.C., Galbraith, C.A. & Stroud, D.A. (eds). 2006.  
*Waterbirds around the world*. The Stationery Office, Edinburgh, UK. 960 pp.

Names used for geographical entities do not imply recognition, by the organisers of the *Waterbirds around the world* conference or other supporting organisations or governments, of the political status or boundaries of any particular territory. Names of territories used (and any alternatives) are included solely to help users of this publication apply information contained within this volume for waterbird conservation purposes. The views expressed in papers included within this volume do not necessarily represent views of the editors or the organisations and governments that supported the conference and this publication.

*Cover photography:* Whooper Swans *Cygnus cygnus* arriving at Martin Mere, England. Photo: Paul Marshall.  
([www.paulmarshallphotography.com](http://www.paulmarshallphotography.com))

Copyright of all photographs used in this publication resides with the named photographers.

## Non-toxic shot – Danish experiences

Niels Kanstrup

Danish Hunters' Association, Molsvej 34, DK-8410 Rønne, Denmark. (email: nk@jaegerne.dk)

Kanstrup, N. 2006. Non-toxic shot – Danish experiences. *Waterbirds around the world*. Eds. G.C. Boere, C.A. Galbraith & D.A. Stroud. The Stationery Office, Edinburgh, UK. p. 861.

Lead poisoning of waterbirds as a consequence hunters' use of lead shot is an issue which needs to be addressed internationally, since migratory waterbirds cross many borders during their migrations. Hence management practices - such as whether the use of lead shot is, or is not, permitted - in one country has consequences for the conservation of waterbirds in all countries on their flyways. The issue is also one of public relations and the image of hunting, and both hunters' and national and local government administrations can benefit from international co-operation and the exchange of knowledge and experience. To phase out lead shot, suitable alternatives must be available, and the research and development of alternatives and analysis of the market for their sale facilitated through international co-operation.

In Denmark, when the use of lead shot was first regulated in 1985, the hunters themselves initiated the use of alternative shot. 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 and that the price of steel shot cartridges was still acceptable. Research by the Hunters Association also demonstrated that steel shot was just as effective as lead shot for killing birds.

Denmark enforced a total ban on the use of lead shot in 1996. However, this led to problems not for hunting in wetlands but in forests, since the use steel shot was 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 led to pressure to develop softer shot alternatives such as bismuth, tin and wolfram products. Five such alternatives have now been introduced and have proved to be popular, even though the prices of these cartridges are significantly higher than those of lead or steel shot.

Many Danish hunters were concerned the phasing out of lead shot would lead to the phasing out of hunting, but this has not been the case and the number of hunters and the annual bag has not changed significantly. In addition, the hunters' initial main concern, that there was increased risk of guns exploding or being damaged by steel shot, proved groundless.

The efficiency of alternative shot has been investigated in several scientific studies and more popular programmes, with results showing that efficiency is more related to hunters' experience and their shooting distances rather than to the performance of the cartridge; and in turn that the performance of the cartridge (its velocity generated, conformity etc.) is more critical than the shot material itself. Although lead is still regarded as an ideal shot material due to its ballistic qualities, there have been many examples of lead shot cartridges operating far less efficiently than cartridges containing alternative shot material.



Concerns by Danish hunters about the consequences of changing from lead to non-toxic shots have proved groundless. Photo: Else Ammentorp, Danmarks Jægerforbund/Danish Hunters Association.

The phasing out of lead shot has now led to more focus on the efficiency and effectiveness of hunting techniques. Steel shot has, to some extent, taught hunters to be more cautious, by shortening their shooting distances to quarry. This seems to have caused an increase in the efficiency of the hunting since shortening the quarry distance will markedly increase the probability of cleanly striking the birds.

Addressing the problems of lead poisoning of waterbirds caused by hunting with lead shot may seem a less important issue in many countries than addressing other pressures on wetland conservation such as safeguarding the future existence of ecosystems such as wetlands themselves. But maintaining and restoring the quality of wetlands, including reducing pollution levels such as from toxic lead, is an important component of their conservation. The Danish example of a total ban on lead for hunting has demonstrated that this can be achieved, and to inspire and motivate the process there is a clear need for a constructive dialogue at both national and international level between governments, nature conservationists and hunters – all of whom share the objective of maintaining wetlands for waterbirds. Such co-operation is a precondition for continuing the momentum and progress towards flyway-wide phasing out the use of lead shot in wetlands.

## PAPER 21

Kanstrup N (2015). Practical and social barriers to switching from lead to non-toxic gunshot – a perspective from the EU. In: Delahay R, Spray C (eds) Oxford Lead Symposium. Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, The University of Oxford. pp 98-103. 2015. doi:<http://oxfordleadsymposium>.

### RIGHTS:

Open access.

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

**Niels Kanstrup**

The Danish Academy of Hunting, Skrejrupsvej 31, 8410 Rønde, Denmark

Corresponding author email address: [nk@danskjagtakademi.dk](mailto:nk@danskjagtakademi.dk)

## 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 elephus* 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		
<b>Total</b>	<b>2,122,700</b>	<b>213,800</b>	<b>33,000</b>

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.

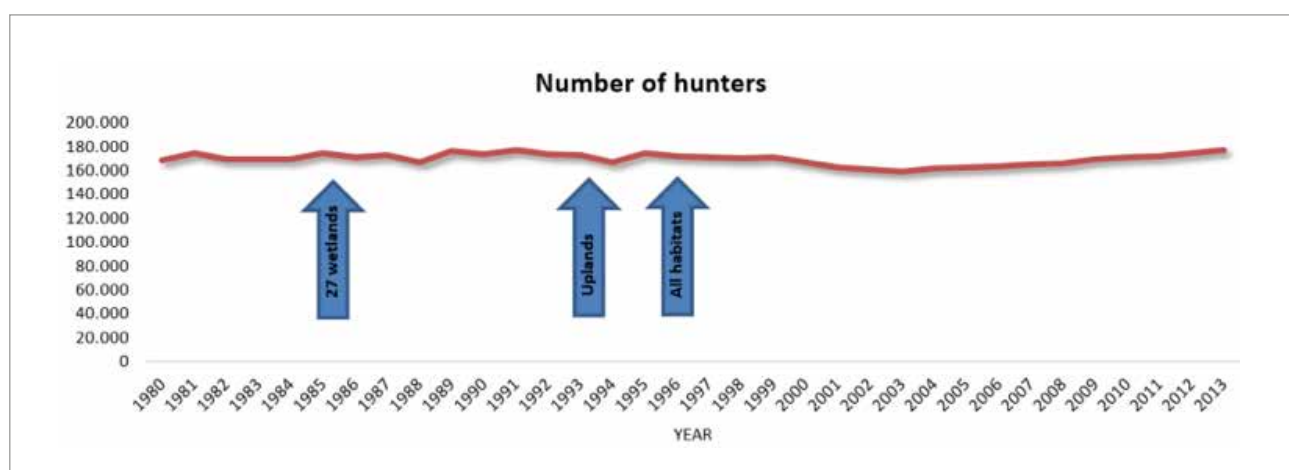


Figure 1: **Number of hunting license holders in Denmark from 1980 to 2013.** Arrows indicate the time of regulation of lead shot in three hunting habitats. Source: Annual publications from the Danish Nature Agency protocols.

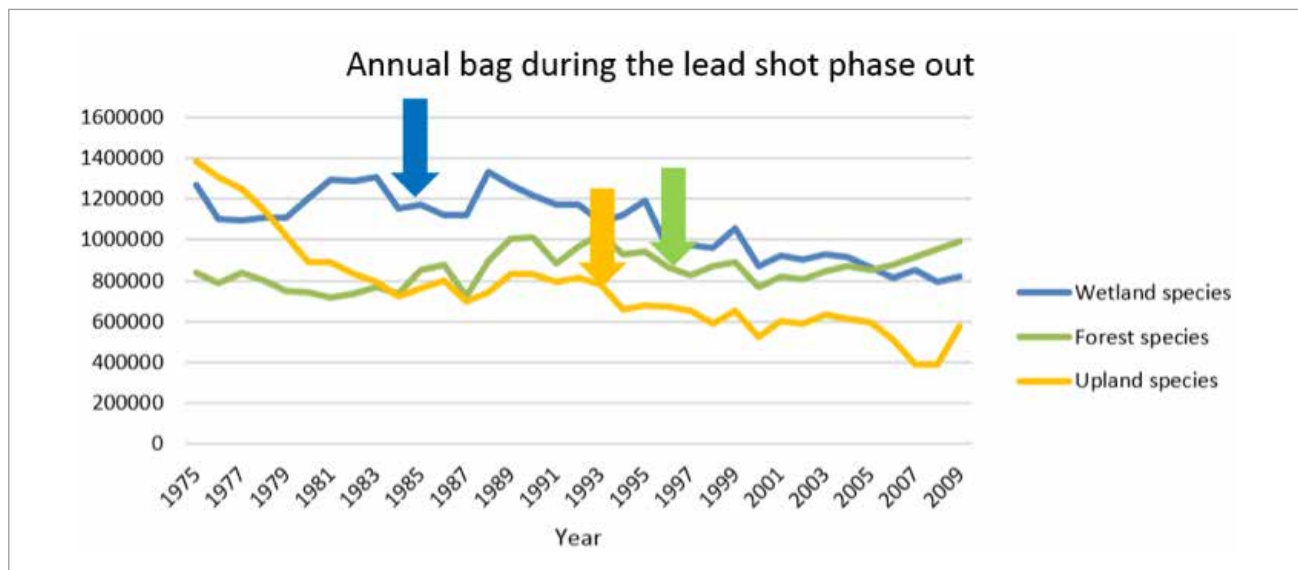


Figure 2: **Annual bag of three groups of quarry species during the period of phase out of lead shot for hunting in the three habitats: wetlands, uplands and forests.** Arrows indicate the time of regulation of lead shot in the particular habitat. Source: The Danish Bag Statistics.

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.

## REFERENCES

ASFERG T, OLESEN C, KAHLERT J, ODDERSKÆR P, BERTHELSEN J (2009). Trange tider for markernes vildt. In: Kanstrup N, Asferg T, Flinterup M, Thorsen BJ, Jensen TS (eds). *Vildt & landskab. Resultater af 6 års integreret forskning i Danmark 2003-2008*.

HARTMANN P (1982). Stålhaglpatroner. Vurdering af stålhaglpatroners egnethed til jagt i Danmark. *Report from Game Biology Station*. 82pp.

HUMBURG DD, SHERIFF SL, GEISSLER PH, ROSTER T (1982). Shotshell and shooter effectiveness: lead vs. steel shot for duck hunting. *Wildlife Society Bulletin* 10(2), 121-126.

KANSTRUP N (1987). Jernhaglpatroners anvendelighed. *Report from Landsjagforeningen af 1923*.

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

NATURSTYRELSEN (2014). Vildtinformation 2014.

NOER H, HARTMANN P, MADSEN J, CHRISTENSEN T, KANSTRUP N, SIMONSEN N (2001). Anskydning af vildt: status for undersøgelser 2001. *Faglig rapport fra DMU No. 367*. 45pp. Danmarks Miljøundersøgelser, Aarhus Universitet.

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



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*



# PAPER 22

Kanstrup N, Chriel M, Dietz R, Søndergaard J, Balsby TJS, Sonne C (2019). Lead and Other Trace Elements in Danish Birds of Prey. Archives of Environmental Contamination and Toxicology 77:359-367 doi:10.1007/s00244-019-00646-5

## RIGHTS:

Open access

## AUTHORS' CONTRIBUTIONS

I hereby confirm the following contribution to the article of which I am an author:

Kanstrup N, Chriel M, Dietz R, Søndergaard J, Balsby TJS, Sonne C (2019) Lead and Other Trace Elements in Danish Birds of Prey Archives of Environmental Contamination and Toxicology 77:359-367 doi:10.1007/s00244-019-00646-5

- Kanstrup, N managed and conceptualized the project, drafted the manuscript, processed and analysed data, edited and revised the manuscript and served as corresponding author.
- Chriél, M managed data sampling and undertook critical review and commentary.
- Søndergaard, J undertook laboratory work, data analysis and critical review and commentary.
- Dietz, R undertook critical review and commentary.
- Balsby TJS ensured statistical data analysis and undertook critical review and commentary.
- Sonne, C undertook data analysis and critical review and commentary.
- All authors approved the final revised manuscript.

Best regards



**Mariann Chriel**

Special Consultant | Nature - Invasive alien species  
+45 21 57 70 75 | [machr@mst.dk](mailto:machr@mst.dk)

### Ministry of Environment of Denmark

Environmental Protection Agency | Tolderlundsvej 5 | 5000 Odense C | Tel. +45 72 54 40 00 | [mst@mst.dk](mailto:mst@mst.dk) | [www.mst.dk](http://www.mst.dk)

Niels Kanstrup, biolog, adjungeret lektor  
Aarhus Universitet, Institut for Bioscience - Kalo  
Grenåvej 14  
DK-8410 Rønde

### Co-author statement

I hereby confirm the following contribution to the article of which I am an author:

Kanstrup N, Chriel M, Dietz R, Søndergaard J, Balsby TJS, Sonne C (2019) Lead and Other Trace Elements in Danish Birds of Prey Archives of Environmental Contamination and Toxicology 77:359-367 doi:10.1007/s00244-019-00646-5

- Kanstrup, N managed and conceptualized the project, drafted the manuscript, processed and analysed data, edited and revised the manuscript and served as corresponding author.
- Chriél, M managed data sampling and undertook critical review and commentary.
- Søndergaard, J undertook laboratory work, data analysis and critical review and commentary.
- Dietz, R undertook critical review and commentary.
- Balsby TJS ensured statistical data analysis and undertook critical review and commentary.
- Sonne, C undertook data analysis and critical review and commentary.
- All authors approved the final revised manuscript.

Kind regards



Rune Dietz  
Professor

Dear Niels,

I hereby confirm the following contribution to the article of which I am an author:

Kanstrup N, Chriél M, Dietz R, Søndergaard J, Balsby TJS, Sonne C (2019) Lead and Other Trace Elements in Danish Birds of Prey Archives of Environmental Contamination and Toxicology 77:359-367 doi:10.1007/s00244-019-00646-5

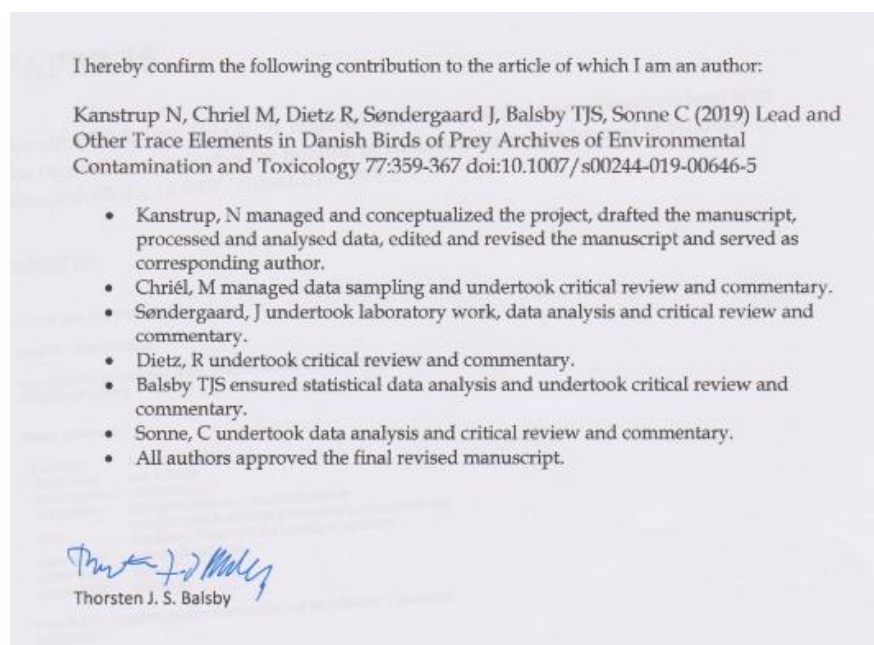
- Kanstrup, N managed and conceptualized the project, drafted the manuscript, processed and analysed data, edited and revised the manuscript and served as corresponding author.
- Chriél, M managed data sampling and undertook critical review and commentary.
- Søndergaard, J undertook laboratory work, data analysis and critical review and commentary.
- Dietz, R undertook critical review and commentary.
- Balsby TJS ensured statistical data analysis and undertook critical review and commentary.
- Sonne, C undertook data analysis and critical review and commentary.
- All authors approved the final revised manuscript.

Kinds regards,

Jens Søndergaard

**Jens Søndergaard**

Senior advisor, Ph.D.  
Head of the trace metal laboratory  
Department of Bioscience, Aarhus University  
Frederiksborgvej 399  
DK-4000 Roskilde  
Denmark  
Email: [js@bios.au.dk](mailto:js@bios.au.dk)  
Phone: +45 23 22 71 03



I hereby confirm the following contribution to the article of which I am an author:

Kanstrup N, Chriél M, Dietz R, Søndergaard J, Balsby TJS, Sonne C (2019) Lead and Other Trace Elements in Danish Birds of Prey Archives of Environmental Contamination and Toxicology 77:359-367 doi:10.1007/s00244-019-00646-5

- Kanstrup, N managed and conceptualized the project, drafted the manuscript, processed and analysed data, edited and revised the manuscript and served as corresponding author.
- Chriél, M managed data sampling and undertook critical review and commentary.
- Søndergaard, J undertook laboratory work, data analysis and critical review and commentary.

- Dietz, R undertook critical review and commentary.
- Balsby TJS ensured statistical data analysis and undertook critical review and commentary.
- Sonne, C undertook data analysis and critical review and commentary.
- All authors approved the final revised manuscript.

Best regards,

---

**Professor (Full) Christian Sonne**

Veterinary Ecotoxicology and Wildlife Health  
 DVM, PhD, dr.med.vet., Dipl. ECZM-EBVS (Wildlife Health)  
 Aarhus University, Faculty of Technical Sciences  
 Department of Bioscience, Arctic Research Centre (ARC)  
 Danish Centre for Environment and Energy (DCE)  
 Frederiksborgvej 399, POBox 358  
 DK-4000 Roskilde, Denmark.  
 E-mail: [cs@bios.au.dk](mailto:cs@bios.au.dk); Tel: +4530783172;  
 Fax: +4587155015



**Affiliation outside AU**

Visiting Adjunct Professor@Henan Agricultural University  
 Distinguished Professor@Nanjing Forestry University  
 Invited Specialist@IUCN PBSG  
 Editor-in-Chief@Environmental Pollution  
 Editor-in-Chief@Environmental Advances  
 Associated Editor@Environmental Research  
 Section Editor@Heliyon & Subject Editor@Wildlife Biology  
 EBM@Environment International & DiB  
 Skype: christian.sonne72  
[PURE](#); [Publons](#); [ResearchGate](#); [ORCID](#); [Google Scholar](#)

---

Confirmed, March 2021

A handwritten signature in dark ink, appearing to read 'Niels Kanstrup'.

Niels Kanstrup



# Lead and Other Trace Elements in Danish Birds of Prey

Niels Kanstrup<sup>1</sup> · Mariann Chriél<sup>2</sup> · Rune Dietz<sup>3</sup> · Jens Søndergaard<sup>3</sup> · Thorsten Johannes Skovbjerg Balsby<sup>1</sup> · Christian Sonne<sup>3</sup>

Received: 11 April 2019 / Accepted: 12 June 2019  
© The Author(s) 2019

## Abstract

Lead is a widely used and toxic heavy metal that poses a serious hazard to wildlife species and their ecosystems. Lead is used for production of hunting ammunition. Via gunshot or rifle projectiles, it spreads in ecosystems and may end up in predators and scavengers feeding on wounded or dead animals shot with lead-based ammunition. To assess to what degree Danish raptors are subject to lead contamination, we measured the content of lead in liver tissue from Danish birds of prey ( $n = 137$ ). Additionally, the study included values for 54 other trace elements. In our analysis, emphasis was put on interpretation of lead levels. Levels of cadmium, mercury and selenium were also discussed, while data for the remaining elements were provided for reference purposes. Bismuth was included to assess if lead originated from bismuth gunshot used as an alternative to lead shot. Concentrations of lead, cadmium, mercury and selenium were generally below the levels in similar studies of birds of prey in other northern European countries and none exceeded known and generally accepted threshold values for adverse health effects. As for lead, this is possibly related to the phase out of lead shot for hunting since 1986. The study confirms results from other studies showing that bismuth shot contains traces of lead that is deposited with bismuth in the target animal.

Lead has been used to produce ammunition for military and civilian purposes including hunting for more than 500 years.

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s00244-019-00646-5>) contains supplementary material, which is available to authorized users.

✉ Niels Kanstrup  
nk@bios.au.dk

Mariann Chriél  
march@vet.dtu.dk

Rune Dietz  
rdi@bios.au.dk

Jens Søndergaard  
js@bios.au.dk

Thorsten Johannes Skovbjerg Balsby  
thba@bios.au.dk

Christian Sonne  
cs@bios.au.dk

<sup>1</sup> Department of Bioscience, Aarhus University, Grenåvej 12, 8410 Rønne, Denmark

<sup>2</sup> National Veterinary Institute, Technical University of Denmark, Kemitorvet, 2800 Kgs. Lyngby, Denmark

<sup>3</sup> Department of Bioscience, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

Lead is a toxic substance, and within the last 40–50 years, there has been an increasing focus on lead poisoning from leaded hunting ammunition (Watson et al. 2009; Delahay and Spray 2015; Thomas et al. 2015; Kanstrup et al. 2019). The main attention to lead exposure in wildlife has been paid to the risk of poisoning of waterbirds ingesting lead pellets as grit and food (Pain 1992). Over the last 10 years, however, there has been an increasing focus on the impact of ammunition lead in other groups of wild birds including birds of prey. It has been documented that predators and scavengers are exposed to lead fragments from rifle ammunition in offal from or carcasses of killed game animals (Kenntner et al. 2001; Helander et al. 2009; Krone et al. 2009; Pain et al. 2010; Nadjafzadeh et al. 2013; Ecke et al. 2017; Pain et al. 2019). Additionally, lead ammunition is a hazard for the health of humans who frequently consume hunted game (Tsuji et al. 2009; Knutsen et al. 2015; Gerofke et al. 2018, Green and Pain 2019). Currently, international scientific literature represents 500–600 studies that support the environmental and health risk of lead in hunting ammunition (Arnemo et al. 2016).

When lead gunshot penetrates a target, traces of microscopic fragments of metal are deposited in meat, connective tissues, organs, blood and bones (Grund et al. 2010; Kollander

et al. 2017). Animals with embedded shot may be left in nature (wounded or killed and non-retrieved) and can thus be preyed upon and ingested by predators and scavengers (Arnemo et al. 2016, Pain et al. 2019). Also, birds that ingest gunshot spread through hunting are a source of lead to enter the food chain (Pain et al. 2009). Lead-based rifle projectiles are designed to fragment upon impact with the targeted wildlife specimen to increase the killing efficacy (Kanstrup et al. 2016). The widespread dispersion of metal fragments in carcasses killed with lead-based rifle bullets has been demonstrated in several studies. Hunt et al. (2009) found that all carcasses in a sample of 30 white-tailed deer showed metal fragments. Cornatzer et al. (2009) showed that 59 of 100 randomly selected packages of ground venison were contaminated with lead fragments. In terms of quantity, the risk of environmental lead exposure from an animal shot with a typical lead rifle projectile is high as the offal often is left in the nature. The amount from just a single deer may contain several grams of lead fragments ranging from visible sizes to nanoparticles (Kollander et al. 2017), hence constitutes a potentially toxic dose to several individual scavengers.

The poisoning risk of lead ammunition is well documented internationally (Pain et al. 2019). In Denmark, previous studies of the risk to waterbirds have shown a high prevalence of ingested lead shot and accordingly high mortality in mute swan (*Cygnus olor*) where autopsy of 298 birds showed that 78 (26%) had died from lead poisoning (Clausen and Wolstrup 1979). However, the risk of lead from gunshot and rifle projectiles to expose predators and scavengers through wounded game animals and from offal is poorly investigated in Denmark. The increasing population of deer, the increased opportunities for hunting and the local need for targeted population control combined with the current handling of offal from killed animals accentuate the need to investigate the risk related to leaded rifle ammunition.

The present study was designed to mainly evaluate levels of lead in Danish birds of prey based on liver samples collected as a spin-off of passive toxicological monitoring of wild animals in Denmark. The methodology offered additional measurement of 54 other trace elements, and out of these, we found it feasible to discuss and evaluate cadmium, mercury and selenium, too, because these are commonly regarded to be trace elements to cause adverse impacts in predator and scavenging species. Consult the electronic supplementary material (ESM) for further information on all chemical data.

## Materials and Methods

### Sampling

The material collected for the study included liver samples from a total of 137 Danish birds of prey distributed on 13

species collected by the Technical University of Denmark in the period 2013–2016. One bird was not attributed to species level but derived from a bird of prey. The birds were submitted to the National Veterinary Institute, Technical University of Denmark, for a veterinary examination as part of the general surveillance of wildlife health. The animals were subjected to necropsy and follow-up diagnostic examination including microbiological examination in the accredited laboratory order to establish the cause of death. From all birds of prey, a minimum of 5 g liver sample was stored at  $-20^{\circ}\text{C}$  in the tissue bank for scientific use. Liver samples are a key indicator of bioaccumulation (Espín et al. 2016) although this differs between elements. For lead, as an example, liver concentrations are indicative of, and can be used to monitor, short-term exposure. Lifetime accumulation is better reflected in bone lead concentrations (García-Fernández et al. 1995, 1997).

For some individuals, sex ( $n=118$ ), age ( $n=43$ ) and cause of death or indications of cause of death ( $n=109$ ) were recorded. The notification “shot” ( $n=61$ ) included birds killed as a part of bird-strike prevention around airports or cases where this cause of death was established at necropsy. The majority (80%) of the shot birds originated from Midtjyllands Airport (situated in central Jutland nearby the city of Karup) where the shooting is practiced with bismuth gunshot. For “other” birds (complementary to “shot” birds), the cause of death was only reported occasionally, in most cases, as unknown. Hence, this group may include shot birds but with no certainty of this cause of death.

### Chemical Analyses

The chemical analyses were conducted at the accredited environmental trace element laboratory at Department of Bioscience in Roskilde. A 1.0 g wet weight liver subsample was cut from the main liver sample and digested in Teflon vials with 8 ml of semi-concentrated (i.e. 33%) nitric acid (Merck Suprapure grade) in a Anton Paar Multiwave 3000 microwave oven (according to the Danish Standard DS 259). The main liver samples were not homogenized in order to minimize the risk of grinding shot fragments into the subsample. The digestion programme used 1000–1400 W power for a total of 60 min. After digestion, digestion solutions were diluted with MilliQ water to 60 g and analysed with inductively coupled plasma mass spectrometry (ICP-MS) (Agilent 7900). Detection limits for the elements were determined as three standard deviations on method blank samples. Three certified reference materials (Tort-3, Dolt-5, and Dorm-4 from National Research Council Canada) were included for QA/QC to check digestion efficiency and measurement accuracy. The measured recovery percentage of the reference materials ranged from 87 to 112% for the elements analysed.

The subsequent data analysis involved lead, cadmium, mercury and selenium, which we consider to be the most important elements for assessment of environmental impact of predators and scavengers. In addition, bismuth was included to assess if lead originated from bismuth gunshot (which may contain traces of lead) that has been used as an alternative to lead shot since mid-1990s. We only made comparisons with other studies when these were based on liver samples. When comparing with data of element concentrations expressed per dry weight basis, we used a conversion factor of 3.6 to calculate the corresponding concentrations on a wet weight basis (based on an average of the dry matter percentage in our measurements). In the statistical analyses, if concentrations were below the detection limit, the values were set at half the detection limit for the element concerned.

## Statistical Analysis

We tested if the concentrations differed between species and between shot and other birds using a general or generalized linear model including both factors in the model. For the post hoc test, we used least square mean differences. Data for lead were log transformed to ensure normal distribution, whereas the concentrations of the other elements were fitted assuming a Poisson distribution because transformation could not normalize the residuals for other elements than lead. We omitted a single outlier that had extremely high lead and bismuth concentrations, presumably due to ammunition fragments embedded in the sample. To test the possibility of contamination from lead residues in bismuth gunshot, we compared lead concentrations in shot birds and other birds by using a nonparametric Spearman rank correlation for each category. The analysis required a nonparametric test since the distribution of bismuth could not be transformed to follow normal distribution. Interspecific differences in levels of lead were tested on the four species with  $n > 7$  (white-tailed eagle (*Haliaeetus albicilla*), common buzzard (*Buteo buteo*), red kite (*Milvus milvus*) and kestrel (*Falco tinnunculus*)) using a general linear model, whereas a generalized linear model with a Poisson distribution was used for testing differences in cadmium, mercury and selenium levels. The statistical analysis was made in SAS 9.4 (SasInstitute, Cary, NC) using the packages: “proc glm” and “proc genmod”.

## Results

Lead concentrations differed between the four selected species ( $F_{3,101} = 10.4$ ,  $p < 0.0001$ ). Common buzzards had significantly higher lead concentrations than kestrels (see statistical output in “Appendix 1”). Cadmium concentrations

also differed between species ( $\chi^2 = 16.9$ ,  $p = 0.0008$ ). The post hoc pairwise comparisons showed significantly higher cadmium and mercury concentrations in common buzzard compared to kestrel (“Appendix 1”). The mercury level differed significantly between species ( $\chi^2 = 23.6$ ,  $p < 0.001$ ). White-tailed eagles showed significantly higher mercury concentrations than in other species (Annex 1). Selenium values did not differ between species ( $\chi^2 = 3.87$ ,  $p = 0.276$ ). However, the highest concentrations across species were found in white-tailed eagles. The molar ratio of selenium/mercury in white-tailed eagles showed that selenium was in surplus (average 15.72, range 0.87–27.59,  $n = 12$ ). Bismuth concentrations differed significantly between species ( $\chi^2 = 21.3$ ,  $p < 0.001$ ). However, the post hoc pairwise comparisons showed no significant differences between species (Annex 1).

The cause of death (shot or other birds) had no significant effect on the concentrations of lead, cadmium and selenium (Pb:  $F_{1,101} = 0.0$ ,  $p = 0.997$ ; Cd:  $\chi^2 = 2.9$ ,  $p = 0.09$ ; Se:  $\chi^2 = 0.34$ ,  $p = 0.558$ ). Shot individuals had significantly lower levels of mercury than other birds ( $\chi^2 = 4.22$ ,  $p = 0.040$ ), whereas birds shot had significantly higher bismuth concentration than other birds ( $\chi^2 = 107.5$ ,  $p < 0.001$ ).

A positive correlation between lead and bismuth content was observed for shot birds (Shot:  $r_s = 0.494$ ,  $n = 61$ ,  $p < 0.0001$ ), whereas this relation did not exist for other birds ( $r_s = 0.018$ ,  $n = 75$ ,  $p = 0.877$ ), see Fig. 1.

Table 1 shows the results reported for each species as median, mean and standard deviation (SD) for 136 samples for lead (Pb), cadmium (Cd), mercury (Hg), selenium (Se) and bismuth (Bi). An extreme lead and bismuth value for one kestrel is omitted from the table data. All concentrations are given in ppm (mg/kg) wet weight.

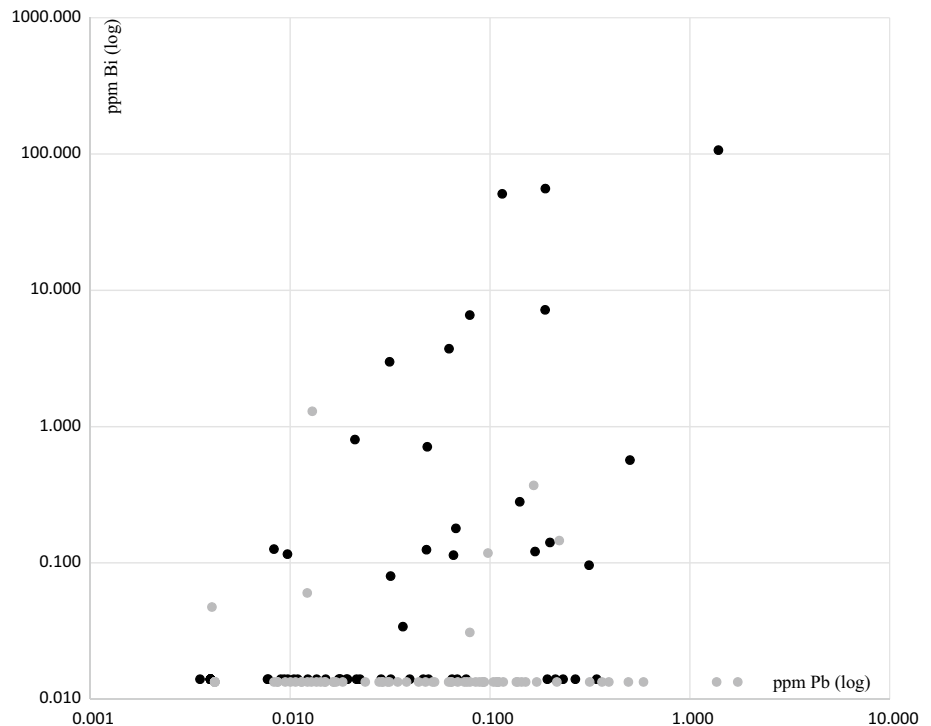
## Discussion

### Lead

Lead from hunting ammunition constitutes a risk for poisoning for a wide range of animal species including predators and scavengers. The relationship is well documented. In 57 white-tailed eagles collected as dead or dying in Germany and Austria, Kenntner et al. (2001) found a mean of 7 ppm lead and a max value of 62 ppm lead and concluded that 28% of the white-tailed eagles had liver lead concentration that could cause acute fatal poisoning ( $> 15$  ppm). The corresponding figure for white-tailed eagles in Poland is 32% (Kitowski et al. 2017) and in Sweden, 12.5% (Helander et al. 2009) and for bald eagles (*Haliaeetus leucocephalus*) in two Great Lakes states, 30% (Nam et al. 2012).

A study of lead in game meat in Denmark found an elevated lead content in pheasants (*Phasianus colchicus*)

**Fig. 1** Correlation between lead and bismuth levels for birds reported as shot (black dots) but not for others (grey dots). For shot birds, we found a significant correlation (Spearman correlation, Shot:  $r_s = 0.494$ ,  $n = 61$ ,  $p < 0.0001$ ), whereas the relation did not exist for other birds (Spearman correlation  $r_s = 0.018$ ,  $n = 75$ ,  $p = 0.877$ ). An extreme value of 15,581 ppm for bismuth in one Kestrel was not included



(Kanstrup 2012). This could be caused by residues of embedded lead shot; in this case, both lead shot and bismuth shot showed to contain up to 6800 ppm lead. Lead shot allocates a trace of larger or smaller fragments in the game meat. Bismuth shot is easily fragment causing both bismuth and lead to be released in the target.

A number of studies have established criteria for assessing the risk of lead exposure. Herring et al. (2017) summarized the most recent studies and found for liver samples (wet weight): background:  $< 2.0$  ppm; subclinical: 2.0–6.0 ppm; clinical toxicity: 6.0–15.0 ppm; severe clinical poisoning:  $> 15.0$  ppm. Of all the samples in the present study, only five lead concentrations exceeded 1 ppm and only one exceeded the criterion for subclinical poisoning (2 ppm). This was an extreme value of 149 ppm, which exceeds the limit of acute poisoning of birds by a factor of 10. This value was found in a kestrel shot at Midtjyllands Airport. The bird was an adult female of 202 grams with no reported signs of altered behaviour. Kanstrup (2012) reported values up to 119 ppm lead in pheasants and concluded that lead from embedded bismuth shot could explain the high lead levels measured. Midtjyllands Airport uses bismuth shot for the control of birds causing risk to air safety (Danish Nature Agency, Midtjylland, personal communication) and it is, therefore, likely that the extreme value of 149 ppm lead in the kestrel was caused by a fragment of a shot. This is

supported by the fact that the content was far above the acute poisoning limit and the bird also contained an extreme bismuth value. Kestrels are not, particularly, exposed to lead from ammunition as its prey usually includes only small mammals, lizards or large insects.

## Cadmium

Cadmium is a heavy metal that accumulates in organs, in particular, kidney and liver (Hauouema et al. 2006). It can pose a serious health risk and cause kidney and bone damage and cancer (Järup and Åkesson 2009).

The threshold level of cadmium poisoning to birds is considered to be about 40 ppm (wet weight, liver) (Sakshaug et al. 2009). All birds in our study had lower values. For common buzzards in Sicily, Licata et al. (2010) found values that correspond to the values of common buzzards in this study. Licata et al. (2010) did not indicate these cadmium levels as critical. For red kites (*Milvus milvus*), Berny et al. (2015) found significantly higher values for cadmium than measured in this study. For white-tailed eagle in Germany and Austria, Kenntner et al. (2001) found cadmium levels in line with our values for both white-tailed eagles and other species, but some high values exceeded these considerably.

Our results showed slightly elevated cadmium levels in some species, e.g. common buzzards. Cadmium

**Table 1** Median, mean and standard deviation (SD) for five trace elements distributed on species

	N	N <sub>s</sub>	Pb	Cd		Hg		Se		Bi		
				Median	Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	
Common buzzard <i>Buteo buteo</i>	48	24	0.09	0.19 ± 0.32	0.38	0.42 ± 0.38	0.32	0.47 ± 0.45	1.20	1.27 ± 0.42	0.01	2.44 ± 15.43
Kestrel <i>Falco tinnunculus</i>	39	31	0.02	0.03 ± 0.04	0.03	0.05 ± 0.04	0.12	0.16 ± 0.17	1.05	1.08 ± 0.22	0.01	3.13 ± 11.92
White-tailed sea-eagle <i>Haliaeetus albicilla</i>	12	0	0.08	0.24 ± 0.40	0.04	0.05 ± 0.03	1.28	1.92 ± 2.05	2.03	1.93 ± 0.80	0.01	0.01 ± 0.00
Red kite <i>Milvus milvus</i>	8	1	0.10	0.11 ± 0.10	0.19	0.15 ± 0.09	0.17	0.16 ± 0.09	1.11	1.07 ± 0.28	0.01	0.02 ± 0.03
Tawny owl <i>Strix aluco</i>	6	0	0.02	0.02 ± 0.02	0.43	0.50 ± 0.40	0.16	0.16 ± 0.09	1.30	1.36 ± 0.37	0.01	0.01 ± 0.00
Goshawk <i>Accipiter gentilis</i>	5	2	0.01	0.02 ± 0.01	0.05	0.06 ± 0.05	0.25	0.27 ± 0.22	0.89	1.16 ± 0.63	0.01	0.01 ± 0.00
Sparrow hawk <i>Accipiter nisus</i>	5	0	0.03	0.04 ± 0.03	0.18	0.18 ± 0.08	1.21	1.66 ± 1.71	0.80	1.07 ± 0.70	0.01	0.01 ± 0.00
Peregrine falcon <i>Falco peregrinus</i>	3	0	0.01	0.01 ± 0.01	0.02	0.06 ± 0.08	0.54	0.52 ± 0.35	1.42	1.25 ± 0.37	0.01	0.01 ± 0.00
Eagle owl <i>Bubo bubo</i>	3	0	0.01	0.01 ± 0.00	0.07	0.08 ± 0.03	0.51	0.48 ± 0.17	1.00	1.00 ± 0.31	0.01	0.03 ± 0.03
Hen harrier <i>Circus cyaneus</i>	2	2	0.00	0.00 ± 0.00	0.07	0.07 ± 0.00	0.17	0.17 ± 0.07	0.74	0.74 ± 0.06	0.01	0.01 ± 0.00
Golden eagle <i>Aquila chrysaetos</i>	2	0	0.05	0.05 ± 0.06	0.16	0.16 ± 0.07	0.33	0.33 ± 0.30	0.69	0.69 ± 0.07	0.01	0.01 ± 0.00
Marsh harrier <i>Circus aeruginosus</i>	1	1	0.08	0.08	0.03	0.03	0.19	0.19	1.07	1.07	0.01	0.01
Barn owl <i>Tyto alba</i>	1	0	0.01	0.01	0.00	0.00	0.03	0.03	0.19	0.19	1.30	1.30
Unknown (bird of prey)	1	0	0.02	0.02	0.36	0.36	3.24	3.24	2.54	2.54	0.01	0.01
	136	61	0.03	0.11 ± 0.24	0.09	0.22 ± 0.30	0.22	0.52 ± 0.91	1.16	1.24 ± 0.51	0.01	1.77 ± 11.12

Unit: ppm (mg/kg wet weight).  $N_s$  = number of birds where the cause of death is reported to be shot. Data for one kestrel with an extreme value of 149 ppm for lead and 15,581 ppm for bismuth were not included

concentrations in common buzzards exceeded levels in kestrels more than tenfold, and this difference was statistically significant (Annex 1). Other studies have shown very high cadmium levels in offal of game animals and concentrations tend to be highest in kidney compared to liver and muscular tissues (Lazarus et al. 2014; Durkalec et al. 2015). These studies indicate that offal from shot game animals may be a cadmium source for scavengers like common buzzards which could be the reason to the concentration we found for this species.

## Mercury

Mercury causes loss of senses, blood parameter changes, altered immune response, kidney function and structure, as well as behavioural changes (Boening 2000). It biomagnifies in the food webs. Predators and scavengers, therefore, have a higher risk of mercury poisoning than animals at a lower trophic level (Dietz et al. 1996; Lourenço et al. 2011). The largest concentrations of mercury are found in predatory fish, predators and birds high in the food chain, including notably fish-eating species. Among the species included in our survey, white-tailed eagles had the highest mercury values. A single bird showed a level of 7.5 ppm. Lucia et al. (2010) indicated mercury levels corresponding to the levels of most species in this study, but for two species of waders (Charadriiformes) levels that were above, approximately in line with levels of the white-tailed eagles in our study. Kenntner et al. (2001) found levels (both mean and max values) for white-tailed eagles, which were approximately half of the values in our study and estimated that liver mercury levels below 10 ppm (wet weight) are not critical. The molar ratio of selenium/mercury in white-tailed eagles in our study showed that selenium was in surplus, which in combination with the relatively low mercury levels observed indicated that these birds were not likely to be at risk of mercury intoxication.

## Selenium

Selenium is an important micronutrient but is toxic in high concentrations especially in aquatic ecosystems and associated organisms (Lemly 1993). Selenium is particularly important in mercury detoxification (Ralston and Raymond 2010). Kitowski et al. (2017) examined common buzzards in East Poland and found an average selenium level of 3–4 ppm dry weight which corresponds to the selenium level in common buzzards in this study. We found the highest selenium levels in white-tailed eagles. However, the level is lower than the reported limit of possible harmful effects in waterbirds at 10 ppm (Lemly 1993).

## Lead in Gunshot

All the investigated bird species, except kestrel, may feed on small game subject of hunting with gunshot. Whether the low lead levels is due to the Danish ban on lead shot since 1996 or if the birds of prey are not exposed via small game cannot be concluded. However, studies in other countries show a clear link between use of lead shot for hunting and lead poisoning of birds of prey. Fisher et al. (2006) found exposure to lead in four species of owls and 23 species of birds of prey from North America and Europe. All species listed as exposed to lead from gunshot in Fisher et al. (2006) were included in our study. The low lead levels observed in our study may, therefore, be due to Danish birds not having a source through prey or carrion containing lead gunshot.

Previous studies have demonstrated a significant content of lead in bismuth cartridges up to 0.7% (Kanstrup 2012). We found an extreme lead concentration in one bird along with a very high bismuth concentration. This indicates that the bird was shot with bismuth shot and that the lead in the sample is most likely due to residues of the shot (as opposed to bio-accumulated lead). Preparation of samples by blending or homogenization samples in a mortar in order to achieve a more representative sample will result in a dispersion of metal fragments contained in ammunition residues in the sample. Consequently, in case of birds killed with gunshot, we recommend minimizing this risk of contamination by avoiding homogenization of the samples. This applies, in particular, to tissues that show macroscopic damage caused by gunshot.

Lead in bismuth shot may pose a risk of lead poisoning of birds according to the same pattern as poisoning by pure lead shot. However, Kanstrup (2012) estimated that at a lead content of up to 1%, the release of lead from bismuth shot would pose a negligible risk for birds ingesting such bismuth shot. It has not been evaluated whether exposure from lead and, possibly, other trace elements in shot used as alternatives to typical lead shot represent a health hazard to consumers of game meat or for the environment. Tungsten in gunshot has been suspected to be carcinogenic (Kalinich et al. 2005; Bank-Mikkelsen 2014). However, pure tungsten has not been shown to exhibit carcinogenic properties when ingested or embedded in animal tissues, but nickel, with which it is often alloyed, has known carcinogenicity properties (Thomas et al. 2009). Fäth et al. (2018) showed that the release of certain metals from non-lead shot types dispersed in wetlands was a greater risk for aquatic organisms than lead from lead shot. The main concern here is zinc and copper, whereas, for example, bismuth is not considered to be dangerous in the environment. Even though the lead content in bismuth shot may not constitute a hazard for acute poisoning attention should still be paid to enforce the limits

for lead in products as well other hazardous substances in non-lead ammunition.

### Lead in Rifle Bullets

This study did not document any serious contamination of Danish birds of prey caused by lead rifle ammunition as documented for white-tailed eagle and golden eagle (*Aquila chrysaetos*) in Germany and Sweden (Kenntner et al. 2001; Krone et al. 2009; Helander et al. 2009). Our survey included 12 white-tailed eagles and two golden eagles, which all showed lead values below background levels. However, our results indicated that lead levels in scavenging species (e.g. common buzzards and red kites) exceeded levels in typical predators (hawks and falcons). For common buzzards, levels were significantly higher e.g. kestrel (Annex 1). This may be explained by exposure from the scavenging species feeding on remains of game animals shot with lead ammunition. In Denmark, lead rifle ammunition is still legal and widely used for deer hunting. Deer populations presently increase considerably in size and distribution. This is accompanied by increased hunting and population control, hence correspondingly increased use of rifle ammunition. Dispersal of lead from rifle ammunition can be reduced if offal from lead shot animals is removed or left inaccessible for scavengers, i.e. buried. Safe handling of meat and remains from animals shot with lead ammunition, and in particular, phasing out all lead rifle ammunition will minimize the risk of poisoning of species and contamination of ecosystems in the future.

### Considerations

Apart from a single extreme value for lead, the observed levels of investigated trace elements in this study are below generally accepted threshold levels and thus not considered critical in terms of impact on behaviour, reproduction or survival of the birds. This applies to birds that have been shot for bird-strike control in airports as well as moribund/found dead birds. As lead gunshot is forbidden for hunting in Denmark, and the regulations are largely enforced and complied with (Kanstrup and Balsby 2019), the exposure to ammunition lead is expected to arise only from fragments of lead rifle bullets in larger game animals. For species that predominately feed on non-hunted species (small birds, rodents, etc.), there is no expected source of ammunition lead. This is complicated by several factors, in particular, that most birds of prey in Denmark are opportunistic and feed depends on season and may consist of both prey and carrions. Furthermore, some of the species included in the study are migratory and may be exposed to lead from ammunition and other sources in other countries at the flyway.

### Conclusion

The examined birds of prey had concentrations of lead, cadmium, mercury, and selenium below the levels demonstrated in comparative studies of birds of prey in other countries and generally below levels considered to be at risk for the bird's health, behaviour, reproduction and for sustaining a favourable conservation status. As for lead, the low concentration is possibly related to the phase out of lead shot for hunting since 1986. However, the results indicated that lead levels in scavenging species exceeded levels in typical predators which may be explained by continued exposure from the scavenging species feeding on remains of game animals shot with lead rifle ammunition as demonstrated in other Northern European countries. There is a correlation between lead and bismuth content in birds reported as shot. This confirms results from other studies showing that bismuth shot contains traces of lead that is deposited with bismuth in the target animal. Attention should be paid to enforce the limits for lead in products as well as other hazardous substances in non-lead ammunition.

**Acknowledgements** We thank Elisabeth Holm, Technical University of Denmark, for liver samples from necropsied birds, Igor Eulears, Aarhus University Bioscience, for technical assistance and comments on previous drafts, and Steen Fjederholt, Nature Agency, Midtjylland, for assisting with information on shot types in the control of wildlife at airports. For funding, we acknowledge The Danish Environmental Protection Agency for the grant to the Danish Academy of Hunting, November 2017 and BONUS BALTHealth that has received funding from BONUS (Art. 185), funded jointly by the EU, Innovation Fund Denmark (Grants 6180-00001B and 6180-00002B), Forschungszentrum Jülich GmbH, German Federal Ministry of Education and Research (Grant FKZ 03F0767A), Academy of Finland (Grant 311966), Swedish Foundation for Strategic Environmental Research (MISTRA), the Ministry of Environment and Food of Denmark (Grant Nos. MST-2013/S 080 135070) and by the National Veterinary Institute. Not least, we thank the reviewers for their constructive comments on this paper.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

### Appendix 1: Statistical Output

See Table 2.

**Table 2** Post hoc least square means differences and estimates between species for each element

	WTE	CB	RK	K	Least square mean estimate
Log Pb					
WTE		0.9362	0.5892	0.0016	− 2.5148
CB			0.4838	< .0001	− 2.4784
RK				0.0205	− 2.8426
K					− 4.1522
Cd					
WTE		0.067	0.429	0.742	− 3.4804
CB			0.18	0.015	− 0.9239
RK				0.53	− 2.1831
K					− 2.9529
Hg					
WTE		0.0013	0.009	0.0003	0.212
CB			0.144	0.062	− 0.8261
RK				0.697	− 2.1549
K					− 1.7624
Bi					
WTE		0.798	0.775	0.803	− 2.0008
CB			0.138	0.702	0.1831
RK				0.142	− 4.6113
K					0.1336
Se					
WTE		0.132	0.127	0.078	0.6328
CB			0.561	0.486	0.2409
RK				0.869	0.02475
K					0.0914

WTE white-tailed eagle (*Haliaeetus albicilla*); CB common buzzard (*Buteo buteo*); RK red kite (*Milvus milvus*); K kestrel (*Falco tinnunculus*)

## References

- Arnemo JM, Andersen O, Stokke S, Thomas VG, Krone O, Pain DJ, Mateo R (2016) Health and environmental risks from lead-based ammunition: science versus socio-politics. *EcoHealth* 13:618. <https://doi.org/10.1007/s10393-016-1177-x>
- Bank-Mikkelsen M (2014) Nye regler for vej for våben og ammunition I: vildtinformation 2014, Miljøministeriet. [https://mst.dk/media/118272/vildtinformation\\_2014.pdf](https://mst.dk/media/118272/vildtinformation_2014.pdf)
- Berny P, Vilagines L, Cugnasse JM, Mastain O, Chollet JY, Joncour G, Razin M (2015) VIGILANCE POISON: illegal poisoning and lead intoxication are the main factors affecting avian scavenger survival in the Pyrenees (France). *Ecotoxicol Environ Saf* 118:71–82. <https://doi.org/10.1016/j.jecoenv201504003>
- Boening DW (2000) Ecological effects, transport, and fate of mercury: a general review. *Chemosphere* 40(12):1335–1351. [https://doi.org/10.1016/S0045-6535\(99\)00283-0](https://doi.org/10.1016/S0045-6535(99)00283-0)
- Clausen B, Wolstrup C (1979) Lead poisoning in game from Denmark. *Dan Rev Game Biol* 11:1–22
- Cornatzer WE, Fogartyand EF, Cornatzer EW (2009) Qualitative and quantitative detection of lead bullet fragments in random venison package donated to the community action food center of North Dakota, 2007. In: Watson RT, Fuller M, Pokras M, Hunt G (eds) Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, Idaho, pp 154–156. ISBN 0-9619389-5-7
- Delahay RJ, Spray CJ (2015) Proceedings of the Oxford Lead Symposium Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, The University of Oxford. <http://oxfordleadsymposium.info/proceedings/>
- Dietz R, Riget F, Johansen P (1996) Lead, cadmium, mercury and selenium in Greenland marine animals. *Sci Total Environ* 186(1–2):67–93. [https://doi.org/10.1016/0048-9697\(96\)05086-3](https://doi.org/10.1016/0048-9697(96)05086-3)
- Durkalec M, Szkoda J, Kolacz R, Opaliński S, Nawrocka A, Zmudzki J (2015) Bioaccumulation of lead, cadmium and mercury in roe deer and wild boars from areas with different levels of toxic metal pollution. *Int J Environ Res* 9:205–212
- Ecke F, Singh NJ, Arnemo JM, Bignert A et al (2017) Sublethal lead exposure alters movement behaviour in free-ranging golden eagles. *Environ Sci Technol* 51:5729–5736
- Espín S, García-Fernández AJ, Herzke D et al (2016) Tracking pancontinental trends in environmental contamination using sentinel raptors—what types of samples should we use? *Ecotoxicology* 25:777. <https://doi.org/10.1007/s10646-016-1636-8>
- Fäth J, Feiner M, Beggel S, Geist J, Göttlein A (2018) Leaching behavior and ecotoxicological effects of different game shot materials in freshwater. *Knowl Manag Aquat Ecosyst* 419:24. <https://doi.org/10.1051/kmae/2018009>
- Fisher IJ, Pain DJ, Thomas VG (2006) A review of lead poisoning from ammunition sources in terrestrial birds. *Biol Cons* 131:421–432
- García-Fernández AJ, Sánchez-García JA, Jiménez-Montalban P, Luna A (1995) Lead and cadmium in wild birds in southeastern Spain. *Environ Toxicol Chem* 14:2049–2058. <https://doi.org/10.1002/etc5620141207>
- García-Fernández AJ, Molas-Guzmán M, Navas I et al (1997) Environmental exposure and distribution of lead in four species of raptors in Southeastern Spain. *Arch Environ Contam Toxicol* 33:76–82
- Gerofke A, Ulbig E, Martin A, Müller-Graf C, Selhorst T et al (2018) Lead content in wild game shot with lead or non-lead ammunition—Does “state of the art consumer health protection” require non-lead ammunition? *PLoS One* 13(7):e0200792. <https://doi.org/10.1371/journal.pone.0200792>
- Green RE, Pain DJ (2019) Risks to human health from ammunition-derived lead in Europe. In Kanstrup N, Thomas VG, Fox AD (eds) Lead in ammunition: Persistent problems and solutions *Ambio* vol 48, Special Issue. <https://doi.org/10.1007/s13280-019-01194-x>
- Grund MD, Cornicelli L, Carlson LT, Butler EA (2010) Bullet fragmentation and lead deposition in white-tailed deer and domestic sheep. *Human Wildlife Interact* 4:257–265
- Haouema S, Hmada N, Najjarb MF, Hania AE, Sakly R (2006) Accumulation of cadmium and its effects on liver and kidney functions in rats given diet containing cadmium-polluted radish bulb. *Exp Toxicol Pathol* 59:77–80
- Helander B, Axelsson J, Borg H, Holm K, Bignert A (2009) Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden. *Sci Total Environ* 407(21):5555–5563. <https://doi.org/10.1016/j.scitotenv.200907027>
- Herring G, Eagles-Smith C, Buck J (2017) Characterizing golden eagle risk to lead and anticoagulant rodenticide exposure: a review. *J Raptor Res* 51(3):273–292. <https://doi.org/10.3356/JRR-16-191>
- Hunt WG, Watson RT, Oaks JL, Parish CN, Burnham KK, Tucker RLJ, Belthoff JR, Hart G (2009) Lead bullet fragments in venison from rifle-killed deer: potential for human dietary exposure. In: Watson RT, Fuller M, Pokras M, Hunt G (eds) Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, Idaho, pp 144–153. ISBN 0-9619389-5-7

- Järup L, Åkesson A (2009) Current status of cadmium as an environmental health problem. *Toxicol Appl Pharmacol* 238(3):201–208. <https://doi.org/10.1016/j.taap.2009.04.020>
- Kalinich JF, Emond CA, Dalton TK, Mog SR, Coleman GD, Kordell J-E, Miller AC, McClain DE (2005) Embedded weapons-grade tungsten alloy shrapnel rapidly induces metastatic high-grade rhabdomyosarcomas in F344 rats. *Environ Health Perspect* 113(6):729–734. <https://doi.org/10.1289/ehp.7791>
- Kanstrup N (2012) Lead in game birds in Denmark: Levels and sources. Article 2012-02-1, Danish Academy of Hunting OneDrive link
- Kanstrup N, Balsby TJS (2019) Danish pheasant and mallard hunters comply with the lead shot ban. In: Kanstrup N, Thomas VG, Fox AD (eds) Lead in ammunition: Persistent problems and solutions *Ambio* vol 48, Special Issue. <https://www.ncbi.nlm.nih.gov/pubmed/30771205>
- Kanstrup N, Balsby TJS, Thomas VG (2016) Efficacy of non-lead rifle ammunition for hunting in Denmark. *Eur J Wildl Res* 62(3):333–334
- Kanstrup N, Thomas, V, Fox AD eds. (2019) Lead in ammunition: Persistent problems and solutions *Ambio* vol 48, Special Issue. In print
- Kenntner N, Tataruch F, Krone O (2001) Heavy metals in soft tissue of white-tailed eagles found dead or moribund in Germany and Austria from 1993 to 2000. *Environ Toxicol Chem* 20:1831–1837
- Kitowski I, Jakubas D, Wiącek D, Sujak A (2017) Concentrations of lead and other elements in the liver of the white-tailed eagle (*Haliaeetus albicilla*), a European flagship species, wintering in Eastern Poland. *Ambio* 46(8):825–841. <https://doi.org/10.1007/s13280-017-0929-3>
- Knutsen HK, Brantsæter A-L, Alexander J, Meltzer HM (2015) Associations between consumption of large game animals and blood lead levels in humans in Europe: the Norwegian experience In: Delahay RJ, Spray CJ (eds) Proceedings of the Oxford Lead Symposium Lead ammunition: understanding and minimising the risks to human and environmental health. Edward Grey Institute, The University of Oxford. [http://www.oxfordleadsymposium.info/wpcontent/uploads/OLS\\_proceedings/papers/OLS\\_proceeding\\_s\\_knutsen\\_brantsaeter\\_alexander\\_meltzer.pdf](http://www.oxfordleadsymposium.info/wpcontent/uploads/OLS_proceedings/papers/OLS_proceeding_s_knutsen_brantsaeter_alexander_meltzer.pdf)
- Kollander B, Widemo F, Ågren E, Larsen EH, Loeschner K (2017) Detection of lead nanoparticles in game meat by single particle ICP-MS following use of lead-containing bullets. *Anal Bioanal Chem* 409:1877–1885. <https://doi.org/10.1007/s00216-016-0132-6>
- Krone O, Kenntner N, Trinogga A, Nadjafzadeh M, Scholz F, Sluwa J, Totschek K, SchuckWersig P, Zieschank R (2009) Lead poisoning in white-tailed sea-eagles causes and approaches to solutions in Germany. In: Watson RT, Fuller M, Pokras M, Hunt G (eds) Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, p 383. ISBN 0-9619389-5-7
- Lazarus M, Crnić AP, Bilandžić N, Kusak J, Reljić S (2014) Cadmium, lead, and mercury exposure assessment among croatian consumers of free-living game. *Arhiv za higijenu rada i toksikologiju* 65(3):281. <https://doi.org/10.2478/10004-1254-65-2014-2527>
- Lemly AD (1993) Guidelines for evaluating selenium data from aquatic monitoring and assessment studies. *Environ Monit Assess* 28(1):83–100. <https://doi.org/10.1007/BF00547213>
- Licata P, Naccari F, Lo Turco V, Rando R, Di Bella G, Dugo G (2010) Levels of Cd (II), Mn (II), Pb (II), Cu (II), and Zn (II) in Common Buzzard (*Buteo buteo*) from Sicily (Italy) by Derivative Stripping Potentiometry. *Int J Ecol* 2010:7. <https://doi.org/10.1155/2010/541948>
- Loureño R, Tavares PC, del Mar Delgado M et al (2011) Superpredation increases mercury levels in a generalist top predator, the eagle owl. *Ecotoxicology* 20:635. <https://doi.org/10.1007/s10646-011-0603-7>
- Lucia M, André JM, Gontier K, Diot N, Veiga J, Davail S (2010) Trace element concentrations (mercury, cadmium, copper, zinc, lead, aluminium, nickel, arsenic, and selenium) in some aquatic birds of the southwest Atlantic coast of France Lucia, M. *Arch Environ Contam Toxicol* 58(3):844–853. <https://doi.org/10.1007/s00244-009-9393-9>
- Nadjafzadeh M, Hofer H, Krone O (2013) The link between feeding ecology and lead poisoning in white-tailed sea eagles. *J Wildl Manag* 77(1):48–57. <https://doi.org/10.1002/jwmg.440>
- Nam D-H, Rutkiewicz J, Basu N (2012) Multiple metals exposure and neurotoxic risk in bald eagles (*Haliaeetus leucocephalus*) from two Great Lakes states. *Environ Toxicol*. <https://doi.org/10.1002/etc.1712>
- Pain DJ (ed) (1992) Lead Poisoning in Waterfowl. In: Proceedings of an IWRB workshop international waterfowl and wetlands research bureau. Brussels, Belgium, p 105
- Pain DJ, Fisher IJ, Thomas VG (2009) A global update of lead poisoning in terrestrial birds from ammunition sources. In: Watson RT, Fuller M, Pokras M, Hunt WG (eds) Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise. <https://doi.org/10.4080/ilsa20090108> (**Key words: Ammunition, glob**)
- Pain DJ, Cromie RL, Newth J, Brown MJ, Crutcher E, Hardman P, Hurst L, Mateo R, Meharg AA, Moran AC, Raab A, Taggart MA, Green RE (2010) Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. *PLoS One* 5(4):e10315. <https://doi.org/10.1371/journal.pone.0010315>
- Pain DJ, Mateo R, Green RE (2019) Effects of lead from ammunition on birds and other wildlife: A review and update. In: Kanstrup N, Thomas, V, Fox AD (eds) Lead in ammunition: persistent problems and solutions. *Ambio* vol 48, Special Issue. In print. <https://doi.org/10.1007/s13280-019-01159-0>
- Ralston NV, Raymond LJ (2010) Dietary selenium's protective effects against methylmercury toxicity. *Toxicology* 278(1):112–123. <https://doi.org/10.1016/j.tox.2010.06.004>
- Sakshaug E, Johnsen GH, Kovacs KM (eds) (2009). *Ecosystem Barents Sea*. ISBN-13: 978-8251924610
- Thomas VG, Roberts MJ, Harrison PTC (2009) Assessment of the environmental toxicity and carcinogenicity of tungsten-based shot. *Ecotoxicol Environ Saf* 72(4):1031–1037. <https://doi.org/10.1016/j.ecoenv.2009.01.001>
- Thomas VG, Kanstrup N, Gremse C (2015) Key questions and responses regarding the transition to use of lead-free ammunition In: Delahay RJ, Spray CJ (eds) Proceedings of the Oxford Lead Symposium Lead ammunition: understanding and minimising the risks to human and environmental health Edward Grey Institute, The University of Oxford. [http://www.oxfordleadsymposium.info/wpcontent/uploads/OLS\\_proceedings/papers/OLS\\_proceeding\\_s\\_thomas\\_kanstrup\\_gremse.pdf](http://www.oxfordleadsymposium.info/wpcontent/uploads/OLS_proceedings/papers/OLS_proceeding_s_thomas_kanstrup_gremse.pdf)
- Tsuji LJS, Wainman BC, Jayasinghe RK, VanSpronsen EP, Liberda EN (2009) Determining tissue-lead levels in large game mammals harvested with lead bullets: human health concerns. *Bull Environ Contam Toxicol* 82(4):435–439
- Watson RT, Fuller M, Pokras M, Hunt G (eds) (2009) Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, Idaho, p 383. ISBN 0-9619389-5-7

# PAPER 23

Arnemo JM, Cromie R, Fox AD, Kanstrup N, Mateo R, Pain DJ, Thomas VG (2019).  
Transition to lead-free ammunition benefits all. *Ambio* 48:1097-1098  
doi:10.1007/s13280-019-01221-x

**RIGHTS:** Open access.

## AUHTORS' CONTRIBUTIONS

To whom it may concern:

This is to confirm that all authors of the following paper contributed equally and were listed alphabetically:

Arnemo JM, Cromie R, Fox AD, Kanstrup N, Mateo R, Pain DJ, Thomas VG (2019) Transition to lead-free ammunition benefits all *Ambio* 48:1097-1098. doi:10.1007/s13280-019-01221-x



Best regards

**Jon M. Arnemo**

DVM, PhD, Professor, Wildlife Veterinarian  
Faculty of Applied Ecology, Agricultural Sciences and Biotechnology  
Department of Forestry and Wildlife Management  
Campus Evenstad, NO-2480 Koppang, Norway  
Mobile phone: +47 995 85 019  
Email: [jon.arnemo@inn.no](mailto:jon.arnemo@inn.no)

To Whom it may Concern

This email is to confirm that Niels Kanstrup made substantial contributions to this paper, of which I am a co-author:

Arnemo, J. M., Cromie, R., Fox, A.D., Kanstrup, N., Mateo, R., Pain, D.J. & Thomas, V.G. 2019. Transition to lead-free ammunition benefits all. *Ambio* 48(9): 1097-1098. Special Issue: LEAD USE IN HUNTING. Online 18 July 2019. <https://doi.org/10.1007/s13280-019-01221-x>

I confirm that the contribution was one of discussion and planning in advance of paper preparation, then reviewing and editing i.e. critical review and commentary.

Yours faithfully,

A handwritten signature in black ink, appearing to read 'Ruth Cromie'.

**Dr. Ruth Cromie,**  
Research Fellow

**Wildfowl & Wetlands Trust (WWT)**  
Slimbridge, Glos GL2 7BT, UK

**M** 07866 942999  
**E** [ruth.cromie@wwt.org.uk](mailto:ruth.cromie@wwt.org.uk)  
**W** [wwt.org.uk](http://wwt.org.uk)

Dear Niels

I hereby confirm the following contribution to the article of which I am an author:

Arnemo, J. M., Cromie, R., Fox, A.D., Kanstrup, N., Mateo, R., Pain, D.J. & Thomas, V.G. 2019. Transition to lead-free ammunition benefits all. *Ambio* 48(9): 1097-1098. Special Issue: LEAD USE IN HUNTING. Online 18 July 2019. <https://doi.org/10.1007/s13280-019-01221-x>

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

A handwritten signature in black ink, appearing to read 'Anthony D. Fox'.

*Professor Anthony D. Fox*  
Department of Bioscience  
Aarhus University  
Køge  
Grenåvej 14  
DK-8410 Rønde  
Denmark

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Rafael Mateo Soria, DVM, PhD  
Group of Wildlife Toxicology  
Instituto de Investigación en Recursos Cinegéticos (IREC) -Spanish Institute of Game and Wildlife Research  
CSIC-UCLM-JCCM  
Ronda de Toledo 12  
13005 Ciudad Real  
Spain

Tel: +34 926 295450 / +34 926 295300 + 6256 or 90321

Fax: +34 926295451

Web <http://www.irec.es>

[https://www.researchgate.net/profile/Rafael\\_Mateo](https://www.researchgate.net/profile/Rafael_Mateo)

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Deborah Pain

Professor Deborah Pain

[dp596@cam.ac.uk](mailto:dp596@cam.ac.uk)

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Dr. Vernon G. Thomas, Professor Emeritus, College of Biological Science, University of Guelph, Guelph, Ontario  
N1G 2W1, Canada

Confirmed, April 2021



Niels Kanstrup

## Transition to lead-free ammunition benefits all

Jon M. Arnemo, Ruth Cromie, Anthony D. Fox, Niels Kanstrup,  
Rafael Mateo, Deborah J. Pain, Vernon G. Thomas

The articles in this Special Issue demonstrate the continued adverse impacts on wildlife, humans, and the environment caused by lead in ammunition and fishing gear. They also show how, to date, actions to eliminate such impacts have been largely confined to the imposition of legal restrictions on the use of lead gunshot for hunting in some wetlands in some countries. The Special Issue concludes that such restrictions address only a subset of risks, often suffer from poor enforcement and compliance, that very few countries have taken fundamental steps to stop the use of lead ammunition and fishing gear, and that the complete and effective phase-out at the national level remains extremely rare. The mismatch between the demonstrable impacts of lead on wildlife, human health, and the environment and the effectiveness of measures taken to remove this avoidable source of pollution could not be starker. While the majority of papers in this Special Issue pertain to Europe, their findings and implications apply globally.

The goal of this Special Issue was not simply to define the problem but also to review solutions and most of the fifteen papers include management options. Understanding the issues, potential solutions, and impediments to their success are crucial in finding effective ways forward. It is our hope that the impact of the Special Issue will be enhanced through the inclusion and review of all of these areas.

The papers in this Special Issue demonstrate the extensive existing scientific understanding of the impacts of lead ammunition on wildlife and humans. Of particular concern is that lead exposure arising from shotgun and rifle shooting, and/or fishing gear, impacts or could impact large numbers of individuals, but also particular populations of waterfowl and scavenging birds, and that increased exposure to dietary lead through the frequent consumption of

wild-shot game presents risks to human health, especially to children and pregnant women.

Despite this substantial evidence base, there remains a need to communicate to a broad range of audiences the benefits that would accrue from the use of non-lead ammunition and fishing gear. These include: avoiding deaths of millions of wild animals from lead toxicosis, which would bolster natural populations and prevent considerable suffering; elimination of risks from ammunition-lead to the health of humans consumers of game; and an end to the annual increase in environmental contamination caused by these persistent lead products, with its concomitant toxic legacy. These benefits would promote the interests of hunters both directly, e.g., through the survival of more quarry animals, and indirectly, through stimulating a more positive public perception of hunting.

Evidence suggests that intransigence of some in the hunting communities and relevant industries, including denial of the scientific evidence upon which phasing-out of lead ammunition is advised, has inhibited progress at the socio-political level. Although such denial has certainly not been universal, evidence suggests that it has impeded progress. Successful transition to the use of non-lead ammunition and fishing weights requires that all sectors support evidence-based progressive policies and regulation at both national and international levels.

### *The Guest Editors and Project Group*

Jon M. Arnemo, Ruth Cromie, Anthony D. Fox, Niels Kanstrup, Rafael Mateo, Deborah J. Pain, and Vernon G. Thomas

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

**Jon M. Arnemo**

*Address:* Inland Norway University of Applied Sciences, Campus Evenstad, 2480 Koppang, Norway.  
e-mail: jon.arnemo@inn.no

**Ruth Cromie**

*Address:* Wildfowl & Wetlands Trust, Slimbridge, Gloucestershire GL2 7BT, UK.  
e-mail: ruth.cromie@wwt.org.uk

**Anthony D. Fox**

*Address:* Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, 8410 Rønde, Denmark.  
e-mail: tfo@bios.au.dk

**Niels Kanstrup** (✉)

*Address:* Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, 8410 Rønde, Denmark.  
e-mail: nk@bios.au.dk

**Rafael Mateo**

*Address:* Instituto de Investigación en Recursos Cinegéticos (IREC), CSIC-UCLM-JCCM, Ronda de Toledo 12, 13005 Ciudad Real, Spain.  
e-mail: rafael.mateo@uclm.es

**Deborah J. Pain**

*Address:* Department of Zoology, University of Cambridge, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK.  
e-mail: pain.debbie@gmail.com

**Vernon G. Thomas**

*Address:* Department of Integrative Biology, College of Biological Sciences, University of Guelph, Guelph, ON N1G 2W1, Canada.  
e-mail: vthomas@uoguelph.ca

# PAPER 24

Kanstrup N, Thomas VG, Fox AD (2019). Foreword. Ambio 48:923-924  
doi:10.1007/s13280-019-01220-y

**RIGHTS:** Open access

## AUTHORS' CONTRIBUTIONS

Kanstrup N, Thomas VG, Fox AD (2019) Foreword Ambio 48:923-924 doi:10.1007/s13280-019-01220-y

- Kanstrup N managed and conceptualized the publication, drafted, edited and revised the manuscript and acted as corresponding author.
- Thomas VG undertook edition and critical commentary.
- Fox AD undertook edition and critical commentary.

I hereby confirm this statement of the authors' contributions to the above mentioned paper.

Vernon G. Thomas, Professor Emeritus, University of Guelph, Guelph, Ontario N1G 2W1

Dear Niels

I hereby confirm the following contribution to the article of which I am an author:

Kanstrup N, Thomas VG, Fox AD (2019) Foreword Ambio 48:923-924 doi:10.1007/s13280-019-01220-y

- Kanstrup N managed and conceptualized the publication, drafted, edited and revised the manuscript and acted as corresponding author.
- Thomas VG undertook edition and critical commentary.
- Fox AD undertook edition and critical commentary.

I hereby confirm this statement of the authors' contributions to the above mentioned paper.

Yours sincerely



Professor Anthony D. Fox  
Department of Bioscience  
Aarhus University  
Kalø  
Grenåvej 14  
DK-8410 Rønde  
Denmark

Confirmed, April 2021



Niels Kanstrup



## Foreword

Niels Kanstrup, Vernon G. Thomas, Anthony D. Fox

The evidence for the adverse impacts of lead in hunting ammunition grows relentlessly. The highly toxic effects of lead gunshot to waterbirds have long been recognized, but many non-wetland species are also prone to ingesting gunshot. Avian predators and scavengers are poisoned when they consume meat from animals shot with either lead gunshot or fragmented lead rifle bullets. The cause for concern about lead ammunitions has widened markedly over the last decade to encompass multiple wildlife taxa, habitats other than wetlands, as well as to embrace food safety and human health.

Impacts of lead ammunition on species and ecosystems have been addressed directly or indirectly in multiple international Multilateral Environmental Agreements. Globally, lead gunshot has been subject to legislative and other forms of regulation in many countries over the last 40 years, especially for the protection of wildfowl and their wetland habitats. However, few countries have regulated lead gunshot outside wetland habitats or lead in rifle ammunition (California now being the exception).

It is evident that (1) the problem exists and requires action, (2) it is well documented, (3) lead-free ammunition is available, (4) the social constituencies responsible are identified, and (5) the solutions are apparent. Nevertheless, action at international and national levels is either lacking or progress is slow. The question is: why is this? Major lobby organizations actively oppose attempts to ban, or even restrict, the use of lead-based ammunition, either out of commercial interests or because it is viewed as an unjustified intervention, which fundamentally affects the right to hunt and is therefore construed as anti-hunting. Hunters are well-organized at national and international levels, and are represented effectively by industry and wealthy, politically influential groups, including heads of state and royalty, which potentially restricts the level of

debate. Indeed, the public can be surprisingly unaware of the problems, and decision-makers fail to act appropriately in the complex and diverse interplay between socio-political and economic interests, especially where the debate may often be dominated by false or anecdotal information.

We believe that the most constructive way to reduce the use of lead ammunition is through continued and persistent documentation of the problems, clear presentation of solutions and more effective outreach at all levels. Clearly, the foundation for this should be sound science. The evidence for the impact of lead from hunting ammunition on wildlife and ecosystems is overwhelming (Arnemo et al. 2016). However, it is often widely scattered and poorly synthesized. A series of scientific publications to improve organization of the existing knowledge would greatly improve our ability to support informed debate and provide the evidence base to international and national decision makers, the press, stakeholders, and the public.

In the last decade, two major compilations of scientific research were published as proceedings from international conferences (Watson et al. 2009; Delahay and Spray 2015). Both are valuable sources of background evidence for the problems and provide tools to manage the problems associated with dispersal of lead from hunting ammunition in the natural environment. This Ambio Special Issue “Lead in ammunition: Persistent problems and solutions” represents a third step to inform further discussion. This Special Issue will contribute significantly to better defining the problems and solutions associated with lead ammunition in the environment and reducing the adverse impacts of lead on species and ecosystems.

This Special Issue has relied upon the work of very many people. We thank the authors for contributing their research results and original data and the many reviewers for ensuring the scientific quality of the submissions. Many

institutions and persons provided significant support to the production of this collection of papers, including grants from the 15. Juni Fonden (Denmark) to produce the Special Issue, and the Aarhus University DCE - Danish Centre For Environment And Energy for the costs of printing and distribution. We thank our colleague members of the Project Group, Dr. Debbie Pain, Dr. Ruth Cromie, Dr. Jon Arnemo, and Dr. Rafael Mateo, for supporting the initial idea of this publication and for prompt feedback on consultations during the whole production process. Finally, we thank the Editor in Chief of Ambio, Dr. Bo Söderström, and his staff for ensuring the production and publication of the final edition.

#### *The Guest Editors*

Niels Kanstrup, Vernon G. Thomas, and Anthony D. Fox

## REFERENCES

- Arnemo, J.M., O. Andersen, S. Stokke, V.G. Thomas, O. Krone, D.J. Pain, and R. Mateo. 2016. Health and environmental risks from lead-based ammunition: Science versus socio-politics. *Eco-Health* 13: 618–622.
- Delahay, R.J., and C.J. Spray. 2015. *Proceedings of the Oxford lead symposium. Lead ammunition: Understanding and minimising the risks to human and environmental health*. Edward Grey Institute, The University of Oxford. <http://oxfordleadsymposium.info>.
- Watson, R.T., M. Fuller, M. Pokras, and G. Hunt, eds. 2009. *Ingestion of lead from spent ammunition: Implications for wildlife and humans*, ed. The Peregrine Fund, Boise, Idaho. ISBN 0-9619389-5-7. [https://www.peregrinefund.org/substitutes/conference-lead/2008PbConference\\_Proceedings.htm](https://www.peregrinefund.org/substitutes/conference-lead/2008PbConference_Proceedings.htm).

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## AUTHOR BIOGRAPHIES

**Niels Kanstrup** (✉) is a biologist, scientist and hunter. His research program is focused on sustainability of hunting with emphasis on dispersal of ammunition components in the natural environment, particularly the impact of ammunition lead.

*Address:* Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, 8410 Rønde, Denmark.

e-mail: nk@bios.au.dk

**Vernon G. Thomas** is a Professor Emeritus specializing in the transfer of scientific knowledge to conservation policy and law, especially in the issue of lead exposure and toxicity in wildlife and humans.

*Address:* Department of Integrative Biology, College of Biological Sciences, University of Guelph, Guelph, ON N1G 2W1, Canada.

e-mail: vthomas@uoguelph.ca

**Anthony D. Fox** is a Professor of Waterbird Ecology at Aarhus University. His research focuses on applied waterbird issues throughout the northern hemisphere.

*Address:* Department of Bioscience, Aarhus University, Kalø, Grenåvej 14, 8410 Rønde, Denmark.

e-mail: tfo@bios.au.dk



# PAPER 25

Sonne C, Alstrup AKO, Ok YS, Dietz R, Kanstrup N (2019). Time to ban lead hunting ammunition. Science 366:961 doi:10.1126/science.aaz8150

## RIGHTS:

**Thank you for your order!**

Dear Mr. Niels Kanstrup,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

## Order Summary

Licensee:	Aarhus University
Order Date:	Mar 8, 2020
Order Number:	4784331485878
Publication:	Science
Title:	Time to ban lead hunting ammunition
Type of Use:	Thesis / Dissertation
Order Ref:	Science
Order Total:	0.00 EUR

View or print complete [details](#) of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777  
[customercare@copyright.com](mailto:customercare@copyright.com)  
<https://myaccount.copyright.com>



## AUTHORS' CONTRIBUTIONS

Sonne C, Alstrup AKO, Ok YS, Dietz R, Kanstrup N (2019) Time to ban lead hunting ammunition Science 366:961 doi:10.1126/science.aaz8150

I hereby confirm, that Kanstrup N made a substantial contribution to the above mentioned paper, of which I am an author. He assisted the conceptualization and provided edition and critical commentary.

Best regards,

---

**Professor (Full) Christian Sonne**

Veterinary Ecotoxicology and Wildlife Health  
DVM, PhD, dr.med.vet., Dipl. ECZM-EBVS (Wildlife Health)  
Aarhus University, Faculty of Technical Sciences  
Department of Bioscience, Arctic Research Centre (ARC)  
Danish Centre for Environment and Energy (DCE)  
Frederiksborgvej 399, POBox 358  
DK-4000 Roskilde, Denmark.  
E-mail: [cs@bios.au.dk](mailto:cs@bios.au.dk); Tel: +4530783172;  
Fax: +4587155015

**Affiliation outside AU**

Visiting Adjunct Professor@Henan Agricultural University  
Distinguished Professor@Nanjing Forestry University  
Invited Specialist@IUCN PMSG  
Editor-in-Chief@Environmental Pollution  
Editor-in-Chief@Environmental Advances  
Associated Editor@Environmental Research  
Section Editor@Heliyon & Subject Editor@Wildlife Biology  
EBM@Environment International & DIB  
Skype: christian.sonne72  
PURE; Publons; ResearchGate; ORCID; Google Scholar

Sonne C, Alstrup AKO, Ok YS, Dietz R, Kanstrup N (2019) Time to ban lead hunting ammunition Science 366:961 doi:10.1126/science.aaz8150

Niels Kanstrup,  
biolog, adjungeret lektor  
Aarhus Universitet,  
Institut for Bioscience  
Kalø Grenåvej 14  
DK-8410 Rønde

**Co-author statement****Aarhus, 15-April 2021.**

I hereby confirm the following contribution to the article of which I am an author:

**Sonne C, Alstrup AKO, Ok YS, Dietz R, Kanstrup N (2019) Time to ban lead hunting ammunition Science 366:961 doi:10.1126/science.aaz8150**

- Sonne, C managed and conceptualized the project, drafted the manuscript, processed and analysed data, edited and revised the manuscript and served as corresponding author.
- Kanstrup, N undertook data analysis and critical review and commentary.
- Alstrup AKO undertook critical review and commentary.
- Dietz, R undertook critical review and commentary.
- Ok YS undertook critical review and commentary.
- All authors approved the final revised manuscript.

Kind regards



**Aage Kristian Olsen Alstrup**  
Specialdyrlæge i Forsøgsdyrsmedicin, ph.d.  
Nuklearmedicinsk Afdeling & PET-center  
Aarhus Universitetshospital,  
kontor J118-158  
Palte Juul-Jensens Boulevard 165,  
Indgang J  
DK- 8200 Aarhus N

I hereby confirm, that Kanstrup N made a substantial contribution to the above mentioned paper, of which I am an author. He assisted the conceptualization and provided edition and critical commentary.

Yes, I confirm.

[Yong Sik Ok](#), Highly Cited Researcher 2018-2020

Full Professor, Korea University, Korea

Honorary Professor, The University of Queensland, Australia

Director, [APRU Sustainable Waste Management](#)

Director, [Korea Biochar Research Center](#)

Conference Chairman

[5th Asia Pacific Biochar Conference](#) (10 - 13 May 2021, Hong Kong)

[3rd Tsinghua Forum on Environmental Remediation](#) (15 - 16 May 2021, Beijing)

[3rd Sustainable Waste Management Conference](#) (4 - 8 August, Virtual)

[Nature Conference](#) (26 - 28 Oct 2021, Seoul)

[PYRO Asia 2021](#) (29 Oct - 2 Nov 2021, Seoul)

Co-Editor-in-Chief, [Critical Reviews in Environmental Science and Technology](#) (IF 8.302)

Editor, [Environmental Pollution](#) (IF 6.762)

Editorial Advisory Board, ACS [Environmental Science and Technology](#) (ES&T)

Advisory Board, RSC [Environmental Science: Water Research & Technology](#) (ESWRT)

Niels Kanstrup, biolog, adjungeret lektor  
Aarhus Universitet, Institut for Bioscience - Kale  
Grenåvej 14  
DK-8410 Rønde

#### Co-author statement

I hereby confirm the following contribution to the article of which I am an author:

Sonne C, Alstrup AKO, Ok YS, Dietz R, Kanstrup N (2019) Time to ban lead hunting ammunition Science 366:961 doi:10.1126/science.aaz8150

- Sonne, C managed and conceptualized the project, drafted the manuscript, processed and analysed data, edited and revised the manuscript and served as corresponding author.
- Kanstrup, N undertook data analysis and critical review and commentary.
- Alstrup AKO undertook critical review and commentary.
- Dietz, R undertook critical review and commentary.
- Ok YS undertook critical review and commentary.
- All authors approved the final revised manuscript.

Kind regards



Rune Dietz  
Professor

Confirmed, April 2021



Niels Kanstrup



## LETTERS

Edited by Jennifer Sills

### EU Court: Science must justify future hunting

For strictly protected species in Europe, the 1992 Habitats Directive requires EU Member States to implement conservation actions that include a ban on their capture and killing (1). Several Member States have creatively evaded this requirement to allow annual hunting of some of these species, including wolf (*Canis lupus*), bear (*Ursus arctos*), and lynx (*Lynx lynx*), by exploiting provisions that allow exceptions to strict protection (2). The Directive allows limited exceptions to achieve particular goals when there is no satisfactory alternative and making the exception would not harm the conservation status of the species' populations. A recent decision by the Court of Justice of the European Union (CJEU) (3) makes it much harder for Member States to interpret these provisions to allow hunting and rightly centers future policy decisions on the results of scientific research.

The case, initiated by the nongovernmental nature-protection organization Tapiola, challenged Finland's justification of wolf hunting as a conservation measure needed to prevent poaching (4). The CJEU ruled that the prevention of poaching is a legitimate conservation goal that might justify exceptions from strict protection. However, it also interpreted the associated conditions in such a strict manner that in

practice it will be difficult to justify hunting for this purpose (3).

This ruling lays out important limitations on hunting strictly protected species throughout the EU (3). First, Member States cannot allow hunting for conservation purposes unless rigorous scientific studies indicate that hunting would have a positive net impact on the strictly protected population. Second, exceptions from strict protection may be used only as a last resort for achieving their claimed purposes. The Member State must be able to demonstrate, with reference to scientific sources, that there is no other satisfactory alternative. Third, the CJEU emphasized that the precautionary principle prevents Member States from making exceptions to strict protection if the best available science leaves uncertainty as to whether the conservation status of populations involved would be negatively affected.

This decision makes explicit the need for good science to inform environmental protection laws. Examples of how conservation scientists and others can contribute include modeling the demographic and ecological impacts of exemptions and identifying scientifically grounded alternative solutions to hunting. A greater awareness of the legal questions that require the help of scientists to answer could result in more policy-relevant research agendas and improved environmental decision-making.

Yaffa Epstein<sup>1\*</sup>, José Vicente López-Bao<sup>2</sup>,

Arie Trouwborst<sup>3</sup>, Guillaume Chapron<sup>4</sup>

<sup>1</sup>Faculty of Law, Uppsala University, 753 09 Uppsala, Sweden. <sup>2</sup>Research Unit of Biodiversity (UO/

An EU decision will make hunting strictly protected species such as the lynx more difficult to justify.

CSIC/PA), Oviedo University, E-33600 Mieres, Spain. <sup>3</sup>Department of European and International Law, Tilburg University, 5000 LE Tilburg, The Netherlands. <sup>4</sup>Department of Ecology, Swedish University of Agricultural Sciences, 73091 Riddarhyttan, Sweden.

\*Corresponding author.

Email: yaffa.epstein@jur.uu.se

#### REFERENCES AND NOTES

1. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (1992); <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31992L0043>.
2. A. Christiernsson, *J. Eur. Environ. Plan. Law* **16**, 237 (2019).
3. Court of Justice of the European Union, *Luonnonsuojeluyhdistys Tapiola Pohjois-Savo—Kainuury, case C-674/17* (2019); <http://curia.europa.eu/juris/celex.jsf?celex=62017CJ0674>.
4. J. Darpö, *J. Eur. Environ. Plan. Law* **16**, 305 (2019).

#### COMPETING INTERESTS

Y.E. and G.C. receive funding for a project that touches on hunting and conservation issues from Riksbankens jubileumsfond and have previously (within the past 3 years) received funding for species conservation research from the Swedish Environmental Protection Agency. J.V.L.-B. is a member of the IUCN Canid Specialist Group. A.T. is a member of the IUCN Large Carnivore Initiative for Europe. G.C. is a member of the IUCN Large Carnivore Initiative for Europe, IUCN Canid Specialist Group, and IUCN Cat Specialist Group.

10.1126/science.aaz8424

### Time to ban lead hunting ammunition

Despite evidence that lead is an extremely neurotoxic and persistent element (1), its use in hunting ammunition continues. The European Chemicals Agency (ECHA) is conducting an investigation into ammunition-derived lead's risk to wildlife and humans, but its results will take time (2). Individuals and organizations must take immediate action—independent of governmental legislation—to stop the use of lead in hunting ammunition.

ECHA estimates that 35,000 tons of lead is released into Europe's environment each year, including 5000 tons dispersed into wetlands (3). Ammunition-derived lead has caused suffering and population declines in the region's birds (4, 5). Losses due to lead ammunition cost USD1.1 billion per year in terms of lost wildlife and biodiversity, environmental health, and socio-economy as measured by hospitalizations and loss of IQ (6). Yet, EU legislation is rare, and only Denmark and the Netherlands have enacted total bans on lead shot (7).

In the United States, documentation of the adverse effects of ammunition-derived lead on wildlife dates back to the 1870s (8). Evidence of millions of water bird deaths annually (9) resulted in a phase-out of lead

# Where Science Gets Social.

## AAAS.ORG/COMMUNITY

AAAS' Member

Community is a one-stop destination for scientists and STEM enthusiasts alike. It's "Where Science Gets Social": a community where facts matter, ideas are big and there's always a reason to come hang out, share, discuss and explore.

Member  
**COMMUNITY**  
AAAS

shot for hunting in 1991 (10). By 2017, a federal ban on all lead ammunition use on federal land was declared; however, the Trump administration revoked the ban shortly afterward (11). Encouragingly, a total ban on all lead hunting ammunition took effect on 1 July 2019 in California (12).

We urge national hunter's organizations across Europe, the United States, and worldwide to collaborate and persuade members and industry to phase out the use and production of lead hunting ammunition. This approach would promote the interests of hunters through the survival of more quarry animals and through the stimulation of a more positive public perception of hunting. Moreover, it would protect the environment and prevent further harm to wildlife.

Christian Sonne<sup>1,2\*</sup> Aage K. O. Alstrup<sup>3</sup>,  
Yong Sik Ok<sup>2,4</sup>, Rune Dietz<sup>1</sup>, Niels Kanstrup<sup>5</sup>

<sup>1</sup>Aarhus University, Roskilde, Denmark. <sup>2</sup>School of Forestry, Henan Agricultural University, Zhengzhou, China. <sup>3</sup>Aarhus University, Aarhus, Denmark. <sup>4</sup>Korea University, Seoul, Korea. <sup>5</sup>Aarhus University, Kåge, Denmark.

\*Corresponding author. Email: cs@bios.au.dk

### REFERENCES AND NOTES

1. World Health Organization, "Preventing disease through healthy environments," (2010); [www.who.int/ipcs/features/lead.pdf](http://www.who.int/ipcs/features/lead.pdf).
2. European Chemicals Agency, "Registry of restriction intentions until outcome" (2019); <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e1840159e6>.
3. European Chemicals Agency, "ECHA identifies risks to terrestrial environment from lead ammunition" (2018); <https://echa.europa.eu/-/echa-identifies-risks-to-terrestrial-environment-from-lead-ammunition>.
4. R. J. Williams *et al.*, *Rev. Environ. Contam. Toxicol.* **245**, 157 (2018).
5. A. H. Boesen *et al.*, *Front. Vet. Sci.* **6**, 285 (2019).
6. D. J. Pain *et al.*, *Ambio* **48**, 969 (2019).
7. R. Mateo *et al.*, *Ambio* **48**, 989 (2019).
8. M. Friend, J. C. Franson, W. L. Anderson, in *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, R. T. Watson, M. Fuller, M. Pokras, W. G. Hunt, Eds. (The Peregrine Fund, Boise, ID, 2009), pp. 34–60.
9. C. F. Bellrose, *Illinois Natural Hist. Survey Bull.* **27**, 235 (1959).
10. D. Avery, R. T. Watson, in *Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans*, R. T. Watson, M. Fuller, M. Pokras, W. G. Hunt, Eds. (The Peregrine Fund, Boise, ID, 2009), pp. 161–168.
11. V. Volcovic, "New Interior head lifts lead ammunition ban in nod to hunters," *Reuters* (2017); [www.reuters.com/article/us-usa-interior-zinke/new-interior-head-lifts-lead-ammunition-ban-in-nod-to-hunters-idUSKBN16930Z](http://www.reuters.com/article/us-usa-interior-zinke/new-interior-head-lifts-lead-ammunition-ban-in-nod-to-hunters-idUSKBN16930Z).
12. California Department of Fish and Wildlife (2019); [www.wildlife.ca.gov/Hunting/Nonlead-Ammunition](http://www.wildlife.ca.gov/Hunting/Nonlead-Ammunition).

10.1126/science.aaz8150

## Beyond meat: Ecological functions of livestock

Livestock production and meat consumption are major drivers of biodiversity

loss and carbon emissions globally (1, 2). Governments and civil society will have to prioritize the reduction of livestock numbers and meat consumption [e.g., (2, 3)] to mitigate impacts and achieve international sustainability goals. However, traditional livestock systems also play a role in biodiversity conservation, climate adaptation, and socioecological resilience at regional and local scales.

In Europe, traditional breeds of free-range livestock are fulfilling conservation goals by securing the ecological role of wild large herbivores that are long absent or in low abundance (4). These livestock breeds may include traditional breeds of cattle, often grazing unattended, and small herds of domestic goats or sheep that contribute to the maintenance of high-nature-value habitats and diverse landscape mosaics, the regulation of vegetation growth and structure (also linked to fire prevention, especially in southern Europe), and the maintenance of genetic diversity, local identity, and knowledge (5, 6).

As the 2021–2030 UN Decade on Ecosystem Restoration approaches (7), agri-environmental schemes and labeling and certification schemes (8) should adopt proactive measures that go beyond impact mitigation. Sustainable use of traditional livestock systems can help restore and manage biodiversity and ecosystem services where their maintenance contributes to local, regional, and ultimately global conservation goals.

Vânia Proença\* and Carlos M. G. L. Teixeira  
MARETEC, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal.

\*Corresponding author.

Email: [vania.proenca@tecnico.ulisboa.pt](mailto:vania.proenca@tecnico.ulisboa.pt)

### REFERENCES AND NOTES

1. A. Marques *et al.*, *Nat. Ecol. Evol.* **3**, 628 (2019).
2. H. C. J. Godfray *et al.*, *Science* **361**, eaam5324 (2018).
3. R. Harrabin, "Plant-based diet can fight climate change—UN," *BBC* (2019); [www.bbc.com/news/science-environment-49238749](http://www.bbc.com/news/science-environment-49238749).
4. S. J. G. Hall, R. G. H. Bunce, *Ecol. Evol.* **9**, 5859 (2019).
5. S. J. G. Hall, *People Nat.* **1**, 284 (2019).
6. R. Lovreglio, O. Meddour-Sahar, V. Leone, *iForest* **7**, 260 (2014).
7. UNEP, "New UN Decade on Ecosystem Restoration offers unparalleled opportunity for job creation, food security and addressing climate change," UNEP (2019); [www.unenvironment.org/news-and-stories/press-release/new-un-decade-ecosystem-restoration-offers-unparalleled-opportunity](http://www.unenvironment.org/news-and-stories/press-release/new-un-decade-ecosystem-restoration-offers-unparalleled-opportunity).
8. Global Nature Fund, Lake Constance Foundation, "Baseline Report : Biodiversity in Standards and Labels for the Food Sector," LIFE (2017); [www.business-biodiversity.eu/en/baseline-report](http://www.business-biodiversity.eu/en/baseline-report).

### COMPETING INTERESTS

V.P. is the scientific coordinator of a project conducted by Terraprima as part of her research activity at MARETEC. V.P. and C.M.G.L.T. have been financially supported in the past through short-term contracts by Terraprima.

10.1126/science.aaz7084

## Time to ban lead hunting ammunition

Christian Sonne, Aage K. O. Alstrup, Yong Sik Ok, Rune Dietz and Niels Kanstrup

*Science* **366** (6468), 961-962.  
DOI: 10.1126/science.aaz8150

### ARTICLE TOOLS

<http://science.sciencemag.org/content/366/6468/961.2>

### REFERENCES

This article cites 8 articles, 0 of which you can access for free  
<http://science.sciencemag.org/content/366/6468/961.2#BIBL>

### PERMISSIONS

<http://www.sciencemag.org/help/reprints-and-permissions>

Use of this article is subject to the [Terms of Service](#)

---

*Science* (print ISSN 0036-8075; online ISSN 1095-9203) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. The title *Science* is a registered trademark of AAAS.

Copyright © 2019 The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works

# PAPER 26

Thomas VG, Pain DJ, Kanstrup N (2021). Restrictions on the use of lead ammunition in the European Union: Issues of enforcement and compliance. Environmental Policy and Law. **Submitted after revision.**

**RIGHTS:** Open access.

## AUTHORS' CONTRIBUTIONS

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above, of which I am first author, was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Prof. Emeritus Vernon Thomas  
Department of Integrative Biology, College of Biological Science, University of Guelph,  
Guelph, Ontario N1G 2W1, Canada

Email: vthomas@uoguelph.ca

\*\*\*

Thomas VG, Pain DJ, Kanstrup N (2021) Restrictions on the use of lead ammunition in the European Union: Issues of enforcement and compliance Environmental Policy and Law. Subm.

To whom it may concern,

I hereby confirm that the contribution of Niels Kanstrup to the paper listed above was one of discussion and planning in advance of paper preparation, then reviewing and editing (i.e. critical review and commentary).

Yours sincerely

Deborah Pain  
Professor Deborah Pain  
[dp596@cam.ac.uk](mailto:dp596@cam.ac.uk)  
<https://www.zoo.cam.ac.uk/directory/debbie-pain>

Confirmed, April 2021



Niels Kanstrup

# Promoting the transition to non-lead hunting ammunition in the European Union through regulation and policy options

Vernon G. Thomas<sup>\*1</sup> Niels Kanstrup<sup>\*\*</sup> and Deborah J. Pain<sup>\*\*\*</sup>

<sup>\*</sup> Professor Emeritus, Department of Integrative Biology, College of Biological Science, University of Guelph, Guelph, Ontario N1G 2W1, Canada.

<sup>\*\*</sup> Adjunct Associate Professor, Department of Biosciences, Aarhus University, Grenåvej 14, 8410 Ronde, Denmark.

<sup>\*\*\*</sup> Honorary Professor, School of Biological Sciences, University of East Anglia, Norwich, NR4 7TJ, UK; Honorary Research Fellow, Department of Zoology, University of Cambridge, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK.

**Abstract** Regulation (EU) 2021/57, banning the use of lead gunshot in wetland hunting, and adoption of the proposed European Union (EU) restriction on lead ammunition use by civilians in other types of hunting and target shooting, would complete the transition to non-lead ammunition use in the EU and ensure major compliance among hunters and shooters. The transition is possible since non-lead substitutes for all types of shotgun and rifle ammunition are produced already by leading European manufacturers. To ensure ammunition non-toxicity, EU standards are needed for lead substitutes to accompany both existing and potential future lead ammunition restrictions. Meat from wild game birds and mammals is a large and important commodity in the EU. Setting a maximum lead level in all marketed game meats under Regulation (EC) 1881/2006, aided by mandatory food labelling, would add extra health protection to human consumers. This regulatory step would help ensure that all wild game destined for retail markets were taken with non-lead ammunition, would complement existing and proposed European Commission restrictions on lead hunting ammunition and aid monitoring and enforcement. Increased public awareness of the risks posed by lead from ammunition to the health of humans, wildlife, and the environment, and especially their associated externalized costs to society, would promote and facilitate the passage of regulation to protect human and environmental health from toxic lead ammunition.

**Keywords:** Hunting, transition, compliance, human, wildlife, health, externalized costs

## 1. Introduction

Lead poisoning in waterfowl resulting from the ingestion of spent lead gunshot, mistakenly for grit or food, has been recognised for more than a century<sup>1</sup>. At an international workshop on lead poisoning in waterfowl in Brussels in 1991<sup>2</sup> it was concluded that solving this problem required the replacement of lead gunshot with non-toxic alternatives, and that suitable alternatives were already available and in use. This stimulated new policy initiatives, and the Contracting Parties to the intergovernmental treaty, the African-Eurasian Migratory Waterbirds Agreement (AEWA) agreed to endeavour to phase out the use of lead shot in wetlands by 2000. The European Union (EU) *en bloc* is an AEWA Party, as are most EU countries individually except Austria, Greece, Malta, and Poland<sup>3</sup>. However, some EU Member States (Ireland, Greece, Poland, Slovenia, and Romania) still have not taken action, and some others have not met their AEWA obligations by not fully enacting restrictions over wetlands (i.e. member states that re-

---

<sup>1</sup> Corresponding author. Tel.: 519-822-7662 (Home) 519-824-4120 Ext 52738 (Office) E-mail: [vthomas@uoguelph.ca](mailto:vthomas@uoguelph.ca)

strict only within designated sites)<sup>4</sup>. Limited progress by 2008 resulted in AEWA further calling on Contracting Parties to phase out the use of lead gunshot over wetlands as soon as possible, whilst obligations made in 2014 by the EU and its member states under the Convention on Migratory Species recommended a full phase out of all lead ammunition<sup>5,6</sup>.

Given limited and inconsistent progress under AEWA, in 2015, the European Commission (EC) initiated a process to evaluate and, if necessary, restrict the use of lead gunshot in wetlands under the REACH Regulation (Regulation for the Registration, Evaluation, Authorisation and Restriction of Chemicals). The process is outlined in Table 1. The EC requested the European Chemicals Agency (ECHA) to propose a restriction on the use of lead gunshot over wetlands. Following calls for and scrutiny of evidence, in April 2017, ECHA completed an Annex XV dossier proposing a restriction on the use of lead gunshot in and over wetlands<sup>7</sup>. Following a wide public consultation, the dossier was passed to the two ECHA technical committees, the Committee for Risk Assessment (RAC) and the Committee for Socio-economic Analysis (SEAC), for assessment. The RAC commented particularly on the relevance of the proposed restriction for reducing risks to human health and the environment. After further consultation, in June, 2018, both technical committees adopted ECHA's proposal that lead gunshot requires restriction in wetlands.

The usual EU procedure is for there to be a period of about three months after receipt of the compiled RAC and SEAC opinions during which the EC can consider and, if necessary, amend the proposal before it is voted upon by the EU REACH Committee (representing EU member states). The EC amended several aspects of the wetland restriction to ensure its enforceability and maximise the health protection of the proposal. The restriction was subject to considerable national lobbying from hunting and ammunition interests and many delays. Consequently, the REACH Committee vote did not take place until September 3, 2020, when it approved the restriction, with 18 of the 27 member states voting for the restriction, 5 against, and 4 abstentions<sup>8</sup>. The 18 States that voted in favour hold c.90% of the EU population, surpassing the required 65% population threshold (i.e. qualified majority) by a considerable margin (Table 1). On November 29, 2020, the European Parliament voted to accept the restriction, and on January 25, 2021, the Members of the European Council ratified European Commission Regulation (EU) 2021/57<sup>9</sup> which is due to take effect on February 15, 2023. This Regulation will satisfy the EU's obligation to the AEWA, but requires individual member states and Schengen states to enforce the ban at their national level.

With this restriction, the EU has adopted a regulatory, as opposed to a non-regulatory, approach to the lead ammunition issue<sup>10</sup> which is similar to the regulative approaches taken by other jurisdictions, both within and outside the EU. The EU Regulation also parallels the regulative approaches taken by the EU to restrict the use of lead in other anthropogenic uses (e.g. gasolines, paints, and solders). In all these cases, regulation is possible because effective and available lead substitutes exist. The same applies to lead gunshot substitutes which are already made by leading European companies<sup>11</sup>.

In September, 2018, ECHA published, at the Commission's request, a report on the use of lead shot in terrestrial environments beyond wetlands, other types of ammunition (bullets), and fishing tackle<sup>12</sup>. This report built on evidence gathered under the earlier restriction proposal for wetlands and concluded that there was sufficient evidence of risk from those other uses to justify additional regulatory measures. Consequently, in July, 2019 the Commission asked ECHA<sup>13</sup> to prepare a restriction proposal on the placing on the market and use of lead in ammunition (gunshot and bullets) and of lead in fishing tackle conforming to the requirements of Annex XV to REACH. This restriction request covered both wetland and terrestrial habitats. Having assessed various risk management options, ECHA identified a preferred option to address the risks to the environment and human health in a proposal brought forward in February 2021. This option was summarised as<sup>14</sup>:

"1. Lead sold and used in hunting, sports shooting and other outdoor shooting:

ban on the sale and use of lead gunshot (with a five-year transition period). As current Olympic rules specify the use of lead ammunition for certain disciplines, ECHA also considered an optional derogation for use of lead gunshot for sports shooting only under strict conditions, i.e. when releases to the environment are minimised.

ban on the use of lead in bullets and other projectiles (small calibre: five-year; large calibre: 18-month transition periods). Derogations for continued use if releases to the environment are minimised, i.e. when sports shooting ranges are equipped with bullet traps.”

Lead fishing tackle is also included within this restriction but not dealt with further in our analysis. The restriction process is ongoing (at the time of writing) with a provisional timetable as outlined in Table 1.

Lead from ammunition presents well-established risks, not only to waterfowl, but also to terrestrial birds, including scavengers and predators, that ingest lead fragments from ammunition when eating shot and injured or unretrieved game, or gralloch (discarded viscera of large game animals<sup>15</sup>). Because of the large body of peer-reviewed literature on the subject<sup>16</sup>, there is a consensus on the risks that lead ammunition poses to human and wildlife health which is supported by the scientific community in Europe and globally<sup>17</sup>. As well as publishing evidence-based consensus statements, scientists with expertise in this area have also recently produced open letters commending the European Commission for initiating the development of restriction proposals and encouraging a rapid transition away from all lead ammunition to non-toxic alternatives<sup>18</sup>.

There was considerable opposition to Regulation (EU) 2021/57 on the use of lead gunshot in and over wetlands, largely from the ammunition industry and the game hunting and shooting communities<sup>19</sup>, and this is also true of broader transitions to the use of all non-lead ammunition. The resistance to change occurs despite available European-made non-lead substitutes for both shotgun and rifle ammunition<sup>20</sup> and widespread acknowledgement that these perform well, and especially for rifle calibres over 0.243. Even bullet calibres of 0.243 and smaller, for which options were previously more restricted, are now produced more widely, partly due to stimulation of the market by enactment of a ban on all lead ammunition use for hunting in California State (USA) from July, 2019<sup>21</sup>. Nonetheless, restrictions on the use of lead gunshot were implemented decades ago in some countries, both within and beyond the EU. These include the USA (1991), and Canada (1999), where it is illegal to shoot migratory wildfowl while in possession of lead gunshot<sup>22</sup>, and also the Netherlands and Denmark where use of lead gunshot was banned for all types of shooting and in all habitats in 1993 and 1996, respectively<sup>23</sup>. However, seven EU nations, Greece, Ireland, Lithuania, Malta, Poland, and Slovenia, had no restrictions on lead ammunition<sup>24</sup>.

A comparison of the efficacy of the complete ban on lead gunshot in Denmark with that of the numerous partial bans (i.e. over some or all wetlands, and/or for shooting wildfowl) in other countries is informative. In some countries, measured compliance by hunters with partial bans is low. In England, measured compliance has remained at about only 30% since a ban on shooting wildfowl using lead gunshot was introduced in 1999, despite a campaign by shooting organisations to improve compliance and informing hunters that continued failure to comply increased chances of a complete ban<sup>25</sup>. However, there has been little enforcement of this legislation in England. In Sweden, a third of people hunting in wetlands used lead gunshot despite its being banned 15 years ago<sup>26</sup>. Where partial, site or species-based bans have been introduced, good compliance appears to have required a high level of monitoring and control of ammunition types used, as illustrated in the protected wetlands of Ebro Delta region of Spain<sup>27</sup>. However, there has been high compliance with the complete ban on all lead gunshot use introduced in 1996 in Denmark, where possession and sale of lead shot cartridges is illegal<sup>28</sup>. Much wetland hunting in Europe is conducted on private lands, and there is no government agency devoted to ensuring hunter compliance with shooting regulations in any EU member state. This contrasts with countries

such as Canada and the USA where itinerant federal and provincial/state government conservation officers are required to meet hunters in the field and enforce prevailing laws<sup>29</sup>. The financial resources required to enable the comprehensive monitoring and enforcement necessary were seldom made available even before the current pandemic-related economic impacts and are unlikely to be of increased priority to EU decision makers today.

In Regulation (EU) 2021/57<sup>30</sup> the carrying of lead gunshot within 100m of a wetland is prohibited “where this occurs while out wetland shooting or as part of going wetland shooting” and this provides an enforcement mechanism. However, the examples above suggest that, in the absence of widespread and active enforcement, this ban on lead gunshot use in EU wetlands is unlikely to be as effective as needed to protect the environment and human health. In this paper we address further policy and regulative options that could be undertaken to complement and make more effective Regulation (EU) 2021/57 on lead gunshot in wetlands, and to facilitate a rapid transition to the use of non-lead ammunition across the EU. The paper also emphasizes the importance of further restrictions on lead ammunition use presently under consideration by the EU as both a critical adjunct to the 2021 EU Regulation and as further protection of wildlife, human, and environmental health. The inclusion of the UK (no longer an EU member state) in this paper derives from this country’s foremost involvement with this issue, its membership in AEWA, its large international ammunition industry, and its game meat sales to the EU.

## **2. Discrete components of European hunting and shooting**

Waterbird hunting mainly involves migratory species whose flyways extend within and beyond the EU. The conservation interests of these species and their wetland habitats, which frequently span national boundaries, are covered by the Ramsar Convention (The Convention on Wetlands of International Importance Especially as Waterfowl Habitat)<sup>31</sup>, and AEWA, developed under the framework of the UN Convention on the Conservation of Migratory Species of Wild Animals (CMS)<sup>32</sup>. The CMS and the AEWA have provided strong focus for the use of non-lead ammunition to protect these and other migratory bird species from avoidable lead poisoning<sup>33</sup>. The EU is a full Party to both AEWA and the CMS. Furthermore, legal acts of the EU address the subject indirectly including the Birds’ Directive<sup>34</sup> requiring that hunting does not jeopardise conservation efforts in the distribution areas of huntable species (Articles 7). At the 25th anniversary conference of the Birds Directive in 2004, a stated intention was to “*Aim to phase of the use of lead shot in wetlands as soon as possible and ultimately by 2009*”<sup>35</sup> and this has been included in subsequent debates in the Directive’s ‘Ornis Committee’ that helps the Commission implement the Birds Directive<sup>36</sup>.

The hunting of birds and smaller-sized mammals (e.g. rabbits (*Oryctolagus cuniculus*) and hares (*Lepus europaeus*)) in terrestrial habitats, including uplands, forest and grasslands is widespread across the EU, and mostly involves shotguns and lead-based ammunition. The many millions of animals shot annually are either consumed directly by hunters, sold into retail markets and the restaurant trade, or are killed as ‘pests’. Most ‘pest’ animals are not eaten by people but disposed of in the environment where they are likely to be scavenged. Hunting of larger mammals is also common practice in most EU nations. Lead rifle ammunition is used traditionally to hunt mainly four species of deer, wild boar (*Sus scrofa*), and several other mammal species. Germany is the leading nation in the transition to use of non-lead rifle ammunition, requiring its use in several regions<sup>37</sup>. In addition, in several UK countries the agencies responsible for managing populations of deer and wild boar in the nation’s forests have required their staff to use non-lead bullets for hunting since 2016 (England) or are currently transitioning to non-lead bullets (Scotland)<sup>38</sup>. In November, 2020, the Danish government announced a nation-wide ban on lead rifle hunting ammunition, effective from 2023<sup>39</sup>.

Clay target shooting is common and widespread within the EU and occurs at both designated shooting grounds and itinerant sporting events. There are different target shooting disciplines (e.g. skeet and trap

events) and lead shotgun ammunition is generally required, especially for international competitive events<sup>40</sup>. Target shooting with rifles and handguns is common and popular in most European countries. Target shooting with rifles is often associated with hunting practice. Lead-core ammunition is most frequently used although comparable non-lead bullets are available for most applications. Bullets are normally fired into earth berms, from which spent bullet fragments can be recovered and recycled regardless of bullet material, hence the environmental impact can potentially be minimised. However, some rifle target shooting disciplines are located in natural environments with limited possibilities of retrieval of ammunition (“field shooting”).

Only 1.8% of the European population hunts, ranging from 0.2% in Belgium and The Netherlands, to 8% in Ireland<sup>41</sup>. However, a recent report found that each year, hunters from just 12 of the 27 EU countries for which data are available, and the UK, shoot over 6 million large game mammals, 12 million rabbits and hares and over 80 million birds. Collectively they support an international game meat market worth over 1.1 thousand million Euros<sup>42</sup>. Many game animals are consumed by individual hunters and their families and friends. In countries such as the UK and Denmark, where much hunting is done on estates with employees engaged to control predators and release captive-bred gamebirds, game may also be consumed by full-time and occasional employees<sup>43</sup>. About 5 million people across the EU (largely associated with hunting) are estimated to be high level consumers of game, i.e. eating one meal or more of game meat per week, with many more consuming game meat less frequently. In a representative survey of 1000 people in Germany, >38% of respondents indicated consuming large game at some time throughout the year<sup>44</sup>.

### **3. Potential non-compliance with the EU ban on lead gunshot use in wetlands**

Regulation (EU) 2021/57 that restricts the use of lead gunshot in and over wetlands is made possible because an array of non-lead gunshot is already made by the leading European manufacturers and distributed throughout Europe<sup>45</sup>. However, lead gunshot continues to be manufactured, and is used for game hunting in forests, farmland and uplands in all EU nations except Denmark and The Netherlands<sup>46</sup>. Thus, hunters can still easily obtain lead gunshot suitable for shooting wetland bird species. For example, lead shot in sizes and cartridge loads suited for hunting hares could be used to hunt different species of geese and large-bodied ducks. Lead shot cartridges used for shooting pheasants could be used effectively to hunt ducks, and the lead-based shot cartridges marketed for clay target shooting could be effectively deployed to hunt small migratory wetland species such as teal (*Anas crecca*) and common snipe (*Gallinago gallinago*).

Potential non-compliance of hunters unwilling to forgo the use of lead ammunition, reinforced by widespread weak regulatory enforcement, would reduce the effectiveness of the EU lead gunshot ban over wetlands and the potential future ban on all lead-based ammunition (depending upon the conditions of such a ban). For migratory species, their protection across the entire flyway is essential<sup>47</sup>. Conservation goals are not realised when birds migrate from a region where toxic risks from spent lead shot are reduced by high hunter compliance to regions where risks remain high due to non-compliance with regulations or lack of regulation. Individual nations within the EU have the right to enact further legislation to complement and enhance the effectiveness of a particular EU regulation (e.g. Birds Directive Article 14<sup>48</sup>). An example would be the passing of a national regulation prohibiting the use of lead gunshot for all categories of hunting and clay target shooting as has been done in Denmark, where possession and trade of lead gunshot cartridges is illegal. Such legislation effectively prohibits the importation, sale, and use of lead gunshot and potentiates the national demand for non-toxic alternatives<sup>49</sup>.

#### 4. Public engagement and awareness of the societal and environmental impacts of lead from ammunition

European society has accepted the regulations removing or limiting the presence of lead in gasolines, paints, glass, and other anthropogenic uses because of its well-established risks to human and environmental health. As well as enabling lead's removal from many products, modern technology has facilitated enhanced recovery and recycling in others. An estimated 39-40,000 tonnes of unreclaimed lead from spent hunting and shooting ammunition are released annually into EU wetland, forested, and upland environments<sup>50</sup>. According to industry figures, annually approximately 21,000 tonnes of lead from shotgun cartridges used in hunting is dispersed into the environment in the EU (28), although some estimates indicate the tonnage is probably significantly higher<sup>51</sup>. While ammunition from target shooting is sometimes recovered, that dispersed in the environment from hunting is not and accumulates over time<sup>52</sup>. If these sports were classified as industries, it is likely that prevailing EU regulations would require an immediate halt to such lead release, especially in the absence of extensive lead reclamation.

As part of the EU REACH restriction process several opportunities exist for interested parties to give their views (Table 1). However, the vast majority of responses have involved hunting and shooting organisations, the arms and ammunition industries, conservation organisations, and scientists specialised in the risks lead-based ammunition poses to human and wildlife health. The non-hunting public is poorly represented in these consultations, probably largely due to lack of awareness of their existence. Pollution from lead ammunition has been regarded as a problem created by the hunting and shooting communities that the political process needs to address, with few attempts by public authorities to inform the public or engage people in debates around the issue, including its wider international and socio-economic implications<sup>53</sup>. The social and economic costs of impaired human, wildlife and environmental health are externalized and paid for by the whole of European society<sup>54</sup>, and the 'polluter pays' principle has been largely ignored, despite this being a tenet of the Treaty on the Functioning of the EU (Article 191, ex Article 174 TEC)<sup>55</sup>.

Risks posed by lead gunshot to waterfowl have been documented for well over a century. Risks to predatory and scavenging birds from lead poisoning following ingestion of lead from gunshot or bullets in their prey have been acknowledged for at least forty years, particularly for Bald Eagles (*Haliaeetus leucocephalus*)<sup>56</sup>, California Condors (*Gymnogyps californianus*) in the USA<sup>57</sup> and White-tailed Sea-Eagles (*Haliaeetus albicilla*) in Europe<sup>58</sup>. However, the extent of this problem in these and other terrestrial birds and the wide range of species affected across the world has only become apparent in recent decades<sup>59</sup>. What was formerly regarded as primarily a disease of waterfowl has become recognised as a disease of all animals that ingest fragments of spent lead-based ammunition, and this appears to include wild mammals<sup>60</sup> as well as birds. The substantial body of scientific literature that has appeared in the past 20 years<sup>61</sup> also documents the risks to human health from frequent ingestion of game shot with lead ammunition<sup>62</sup>.

Chronic low level exposure to lead is associated with a range of critical effects in humans, including elevation of systolic blood pressure and kidney disease in adults, and reduced IQ in children<sup>63</sup>. Children are particularly vulnerable to the effects of lead as they absorb a higher proportion of ingested lead than adults. Also, their developing nervous systems are particularly sensitive to its effects and there is currently no evidence for a threshold for critical lead induced effects<sup>64</sup>. Even low blood lead concentrations have been associated with reduced Intelligence Quotient (IQ) in children and associated behavioural impacts<sup>65</sup> that may be irreversible<sup>66</sup>. Green and Pain<sup>67</sup> estimated that least 83,000 children a year in the EU and Britain aged eight years or younger were at risk of suffering a 1 point reduction in IQ from the consumption of game killed with lead-based ammunition. This was linked to an ongoing potential yearly loss

of at least 40 million to 104 million Euros to the EU economy for each year that game consumption continues<sup>68</sup>. For those cohorts of children experiencing more than a 1 point IQ loss because of a greater than average consumption of game meats, the costs would be greater. At least 5 million adults across the EU are estimated to be frequent consumers of game<sup>69</sup> increasing their risks to negative effects on the cardiovascular and renal systems<sup>70</sup>.

The direct loss of wildlife due to lead exposure also has a cost to society, for example through the loss of European species of predatory and scavenging birds that die following the ingestion of lead in contaminated game carcasses<sup>71</sup>. It is estimated that about 1 million European waterfowl die from lead poisoning, and three times that number suffer chronic sub-lethal effects<sup>72</sup>. The ingestion of lead shot may also be affecting the population trends of some European wildfowl, including the globally threatened (Vulnerable) Common Pochard (*Aythya ferina*)<sup>73</sup>. This avoidable loss of avian biodiversity is of concern to society. Using a “willingness to pay” approach the societal value of wildfowl losses alone was estimated, broadly, to be 2.2 thousand million Euros<sup>74</sup>. Where local governments are required to reclaim accumulated lead from long-abandoned shooting grounds, local authorities must pay for the recovery, which normally far exceeds the value of the lead removed from the ground<sup>75</sup>.

The general public across the EU remain largely unaware of the risks associated with the use of lead ammunition and the related health, environmental and economic costs<sup>76</sup> incurred by society. On the contrary, there has been promotion by some hunting organisations of game meat as a healthy alternative to meat from domesticated species. This contrasts strongly with relatively high levels of public awareness of the risks associated with lead in petrol, paint, and water, which are all strictly regulated across the EU, as well as other highly recognized historical environmental toxicants, e.g. DDT and mercury. This may initially appear understandable, as societal exposure to lead from these and some other industrial sources was generally of greater magnitude and/or more widespread across the population, especially for lead in petrol. However, lead is unusual in that the dose-effect relationship between blood lead levels and IQ does not appear to be linear, but rather to reflect a greater relative impact at lower lead concentrations<sup>77</sup>. Consequently, for health protection, exposure should be reduced to the minimum possible. Society needs to be aware of and understand the need for this, and that lead from ammunition is one dietary source of exposure that is technically straightforward to remove. High profile global campaigns and publications aimed at increasing lead awareness omit discussion of this remaining, largely unregulated, source of dietary lead exposure<sup>78</sup>. Since 2011, food safety and standards organisations in a range of EU countries have published guidance on the risks to human health associated with the consumption of wild game shot with lead ammunition<sup>79</sup>. These agencies advise pregnant women and children to limit their consumption or avoid eating game shot with lead ammunition. In the UK, the National Health Service (NHS) also advises pregnant women to avoid game meats such as goose, pheasant and partridge that may contain lead shot<sup>80</sup>. However, finding advice from these agencies usually involves proactive searching on websites and it is unlikely that many people are aware of such advice. For example, in the UK, public awareness is more likely to have resulted from the actions of supermarket chain Waitrose than advice provided by the Food Standards Agency and NHS. The company Waitrose is the largest retailer of game meat in the UK and proactively initiated food labelling in 2018, highlighting the risks from lead ammunition to consumers. In 2019, Waitrose pledged that all of the game they sell would be harvested without the use of lead ammunition from the 2020-21 season<sup>81</sup>. This received public attention in several major daily newspapers<sup>82</sup>, reaching millions and possibly tens of millions of people.

There is a clear need for greater social awareness of and involvement in decisions relating to the use of lead-based ammunition in Europe, especially given the political influence of the European hunting and ammunition organisations<sup>83</sup>. The evidence, collectively, warrants a wider adoption of lead substitutes in European hunting and shooting, and the decision by the European Commission to ban the use of lead

shot over wetlands marks an important first step in this direction. It is notable though that this recent decision trails behind by three decades of comparable regulatory action taken in the USA (in 1991/92), a country with a broadly similar population size (c.75% of the EU) and double the land area of the EU.

## **5. Complementary actions to enhance compliance with EU restrictions on the use of lead ammunition and better manage risks**

### **4.1. EU Regulatory measures**

The need for further measures to protect wildlife and human health, beyond restricting lead gunshot in wetlands, was identified in an ECHA Annex XV Investigation Report<sup>84</sup>. A restriction proposal on the placing on the market and use of lead in ammunition (gunshot and bullets) in all habitats and of lead in fishing tackle is currently being prepared (Table 1). Both hunting and target shooting activities are being considered and while target shooting does not impact human health via dietary exposure, its retention in the restriction is important as it nonetheless results in significant local environmental contamination and can present associated risks to environmental health<sup>85</sup>. It also presents risks to target shooters directly through the inhalation and/or ingestion of lead particles. A review of relevant literature<sup>86</sup> concluded that at firing ranges, shooting with lead ammunition results in the discharge of lead dust, raised blood lead concentrations, and exposure levels associated with a range of negative health outcomes. With respect to target shooting, detailed scientific and policy rationales for using non-lead ammunition for all Olympic and related sporting events have already been defined<sup>87</sup>. Kanstrup and Thomas<sup>88</sup> indicated that it is feasible to make this transition for target shooting with shotguns within five years of an EU ban on lead gunshot use in wetlands.

The non-lead ammunition types required to effect transition to non-lead ammunition for all civilian uses are already produced in Europe and marketed and distributed in the EU<sup>89</sup>. Any restriction on lead ammunition would increase the demand for, and availability of, a wider selection of non-lead substitutes<sup>90</sup>. A total regulatory ban on lead ammunition would practically eliminate the demand for lead-based ammunition (except for limited specific uses, e.g. by the military and police, excluded from the EU restriction under development). It would build upon voluntary and statutory restrictions on rifle ammunition already in place in parts of the EU including Germany and the UK as described above, and the recently announced intention of the Danish Government to replace lead-based bullets with alternatives in Denmark from 2023<sup>91</sup>. A successful precedent for this regulatory proposal is provided by the state of California, which has required since July 2019 use of non-lead shotgun and rifle ammunition for all types of hunting on both private and state-owned lands<sup>92</sup>. Kanstrup and Thomas<sup>93</sup> indicated that such a transition across the EU could be implemented within 3-4 years of passage of an EU regulation applied to wetland hunting. The introduction of a comprehensive regulation restricting the importation, sale, carrying and use of lead ammunition for all hunting would substantially facilitate monitoring, enforcement and compliance and seen, for example, in Denmark after the total ban of use, sale and possession of lead gunshot<sup>94</sup>. The burden of responsibility would include importers and retailers and this is far easier and more cost effective to monitor and enforce than partial bans where activities need to be monitored at the level of the individual hunter.

For both the existing EU regulation on lead gunshot use in wetlands, and the potential more comprehensive ban including all ammunition and habitats, certain additional regulatory activities would further facilitate monitoring of compliance, aid enforcement and thus reduce risks to human and wildlife health. Among these is a regulation aimed at protecting human health. The established health risks to people that frequently consume game meats containing lead particles from ammunition and especially to pregnant women and young children are described above. These apply to not only hunters and their families, but also to employees on shooting estates who receive game meat as an employment benefit and other people who purchase wild game meat which is widely traded in Europe. Based on data provided by the

Food and Agricultural Organization of the United Nations<sup>95</sup> Thomas *et al.*<sup>96</sup> estimated the export trade value of wild game meat to be approximately 1,123 million (1.1 billion) Euros a year across the EU. Commission Regulation (EC) 1881/2006<sup>97</sup> sets maximum allowable levels (MLs) of various contaminants, including lead, for a wide range of food products put on the market including the meat of domestic and some wild animals. However, despite being widely consumed, and in relatively large quantities by some communities, MLs are not listed for wild game. Thomas *et al.*<sup>98</sup> proposed that Regulation (EC) 1881/2006 be amended to include all types of game meats marketed within, and imported into, the EU. Such harmonisation would ultimately result in reduced incidence of lead particles from ammunition in all wild game animals sold in retail markets and restaurants. Meeting MLs for game would almost certainly require that wild game entering the food chain be obtained from game shoots or other sources that only use non-lead ammunition. While such a regulatory change would not protect the substantial numbers of people who hunt and consume their own game or meat they obtain informally, it would protect the retail market and the general public that purchase game meat from retailers for domestic consumption and/or eat game meals in restaurants.

While the setting of MLs for lead in game would not preclude the use of lead-based ammunition by hunters who do not sell their quarry, it would nonetheless increase and extend awareness of the associated risks to all hunting communities (i.e. hunters of waterfowl, upland game birds and mammals, and large game), and would promote the transition to non-lead ammunition. The reduced demand for lead-based ammunition would be offset by increased demands and production of non-lead ammunition<sup>99</sup>. An immediate and positive effect would be to enhance compliance with the ban on lead gunshot use in wetlands, as wild waterfowl containing lead shot, or traces thereof, could not be sold in the marketplace.

Setting a maximum level of lead in game meat would harmonise the regulations across domestically reared and wild game animals in EU and would also apply to non-EU countries where wild game meat and meat products are traded commercially; this would be a logical and health-protective move independent of broader concerns. However, while practical, enforceable and capable of being monitored, we appreciate that setting MLs for lead in game meat alone would neither fully nor adequately address the risks that lead ammunition use presents to either human or environmental health.

#### **4.2. Other policy and practice measures**

While numerous safe alternatives exist to replace lead-based ammunition, it is essential that any existing or new products do not themselves present unacceptable risks, and there is no mandatory safety testing system for alternative gunshot types in the EU. However, both the USA and Canada conduct a mandatory process to approve non-toxic shot types. This is a rigorous process that ensures that materials do not pose a significant risk of toxicity to migratory birds and other wildlife or their habitats<sup>100</sup>. A range of non-toxic shot types has been approved for use including iron (steel) and shot types largely based on iron, tungsten and bismuth<sup>101</sup>. The same shot types can, therefore, be used in other countries in the knowledge that they have met strict environmental safety standards. Some shot types have not been approved, e.g. shot made from zinc failed the testing and cannot be used legally in North America and as such should not be used elsewhere<sup>102</sup>. Lead shot coated with plastic and other various materials should not be used as the coating can be ground down rapidly in a waterbird's gizzard exposing the lead<sup>103</sup>. The coating can also be damaged when pellets strike the ground, collide with each other or hit the target, exposing the lead core to the environment. Consequently, as a matter of policy and practice, the EU could recommend that only shot types approved for use in the USA or Canada be used in the EU.

The Codex Alimentarius<sup>104</sup> international food standards, guidelines and codes of practice help ensure the safety, quality and fairness of international food trade. Codex standards are based on science provided

by independent risk assessment bodies or consultations organized by the Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO). Surprisingly, ingestion of meat from game shot with lead ammunition is not identified as a route of exposure to dietary lead in the Codex Alimentarius Code of Practice on reducing exposure to lead in food<sup>105</sup>. This may be because it was supposed until a couple of decades ago that little of the lead from gunshot and bullets shot into game animals was eaten by human consumers and was not bioavailable. However, if this were the case, these assumptions were not made explicit. This may also be why no maximum level (ML) for lead in human foodstuffs derived from wild shot game animals has been set in the Codex Alimentarius General Standard for Contaminants and Toxins<sup>106</sup> and in EU Maximum Levels (MLs) under Regulation (EC) 1881/2006. It is however possible that lead from ammunition will be included in an upcoming revision of Codex Alimentarius following comments made by the EU on the proposed draft revision of the code of practice for the prevention and reduction of lead contamination in foods<sup>107</sup>. If translated into MLs in Codex Alimentarius and Regulation (EC) 1881/2006 as described above, and international food standards advice, this will begin the removal of a significant health risk to European citizens.

Changes in policy and/or practice have been implemented by many agencies, organisations, businesses and landowners to reduce the risks from lead ammunition use. These include state-wide restrictions on the use of lead bullets in some parts of Germany and similar actions by national agencies in other countries, like the bodies managing state forests in the UK, as described above, and also conservation organisations, individual landowners, and hunters. Such actions are important and can be very effective at the scale at which they are implemented, i.e. on land over which these decision makers have direct control. The decision announced in July 2019 by UK by supermarket chain Waitrose to market only game brought to bag without the use of lead ammunition was particularly significant as it had implications not only for consumers but also for game shoots and game dealers distributing to Waitrose. Subsequently, in February 2020, nine major UK organisations associated with hunting publicly called for an end to lead in ammunition used by people shooting all live quarry with shotguns within five years '*in consideration of wildlife, the environment and to ensure a market for the healthiest game products...*'<sup>108</sup>. More recently Highland Game, the largest processor of venison in the UK, report that the majority of their venison is currently shot with lead-free ammunition and they are aiming to ensure that their retail supply chain is lead-free by the end of 2021 (E. Ross, *pers. comm*). The decision by Waitrose is the first example we are aware of where the market place has had a direct effect upon the use of hunting ammunition in any country. Unfortunately the evidence indicates that voluntary bans (such as that proposed by the UK shooting organisations mentioned above) are generally ineffective with poor compliance and the risks from lead ammunition are unlikely to be adequately controlled in the absence of comprehensive regulation<sup>109</sup>. Nonetheless, such positive interim steps are valuable in the broader transition to non-lead ammunition use.

#### **4.3 Public awareness**

Improved public awareness can be achieved in a variety of ways. From a human health perspective, public awareness campaigns associated with food safety advice provided by national agencies have been inadequate or absent and would be beneficial. Such advice is sometimes brought to the attention of the public when NGOs highlight this to the media. However, the risks posed to human health by dietary exposure to lead from ammunition have been largely overlooked by major agencies such as the WHO and UNICEF<sup>110</sup>, whose campaigns often receive public attention. It is essential that such agencies take account of the risks posed by lead from ammunition which affects sectors of society in both the developed and developing world<sup>111</sup>, and may disproportionately affect some of the poorer sectors of society, such as subsistence shooting communities. Inclusion of lead ammunition as a route of dietary exposure in the

next revision of the code of practice for the prevention and reduction of lead contamination in foods of Codex Alimentarius<sup>112</sup>, as proposed by the EU, would raise awareness.

Food labelling can be an effective way of highlighting risks to the public. Game meat products from animals shot with lead gunshot in the UK have traditionally carried labels indicating that the product ‘may contain lead shot’ but with no indication of the associated implications. This type of labelling may also be interpreted as implying that, if the consumer does not find any shot, then the product does not contain lead. This is erroneous, because many meals prepared from gamebirds found by X-radiography to contain no gunshot still had markedly elevated lead levels because of fragmentation of lead pellets<sup>113</sup>. However, during the transition period to non-lead ammunition, Waitrose’s labels gave clear advice: *“Based on public health advice vulnerable groups, in particular children, pregnant women, & women trying for a baby, should not consume this product due to the possible presence of lead shot residue”*. There are several advantages to making similar clear and informative food labelling a mandatory requirement for all game retailers. The health risks from exposure to elevated dietary lead are already widely acknowledged and this approach would be entirely consistent with governments’ traditional role of mandating food labelling where safety issues are concerned<sup>114</sup>. It would both ensure that a much wider proportion of consumers are informed of the risks and would set a level playing field for game retailers in advance of lead ammunition being replaced by non-toxic materials.

## 5. Conclusion

Lead exerts its toxic effects on humans, wildlife and the environment independent of source, whether from use in paints, gasolines, solders, or hunting ammunition<sup>115</sup>. In the interests of public and environmental health, EU regulations now restrict most uses, except for ammunition. This omission has been partly dealt with under Regulation (EU) 2021/57 banning the use of lead gunshot cartridges in wetlands. If adopted, the further, broader, restriction proposal covering all lead ammunition and fishing tackle (Table 1), currently under preparation, would correct this omission leading to a virtually complete transition to non-lead hunting ammunition in the EU.

It is important for any EU regulation to be effectively enforced across all member states. Given the highly traditional and locally organised nature of European hunting, weak enforcement of the wetland gunshot ban will be of concern. This is especially the case given low compliance levels with existing long-established regulations in countries such as the UK and Sweden, where a reasonably high level of awareness across the hunting community about the risks associated with lead-based ammunition exists, and alternative ammunition types are available for all applications. However, the ability to monitor and enforce the wetland restriction will be facilitated by the inclusion of the restriction on carrying lead gunshot within 100m of a wetland where this occurs while out wetland shooting.

More comprehensive restriction of the use of lead-based ammunition, and its replacement with non-toxic alternatives, as is currently being considered under the next phase of the REACH process, is essential to protect human health, the health of predatory, scavenging and other terrestrial birds and the environment. The introduction of such restrictions would greatly enhance compliance, especially if such restrictions include importation and carrying of lead ammunition in addition to placing on the market and use. This is because a large part of the burden of responsibility would shift from individual hunters to importers and retailers, making monitoring and enforcement straightforward and cost-effective. Comprehensive regulation is also required because ammunition manufacturers need a guaranteed market to innovate and scale up production. While lead ammunition can still be legally purchased and used for some types of shooting, it can also be obtained and used for illegal purposes.

Before such regulation exists, a range of interim measures would reduce risks from lead ammunition, help protect human and environmental health, and help pave the way for a lead-free future. Including

wild game as a food for which MLs are set within Regulation (EC) 1881/2006 is an important step to promote healthy food and protect human health. Inclusion of lead from ammunition as a source of dietary exposure within revisions under consideration for the Codex code of practice for the prevention and reduction of lead contamination in foods<sup>116</sup> may facilitate this. Establishing MLs of lead in game would also, incidentally, provide one monitoring mechanism for ammunition types used to shoot both wetland and other game species, and be a complementary adjunct to lead ammunition restrictions.

Beneficial policies and practices include adoption of non-lead gunshot types that have passed the stringent USA approval system. This would ensure that one toxic substance is not replaced with another. The rapid introduction of further national or sub-national restrictions with broader reach than the wetland restrictions, as has happened in Denmark and the Netherlands, would be highly beneficial and reduce environmental and human health risks. Measures taken by national agencies, organisations and individual landowners also help to reduce the cumulative and persistent effects of lead contamination, while enhancing awareness and shifting public opinion. Retail organisations can also be influential and effective, as markets are needed for the large amounts of game animals killed annually. Beyond the hunting and shooting communities, public awareness of this issue appears to be low, especially when compared to knowledge of the risks associated with other sources of lead contamination. Food labelling can help with this<sup>117</sup>, and national food standards and safety agencies should be encouraged to ensure that their advice is proactively publicised to ensure that it reaches those in society most vulnerable to the effects of lead.

The impacts of dietary exposure to lead from ammunition on wildlife have been communicated for far longer than risks to human health, but there remains limited public understanding of the issue, particularly beyond impacts on waterbirds. Public agencies have a responsibility to communicate these risks effectively to European citizens. Hunting organisations have been largely ambivalent about the use of non-lead ammunition but could play a key role in education and awareness, both at national level and across the EU via The European Federation for Hunting and Conservation (FACE). Non-toxic substitutes for lead ammunition are already available and used in the EU. They have been shown to be very effective in hunting all types of game<sup>118</sup>. The adoption of non-lead ammunition by the European hunting community would increase the sustainability of hunting<sup>119</sup> and demonstrate a responsible approach regarding the safety of an important European food source. Economic benefits would also accrue from the adoption of non-lead ammunition for all hunting and shooting. These include benefits to human and environmental health and a reduction in sites where remediation for lead contamination is needed. The use of lead-based ammunition imposes substantial externalized costs to society. Minimum annual costs of a limited selection of the impacts on humans, wildlife, and the environment were estimated at 383-960 million Euros for the EU, and 444 million – 1.3 thousand million Euros for Europe<sup>120</sup>. All society, European and beyond, would benefit from the reduced toxic threats to avian biodiversity much of which is already under EU-wide legal protection<sup>121</sup>.

### **Acknowledgements**

The authors thank Professor Rhys Green, Dr Ruth Cromie, and the journal reviewers for their helpful comments on the manuscript. This paper was produced with the personal financial resources of the authors.

### **Conflicts of interest**

The authors declare no conflicts of interest. Neither author is supported by resources from arms and ammunition makers, nor support from organizations and agencies promoting an end to the use of lead-based ammunition in hunting.

## Notes

- 1 Wetmore, A. 1919. *Lead poisoning in waterfowl*. United States Department of Agriculture Bulletin No:793. Professional paper, July 31, 1919. pp 12.
- 2 Pain, D. J. Ed. 1992. *Lead poisoning in waterfowl. Proceedings of IWRB workshop, Brussels*, June 1991. Slimbridge, UK. IWRB Special Publication No. 16.
- 3 African-Eurasian Migratory Waterbirds Agreement (AEWA). 1999. Resolution 1.14. Phasing out of lead shot in wetlands. First Meeting, 6–9 November 1999, Cape Town, South Africa: [www.unep-aewa.org/sites/default/files/document/final\\_res1\\_14\\_0.doc](http://www.unep-aewa.org/sites/default/files/document/final_res1_14_0.doc); and See [https://www.unep-aewa.org/en/parties-perregion/238?title\\_field\\_value=&field\\_country\\_status\\_tid=All](https://www.unep-aewa.org/en/parties-perregion/238?title_field_value=&field_country_status_tid=All); and See Resolution 4.1 on “Phasing out lead shot for hunting in wetlands” (Meeting of the Parties to AEWA, September, 2008, Antananarivo, Madagascar).
- 4 [https://echa.europa.eu/documents/10162/13641/restrictions\\_lead\\_shot\\_axv\\_report\\_en.pdf/6ef877d5-94b7-a8f8-1c49-8c07c894fff7](https://echa.europa.eu/documents/10162/13641/restrictions_lead_shot_axv_report_en.pdf/6ef877d5-94b7-a8f8-1c49-8c07c894fff7); and Treu, G., Drost, W. and Stok, F. 2020. “An evaluation of the proposal to regulate lead in hunting ammunition through the European Union’s REACH regulation”. *Environmental Sciences Europe* 32:68. doi.org/10.1186/s12302-020-00345-2
- 5 <https://www.cms.int/en/document/cms-resolution-1115-preventing-poisoning-migratory-birds>
- 6 <https://www.cms.int/en/document/review-and-guidelines-prevent-poisoning-migratory-birds>
- 7 *Supra*, note 4.
- 8 <https://ec.europa.eu/transparency/comitology-register/screen/documents/068887/1/consult>
- 9 <https://eur-lex.europa.eu/eli/reg/2021/57/oj>
- 10 *Supra*, note 4; and Thomas, V.G. and Owen, M. 1996. “Preventing lead toxicosis of European waterfowl by regulatory and non-regulatory means”. *Environmental Conservation* 23(4): 358-364.
- 11 Kanstrup, N., and Thomas, V.G. 2019. “Availability and price of non-lead hunting ammunition in Europe”. *AMBIO Special Issue* 48:1039-1043. doi.org/10.1007/s13280-019-01151-8
- 12 Annex XV Investigation Report – a review of the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle. [https://echa.europa.eu/documents/10162/13641/lead\\_ammunition\\_investigation\\_report\\_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a](https://echa.europa.eu/documents/10162/13641/lead_ammunition_investigation_report_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a) This covers civilian use of ammunition: military uses and uses for police purposes are not covered in this report.
- 13 [https://echa.europa.eu/documents/10162/13641/rest\\_lead\\_ammunition\\_COM\\_request\\_en.pdf/f607c957-807a-3b7c-07ae-01151001d939](https://echa.europa.eu/documents/10162/13641/rest_lead_ammunition_COM_request_en.pdf/f607c957-807a-3b7c-07ae-01151001d939)
- 14 <https://echa.europa.eu/-/towards-sustainable-outdoor-shooting-and-fishing-echa-proposes-restrictions-on-lead-use#:~:text=Helsinki%2C%203%20February%202021%20%E2%80%93%20At,wide%20restriction%20would%20be%20justified>.
- 15 Pain, D. J., Mateo, R. and Green, R.E. 2019. “Effects of lead from ammunition on birds and other wildlife: a review and update”. *AMBIO Special Issue* 48(9): 935-953. doi: org/10.1007/s13280-019-01159-0
- 16 Kanstrup, N., Thomas, V.G. and Fox, A.D. Eds. 2019. “Lead in hunting ammunition: Persistent problems and solutions”. *AMBIO Special Issue* 48(9): 923-1098. Seventeen scientific papers comprise this Issue; and Delahay, R.J., and Spray, C.J. (Eds). 2015. *Proceedings of the Oxford Lead Symposium. Lead Ammunition: Understanding and minimising the risks to human and environmental health*. Oxford: Edward Grey Institute, The University of Oxford. This Proceedings contains ten papers on the lead exposure issue.
- 17 Bellinger, D. C., Burger, J., Cade, T., Cory-Slechta, D.A. *et al.* 2013. “Health risks from lead-based ammunition in the environment: a consensus statement of scientists”. University of

- California, Santa Cruz. <https://bit.ly/35HpXdM>; and Group of Scientists. 2014. Wildlife and human health risks from lead-based ammunition in Europe: a consensus statement by scientists. [www.zoo.cam.ac.uk/system/files/documents/European-Statement.pdf](http://www.zoo.cam.ac.uk/system/files/documents/European-Statement.pdf).
- 18 Andersen, O., *et al.* 2018. European scientists' open letter on the risks of lead ammunition. ECHA proposal under REACH regulations. [www.europeanscientists.eu/open-letter](http://www.europeanscientists.eu/open-letter); and Andersen, O., *et al.* 2020. "Scientists' open letter on the risks of lead ammunition. ECHA proposal under REACH Regulations: Restriction proposal on the use of lead gunshot in or over wetlands". <http://www.europeanscientists.eu/open-letter-2020/>
  - 19 Arnemo, J.M., Andersen, O., Stokke, S., Thomas, V.G., *et al.* 2016. "Health and environmental risks from lead-based ammunition: science versus socio-politics". *EcoHealth* 13(4): 618-622. doi: 10.1007/s10393-016-1177-x; and Kanstrup, N., and Thomas, V.G. 2020. "Transitioning to lead-free ammunition use in hunting: socio-economic and regulatory considerations for the European Union and other jurisdictions". *Environmental Science Europe* 32: 91. doi: org/10.1186/s12302-020-00368-9
  - 20 Thomas, V.G. 2013. "Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation". *AMBIO* 42(6): 737-745. doi: 10.1007/s13280-012-0361-7; and Kanstrup, N. and Thomas, V.G. 2019. "Availability and prices of non-lead gunshot cartridges in the European retail market". *AMBIO Special Issue* 48: 1039-1043. doi: org/10.1007/s13280-019-01151-8; and Kanstrup, N., Balsby, T.J.S. and Thomas, V.G. 2016. "Efficacy of non-lead rifle ammunition for hunting in Denmark". *European Journal of Wildlife Research* 62(3): 333-340. doi: 10.1007/s10344-016-1006-0; and Thomas, V.G., Gremse, C. and Kanstrup, N. 2016. "Non-lead rifle ammunition: issues of availability and performance in Europe". *European Journal of Wildlife Research* 62(6): 633-644. doi: 10.1007/s10344-016-1044-7
  - 21 AB 711. 2013. Assembly Bill 711, Rendon. "Hunting: Nonlead ammunition. Chapter 742. An act to amend Section 3004.5 of the Fish and Game Code, relating to hunting". [http://leginfo.ca.gov/faces/billNavClient.xhtml?bill\\_id=201320140AB711](http://leginfo.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB711).
  - 22 Scheuhammer, A.M. and Thomas V.G. 2011. "Eliminating lead from recreational shooting and angling: Relating wildlife science to environmental policy and regulation". Ch. 12, pp 359-382, In: Elliott J.E., Bishop C.A., Morrissey C.A. (Eds). *Wildlife Ecotoxicology – Forensic Approaches*. Springer, New York, NY.
  - 23 Avery, D. and Watson, R.T. 2009. "Regulation of lead-based ammunition around the world". In: Watson, R.T., Fuller, M., Pokras, M. and Hunt, W.G. (Eds) *Ingestion of lead from spent ammunition: implications for wildlife and human health*. Boise, Idaho: The Peregrine Fund.
  - 24 Mateo, R., and Kanstrup, N. 2019. "Regulations on lead ammunition adopted in Europe and evidence of compliance". *AMBIO Special Issue* 48(9): 989–998. doi.org/10.1007/s13280-019-01170-5
  - 25 Cromie, R., Newth, J., Reeves, J., O'Brien, M. *et al.* 2015. "The sociological and political aspects of reducing lead poisoning from ammunition in the UK: why the transition to non-toxic ammunition is so difficult". In: Delahay R.J., Spray, C.J. (Eds) *Proceedings of the Oxford Lead Symposium: Lead ammunition: understanding and minimizing the risks to human and environmental health*. Edward Grey Institute: Oxford University, pp 104–124. [http://www.oxfordleadsymposium.info/wpcontent/uploads/OLSpceedings/papers/OLSpceedingscromie\\_newth\\_reeves\\_obrien\\_beckman\\_brown.pdf](http://www.oxfordleadsymposium.info/wpcontent/uploads/OLSpceedings/papers/OLSpceedingscromie_newth_reeves_obrien_beckman_brown.pdf)
  - 26 Widemo, F. 2021. "Shooting habits and habitats – effects of education and legislation on the phasing out of lead shot". *Environmental Science and Policy* 118:56-62. doi.org/10.1016/j.envsci.2021.01.010
  - 27 *Supra*, note 24.

- 28 Kanstrup N. and Balsby T.J.S. 2019. "Danish pheasant and mallard hunters comply with the lead shot ban". *AMBIO Special Issue* 48(9): 1009-1014. doi.org/10.1007/s13280-019-01152-7
- 29 Officials can test a hunter's ammunition directly using a portable electronic device and magnets to ensure that it complies with non-lead criteria.
- 30 *Supra*, note 9.
- 31 The Ramsar Convention. <https://www.ramsar.org/>
- 32 The Convention on Migratory Species. <https://www.cms.int/>
- 33 Stroud, D.A. 2015. "Regulation of some sources of lead poisoning: a brief review". In: Delahay, R.J. and Spray, C.J. (Eds) *Proceedings of the Oxford Lead Symposium: Lead ammunition: understanding and minimizing the risks to human and environmental health*. pp 8-26, Oxford: University of Oxford, Edward Grey Institute; and Kanstrup, N., Swift, J. D.A. Stroud, D.A. and Lewis, M. 2018. "Hunting with lead ammunition is not sustainable: European perspectives". *AMBIO* 47: 846–857. doi.org/10.1007/s13280-018-1042-y.
- 34 The Birds Directive. [https://ec.europa.eu/environment/nature/legislation/birdsdirective/index\\_en.htm](https://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm)
- 35 Ministry of Agriculture, Nature and Food Quality of the Netherlands and the Directorate General for the Environment of the European Commission, April 2005. Report of the EU Conference "25 Years of the Birds Directive: Challenges for 25 Countries" 7-9 November 2004, Bergen op Zoom, The Netherlands. <https://edepot.wur.nl/118449>
- 36 See Stroud, *supra*, note 33.
- 37 *Supra*, note 24; and Gerofke, A., Ulbig, E., Martin, A.C., Müller-Graf, C., *et al.* 2018. "Lead content in wild game shot with lead or non-lead ammunition: Does state of the art consumer health protection require non-lead ammunition"? *PLoS ONE* 13: e0200792. doi.org/10.1371/journal.pone.0200792; and Gerofke, A., Martin A., Schlichting, D., Gremse, C. and Müller- Graf, C. 2019. "Heavy metals in game meat". In *Chemical hazards in foods of animal origin. Food safety assurance and veterinary public health*, No. 7, Eds. Smulders, F.J.M., Rietjens, I.M.C.M. and Rose, M.D. pp 585–609. Wageningen: Wageningen Academic Publishers. doi.org/10.3920/978-90-8686-877-3\_24
- 38 Pain, D.J., Swift, J., Green, R.E. and Cromie, R. 2020. "The tide is turning for lead ammunition". *British Birds* 113: 110-118.
- 39 Kanstrup, N., Hansen, H.P., Balsby, T.J.S., and Møllerup, K.A. 2021. "Non-lead rifle ammunition: Danish hunters' attitudes". *Environmental Sciences Europe*. doi:10.1186/s12302-021-00485-z
- 40 Thomas, V.G. and Guitart, R. 2013. "Transition to non-toxic gunshot for Olympic shooting: policy implications for IOC and UNEP in resolving an environmental problem". *AMBIO* 42(6): 746-754. doi: 10.1007/s13280-013-0393-7; and Thomas, V.G., and Guitart, R. 2016. "Exposure to lead through ammunition, - need to revise strategies". *Environmental Policy and Law* 46(2): 127-131.
- 41 FACE. 2020. Hunters in Europe. Annual Report 2009-2010, page16.
- 42 Thomas, V.G., Pain, D.J., Kanstrup, N. and Green, R.E. 2020. "Setting maximum levels for lead in game meat in EC regulations: an adjunct to replacement of lead ammunition". *AMBIO*: doi:10.1007/s13280-020-01336-6.
- 43 PACEC 2014. The Value of Shooting. The economic, environmental, and social benefits of shooting sports in the UK. May 2014, Cambridge.
- 44 See Gerofke *et al.*, *Supra*, note 37.
- 45 *Supra*, note 20.
- 46 *Supra*, note 24.
- 47 See Thomas and Owen, *supra*, note 10.

- 48 <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0147&from=EN>
- 49 Kanstrup, N. 2019. "Lessons learned from 33 years of lead shot regulation in Denmark". *AM-BIO Special Issue* 48(9): 999–1008. doi.org/10.1007/s13280-018-1125-9; and Kanstrup and Thomas, *supra*, Note 13.
- 50 Thomas, V.G., and Guitart, R. 2010. "Limitations of European Union policy and law for regulating use of lead shot and sinkers: comparisons with North American regulation". *Environmental Policy and Governance* 20: 57–72. doi: 10.1002/eet.527. Table 1 in this paper indicates the amounts of lead shot released by each member nation of the EU using estimates from several distinct sources.
- 51 AMEC. 2012. Abatement Costs of Certain Hazardous Chemicals. Lead in shot—Final Report December 2012. Report for European Chemicals Agency (ECHA). Contract No: ECHA 2011/140, Annankatu 18, 00121 Helsinki, Finland. doi:[https://echa.europa.eu/documents/10162/13580/abatement+costs\\_report\\_2013\\_en.pdf/6e85760e-ec6d-4c8a-8fcf-e86a7ffd037d](https://echa.europa.eu/documents/10162/13580/abatement+costs_report_2013_en.pdf/6e85760e-ec6d-4c8a-8fcf-e86a7ffd037d); and ECHA. 2018. A review of the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle. Annex XV. Investigation Report Version Number 1.4. Helsinki: European Chemicals Agency; and Tukker, A., Buist, H., van Oers, L. and van der Voet, E. 2006. "Risks to health and environment of the use of lead in products in the EU". *Resources, Conservation and Recycling* 49: 89-109. doi.org/10.1016/j.resconrec.2006.03.005
- 52 Kanstrup, N., Fox, A.D. and Balsby, T.J.S. 2020 "Toxic lead gunshot persists accessible to water-birds after a 33-year ban on their use". *Science of The Total Environment*:136876. doi.org/10.1016/j.scitotenv.2020.136876
- 53 Thomas, V.G. 2010. "Achieving uniform regulation of environmental lead exposure and poisoning in wildlife and humans". *The Environmentalist* 30(2): 206-210. doi:10.1007/s10669-010-9263-z
- 54 Pain, D.J., Dickie, I., Green, R.E., Kanstrup, N. and Cromie, R. 2019. "Wildlife, human and environmental costs of using lead ammunition: An economic review and analysis". *AMBIO Special Issue* 48(9): 969–988. <https://doi.org/10.1007/s13280-019-01157-2>.
- 55 Consolidated version of the treaty on the functioning of the European Union: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?Uri=CELEX:12012E/TXT&from=EN#page86>
- 56 Kaiser, T. E., Reichel, W.L., Locke, L.N., Cromartie, E. *et al.*. 1980. "Organochlorine pesticide, PCB, and PBB residues and necropsy data for bald eagles from 29 states 1975-77". *Journal of Pesticide Monitoring* 14: 145-149.
- 57 Wiemeyer, S., Scott, J., Anderson, M., Bloom, P. and Stafford, C. 1988. "Environmental contaminants in California Condors". *Journal of Wildlife Management* 52(2): 238-247. doi:10.2307/3801228
- 58 Helander, B., Axelsson, J., Borg, H., Holm, K., and Bignert, A. 2009. "Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden". *Science of The Total Environment* 407:5555-5563. doi.org/10.1016/j.scitotenv.2009.07.027; and Kenntner, N., Tataruch, F., and Krone, O. 2001. "Heavy metals in soft tissue of white-tailed eagles found dead or moribund in Germany and Austria from 1993 to 2000". *Environmental Toxicology and Chemistry* 20:1831-1837 doi:10.1897/1551-5028(2001)020<1831:hmisto>2.0.co;2; and Menzel, A.-C., and Krone, O. 2021. "Using regurgitated pellets from white-tailed sea-eagles as noninvasive samples to assess lead exposure caused by hunting in Germany". *Journal of Raptor Research*. doi:10.3356/jrr-20-52
- 59 Pain, D. J., Mateo, R. and Green, R.E. 2019. "Effects of lead from ammunition on birds and other wildlife: a review and update". *AMBIO Special Issue* 48(9):935-953. doi:10.1007/s13280-019-01159-0; and Monclús, L., Shore, R.F. and Krone, O. 2020. "Lead

- contamination in raptors in Europe: A systematic review and meta-analysis". *Science of the Total Environment* 748: 141437. doi.org/10.1016/j.scitotenv.2020.141437
- 60 See Pain *et al. Supra*, note 59.
- 61 See Arnemo *et al., Supra*, note 19.
- 62 Green, R.E. and Pain, D.J. 2019. "Risks to human health from ammunition-derived lead in Europe". *AMBIO Special Issue* 48(9): 954–968. doi.org/10.1007/s13280-019-01194-x.
- 63 EFSA. 2010. "Scientific Opinion on Lead in Food". *EFSA Journal* 8:1570 doi:10.2903/j.efsa.2010.1570.
- 64 *Supra*, Note 63.
- 65 Lanphear, B.P., Hornung, R., Khoury, J., Yolton, K., *et al.* 2005. "Low-level environmental lead exposure and children's intellectual function: An international pooled analysis". *Environmental Health Perspectives* 113: 894–899. <https://doi.org/10.1289/ehp.7688>.
- 66 *Supra*, note 65; and WHO 2019. World Health Organization. Fact Sheet: Lead poisoning and health. 23 August 2019. <https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-andhealth#:~:text=The%20neurological%20and%20behavioural%20effects,behavioral%20difficulties%20and%20learning%20problems>.
- 67 *Supra*, note 62.
- 68 *Supra*, note 54.
- 69 *Supra*, note 55.
- 70 *Supra*, note 63.
- 71 Krone, O. 2018. "Lead Poisoning in Birds of Prey". In: *Birds of Prey: Biology and Conservation in the XXI century*. Eds. Saratola, J.H., Grande, J.M. and Negro, J.J. pp 251–272. Springer, Cham. doi.org/10.1007/978-3-319-73745-4\_11; and Plaza P.I. and Lambertucci, S.A. 2019. "What do we know about lead contamination in wild vultures and condors? A review of decades of research". *Science of the Total Environment* 654: 409–417. doi.org/10.1016/j.scitotenv.2018.11.099.
- 72 *Supra*, note 15.
- 73 Green, R.E. and Pain, D.J. 2016. "Possible effects of ingested lead gunshot on populations of ducks wintering in the UK". *Ibis* 158 (4): 699–710. doi.org/10.1111/ibi.12400
- 74 *Supra*, note 54.
- 75 See Kanstrup and Thomas, *supra*, note 19.
- 76 *Supra*, note 54; See Kanstrup and Thomas, *Supra*, note 19.
- 77 *Supra*, note 63.
- 78 UNICEF and Pure Earth. 2020. "The Toxic Truth: Children's Exposure to Lead Pollution Undermines a Generation of Future Potential". UNICEF and Pure Earth, New York. pp 96. <https://www.unicef.org/media/73246/file/The-toxic-truth-children%E2%80%99s-exposure-to-lead-pollution-2020.pdf>; and Pain, D., Green, R. and Taylor, C. 2020. Children are at risk from game shot with lead. *Guardian Letters* 10 August 2020. <https://www.theguardian.com/society/2020/aug/10/children-are-at-risk-from-game-shot-with-lead>.
- 79 Knutsen, H.K., Brantsaeter, A.-E., Alexander, J. and Meltzer, H.M. 2015. "Associations between consumption of large game animals and blood lead levels in humans in Europe: the Norwegian experience". pp 44–50, In: Delahay and Spray (Eds), *supra*, note 16.
- 80 <https://www.nhs.uk/conditions/pregnancy-and-baby/foods-to-avoid-pregnant/>
- 81 This has subsequently been changed to the 2021–22 season as the Covid 19 situation resulted in many game shoots closing and difficulty in accessing game shot with lead free ammunition.
- 82 <https://www.theguardian.com/business/2019/jul/29/experts-call-for-ban-on-lead-shot-as-waitrose-overhauls-sale-of-game>; <https://www.telegraph.co.uk/news/2019/07/29/waitrose->

- stop-selling-game-killed-lead-shot-following-warning/; and <https://www.dailymail.co.uk/news/article-7299583/Waitrose-ends-sale-game-birds-shot-toxic-lead-experts-call-Government-ban-use.html>
- 83 *Supra*, note 19.
  - 84 *Supra*, note 12.
  - 85 Payne, J.H., Holmes, J.P., Hogg, R.A., Van Der Burgt, G.M., *et al.* 2013. "Lead intoxication incidents associated with shot from clay pigeon shooting". *Veterinary Record* 173(22): 552. doi: 10.1136/vr.102120.
  - 86 Laidlaw, M. A. S., Filippelli, G., Mielke, H., Gulson, B. and Ball, A. S. 2017. "Lead exposure at firing ranges – a review". *Environmental Health* 16: 34. doi: 10.1186/s12940-017-0246-0
  - 87 Thomas, V.G. and Guitart, R. 2013. "Transition to non-toxic gunshot for Olympic shooting: policy implications for IOC and UNEP in resolving an environmental problem". *AMBIO* 42(6): 746-754. doi: 10.1007/s13280-013-0393-7; and Thomas, V.G., and Guitart, R. 2016. Exposure to lead through ammunition, - need to revise strategies. *Environmental Policy and Law* 46(2): 127-131; and Thomas, V.G. and Anderson, D.A. 2013. "Banning the use of lead shot: policy options for the International Olympic Committee". *Environmental Policy and Law* 43(6): 300-306.
  - 88 See Kanstrup and Thomas, *supra*, note 19.
  - 89 *Supra*, note 20.
  - 90 See Kanstrup and Thomas, *supra* note 19.
  - 91 Kanstrup, N., Hansen, H.P., Balsby, T.J.S., Møllerup, K.A. 2021. "Non-lead rifle ammunition: Danish hunters' attitudes". *Environmental Sciences Europe*. doi:10.1186/s12302-021-00485-z
  - 92 AB 711. 2013. Assembly Bill 711, Rendon. "Hunting: Nonlead ammunition. Chapter 742. An act to amend Section 3004.5 of the Fish and Game Code, relating to hunting". [http://leginfo.ca.gov/faces/billNavClient.xhtml?bill\\_id=201320140AB711](http://leginfo.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB711).
  - 93 See Kanstrup and Thomas, *supra*, note 19.
  - 94 *Supra*, notes 28 and 49.
  - 95 FAO. 2018. "Game meat. Production and trade in the ENECE region". Rome: Food and Agricultural Organization of the United Nations.
  - 96 *Supra*, note 42.
  - 97 EC. 2006. "European Commission Regulation EC 1881/2006. Setting maximum levels for certain contaminants in foodstuffs". Official Journal of the European Union EC 1881/2006 (20.12.2006), L364/365-L364/324. <http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1442063437890&uri=CELEX:32006R1881>.
  - 98 *Supra*, note 42.
  - 99 See Kanstrup and Thomas, *supra*, note 19.
  - 100 <https://www.law.cornell.edu/cfr/text/50/20.134>
  - 101 FWS. 2018. U.S. Fish and Wildlife Service. "Nontoxic shot regulations for hunting waterfowl and coots in the U.S.". <https://www.fws.gov/birds/bird-enthusiasts/hunting/nontoxic.php>; and Thomas, V.G. 2019. "Chemical composition standards for non-lead hunting ammunition and fishing weights". *AMBIO Special Issue* 48(9): 1072-1078. doi.org/10.1007/s13280-018-1124-x
  - 102 Levensgood, J.M., Sanderson, G.C., Anderson, W.L., Foley, G.L. *et al.* 1999. "Acute toxicity of ingested zinc shot to game-farm mallards. *Illinois Natural History Survey Bulletin* 36: 1-36.
  - 103 Irby, H.D., Locke, L.N. and Bagley, G.E. 1967. "Relative toxicity of lead and selected substitute shot types to game farm mallards". *Journal of Wildlife Management* 31(2): 253-257. <https://www.jstor.org/stable/3798314>
  - 104 <http://www.fao.org/fao-who-codexalimentarius/en/>

- 105 Codex Alimentarius. 2004. "Code of Practice for the prevention and reduction of lead contamination in foods". CAC/RCP 56-2004. <http://www.codexalimentarius.org/standards/list-of-standards/>. [fao.org/fao-who-codexalimentarius/sh-proxy/en/?Ink=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B56-2004%252FCXP\\_056e.pdf](http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?Ink=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B56-2004%252FCXP_056e.pdf)
- 106 Codex Alimentarius. 2019. General standard for contaminants and toxins in food and feed CXS 193-1995. Adopted in 1995. Revised in 1997, 2006, 2008, 2009. Amended in 2010, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019. Rome: Food and Agriculture Organization. [http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?Ink=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B193-1995%252FCXS\\_193e.pdf](http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?Ink=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B193-1995%252FCXS_193e.pdf)
- 107 See: Joint FAO/WHO food standards programme codex committee on contaminants in foods 14th Session Utrecht, The Netherlands, 20 – 24 April 2020. Proposed draft revision of the code of practice for the prevention and reduction of lead contamination in foods (CXC 56-2004) Agenda Item 9 CX/CF 20/14/9-Add.1 July 2020 [http://www.fao.org/fao-who-codexalimentarius/sh-proxy/tr/?Ink=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FMeetings%252FCX-735-14%252FWD%252Fcf14\\_09\\_Add1e.pdf](http://www.fao.org/fao-who-codexalimentarius/sh-proxy/tr/?Ink=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FMeetings%252FCX-735-14%252FWD%252Fcf14_09_Add1e.pdf)
- 108 See BASC, "A joint statement on the future of shotgun ammunition for live quarry shooting". <http://bit.ly/2Vv8i7u>
- 109 Green, R.E., Taggart, M.A., Pain, D.J., *et al.* 2021. "Effect of a joint policy statement by nine UK shooting and rural organisations on the use of lead shotgun ammunition for hunting common pheasants *Phasianus colchicus* in Britain". *Conservation Evidence Journal* 18: 1-9. doi:<https://conservationevidencejournal.com/reference/pdf/8858>
- 110 *Supra*, note 78.
- 111 Pain, D.J. and Green, R.E. 2019. "Risks from Lead Ammunition: Correspondence". *Nature Sustainability*. doi.org/10.1038/s41893-019-0406-z
- 112 *Supra*, note 107.
- 113 Pain, D.J., Cromie, R.L., Newth, J., Brown, *et al.* 2010. "Potential Hazard to Human Health from Exposure to Fragments of Lead Bullets and Shot in the Tissues of Game Animals". *PLoS ONE* 5(4):e10315.doi:10.1371/journal.pone.0010315
- 114 Crinis, G., Parker, C. and Carey, R. 2017. "The caged chicken or the free-ranged egg? The regulatory dynamics of layer hen welfare in the UK, Australia and the USA. *Journal of Agricultural and Environmental Ethics* 30: 783-808. doi.org/10.1007/s10806-017-9699-y
- 115 *Supra*, note 53.
- 116 *Supra*, note 107.
- 117 *Supra*, note 114.
- 118 *Supra*, note 20.
- 119 See Kanstrup *et al.*, *supra* note 33.
- 120 *Supra*, note 54.
- 121 Arnemo, J.M., Cromie, R., Fox, A.D., Kanstrup, N. *et al.* 2019. "Transition to lead-free benefits all". *AMBIO Special Issue* 48(9): 1097-1098. doi.org/10.1007/s13280-019-01221-x

**Table 1. Chronology of stages and outcomes for restrictions and proposed restrictions on the use of lead ammunition under EU REACH Regulations (as of May 2021).**

Sequence of stages in the restriction process	Restriction on the use of lead gunshot in wetlands (EU) 2021/57	Proposed restriction on the placing on the market and use of lead in ammunition (gunshot and bullets) and of lead in fishing tackle <sup>a</sup> .
Investigation Report		September 2018 <sup>b</sup> (v1)
Request from the Commission	03 December 2015 <sup>c</sup>	03 December 2015 <sup>c</sup> ; 16 July 2019 <sup>d</sup>
Intention to prepare restriction dossier	12 April 2016	03 October 2019
Call for evidence	April 2016-21 July 2016	3 October 2019 – 16 December 2019
Annex XV Restriction Report submitted	7 April 2017 <sup>e</sup>	15 January 2021 <sup>f</sup>
Consultation of the Annex XV dossier (if conformity is passed)	Comments and contributions by 21 December 2017.	24 March 2021 – 24 September 2021
RAC opinion	Adopted 9 March 2018 <sup>g</sup>	Q4 2021
Draft SEAC opinion	Adopted 14 June 2018 <sup>g</sup>	Q4 2021
Consultation on draft SEAC opinion		Q1 2022
Combined final opinion submitted to the Commission	17 August 2018	Q2 2022
Draft amendment to the Annex XVII (draft restriction) by Commission	Planned for within 3 months of receipt of opinions but subject to numerous delays	Within 3 months of receipt of opinions
Discussions with member state authorities and vote	3 September 2020. 18 member states representing 89.99% of the EU population voted in favour of the restriction, with 5 against and 4 abstentions <sup>h</sup>	Q3/Q4 2022
Scrutiny by Council and European Parliament		Before adoption (3 months)

Vote in ENVI	Two objections tabled were rejected 29 <sup>th</sup> October 2020 <sup>i</sup>	
Vote in the European Parliament	24 <sup>th</sup> and 25 <sup>th</sup> November 2020. European Parliament voted to reject two objections to the proposal <sup>j</sup> leaving the Commission free to adopt the proposal.	
Adoption by the European Commission	Adopted on 25 January 2021 <sup>k</sup> . It will become operational 24 months after the date of entry into force of the Regulation or 36 months after entry into force in those Member States where at least 20 % in total of the territory, excluding the territorial waters, are wetlands.	If Agreed - Q1/Q2 2023

<sup>a</sup> Timings subsequent to 15 May 2021 are tentative and subject to change. From references given and adapted on 15 May 2021 from: <https://echa.europa.eu/hot-topics/lead-in-shot-bullets-and-fishing-weights> Accessed 15 May 2021

<sup>b</sup> ANNEX XV INVESTIGATION REPORT. A review of the available information on lead in shot used in terrestrial environments, in ammunition and in fishing tackle. Version 1.4 27 November 2018. [https://echa.europa.eu/documents/10162/13641/lead\\_ammunition\\_investigation\\_report\\_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a](https://echa.europa.eu/documents/10162/13641/lead_ammunition_investigation_report_en.pdf/efdc0ae4-c7be-ee71-48a3-bb8abe20374a) Accessed 15 May 2021

<sup>c</sup> Request to the European Chemicals Agency to prepare restriction proposals conforming to the requirements of Annex XV to Reach. Brussels 2015, 12-03. [https://echa.europa.eu/documents/10162/13641/echa\\_annex\\_xv\\_restriction\\_proposals\\_en.pdf/ed07424a-328d-88e0-b7c6-412251426582](https://echa.europa.eu/documents/10162/13641/echa_annex_xv_restriction_proposals_en.pdf/ed07424a-328d-88e0-b7c6-412251426582) Accessed 15 May 2021

<sup>d</sup> Request to the European Chemicals Agency to prepare a restriction proposal on the placing on the market and use of lead in ammunition (gunshot and bullets) and of lead in fishing tackle conforming to the requirements of Annex XV to REACH 16 July 2019. [https://echa.europa.eu/documents/10162/13641/rest\\_lead\\_ammunition\\_COM\\_request\\_en.pdf/f607c957-807a-3b7c-07ae-01151001d939](https://echa.europa.eu/documents/10162/13641/rest_lead_ammunition_COM_request_en.pdf/f607c957-807a-3b7c-07ae-01151001d939)

<sup>e</sup> ANNEX XV RESTRICTION REPORT PROPOSAL FOR A RESTRICTION. Lead in shot. Version 1. [https://echa.europa.eu/documents/10162/13641/restrictions\\_lead\\_shot\\_axv\\_report\\_en.pdf/6ef877d5-94b7-a8f8-1c49-8c07c894fff7](https://echa.europa.eu/documents/10162/13641/restrictions_lead_shot_axv_report_en.pdf/6ef877d5-94b7-a8f8-1c49-8c07c894fff7) Accessed 15 May 2021

<sup>f</sup> Annex XV Restriction Report. Lead in outdoor shooting and fishing. Version 2. 24 March 2021. <https://echa.europa.eu/documents/10162/1a42c9e1-e36a-65b0-da45-bc1ca093b632> Accessed 15 May 2021

<sup>g</sup> Committee for Risk Assessment (RAC) Committee for Socio-economic Analysis (SEAC) Opinion on an Annex XV dossier proposing restrictions on LEAD IN GUNSHOT. Compiled version prepared by the ECHA Secretariat of RAC's opinion (adopted 9 March 2018) and SEAC's opinion (adopted 14 June 2018) <https://echa.europa.eu/documents/10162/b092e670-3266-fb5d-6296-544eacbb5d4a> Accessed 15 May 2021

<sup>h</sup> Comitology Register. External voting sheet - Draft Commission Regulation (EU) amending Annex XVII to the REACH Regulation (EC) No 1907/2006 as regards lead in gunshot in or around wetlands

<https://ec.europa.eu/transparency/comitology-register/screen/documents/068887/1/consult> Accessed 15 May 20.21

<sup>i</sup> European Parliament. Committee on Environment, Food Safety and Public Health Result of roll-call votes of 29.10.2020. [https://www.europarl.europa.eu/cmsdata/214593/2020-10-29\\_roll-call-votes.pdf](https://www.europarl.europa.eu/cmsdata/214593/2020-10-29_roll-call-votes.pdf) Accessed 15.05.21

<sup>j</sup> European Parliament Results of Votes P9\_PV(2020)11.23-26(VOT)\_EN.docx [https://www.europarl.europa.eu/doceo/document/PV-9-2020-11-25-VOT\\_EN.pdf](https://www.europarl.europa.eu/doceo/document/PV-9-2020-11-25-VOT_EN.pdf) Accessed 15.05.21

<sup>k</sup> COMMISSION REGULATION (EU) 2021/57 of 25 January 2021 <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0057&from=EN>

## THE TRANSITION TO NON-LEAD AMMUNITION

– an essential and feasible prerequisite for sustainable hunting in modern society

This dissertation is the result of 35 years of professional advisory, research and practical experience in wildlife management. It consists of a synthesis of 26 peer-reviewed articles of relevance to the work first-authored or co-authored by the dissertation author.

Hunting disperses ammunition fragments into the environment, which constitutes part of hunting's footprint on nature and ecosystems and, as such, contributes to hunting pressure on the environment. Society needs to integrate the consequences of dispersing such material into the environment into the overall evaluation of hunting sustainability.

The dissertation identifies the highly toxic consequences of dispersing lead fragments into the natural environment and the human food chain through the traditional use of lead in hunting ammunition. It presents proposals for future management to ensure the effective change from the use of lead to non-lead ammunition in all types of hunting.

Evidence shows that the successful transition from lead to non-lead hunting ammunition will only occur through direct and indirect regulation backed by effective enforcement. Such a transition will not only eliminate continuing contributions to an environmental problem and the additional associated costs for society, but demonstrate that nature and wildlife management has the capacity to adapt to new sustainability challenges that arise as a result of a modern society in rapid change.

The transition from lead to non-lead ammunition will benefit all by eliminating the continued contribution to ecosystems, and the resulting exposure to wildlife and humans. Hunters themselves benefit through strengthening of the positive long-term public perception of hunting.

The dissertation represents an expression of a personal deep passion and respect for wild animals - for these animals as individuals and collectively in strong and healthy populations. The gathered experiences presented here are an important reminder that hunting needs to review its practices on a regular basis to ensure they align with current thinking, which, together with its broader sustainability, will safeguard its future acceptance in society.